Pearson BTEC

Pearson BTEC Level 3 Foundation Award in Advanced Manufacturing Engineering (Development Technical Knowledge)

Pearson BTEC Level 3 Award in Advanced Manufacturing Engineering (Development Technical Knowledge)

Pearson BTEC Level 3 Certificate in Advanced Manufacturing Engineering (Development Technical Knowledge)

Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

Pearson BTEC Level 3 Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

Unit specification

BTEC Specialist qualification

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Issue 7

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This unit specification is Issue 7. Key changes are summarised on the next page. We will inform centres of any changes to this issue. The latest issue can be found on our website.

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Summary of changes to Pearson BTEC Level 3 Award, Certificate, Diploma and Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) Unit Specification Issue 7

Summary of changes made between previous issue and this issue	Page number
Reference to The Health and Safety at Work (Northern Ireland) Order 1978 added to *Unit 1: Health and Safety in the Engineering Workplace* - 1 Understand health and safety legislation and regulations.	4

Earlier issues show previous changes.

If you need further information on these changes or what they mean, please contact us via our website at: qualifications.pearson.com/en/support/contact-us.html.

Contents

1	**Units**	**1**
Unit 1:	Health and Safety in the Engineering Workplace	3
Unit 2:	Communications for Engineering Technicians	13
Unit 3:	Mathematics for Engineering Technicians	23
Unit 4:	Engineering Project	32
Unit 5:	Calculus to Solve Engineering Problems	43
Unit 6:	Further Engineering Mathematics	54
Unit 7:	Properties and Applications of Engineering Materials	67
Unit 8:	Mechanical Principles of Engineering Systems	75
Unit 9:	Applications of Mechanical Systems in Engineering	85
Unit 10:	Organisational Efficiency and Improvement	93
Unit 11:	Electro-pneumatic and Hydraulic Systems and Devices	102
Unit 12:	Engineering Drawing for Technicians	111
Unit 13:	Computer-aided Drafting in Engineering	120
Unit 14:	Advanced Mechanical Principles and Applications	129
Unit 15:	Engineering Primary Forming Processes	138
Unit 16:	Engineering Secondary and Finishing Techniques	147
Unit 17:	Fabrication Processes and Technology	157
Unit 18:	Welding Technology	165
Unit 19:	Selecting and Using Programmable Controllers	176
Unit 20:	Applications of Computer Numerical Control in Engineering	185
Unit 21:	Welding Principles	195
Unit 22:	Computer-aided Manufacturing	204
Unit 23:	Electronic Circuit Design and Manufacture	214
Unit 24:	Principles and Applications of Electronic Devices and Circuits	226
Unit 25:	Engineering Maintenance Procedures and Techniques	235
Unit 26:	Monitoring and Fault Diagnosis of Engineering Systems	246
Unit 27:	Principles and Applications of Engineering Measurement Systems	256
Unit 28:	Electrical Technology	264
Unit 29:	Electrical Installation	273
Unit 30:	Electronic Measurement and Testing	282
Unit 31:	Features and Applications of Electrical Machines	293
Unit 32:	Three-phase Motors and Drives	302
Unit 33:	Further Electrical Principles	310
Unit 34:	Manufacturing Planning	320
Unit 35:	Setting and Proving Secondary Processing Machines	327
Unit 36:	Business Operations in Engineering	339

Unit 37:	Industrial Plant and Process Control	349
Unit 38:	Industrial Process Controllers	355
Unit 39:	Principles and Operation of Three-phase Systems	362
Unit 40:	Industrial Robot Technology	371
Unit 41:	Vehicle Electronic Ancillary and Information Systems	377
Unit 42:	Light Vehicle Suspension, Steering and Braking Systems	384
Unit 43:	Mechanical Measurement and Inspection Techniques	392
Unit 44:	Vehicle Engine Principles, Operation, Service and Repair	399
Unit 45:	Vehicle System Fault Diagnosis and Rectification	409
Unit 46:	Applications of Vehicle Science and Mathematics	417
Unit 47:	Electrical and Electronic Principles for Vehicle Technology	424
Unit 48:	Vehicle Electrical Charging and Starting Systems	434
Unit 49:	Function and Operation of Vehicle Petrol Injection Systems	443
Unit 50:	Diesel Fuel Injection Systems for Compression Ignition Engines	451
Unit 51:	Operation and Testing of Vehicle Electronic Ignition Systems	459
Unit 52:	Vehicle Engine Management Systems	466
Unit 53:	Operation and Maintenance of Light Vehicle Transmission Systems	475
Unit 54:	Operation of Vehicle Chassis Systems	483
Unit 55:	Further Mechanical Principles and Applications	491
Unit 56:	Electrical and Electronic Principles in Engineering	500
Unit 57:	Helicopter Gas Turbine Engines, Transmission, Rotors and Structures	511
Unit 58:	Aircraft Flight Principles and Practice	522
Unit 59:	Airframe Construction and Repair	534
Unit 60:	Airframe Mechanical Systems	545
Unit 61:	Aircraft Electrical and Instrument Systems	558
Unit 62:	Shipbuilding Principles	570
Unit 63:	Utility System Maintenance	580
Unit 64:	Operations Management and Costing	591
Unit 65:	Engineering Design	600
Unit 66:	Principles and Applications of Fluid Mechanics	610
Unit 67:	Commercial Aspects of Engineering Organisations	619
Unit 68:	Lean Production System Design	627
Unit 69:	Statistics and Business Improvement Techniques	636
Unit 70:	Applications of Thermodynamic Principles	645
Unit 71:	Principles and Applications of Analogue Electronics	652
Unit 72:	Construction and Applications of Digital Systems	661
Unit 73:	Electronic Fault Finding	670

Unit 74: Advanced Composite Materials Manufacturing 679
Unit 75: Microprocessor Systems and Applications 688
Unit 76: Principles and Applications of Microcontrollers 698
Unit 77: The Role of the Medical Engineer 708
Unit 78: Acceptance Testing, Maintaining, Fault Finding and Decommissioning of Medical Equipment 720
Unit 79: Anatomy, Physiology and Measurement 733
Unit 80: ICT for Medical Engineers 743
Unit 81: Principles of Servicing Cardiovascular Equipment 756
Unit 82: Principles of Servicing Physiological Monitoring Equipment 769
Unit 83: Principles of Servicing Infusion Equipment 781
Unit 84: Principles of Servicing Medical Therapeutic Equipment 792
Unit 85: Principles of Servicing Operating Theatre and Surgical Equipment 803
Unit 86: Principles of Servicing Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment 814
Unit 87: Principles of Medical Imaging 829
Unit 88: Principles of Servicing Dental Equipment 841
Unit 89: Principles of Servicing Medical Laboratory Equipment 852
Unit 90: Basic Polymer Technology 864
Unit 91: Plastics Materials 870
Unit 92: Plastics Processing 877
Unit 93: Polymer Process Engineering 883
Unit 94: Composite Materials and Processing 891
Unit 95: Aircraft Gas Turbine Engines 899
Unit 96: Human Factors and Performance in Aviation 912
Unit 97: Aircraft Radio and Radar Principles 933
Unit 98: Helicopter Aerodynamics and Flight Principles 943
Unit 99: Aircraft Workshop Methods and Practice 954
Unit 100: Aircraft Propulsion Systems 966
Unit 101: Aircraft First Line Maintenance Operations 979
Unit 102: Industrial Process Measurement 991
Unit 103: Understanding and Using Fabrication Skills for Blacksmithing and Metal working 1000
Unit 104: Understanding and Using Fabrication Techniques for Blacksmithing and Metal working 1009
Unit 105: Motorsport Workshop Practices 1018
Unit 106: Motorsport Vehicle Preparation and Inspection 1027
Unit 107: Professional Practice and Logistics for Motorsports 1037
Unit 108: Industry 4.0 1045
Unit 109: Data Analytics/Big Data 1057

Unit 110: Simulation and Digital Twinning 1069
Unit 111: Cyber Security in Engineering 1078
Unit 112: Additive Manufacturing Processes 1091
Unit 113: Autonomous Systems 1105
Unit 114: Environmental Engineering and Sustainability 1119
Unit 115: Aircraft Materials and Hardware 1130
Unit 116: Installing and Commissioning Engineering Equipment 1143
Unit 117: Battery Manufacturing 1154
Unit 118: Electric and Hybrid Vehicle Motors 1164
Unit 119: Electric Vehicle Drives 1174
Unit 120: E-mobility 1185
Unit 121: Industrial Robotics 1197
Unit 122: Autonomous Mobile Robotics 1206
Unit 123: Aircraft Computers and Electronic Systems 1217
Unit 124: Avionic Systems 1226

1 Units

Internal units

Section	Explanation
Unit number	The number is in a sequence in the specification. Where a specification has more than one qualification, numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that will always be used and which will appear on certificates.
Level	All units and qualifications have a level assigned to them. The level assigned is informed by the level descriptors defined by Ofqual, the qualifications regulator.
Unit type	This says if the unit is mandatory or optional for the qualification. See structure information in *Section 4 Pathways* for full details.
Assessment type	This says how the unit is assessed – i.e. whether it is internal or external. See information in *Section 4 Pathways* for details.
GLH	This indicates the number of hours of activities that directly or immediately involve tutors and assessors in teaching, supervising, and invigilating learners Units may vary in size.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, what will be learned and how the learning might be applied in the workplace.
Learning outcomes	These help to define the scope, style and depth of learning of the unit.
Unit content	This section sets out the required teaching content of the unit. Content is compulsory except when shown as 'e.g.'. Learners should be asked to complete summative assessment only after the teaching of content for the unit or learning outcome(s) has been covered.
Assessment and grading criteria	Assessment criteria specify the standard required by the learner to achieve each learning outcome. Each learning outcome has Pass criteria. In addition to Pass criteria, each learning outcome has Merit or both Merit and Distinction criteria.

Section	Explanation
Essential guidance for tutors	This section gives information to support the implementation of assessment. It is important that this information is used carefully, alongside the assessment criteria. This information gives guidance for each learning outcome or assignment of the expectations for Pass, Merit and Distinction standard. This section contains examples and essential clarification.
Programme of suggested assignments	This section shows a programme of suggested assignments that covers the Pass, Merit and Distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.
Essential resources	This section lists any specific resources that are needed to be able to teach and assess the unit.
Indicative reading for learners	Lists resource materials that can be used to support the teaching of the unit, for example books, journals, websites.

Unit 1: Health and Safety in the Engineering Workplace

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The welfare of people working or operating in any manufacturing or engineering environment is of prime importance. All workers should be able to carry out their work in a safe manner that has no negative effect on their health and wellbeing. In fact, many organisations not only reduce risks and make improvements to the working environment, but try to make their own working environment superior to others, making it a competitive aspect when recruiting staff.

Health and safety in the workplace is about measures designed to protect the health and safety of employees, visitors and the general public who may be affected by workplace activities. Safety measures are concerned with controlling and reducing risks to anyone who might be affected by these activities.

Health and safety is controlled largely by legislation and regulations, with the law being continually revised and updated. It is important that organisations are aware of these changes and keep up to date with developments.

This unit will give learners an understanding of hazards and risks associated with health, safety and welfare in an engineering workplace, the associated legislation and regulations, and of their roles in complying with the related legal obligations. Learners will be required to undertake full risk assessments and to appreciate the significant risks encountered in the workplace and the measures taken to deal with them. They will study the principles of reporting and recording accidents and incidents, again within a legal context.

This unit could form a key component in many learning programmes since the content is highly applicable to many manufacturing, engineering and industrial situations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand health and safety legislation and regulations
2. Know about hazards and risks in the workplace
3. Understand the methods used when reporting and recording accidents and incidents.

Unit content

1 Understand health and safety legislation and regulations

Key features of legislation and regulations: the general contents of legislation and regulations or other relevant international equivalents and how they are satisfied by safe systems of work/procedures, including:

- Health and Safety at Work Act – duties of employers, employees, Health and Safety Executive (HSE) and others, The Health and Safety at Work (Northern Ireland) Order 1978 (where applicable to locality), general prohibitions
- Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) – duties of employers, self-employed and people in control of work premises (the Responsible Person) to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences
- Personal Protective Equipment (PPE) at Work Regulations – appropriate if risk cannot be controlled in any other way, types, assessing suitable PPE given the hazard, supply, instructions/training, correct use, maintenance and storage
- Control of Substances Hazardous to Health (COSHH) Regulations – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Manual Handling Operations Regulations (MHOR) – avoid the need for manual handling, types of hazard, assess risk of injury when manual handling is required, control and reduce the risk of injury, training in use of techniques/mechanical aids
- Environmental legislation and EU directives: Environmental Protection Act; Pollution Prevention and Control Act; Clean Air Act; Radioactive Substances Act; Controlled Waste Regulations; Controls on Dangerous Substances and Preparations Regulations
- *Roles and responsibilities of those involved*: employers; employees; HSE, e.g. span of authority, right of inspection, guidance notes and booklets; others, e.g. management, subcontractors, public, suppliers, customers, visitors
- *Application of environmental management systems*: ISO 14000 (family of standards, a management tool); environmental management (what an organisation does to minimise the harmful effects on the environment caused by its activities, **e.g. related to procurement and design, energy sources and usage, management of resources**); ISO 14004 (guidelines on the elements of an environmental management system and its implementation, and examines principle issues involved); ISO 14001 (specifies the requirements for such an environmental management system)

2 Know about hazards and risks in the workplace

- *In the workplace*: methods to identify hazards, e.g. statements, analysis of significant risks, prediction of results or outcomes of those risks, use of accident data, careful consideration of work methods
- *Working environment*: consideration of the workplace and its potential for harm, e.g. confined spaces, working over water or at heights, electrical hazards, chemicals, noise
- *Hazards that become risks*: identification of trivial or significant risk; potential to cause harm; choosing appropriate control measures; electrical safety, e.g. identifying and controlling hazards, cause of injury, effects of electricity on the body, circuit overloading; mechanical safety, e.g. identifying and controlling hazards, cause of injury, rotating equipment, sharp edges; safety devices, e.g. residual current device (RCD), fuses, guards, fail safe, sensors
- *Risk assessments*: items/area to be assessed, e.g. machine operation, work area; five steps (principal hazards, who is likely to be injured/harmed, evaluation of the risks and decisions on adequacy of precautions, recording findings, review assessment)
- *Use of control measures*: e.g. removing need (design out), use of recognised procedures, substances control, guarding, lifting assessments and manual handling assessments, regular inspection, use of PPE, training of personnel, other personal procedures for health, safety and welfare

  Application of aids to lift or move loads: e.g. pinch bars, rollers, skates, pallet trucks, scissor lifts, forklift trucks, wall and overhead cranes; ancillary equipment, e.g. block and tackle, pull lifts, slings (chain, rope, polyester), shortening clutches, lifting/plate clamps, eye bolts (dynamo, collar), shackles (dee, bow)
- *Regulations*: e.g. Provision and Use of Workplace Equipment Regulations (PUWER), Lifting Operations and Lifting Equipment Regulations (LOLER)
- *Procedures*: safe working load (SWL) capacity of equipment; safe working load limits and angles for slings when lifting; ensuring clearway and not moving loads over others' heads; not transporting people on loads; correct hand signals from floor staff to crane drivers; protection of chains and slings from sharp corners; setting hooks and sling/chain lengths correctly
- *Storage of gases, oil, acids, adhesives and engineering materials*: COSHH regulations; structure of storage buildings, stillages and shelving; control of ventilation, extraction and temperature; good housekeeping and stock management; storage of flammable liquids/compressed gases, oil, acids and adhesives; **storage to enhance sustainable use**

3 Understand the methods used when reporting and recording accidents and incidents

- *Principles*: why employers keep records of serious accidents, incidents and emergencies; responsibilities of competent persons; cost of accidents, e.g. direct, indirect, human consequences; trends, e.g. major causes, fatal and serious injury, methods of classification, statistics.
- *Recording and reporting procedures*: regulations on accident recording and reporting, e.g. RIDDOR, accident book, company procedures, **advantages of digital accessibility**; procedures to deal with near misses or dangerous occurrences

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the key features of relevant regulations on health and safety as applied to a working environment in two selected or given engineering organisations	**M1** explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in a given health and safety situation	**D1** assess the extent to which legislation and regulations are satisfied in a given health and safety situation
P2 describe the roles and responsibilities under current health and safety legislation and regulations of those involved in two selected or given engineering organisations		
P3 explain the key features of the relevant legislation and EU directives, with regard to environmental management	**M2** explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities, with regard to environmental management	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 explain the requirements for the safe disposal of waste		
P5 describe the methods used to identify hazards in a working environment	**M3** explain how hazards that become risks can be controlled	**D2** justify the methods used to deal with hazards in accordance with workplace policies and legal requirements
P6 carry out a risk assessment on a typical item/area of the working environment	**M4** explain the importance of carrying out all parts of a risk assessment in a suitable manner	
P7 suggest suitable control measures after a risk assessment has been carried out and state the reasons why they are suitable		
P8 suggest a suitable process or equipment to assist in moving different loads correctly and safely		
P9 describe the precautions needed for the safe storage of gases, oil, acids, adhesives and engineering materials		
P10 explain the principles that underpin reporting and recording accidents and incidents		
P11 describe the procedures used to record and report accidents, dangerous occurrences or near misses.	**M5** explain how control measures are used to prevent accidents.	**D3** assess the potential costs and implications for the organisation and the individual as a result of an accident in the workplace.

Essential guidance for tutors

Assessment

Evidence of criteria can be collected from case studies, assignments and projects, which should enable learners to explore the application of legislation and regulations, and hazards and risks in the workplace.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require answers that demonstrate additional depth and/or breadth of treatment.

To achieve a pass, learners must demonstrate an understanding of health, safety and welfare issues as applied to engineering processes and companies. They will need to explain the key features of legislation and regulations and describe a range of roles and responsibilities. They will understand the connection between hazard identification, risk assessment and accident prevention. Learners will carry out a risk assessment, suggest suitable controls and show they understand the principles and procedures for reporting and recording accidents and other occurrences relative to health and safety.

This unit could be assessed through three assignments. The first assignment could have a series of written tasks. The first task could ask learners to research and then explain the key features of relevant regulations as applied to two separate working environments (P1). It would be expected that at least four regulations should be considered across the two selected or given engineering organisations.

Another task could require them to describe the roles and responsibilities of those involved in the environments selected above (P2). The organisations selected could include learners' places of work, or a training workshop or machine shop environment.

A combination of one electrical and one mechanical type would be most appropriate.

The assignment should cover legislation and regulations. It is not expected that all the legislation and regulations listed in the content would be covered, just those applicable to the given context.

The roles and responsibilities of those involved could include employers, employees, the HSE and any one from the list of others in the unit content. A further task could then be used, asking learners to explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in one of these situations (M1). For the same situation, learners could carry out research to assess how the legislation and regulations are satisfied (D1). They might consider reviewing workplace incident/accident records/reports.

P3 and M2 could be achieved using a similar approach and applying this to environmental management. All responses could be in a written format, although for the pass criteria a presentation to the class or annotated poster could be used. In these cases it must be remembered that the presentation skills or poster design skills are not being assessed.

The second assignment could cover P4 to P9, along with the higher criteria M3, M4 and D2. The whole assignment could be based on a practical activity to produce a risk assessment on a typical item or area of a working environment. Again, this working environment could be learners' workplace or one from the centre's own workshops. Whichever item or area is chosen, it should have a range of hazards that can be identified, for example a machining operation or electrical assembly/wiring type activity could be used.

Written tasks would have to be set to give learners opportunities to achieve the explanations required for P4 to P9, M3 and M4, and the justification required for D2.

P7 could be achieved through an oral question and answer session after carrying out the risk assessment. A standard template can be used to capture the outcomes of the risk assessment as this is what would be found in normal company use. A witness statement/observation record could be used to show learner performance against the requirement of P6.

The final assignment could cover the remaining criteria P10, P11, M5 and D3, with a written task given for each. Learners should be given opportunities to investigate trends in an area they are interested in, which again may be an area similar to their workplace. The assignment should include a range of data given to each learner, some of which may have been researched and collected during the delivery of this part of the unit content.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Health and Safety Legislation and Regulations	A written activity requiring learners to explain the key features of relevant legislation and regulations and describe the roles and responsibilities of management and the personnel involved.	A report containing written responses about the key features, responsibilities and management of health and safety legislation and regulations set in a relevant context for learners.
P4, P5, P6, P7, P8, P9, M3, M4, D2	Controlling Hazards and Risks in the Workplace	A practical activity to carry out a risk assessment, plus a written report and oral questioning.	A report, carried out under controlled conditions, describing the methods used to identify hazards and how hazards become risks. A written risk assessment of a typical working environment. A report with written responses that identify control measures and their justification. A record of observation by the tutor of the learner's practical risk assessment.

Criteria covered	Assignment title	Scenario	Assessment method
P10, P11, M5, D3	Reporting and Recording Accidents and Incidents	A written activity requiring learners to explain principles of reporting accidents, incidents and near misses.	A report, carried out under controlled conditions, explaining reporting accidents, incidents and near misses.

Essential resources

Learners will require access to a wide range of safety literature. Ideally, the centre will be able to provide access to health and safety legislation and learning materials on DVD.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Health and Safety Executive – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Health and Safety Executive – *Management of Health and Safety at Work* (HSE Books, 2000) ISBN 9780717624881

Health and Safety Executive – *Health and Safety in Engineering Workshops* (HSE Books, 2004) ISBN 9780717617173

Websites

HSE www.hse.gov.uk

Unit 2: Communications for Engineering Technicians

Level:	**3**
Unit type:	**Mandatory**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The ability to communicate effectively is an essential skill in all aspects of life. The usual methods of communication – speaking, reading and writing – receive considerable attention and learning time during all stages of education.
For engineers, these skills are of no less importance, but there are further complications with the need to also convey technical information such as scale, perspective and standards of working.

The drive towards greater use of information and communication technology (ICT) is very much a part of modern life and this again is certainly the case for engineering. The engineering industry is in the front line of working towards paperless communication methods, for example the electronic transfer of data from the concept designer straight to the point of manufacture.

This unit will give a foundation for employment in a wide range of engineering disciplines (for example manufacturing, maintenance, communications technology), in addition to giving a foundation for further study. It aims to develop learners' ability to communicate using a diverse range of methods. These include visual methods, such as drawing and sketching, and computer-based methods, such as two-dimensional (2D) computer-aided design (CAD) and graphical illustration packages. It will also develop learners' ability to write and speak in a framework of technology-based activities, using relevant and accurate technical language appropriate to the task and the audience.

The unit will introduce learners to a variety of skills and techniques to obtain and use information, for example the presentation of technical reports, business and technical data and the use of visual aids for presentations. Learners will consider how to make best use of ICT in technological settings that are relevant to their programme of study or area of employment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information

2 Be able to use verbal and written communication skills in engineering settings

3 Be able to obtain and use engineering information

4 Be able to use information and communication technology (ICT) to present information in engineering settings.

Unit content

1 Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information

Interpret: obtain information and describe features, e.g. component features, dimensions and tolerances, surface finish; identify manufacturing/assembly/ process instructions, e.g. cutting lists, assembly arrangements, plant/process layout or operating procedures, electrical/electronic/communication circuit requirements; graphical information used to aid understanding of written or verbal communication, e.g. illustrations, technical diagrams, sketches

Engineering sketches/circuit/network diagrams: freehand sketches of engineering arrangements using 2D and 3D techniques, e.g. components, engineering plant or equipment layout, designs or installations; electrical/ electronic circuit diagrams, system/network diagrams; use of common drawing/circuit/network diagram conventions and standards, e.g. layout and presentation, line types, hatching, dimensions and tolerances, surface finish, symbols, parts lists, circuit/component symbols, use of appropriate standards (British (BSI), International (ISO))

2 Be able to use verbal and written communication skills in engineering settings

Written work: note taking, e.g. lists, mind mapping/flow diagrams; writing style, e.g. business letter, memo writing, report styles and format, email, fax; proofreading and amending text; use of diary/logbook for planning and prioritising work schedules; graphical presentation techniques, e.g. use of graphs, charts and diagrams **using file sharing/synchronisation tools, e.g. online documents that can be shared/edited by multiple users**

Verbal methods: speaking, e.g. with peers, supervisors, use of appropriate technical language, tone and manner; listening, e.g. use of paraphrasing and note taking to clarify meaning; impact and use of body language in verbal communication; **differences when using digital devices and platforms, e.g. mobile phones, videoconferencing**

3 Be able to obtain and use engineering information

Information sources: non-computer-based sources, e.g. books, technical reports, institute and trade journals, data sheets and test/experimental results data, manufacturers' catalogues; computer-based sources, e.g. inter/intranet, DVD-based information (manuals, data, analytical software, manufacturers' catalogues), spreadsheets, databases, **importance of using devices and settings that are digitally secure to reduce the risks when handing information/data**

Use of information: e.g. for the solution of engineering problems, for product/ service/topic research, gathering data or material to support own work, checking validity of own work/findings, **making use of digital tools and techniques to enhance efficiency when problem solving, e.g. for fault finding, when analysing data**

4 Be able to use information and communication technology (ICT) to present information in engineering settings

Software packages: word processing; drawing, e.g. 2D CAD, graphics package; data handling and processing, e.g. database, spreadsheet, presentation package, simulation package such as electrical/electronic circuits, plant/process systems; communication, e.g. email, inter/intranet, video conferencing, optical and speech recognition system

Hardware devices: computer system, e.g. personal computer, network, plant/process control system; input/output devices, e.g. keyboard, scanner, optical/speech recognition device, printer, plotter, **mobile phone**

Present information: report that includes written and technical data, e.g. letters, memos, technical product/service specification, email, tabulated test data, graphical data; visual presentation, e.g. overhead transparencies, charts, computer-based presentations (PowerPoint)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 interpret an engineering drawing/circuit/ network diagram		
P2 produce an engineering sketch/circuit/ network diagram		
P3 use appropriate standards, symbols and conventions in an engineering sketch/circuit/ network diagram		
P4 communicate information effectively in written work	**M1** evaluate a written communication method and identify ways in which it could be improved	**D1** justify choice of a specific communication method and the reasons for not using a possible alternative
P5 communicate information effectively using verbal methods		
P6 use appropriate information sources to solve an engineering task	**M2** review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected	
P7 use appropriate ICT software packages and hardware devices to present information.	**M3** evaluate the effectiveness of an ICT software package and its tools for the preparation and presentation of information.	**D2** evaluate the use of an ICT presentation method and identify an alternative approach.

Essential guidance for tutors

Assessment

Unit 4: Engineering Project could provide an excellent vehicle for an integrated approach to the assessment of this unit. The project work undertaken will require learners to use communication skills to interpret information, prepare sketches and drawings, give presentations, develop and use data sheets, produce technical reports and letters etc. Other units in the programme could also be used to provide effective and relevant learning and formative or even summative assessment opportunities. However, using *Unit 4: Engineering Project* for assessment has the advantage of providing a structured focus for the work and a coherent source of relevant evidence.

To achieve a pass, learners should interpret (P1) and produce (P2) engineering sketches (2D and 3D)/circuit/network diagrams and sketches. This will need to be at a level sufficient for them to understand and communicate technical information. This must include identification and use of appropriate standards, symbols and conventions (P3). The use of sketches/circuit/network diagrams in the criteria P1 and P2 is intended to indicate a choice that will depend on the focus of the learning programme in which this unit is being delivered. For example, a learner on a mechanical programme is likely to choose to interpret and produce sketches of components, while a learner studying electrical/electronics is more likely to interpret and produce circuit diagrams.

A single assessment activity could be used to link and capture evidence for the first three pass criteria (P1, P2 and P3). The activity would need to ensure that learners had an opportunity to obtain information, describe features, identify instructions and make use of graphical information (P1). For example, the task could be to work with written operating instructions that include supporting diagrams and sketches (2D and 3D). From the initial investigation, the activity could then require learners to produce their own drawing and sketches (P2). The criterion P3 would need to be applied to both the interpretation (identify) and the production (use) of their working document.

Learners should use written (P4) and verbal (P5) communication methods. The written work must include evidence of note taking, the ability to use a specific writing style, proofread and amend text, use a diary/logbook and use graphical presentation techniques. It might be that all of these will not necessarily occur in a single task/activity. If not, it would be acceptable for a number of pieces of assessment evidence to be brought together to meet this criterion.

The use of verbal methods (P5) will require learners to demonstrate speaking and listening skills and an understanding of the impact and use of appropriate body language. The evidence for this should come from one task/activity so that all three aspects are being dealt with at the same time. This could be a meeting with either peers and/or a supervisor, or could come from a presentation delivered by the learner to a group.

It would be important to ensure that the learner had to take questions from the group to enable the tutor to capture evidence of their ability to listen. The evidence for this criterion is likely to be a tutor observation record or witness statement.

P6 can be assessed using any structured activity that requires learners to identify and use appropriate information sources to solve an engineering task. It is essential that the information comes from both computer-based and non-computer-based sources. The evidence for this criterion could be as simple as suitably referenced work (a bibliography would not be sufficient). However, it would be preferable to have a record of the original source and a hard copy, annotated to show the information identified and used for the task (or at least an example of this process).

The final pass criterion (P7) could be assessed using any relevant tasks that require learners to select and use appropriate ICT software packages and hardware devices to present information. It is essential that the task or tasks chosen for this criterion give learners opportunities to use appropriate software to cover all the ICT applications listed in the content, i.e. there must be evidence of learners' selection and use of ICT for word processing, drawing, data handling and communication (such as email). The requirement for hardware devices is limited to the choice and use of a computer system and relevant input/output devices that would be needed for the task carried out. It is expected that the range of information presented using ICT will include a technical report and visual presentation material, for example overhead transparencies, chart, computer-based presentation (PowerPoint).

As already suggested, *Unit 4: Engineering Project* could provide an excellent vehicle for assessment of this unit since it could provide a central focus and therefore a source of coherent assessment evidence. Any alternatives should try to establish a similar coherence and avoid fragmentation of the pass criteria wherever possible.

To achieve a merit, learners should evaluate a written communication method and identify ways in which it could be improved (M1). This could be learners' own written work or the written work of someone else. The important aspect of this criterion is the learners' ability to use their skills and understanding of communication methods to appraise the work and identify enhancements.

In addition, learners will need to review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected (M2). This criterion is about reflection and the need to carefully consider, measure and express the value (or not) of other people's work as a source of information. Learners need to have identified both non-computer-based and computer-based information sources for P6 and it is this material that they should be reviewing for M2. Achievement might well be implicit if the task undertaken for P6 has reached a satisfactory solution. However, the expected evidence for this criterion would be a copy of the source material used, suitably annotated to explain its value or why it has been rejected.

Finally, merit criterion M3 requires learners to evaluate an ICT software package and its tools for the preparation and presentation of information. This criterion requires learners to have taken time to reflect on their work and consider the use of software tools available (for example good/consistent use of font size/colour, alignment of text, positioning on the page, use of automated labels, legends and titles for graphs).

To achieve a distinction, learners should justify their choice of a specific communication method and the reasons for not using a possible alternative (D1). This could be any communication method that the learner has chosen to use (for example drawings, written, verbal).

It does require learners to have considered at least one possible alternative during the initial selection of the method used. Learners will therefore need to be briefed to collect evidence of this selection process, which might otherwise be lost or ignored (for example initial outlines/drafts, notes of any consultation with others on method to be employed). The key issue for this criterion is learners' ability to reflect and evaluate. At pass level, learners will have shown their ability to communicate information effectively and, at merit, to be critical of the content of their own or other people's work. At distinction level, they should be critical of the choice of communication method used.

D2 requires learners to evaluate their use of an ICT presentation method and identify an alternative approach. This criterion is about the method of presentation and not the method of communication. It also has a direct link with related pass (P7) and merit (M3) criteria. At pass, learners need to use ICT to present information and, at merit, to evaluate the effectiveness of the presentation.
For D2, learners should consider the overall approach taken. For example, could a word-processed technical report have been presented using a computer-based presentation package, such as PowerPoint, including automated routines and animated graphics or video clips? The evidence for this is likely to be a written evaluation. A rough outline illustrating their identified alternative approach or even a small section of the original reworked using an alternative approach could be used to support the written evaluation.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and P3	Communicating Technical Information	Explore a product/circuit/ network and interpret and prepare appropriate engineering sketches/circuit/ network diagrams.	A written report providing the learner's interpretation of the information and features found. Engineering sketches/circuit/ network diagram prepared by the learner.
P4, P5, M1 and D1	Writing, Talking and Listening	A series of tasks focused on written work and verbal communication methods.	A portfolio of evidence containing examples of note taking, writing styles, use of diary/logbook and use of graphical presentation techniques. Tutor observation of speaking, listening and use of body language.
P6, M2	Finding and Using Information	Solving an engineering problem through research and use of information.	A written report with suitable reference to the range of sources found and used, including non-computer-based and computer-based resources.

Criteria covered	Assignment title	Scenario	Assessment method
P7, M3, D2	The Use of ICT in Engineering	Presenting engineering information using ICT.	A written report on the selection and use of computer hardware devices. A portfolio of evidence of the use of word processing, drawing, data handling and communication software packages to present engineering information.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be given a variety of sample written materials (letters, memos, technical reports, data sheets, catalogues) and sketches. Centres will need to provide access to appropriate presentation and graphics software (for example Microsoft PowerPoint, Visio), spreadsheet/database software (for example Microsoft Excel/Access) and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 3: Mathematics for Engineering Technicians

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

One of the main responsibilities of engineers is to solve problems quickly and effectively. This unit will enable learners to solve mathematical, scientific and associated engineering problems at technician level. It will also act as a basis for progression to study other units, both in the qualification, such as *Unit 6: Further Engineering Mathematics*, and at BTEC Higher National level.

This unit enables learners to build on knowledge gained at GCSE and use it in a more practical context for their chosen discipline. Learning outcome 1 will develop learners' knowledge and understanding of algebraic methods, from a look at the use of indices in engineering to the use of the algebraic formula for solving quadratic equations. Learning outcome 2 involves the introduction of the radian as another method of angular measurement, the shape of the trigonometric ratios and the use of standard formulae to solve problems involving surface areas and volumes of regular solids. Learning outcome 3 requires learners to represent statistical data in a variety of ways and calculate the mean, median and mode. Finally, learning outcome 4 is intended as a basic introduction to the arithmetic of elementary calculus.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use algebraic methods

2 Be able to use trigonometric methods and standard formulae to determine areas and volumes

3 Be able to use statistical methods to display data

4 Be able to use elementary calculus techniques.

Unit content

1 Be able to use algebraic methods

Indices and logarithms: laws of indices $a^m \times a^n = a^{m+n}$, $\frac{a^m}{a^n} = a^{m-n}$, $(a^m)^n = a^{mn}$; laws of logarithms: $\log A + \log B = \log AB$, $\log A^n = n\log A$, $\log A - \log B = \log \frac{A}{B}$; common logarithms (base 10), natural logarithms (base e), exponential growth and decay.

Equations and graphs: linear equations, e.g. $y = mx + c$; straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph $y = ax^2 + bx + c$; experimental data, e.g. Ohm's law; pair of simultaneous equations in two unknowns (two linear or one linear and one quadratic)

Factorisation and quadratics: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor, e.g. $ax + ay$, $a(x+2) + b(x+2)$; by grouping, e.g. $ax - ay + bx - by$; quadratic expressions, e.g. $a^2 + 2ab + b^2$; roots of an equation, e.g. quadratic equations with real roots by factorisation, and by the use of formula

2 Be able to use trigonometric methods and standard formulae to determine areas and volumes

Circular measure: radian; conversion of degree measure to radians and vice versa; angular rotations (multiples of π radians); problems involving areas and angles measured in radians; length of arc of a circle $s = r\theta$; area of a sector $A = \frac{1}{2}r^2\theta$

Triangular measurement: functions (sine, cosine and tangent); sine/cosine wave over one complete cycle; graph of $\tan A$ as A varies from 0° and 360° confirming $\tan A = \frac{\sin A}{\cos A}$; values of the trigonometric ratios for angles between 0° and 360°; periodic properties of the trigonometric functions; the sine and cosine rule; practical problems, e.g. calculation of the phasor sum of two alternating currents, resolution of forces for a vector diagram

Mensuration: standard formulae to solve surface areas and volumes of regular solids, e.g. volume of a cylinder $V = \pi r^2 h$, total surface area of a cylinder $TSA = 2\pi rh + 2\pi r^2$, volume of sphere $V = \frac{4}{3}\pi r^3$, surface area of a sphere $SA = 4\pi r^2$, volume of a cone $V = \frac{1}{3}\pi r^2 h$, curved surface area of cone $CSA = \pi rl$

3 Be able to use statistical methods to display data

Data handling: data represented by statistical diagrams, e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table; variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves; **use of spreadsheets**

Statistical measurement: arithmetic mean; median; mode; discrete and grouped data.

4 Be able to use elementary calculus techniques

Differentiation: differential coefficient; gradient of a curve $y = \mathrm{f}(x)$; rate of change; Leibniz notation $\left(\frac{\mathrm{d}y}{\mathrm{d}x}\right)$; differentiation of simple polynomial functions, exponential functions and sinusoidal functions; problems involving evaluation, e.g. gradient at a point.

Integration: integration as reverse of differentiating basic rules for simple polynomial functions, exponential functions and sinusoidal functions; indefinite integrals; constant of integration; definite integrals; limits; evaluation of simple polynomial functions; area under a curve, e.g. $y = x(x - 3)$, $y = x^2 + x + 4$

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 manipulate and simplify three algebraic expressions using the laws of indices and two using the laws of logarithms		
P2 solve a linear equation by plotting a straight-line graph using experimental data and use it to deduce the gradient, intercept and equation of the line	**M1** solve a pair of simultaneous linear equations in two unknowns	**D1** solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P3 factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	**M2** solve one quadratic equation by factorisation and one by the formula method	
P4 solve circular and triangular measurement problems involving the use of radian, sine, cosine and tangent functions		
P5 sketch each of the three trigonometric functions over a complete cycle		
P6 produce answers to two practical engineering problems involving the sine and cosine rule		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 use standard formulae to find surface areas and volumes of regular solids for three different examples respectively		
P8 collect data and produce statistical diagrams, histograms and frequency curves		
P9 determine the mean, median and mode for two statistical problems		
P10 apply the basic rules of calculus arithmetic to solve three different types of function by differentiation and two different types of function by integration.	**M3** apply the rules for definite integration to two engineering problems that involve summation.	**D2** apply graphical methods to the solution of two engineering problems involving exponential growth and decay, analysing the solutions using calculus.

Essential guidance for tutors

Assessment

The centre's assessment strategy used will need to cover all the learning outcomes and associated pass criteria but not necessarily all the topics included in the unit content.

Criterion P1 could be assessed in the form of a short written test and could possibly also include criterion P3.

P2 could be assessed through an assignment using data from *Unit 56: Electrical and Electronic Principles*, which ideally would be delivered concurrently with this unit.

If this is not possible, learners should be given a range of data sufficient for them to plot the graph and work out the gradient, intercept and the equation. Data forcing them to draw the line of best fit, as opposed to a set of points directly on the graphical line, might be most appropriate.

For P4, learners could be given a range of different values and assessed by an assignment or a short formal test. The problems given should collectively cover radian, sine, cosine and tangent functions. When considering the content part of this learning outcome, it is important that these problems give learners the opportunity to convert multiples of π radians to degrees and vice versa. The circular measurement problems also need to cover the length of an arc and area of a sector, as well as areas and angles measured in radians. Obviously the triangular measurement problems are more basic and only expect application of the three functions.

P5 requires learners to sketch each of the three trigonometric ratios, this is probably best done as a classroom exercise. Similarly, P6 could take the form of a written assignment where learners must produce answers to two practical engineering problems involving the sine and cosine rule (for example calculate the phasor sum of two alternating currents and evaluate the resultant and the angle between two forces).

Criterion P7 requires learners to calculate the surface areas and volumes for three different regular solids. This could be achieved through an assignment or perhaps by combining it with other criteria in a short formal test.

An assignment could be used for P8 where learners collect meaningful data (for example classification of workers within their company) and display this information using different graphical methods (for example bar charts). They also need to produce a histogram and plot frequency curves (for example resistance values of 100 resistors or external diameter of pins).

For P9, learners must provide evidence that they are able to determine and then explain the relevance of the mean, median and mode for a set of discrete and grouped data (for example time taken to produce components on a machine rounded to the nearest ten seconds and the 100 resistor values or diameters of pins from P8). This could be done by an assignment. P10 may be assessed through a short formal test, with learners being given a list of the standard differential coefficients and integrals to use.

For M1, learners will need to provide evidence that they can solve a pair of simultaneous linear equations in two unknowns (for example equations formed after the application of Kirchhoff's laws, power transmitted for different belt tensions in a mechanical system). This could be extended to D1 by the introduction of a quadratic equation to be solved simultaneously with a linear equation.

It would be appropriate to use the same assessment method and instrument as P2, possibly combining these two criteria as one assessment activity.

M2 could also be assessed by assignment as it requires learners to evaluate the roots of a quadratic equation by factorisation and by the formula method (for example evaluation of an equation formed after the realisation of a practical situation).

Both the criteria required to achieve D2 could be assessed through a written assignment. Learners need to apply the graphical methods to the solution of two engineering problems involving exponential growth and decay (for example growth of voltage in a capacitor, radioactive decay, application of Taylor's tool life equation $C = VT^n$) and then analyse the results by applying the appropriate method of differential calculus to check the results.

M3 requires learners to demonstrate that they can accurately evaluate two engineering problems involving definite integration (for example area under a velocity-time graph, area under a voltage-current graph).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Algebraic Methods	A written activity/test requiring learners to complete five tasks, one for each of the criteria.	A report containing written solutions to each of the five tasks carried out under controlled conditions.
P4, P5, P6, P7	Trigonometric Methods and Standard Formulae	A written activity requiring learners to use trigonometric methods and standard formula to determine areas and volumes.	A report containing the results of calculations and graphic evidence to support the use of trigonometric methods and standard formula for the determination of areas and volumes.
P8, P9	Statistical Methods	A written activity requiring learners to collect and display data using different graphical methods, also evaluate the mean, median and mode for a set of discrete and grouped data.	A report containing bar charts, pie charts and the results of calculations to determine the mean, median and mode for a set of discrete and grouped data.
P10, M3, D2	Calculus Techniques	A written activity requiring learners to produce calculations, graphical solutions and analysis to demonstrate use of calculus techniques.	A report containing the solutions to calculations, graphs and analysis of several calculus techniques. Carried out under controlled conditions.

Essential resources

For this unit, learners will need to possess an electronic scientific calculator and have access to software packages that support understanding of the principles and their application to engineering.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Fuller A, Greer A, Taylor G W – *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Websites

Science, Technology, Engineering and Mathematics Network www.stemnet.org.uk

Unit 4: Engineering Project

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 120

Unit introduction

In the modern world engineers and technicians are often involved fully or in part with identifying problems and finding suitable solutions. These engineering problems may range from a very large project, such as designing and building a hydroelectric power station, to smaller projects, such as designing and producing a paper clip to keep notes secure. No matter how large or small, these problems need to be project managed in order to find engineered solutions. This unit will provide learners with opportunities to present their own solutions to engineering projects and should enable them to feel confident in carrying out project work within their chosen engineering discipline at the technician level.

The unit aims to integrate the knowledge and skills learners have gained throughout their programme of study, into a major piece of work that reflects the type of performance expected of an engineering technician. The project is intended to develop the learner's ability to identify and plan a course of action and follow this through to produce a viable solution/outcome to an agreed specification and timescale.

The end result of the project could be an engineering product, device, service or process or a modification to an existing process or product. As in the real world, the outcome of the project and its presentation are very important, although this project is also about developing the process skills necessary to carry out the project. Throughout the project learners will need to apply the technical skills developed in the other units in the qualification.

Learning outcomes

On completion of this unit a learner should:

1 Be able to keep records, specify a project, agree procedures and choose a solution

2 Be able to plan and monitor a project

3 Be able to implement the project plan within agreed procedures

4 Be able to present the project outcome

Unit content

1 Be able to keep records, specify a project, agree procedures and choose a solution

Project records: written, e.g. notes, sketches, drawings; plans and modified plans; targets (setting, monitoring); use of planning tools, e.g. paper based, electronic; recording initial concepts, e.g. lists, notes, mind mapping, flow diagrams, sketches

Initial concepts: setting limits, e.g. time, cost, feasibility, need; value–cost–benefit analysis; generating ideas, e.g. group discussion, brainstorming, mind mapping; research techniques; lines of communication

Specification: type of project, e.g. product design, plant layout/maintenance, production methods or similar engineering-related topics; technical information, e.g. functionality, reliability, operational conditions, process capability, scale of operation, size, capacity, cost, style, ergonomics, present and future trends; health and safety issues; environmental and sustainability issues; quality standards and legislation; timescales; physical and human resource implications

Procedures: roles and responsibilities, e.g. decision making, budget planning and control; reporting methods; resource allocation and limits

Techniques: comparison methods, e.g. statistical, graphical, quality and resource requirements/limitations, process capability, fitness-for-purpose; analysis, e.g. cost–benefit, feasibility

2 Be able to plan and monitor a project

Planning: long-term planning, e.g. planners, charts and scheduling techniques (flow charts, Gantt charts, critical path methods, software packages); setting priorities; useful resource information, e.g. human and physical

Monitoring: monitor and record achievement, e.g. use of logbook and/or diary for record keeping (names, addresses, telephone numbers, meeting dates, email and other correspondence lists); use of logbook, e.g. for recording and analysing data or performance records, modifying/updating charts/planners, recording project goals and milestones, initial concepts, project solution technical decisions and information

3 Be able to implement the project plan within agreed procedures

Implement: proper use of resources, e.g. equipment, tools, materials, within agreed timescale, use of appropriate techniques for generating solutions, adapting project plan where appropriate, maintaining appropriate records

Checking solutions: use of evaluative and analytical techniques, e.g. graphs, matrix methods, statistics, Gantt charts, sequencing, scheduling, critical path methods, computer software packages

4 Be able to present the project outcome

Presentation: deliver a presentation to a small group, e.g. audience including known (peer group, tutors) and unknown (actual or simulated customer or client) participants; use of preparation techniques, presentation styles and techniques; preparation and use of visual aids, e.g. overhead transparencies, software packages and projectors, charts, models, video/DVD clips

Project report: logbook/diary record of all events; written technical report including relevant drawings/ circuit diagrams, sketches, charts, graphs etc appropriate to the project solution; use of information and communication technology (ICT) as appropriate to present findings, e.g. CAD, DTP, spreadsheets, databases, word processing

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 prepare and maintain project records from initial concepts through to solution that take account of and record changing situations	**M1** maintain detailed, concurrent records throughout the project that clearly show progress made and difficulties experienced	**D1** independently manage the project development process, seeking support and guidance where necessary
P2 prepare a project specification	**M2** use a wide range of techniques and selection criteria to justify the chosen option	**D2** evaluate the whole project development process, making recommendations for improvements.
P3 agree and prepare the procedures that will be followed when implementing the project	**M3** evaluate the project solution and suggest improvements	
P4 use appropriate techniques to evaluate three potential solutions and select the best option for development	**M4** present coherent and well-structured development records and final project report.	
P5 outline the project solution and plan its implementation		
P6 monitor and record achievement over the life cycle of the project		
P7 implement the plan and produce the project solution		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 check the solution conforms to the project specification		
P9 prepare and deliver a presentation to a small group outlining the project specification and proposed solution		
P10 present a written project report.		

Essential guidance for tutors

Assessment

Assessment of this unit will be based primarily on the learner's logbook/diary and other evidence of the work carried out and the processes adopted. Use will also be made of the learner's specification document, presentation and technical project report.

It should be noted that the logbook/diary is intended to be a working document and should contain the learner's notes and records as they are made at the time. It does not need to be a well-presented/neat document, but should be an effective tool to capture events and information as and when they happen and provide a useful source of reference for the learner when preparing their presentation and final written report. The tutor/project supervisor could also annotate the logbook/diary to indicate and record their observations and interactions with the learner, for example use of ICT, the logical formulation of ideas, use of technical knowledge, analysis and the outcomes/recommendations from these meetings.

Learners will need to include, possibly as an annexe (under separate cover) to the technical report, their own sketches, drawings/circuit diagrams, notes, lists, charts, raw calculations etc. to support their project report findings. Appropriate methods of presentation and management of the total evidence package should be discussed and used by the learner.

Learners may well be working closely with their own company/employer on their project and may be required to adopt the company's own 'house style' for the presentation of the report. This would of course be acceptable, since it will be in line with standard industry practice and report writing protocols and because it is the content of the report (i.e. its technical information, logical presentation methods and coherence) that is assessed, not its style.

Care should be taken to identify learners who may be genuinely terrified of standing in front of a group to make a presentation. The experience of making such a presentation is valuable and is recommended. However, as a minimum, learners only have to make an informal presentation to one or two people (which would reflect the typical minimum required in employment at this level) to achieve the unit.

As many of the activities undertaken by learners will be practical and skills-based, it is important to think about the method of capturing and presenting such evidence for assessment purposes. Often, witness testimony or records of tutor observation will be necessary. Copies of these will need to be placed in the final portfolio of evidence.

In order to achieve P1, learners will need to prepare and maintain project records from initial concepts through to solution that take account of and record changing situations. Evidence could be collected by tutors from the learner's logbook. It is suggested that learners prepare and submit a written project specification for scrutiny in order to provide evidence for the achievement of P2 (i.e. that they have produced a specification to an acceptable standard). As part of the project specification learners could also include written evidence for the procedures (P3) that they have agreed to follow, after discussion with their tutor, when implementing their project solution. Particular emphasis should be placed on ensuring that learners consider budgetary constraints and resource/time limitations. Evidence for the achievement of P4, concerning the evaluation of potential solutions and the techniques used to select the best option, might best be obtained from scrutiny of the learner's logbook, or again form part of the written project specification/interim report.

To achieve learning outcome 2 learners will need to outline their chosen project solution and plan for its implementation (P5), in addition to monitoring and recording achievement over the life cycle of the project (P6). Evidence of achievement will again be through the logbook. Tutors may also wish to record some of this performance as an observation record or use witness statements. The observations might well take place when learners are using computer-aided or manual planning tools in the learning centre. Additional evidence for P6 might come from the annotation of planning documentation or plans in the learner's logbook, that show the changing situations.

Learning outcome 3 is concerned primarily with the implementation of the project solution while adhering to agreed procedures (P7) and checking throughout the implementation phase that the solution produced conforms with the project specification (P8). The type of project chosen by the learner will, to a degree, dictate the methods used to provide evidence of achievement. Learners who are engaged on design/build or physical testing/modification type projects on a system or component, will be spending most of their project implementation phase in workshops and/or laboratories. Therefore, tutors will need evidence from observation records and from the physical solution itself. Evidence of achievement of P7 for those learners engaged in the production of a modified procedure/service, will provide evidence of achievement via their logbook records, presentation and final written report.

No matter what type of project learners choose, the primary source of evidence for achievement of P8 is likely to be the learner's logbook, where comparisons can be made with the agreed procedures to see whether or not learners abided by these procedures when producing their project solution.

In order to meet learning outcome 4, learners will need to prepare and deliver a presentation outlining their project specification and proposed solution to a small group (P9) and present a written project report with supporting documentation (P10). Evidence for P9 will be obtained from a combination of hard copies of the presentation, such as handouts, slides etc. and witness statements, together with the results of observation records from those present. The evidence for the achievement of P10 will come from the written report itself. Clear guidelines as to what is expected need to be given to learners well before the submission of their report.

To achieve M1, learners need to be able to work with greater autonomy and will have produced, and kept to, a workable plan. This will be demonstrated by their ability to maintain records throughout the project that are detailed, concurrent and clearly show progress made and the difficulties experienced. For M2 learners will need to have arrived at their project choice having used a wide range of techniques and from the use of these be able to justify their chosen option. The range of techniques used will need to show both statistical and graphical comparison methods for the potential solutions. Evidence will come from the learner's logbook and/or from the submitted written specification/interim report, (as was the case for achievement of P3).

Evidence for the achievement of M3 will come from observation records (particularly for design and build type solutions), scrutiny of logbook records and from the learner's reflections, written in the final report. It is expected that having evaluated their solution against the specification and/or from field evaluation and customer feedback, learners will then be able to suggest improvements that genuinely enhance the value of their project solution. Learners will have to present coherent and well-structured development records and final project report to achieve M4. The report structure is expected to adhere to standard technical report writing protocols, in order to achieve the criteria. The development records are likely to be included, as part of the learner's logbook and this should be submitted for final scrutiny, at the same time as the report.

To achieve a distinction, learners will have been able to work consistently towards a successful outcome and in doing so they will have independently managed the project development process, seeking support and guidance where necessary (D1). They will have shown the ability to reflect on their work throughout the project. Through this, they will have been able to evaluate the whole of the project development process and provide suggestions as to what they would have done differently to make improvements (D2). The evidence for both criteria is likely to come from the logbook and portfolio notes with the addition of witness statements and observation records for D1 and a separate written statement or statement in the final report, clearly evaluating the project making recommendations for improvements for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Prepare and Maintain Project Records	Tutor to scrutinise learner's project records and/or take account of observation records or witness testimony.	Through scrutiny of learner's logbook, observation records and/or witness testimony. Detailed and concurrent records need to be demonstrated to achieve M1.
P2, P3, P4, M2	Project Specification and Selection of Best Project Option	Tutor to consider submitted work and scrutinise learner records and/or take account of observation records or witness testimony.	Marked submission of project specification to acceptable standard, including written procedures to be adopted and evidence for the evaluation of solution. A wide range of statistical and graphical comparison methods demonstrated to meet criterion M2.
P5, P6	Production of Project Plan and Monitor Project over its Lifecycle	Tutor to scrutinise project records and take account of observation records or witness testimony	Scrutinise learner's long-term plans and logbook, identify and sanction achievement and changes made to plan, over the life of the project.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, M3	Implement the Project and Produce the Project Solution	Tutor to observe learner progress in the implementation of project plan and in the production of project solution.	Through scrutiny of learner's logbooks and observation records for implementation of project solution and written/ observational evidence for evaluation of solution in order to meet M3 criterion.
P9, P10, M4	Presenting the Project Outcome	Observation of oral presentation and consideration of written report and other project records and deliverables.	Through observation records and written oral presentation material and the marking of the final written report and consideration of all other project deliverables. Identification of well-structured and coherent development records and final report in order to meet M4.
D1, D2	Independently Manage and Critically Evaluate the Whole Project	Tutor/supervisor observation records or independent witness statements and take account of learners' project records and written submissions.	Scrutinise learner's logbook and take account of observation records (D1) and mark written submission (D2).

Essential resources

Learners will need access to a wide variety of physical resources, dependent on the type of project they pursue. Many of these resources are detailed within the other units in the qualification. There is also a need to provide some form of access to audio-visual aids as well as access to libraries and computer aided learning centres. Learners may also require access to workshops, laboratories and specialist catalogues and other documentation. Centres should also subscribe to engineering journals and stock other useful literature, specific to the branches of engineering being covered.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Lock D – *Project Management* (Gower Publishing, 2007) ISBN 9780566087721

Melton T– *Project Management Toolkit, the Basics for Project Success* (Butterworth-Heinemann, 2007) ISBN 9780750684408

Melton T– *Real Project Planning: Developing a Project Development Strategy* (Butterworth-Heinemann, 2007) ISBN 9780750684729

Project Management Institute – *A Guide to the Project Management Body of Knowledge* (Project Management Institute, 2009) ISBN 9781933890517

Smith N J – *Engineering Project Management* (Blackwell Publishing, 2007) ISBN 9781405168021

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 5: Calculus to Solve Engineering Problems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Many of the products, components and systems that we use have been subject to a rigorous design process that will have involved the use of calculations including mathematical calculus. During the design stage, it is important to be able to predict how a product will perform in service, for example the handling characteristics of a car or the power output from an electrical power supply. Also, investing time and resources in setting up manufacturing machinery and supply chains is very expensive – working with formulae and numbers on paper or using a computer involves a lot less cost and allows engineers to determine optimal (or near-optimal) solutions.

In this unit, learners will investigate how to apply differential and integral calculus methods to solve engineering problems. They will learn about the rules and procedures of calculus mathematics to obtain solutions to a variety of engineering problems. Learners will solve a complex problem from their specialist area of study and perhaps from a local organisation, by breaking it down into a series of linked manageable steps. Each step will be solved using calculus methods learned through investigation and practice. These mathematical skills are transferable and will be used to support learners' study of other topics in this qualification, for example in mechanical principles and electrical systems.

As an engineer, learners need to understand and develop the skills required to solve problems using calculus and other mathematical procedures. This unit will prepare them well for progressing to higher education to study for an engineering degree or a Higher National Diploma (HND). It will also help prepare learners for an apprenticeship or for employment in a range of engineering disciplines as a technician, and will help them work with professional engineers as part of a team working on cutting-edge products and systems.

Learning outcomes

On completion of this unit a learner should:

1 Examine how differential calculus can be used to solve engineering problems

2 Examine how integral calculus can be used to solve engineering problems

3 Investigate the application of calculus to solve a defined specialist engineering problem.

Unit content

1 Examine how differential calculus can be used to solve engineering problems

Functions, rate of change, gradient

- Function notation, e.g. $y = f(x)$, $s = f(t)$, $Q = f(t)$
- Types of functions: polynomial, trigonometric (sine, cosine), logarithmic and exponential.
- Routine functions are differentiated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
  - polynomial, e.g. $s = 5t^2 - 3t + 4$
  - trigonometric (sine, cosine), e.g. $y = \sin^2 4x$
  - logarithmic, e.g. $v = 8\log_e(5x)$
  - exponential, e.g. $y = 2e^{(3x+5)}$
- Non-routine functions are differentiated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
  - polynomial, e.g. $I = \frac{z+3}{5-4z}$
  - trigonometric (sine, cosine), e.g. $v = (\sin 2t \cos 3t)$
  - logarithmic, e.g. $y = 5x^2\log_e(3x)$
  - exponential, e.g. $v = 5e^{3t}(2t^2 - 3)$
- Expanding or simplifying polynomial functions.
- Rate of change of a function.
- Graphical representation of a function.
- Gradient of a function – graphically by tangent.
- Time-based functions, e.g. velocity, charge rate, energy transfer.

Methods of differentiation

- Gradient of a function.
- Small change in a quantity.
- Differentiation from first principles to produce the limiting value (derivative) of a simple power function, e.g. $y = 2x^2$
- Leibniz notation $\left(\frac{dy}{dx}\right)$ or representing the derivative of a function.
- Engineering notation for the derivative, e.g. $\left(\frac{ds}{dt}\right)$, $\left(\frac{dQ}{dt}\right)$
- Independent variable and the coding method 'with respect to' (w.r.t.).
- Differentiation by standard results ($y = ax^n$, where $\frac{dy}{dx} = nax^{(n-1)}$)
- The derivatives of algebraic (power), trigonometric (sine, cosine), logarithmic and exponential functions (ax^n, $\sin ax$, $\cos ax$, $\log_e(ax)$, e^{ax})
- Product and quotient rules: $\frac{dy}{dx} = v\frac{du}{dx} + u\frac{dv}{dx}$, $\frac{dy}{dx} = \frac{\left(v\frac{du}{dx} - u\frac{dv}{dx}\right)}{v^2}$

- Function of a function (chain rule) method.
- Substitution method.

Numerical value of a derivative

- Substitution of numerical values into the expression for the derivative.
- Instantaneous gradient at a point on a curve.
- Positive, negative and zero values for gradients.
- Gradient values obtained analytically and graphically.
- Engineering examples of rates of change, e.g. velocity/acceleration of a moving object, rate of charge/discharge of a capacitor, heat flow, radioactive decay, cutting tool life, charge/discharge rate for an air receiver, hydraulic flow rates.

Second derivative and turning points

- Leibniz notation for the second derivative $\left(\frac{\mathrm{d}^2 y}{\mathrm{d}x^2}\right)$
- Second derivative of algebraic (polynomial) and trigonometric (sine, cosine) functions.
- Turning points on a function.
- Graphical representation of an algebraic function with two turning points, e.g. $y = x^3 - 5x^2 + 2x + 6$
- Maximum (max) and minimum (min) turning points, inflection point.
- Second derivative test for max/min points on a function.
- Numerical value of the dependent variable at the max/min points of a function.
- Engineering applications, e.g. maximising the volume of a container for a given surface area, minimising the cost of mass-producing components on a machine tool, resistance matching in electrical power circuits to achieve maximum power transfer.

2 Examine how integral calculus can be used to solve engineering problems

Integration as the reverse/inverse of differentiation

- Symbolic representation $\int (\ )\mathrm{d}x$
- Algebraic expressions and the constant of integration.
- Types of functions: polynomial, trigonometric (sine, cosine), reciprocal and exponential.
- Routine functions are integrated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
  - polynomial, e.g. $\int \left(x^2 - 3x + 4\right)\mathrm{d}x$
  - trigonometric (sine, cosine), e.g. $\int \left(\sin 5\theta - 3\cos 4\theta\right)\mathrm{d}\theta$
  - reciprocal, e.g. $\int \left(\frac{3}{x}\right)\mathrm{d}x$
  - exponential, e.g. $\int \left(e^{3t}\right)\mathrm{d}t$

- Non-routine functions are integrated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
  - polynomial, e.g. $\int x^2\left(x^3+5\right)^2 \mathrm{d}x$
  - trigonometric (sine, cosine), e.g. $\int\left(\frac{\cos\theta}{1-\sin\theta}\right)\mathrm{d}\theta$
  - exponential, e.g. $\int \mathrm{e}^t \cos t \mathrm{d}t$
- Integration of common functions by standard results: ax^n, $\sin ax$, $\cos ax$, $\frac{1}{x}$, e^{ax}
- Indefinite integrals, constant of integration, initial conditions.
- Definite integrals – limits and square bracket notation.
- Integration by substitution.
- Integration by parts.

Integration as a summating tool

- Area under a curve from first principles – strip theory (approximate area of the elemental strip = $y\delta x$).
- Area under a curve as a summation between the upper and lower limits applied to the function.
- Mean value and root mean square (RMS) value of periodic functions.
- Engineering applications, e.g. work done by force producing displacement of an object, distance travelled by a vehicle, mean and RMS values of waveforms in electrical circuits.

Numerical integration

- Trapezoidal rule, mid-ordinate rule, Simpson's rule – comparison of methods in terms of their complexity and accuracy.
- Area under a curve obtained by integrating its function – comparison with the value obtained using Simpson's method.
- Numerical integration using a spreadsheet.
- Engineering applications, e.g. determination of mechanical, electrical and thermal energy.

3 Investigate the application of calculus to solve a defined specialist engineering problem.

Thinking methods

- Reductionism – considering a complex problem as the sum of its elements/parts or breaking a problem down into its parts.
- Synectics – creativity in mathematics, idea generating methods.
- Logical thinking – coherent and logical approach to solving a problem, e.g. Polya's problem-solving method.

Mathematical modelling of engineering problems

- Analytical methods.
- Numerical methods.
- 'What if' repetitive calculation, 'Goal Seek'.

- Benefits of using mathematical modelling, e.g. design viability, structural integrity of a product, accurate prediction of how a new product will perform in service, cost benefit of accurate simulation, e.g. in the design of aircraft.
- Engineering applications, e.g. mechanical design, stress analysis, performance calculation for an electronic or fluid-powered hydraulic circuit.

Problem specification and proposed solution

- Application of thinking methods to understand a given engineering problem.
- The use of mathematical modelling to devise a method to solve the given engineering problem.

Solution implementation

- The use of calculus and other appropriate mathematical methods to solve the given engineering problem.
- Reflection on the problem-solving process and the solution obtained, making refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 find the first and second derivatives for each type of given routine function **P2** find, graphically and analytically, at least two gradients for each type of given routine function **P3** find the turning points for given routine polynomial and trigonometric functions	**M1** find accurately the graphical and analytical differential calculus solutions and, where appropriate, turning points for each type of given routine and non-routine function and compare the results	**D1** evaluate, using technically correct language and a logical structure, the correct graphical and analytical differential calculus solutions for each type of given routine and non-routine function, explaining how the variables could be optimised in at least two functions
P4 find the indefinite integral for each type of given routine function **P5** find the numerical value of the definite integral for each type of given routine function **P6** find, using numerical integration and integral calculus, the area under curves for each type of given routine definitive function	**M2** find accurately the integral calculus and numerical integration solutions for each type of given routine and non-routine function, and find the properties of periodic functions	**D2** evaluate, using technically correct language and a logical structure, the correct integral calculus and numerical integration solutions for each type of given routine and non-routine functions, including at least two set in an engineering context

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 define a given engineering problem and present a proposal to solve it **P8** solve, using calculus methods and a mathematical model, a given engineering problem.	**M3** analyse an engineering problem, explaining the reasons for each element of the proposed solution **M4** solve accurately, using calculus methods and a mathematical model, a given engineering problem.	**D3** critically analyse, using technically correct language and a logical structure, a complex engineering problem, synthesising and applying calculus and a mathematical model to generate an accurate solution.

Essential guidance for tutors

Assessment

For P1, learners will apply the correct skills and methods when differentiating at least six given routine mathematical functions. Learners will correctly manipulate at least two polynomial, two trigonometric, one logarithmic and one exponential. Some functions will be sufficiently complex to enable apprentices to select and apply the correct method (product, quotient, function of a function and substitution) when producing first and second derivatives.

For P2, learners will demonstrate that they can find, graphically and analytically, at least two gradients for each type of function. For P3, for the polynomial and trigonometric functions, learners will calculate the turning points in the context of rates of change.

Overall, learners must demonstrate the correct use of method when differentiating functions and use the correct units. Minor arithmetic and scaling errors are acceptable. There will be evidence of simple checks to determine if numerical answers are 'reasonable'. Graphical presentation of functions and determination of their gradients can be done using a spreadsheet, provided that formulae are visible (printed out).

For P4, P5 and P6, learners will demonstrate mastery in the application of integral calculus methods to the solution of given problems using mathematical functions. Learners will correctly and efficiently manipulate eight routine and three non-routine functions.

Learners must present reasoned arguments when evaluating the use of analytical and numerical integration methods on at least two non-routine functions, for example, finding work done by expressing parameters as a definite integral and then repeating the operation using Simpson's rule.

Overall, the evidence will be logically structured, easy to understand by a third party with a mathematical background, who may or may not be an engineer, and there will be correct use of mathematical terminology. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Learners will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

For P7 and P8, learners will present the solution of a given complex engineering problem. The solution may not be complete, and there may be some inaccuracies or omissions, but there should be evidence of some proficiency in the use of differential and integral calculus. For example, learners solving a dynamics problem based on the acceleration and energy transfers involved with a moving vehicle would be expected to determine the maximum accelerating force and work done getting the vehicle up to given velocity.

Overall, the report should be logically structured and contain commentary on each stage of the solution. Rules of differentiation and integration should be applied correctly. It may contain some minor arithmetic errors, for example the value of a definite integral may be incorrect though the indefinite integral has been correctly deduced and the method chosen may not be optimal, for example expanding a function such as to integrate rather than using a substitution method. Minor 'carry through' errors are acceptable and there will be an appreciation of correct use of units, but there may be errors in their application.

For M1, learners will apply the correct skills and methods when producing the derivatives of functions and evaluating their gradients. Learners will correctly manipulate six routine and six non-routine functions (four polynomial, four trigonometric, two logarithmic and two exponential). Learners will compare the results, obtained graphically and analytically, for the two gradients being investigated, for example, there will be discussion about the numerical accuracy of the two methods.

Overall, learners' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. Limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For M2, learners will apply the correct skills and methods when producing the integrals of functions and determining the properties of periodic functions. Learners will correctly manipulate eight routine and three non-routine definitive functions. At least eleven functions in total, including a polynomial, a trigonometric and an exponential non-routine function.

Numerical integration will be accurately completed for four definitive routine functions.

Overall, learners' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. Limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For M3 and M4, learners will produce a reasoned analysis of a complex engineering problem, breaking it down into planned stages to obtain a solution. The method will apply differential and integral calculus appropriately at each stage, and the resulting solution will be of an acceptable degree of accuracy (as determined by the assessor).

Overall, the evidence will be logically structured, technically accurate and easy to understand. The planned method may contain some simplification and approximations to allow a solution to be calculated. Rules of differentiation and integration should be selected and applied correctly, for example using a substitution method to integrate terms rather than by expansion.

For D1, learners will demonstrate mastery in the application of differential calculus methods to the solution of given problems using mathematical functions. Learners will correctly and efficiently manipulate six routine and six non-routine functions.

A reasoned and balanced evaluation (argument) will be presented when considering how variables can be optimised for at least two non-routine functions related to an engineering context, for example determining the dimensions of a container of given volume so that its surface area is minimised, thereby minimising the material cost and environmental impact of the container.

Overall, the evidence will be logically structured and easy to understand by a third party with a mathematical background, who may or may not be an engineer. For example, learners will use mathematical terminology correctly and use relevant units when working with functions set in engineering contexts. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Learners will work to a specified numerical precision (as determined by the assessor), through the use of appropriate significant figures or decimal places.

For D2, learners will demonstrate mastery in the application of integral calculus methods to the solution of given problems using mathematical functions. Learners will correctly and efficiently manipulate eight routine and three non-routine functions.

Learners must present reasoned arguments when evaluating the use of analytical and numerical integration methods on at least two non-routine functions, for example finding work done by expressing parameters as a definite integral and then repeating the operation using Simpson's rule.

Overall, the evidence will be logically structured, easy to understand by a third party with a mathematical background, who may or may not be an engineer, and there will be correct use of mathematical terminology. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Learners will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

In order to achieve D3, learners will demonstrate mastery in the application of calculus methods to the solution of a complex engineering problem. The identified problem must be sufficiently complex to allow learners to apply thinking methods, mathematical modelling and both differential and integral calculus methods to the solution of the problem. Learners must show that they are able to break a complex problem down into a series of manageable steps through the application of reductionism and logical thinking.

Learners will produce a full specification for the problem, based on gathered and given information and use this to produce a proposal; there must be evidence that this has been done before they embark on the mathematical manipulations. Evidence for this could be supported by an assessor observation record.

Overall, the evidence will be straightforward to understand by a third party with a mathematical background, who may or may not be an engineer, and there will be correct use of mathematical terminology and the application of relevant units. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation. Learners will work to specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

Mathematical methods will be applied efficiently to the solution of the problem,
for example using a logical approach to the solution and/or efficient use of a spreadsheet for a numerical analysis.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Differential Calculus to Solve Engineering Problems	An activity requiring learners to apply differential calculus methods to solve an engineering problem.	A report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P4, P5, P6 M2, D2	Integral Calculus to Solve Engineering Problems	An activity requiring learners to apply integral calculus methods to solve an engineering problem.	A report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P7, P8, M3, M4, D3	Applying Calculus to Solve a Specialist Engineering Problem	An activity requiring learners to apply calculus methods to solve a specialist engineering problem.	A report containing the results of learners' analysis, planning and calculation; carried out under controlled conditions.

Essential resources

Learners will need access to maths support websites, spreadsheet software, e.g. www.mathcentre.ac.uk/students/topics

Indicative reading for learners

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A and Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 6: Further Engineering Mathematics

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Mathematics can be used to evaluate the intended and actual performance of a product or system at every stage of its life cycle. For example, mathematics may be used during the design of a product to determine whether it performs to specification. Statistics may be used during manufacturing processes as part of the quality control (QC) system and to determine the in-service reliability of a product. Statistics can also be used to evaluate the vast amounts of data that can be gathered about products and customers using mobile communications and the Internet of Things (IoT).

In this unit, learners will use algebraic techniques to solve engineering problems involving sequences, series, complex numbers and matrices. You will investigate the use of statistics as a data-processing and analysis tool, for example applying techniques used by a quality assurance engineer to monitor the output from a manufacturing process.

As a future engineer, you will need to understand and develop skills to solve problems using algebraic and statistical procedures. These are transferable skills and you will use them to support your study of other units in this course. This unit will help to prepare you for an apprenticeship or for employment in a range of engineering disciplines as a technician. You could also progress to a higher-level course, such as a Higher National Diploma (HND) or a degree in an engineering discipline.

Learning outcomes

On completion of this unit a learner should:

1 Examine how sequences and series can be used to solve engineering problems

2 Examine how matrices and determinants can be used to solve engineering problems

3 Examine how complex numbers can be used to solve engineering problems

4 Investigate how statistical and probability techniques can be used to solve engineering problems.

Unit content

1 Examine how sequences and series can be used to solve engineering problems

Arithmetic and geometric progressions

- Definitions:
  - sequence as an ordered collection of numbers a, b, c, d
  - progression as a sequence that increases in a particular pattern, i.e. there is a constant relationship between a number and its successor
  - series as the sum of the values in a sequence $a + b + c + d \ldots$
  - terminology – first term a, last term l, connection by law.
- Routine operations involve:
  - arithmetic progression (AP):
    common difference d
    general expression for a sequence in AP:
    a, $(a + d)$, $(a + 2d)$, $(a + 3d)$, … , $(a + nd)$
    nth term (last term) $l = a + (n - 1)d$
    sum of an AP to nth term (arithmetic series):

$$s = a + (a + d) + (a + 2d) + \ldots + (l - d) + l = \frac{1}{2}n(a + l)$$

  - geometric progression (GP):
    common ratio r
    general expression for a sequence in GP a, ar, ar^2, ar^3, …, ar^n
  - sum of a GP to nth term (geometric series):

$$s = a + ar + ar^2 + ar^3 + \ldots + ar^n = \frac{a(1 - r^n)}{(1 - r)}$$

    convergence
    sum to infinity.
- Non-routine operations involve:
  - engineering applications, e.g. lathe spindle speeds, cost of deep drilling, depreciation costs of capital equipment, gear box ratios, manufacturing estimation.

Binomial expansion

- Definitions:
  - binomial expression that takes the form $(a + b)^n$
  - binomial theorem: when n is a positive integer

$$(a+b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \frac{n(n-1)(n-2)}{3!}a^{n-3}b^3 + \ldots + b^n$$ (a finite series)

which can be written as $(a+b)^n = \sum_{k=0}^{k=n} {}_nC_k\, a^{n-k}b^k$ where ${}_nC_k = \frac{n!}{(n-k)!\,k!}$

alternative form $(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \ldots + x^n$

- binomial theorem when n is not a positive integer:

  $$(1+x)^n = 1+nx+\frac{n(n-1)}{2!}x^2+\frac{n(n-1)(n-2)}{3!}x^3+...+x^n$$ for $-1 < x < 1$ only

  (an infinite series)

- Routine operations involve:
  - construction of Pascal's triangle
  - expansion of $(a+b)^n$ for positive values of n using Pascal's triangle.
- Non-routine operations involve:
  - expansion of $(1+x)^n$ for non-positive integer values of n using the binomial theorem
  - calculation of the nth term using the binomial theorem
  - engineering applications, e.g. small errors, small changes, percentage changes, approximation of errors.

Power series

- Definitions:
  - a power series as $f(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + \ldots + a_nx^n$
  - a Taylor series as $f(x) =$

    $$f(a)+f'(a)(x-a)+\frac{f^2(a)}{2!}(x-a)^2+...+\frac{f^{(n)}(a)}{n!}(x-a)^n$$
- Routine operations involve:
  - a Maclaurin series as a Taylor series with $a = 0$
  - convergence and divergence
  - conditions for convergence and divergence.
- Non-routine operations involve:
  - numerical value for e using a power series
  - proof that $\frac{dy}{dx}(e^x) = e^x$ using series
  - engineering applications, e.g. error in area or volume for small error in measurement of length, oscillator frequency for an electrical circuit if components have small errors in their values.

2 Examine how matrices and determinants can be used to solve engineering problems

Matrices

- Definitions:
  - matrix type – element and order (row × column)
  - matrix terminology – element, row, column, order (row × column), equality, zero (null matrix), identity (unit) matrix, transpose, square, leading diagonal, triangular.
- Routine operations involve:
  - addition, subtraction, multiplication by a real number
  - inverse of a (2 × 2) matrix
  - solution of sets of simultaneous equations with two variables using inverse matrix methods.
- Non-routine operations involve:
  - multiplication of matrices

- solution of sets of simultaneous equations with two variables using Gaussian elimination.

Determinants

- Definitions:
  - the determinant of a matrix as a useful value that can be computed from the elements of a square matrix, denoted by $\det(A)$ or $|A|$
  - a singular matrix is one with the determinant $|A| = 0$
- Routine operations involve:
  - the determinant of a (2 × 2) matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $|A| = ad - bc$
  - the inverse of a two-dimensional matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using

    $$A^{-1} = \frac{1}{|A|}\begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$
- Non-routine operations involve:
  - the determinant of a (3 × 3) matrix $A = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$ using

    $$|A| = a\begin{pmatrix} e & f \\ h & i \end{pmatrix} - b\begin{pmatrix} d & f \\ g & i \end{pmatrix} + c\begin{pmatrix} d & e \\ g & h \end{pmatrix}$$
  - use of Cramer's rule to solve for sets of simultaneous equations with two variables
  - engineering applications, e.g. simultaneous linear equations with more than two variables (electrical circuits, vector arrays, machine cutter paths).

3 Examine how complex numbers can be used to solve engineering problems

Complex numbers

- Definitions:
  - algebraic form (Cartesian, rectangular notation): $(a + jb)$
  - real part, imaginary part, j notation, j-operator, powers of j
  - modulus: $|a + jb| = \sqrt{a^2 + b^2}$
  - argument: $\arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$
  - polar form $r\angle\theta$; θ is usually expressed in radians but may be in another angular measure
  - complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$
- Routine operations involve:
  - placement of complex numbers on an Argand diagram
  - addition and subtraction in rectangular form
  - multiplication by a constant coefficient
  - conversion between rectangular and polar forms ($r \to p$ and $p \to r$) using trigonometry and a scientific calculator
  - multiplication and division of complex numbers in polar form.

- Non-routine operations involve:
  - multiplication in rectangular form
  - division in rectangular form using the complex conjugate
  - de Moivre's theorem: $(r\angle\theta)^n = r^n\angle n\theta$
  - engineering applications, e.g. vectors, electrical circuit phasor diagrams, algebraic form (Cartesian, rectangular notation): $(a + jb)$
  - real part, imaginary part, j notation, j-operator, powers of j
  - modulus: $|a + jb| = \sqrt{a^2 + b^2}$
  - argument: $\arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$
  - polar form $r\angle\theta$; is usually expressed in radians but may be in another angular measure
  - complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$

4 Investigate how statistical and probability techniques can be used to solve engineering problems

Statistical techniques

- Routine operations involve:
  - discrete data, continuous data, ungrouped data, grouped data, rogue values
  - presentation of data: bar charts, pie charts, histograms, cumulative frequency curves
  - measures of central tendency (location): arithmetic mean, median, mode
  - measures of dispersion: variance, standard deviation, range and inter-percentile ranges
  - linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ represented graphically.
- Non-routine operations involve:
  - equation of linear regression line $y = mx + c$ where

$$m = \frac{N\sum_1^N (x_i y_i) - \sum_1^N (x_i)\sum_1^N (y_i)}{N\sum_1^N x_i^2 - \left(\sum_1^N x_i\right)^2} \text{ and } c = \overline{y} - m\overline{x}$$

$$\overline{x} = \frac{\sum_1^N x_i}{N} \text{ and } \overline{y} = \frac{\sum_1^N y_i}{N}$$

  - correlation coefficient using Pearson's correlation

$$r_{x,y} = \frac{N\sum_1^N x_i y_i - \sum_1^N x_i \sum_1^N y_i}{\sqrt{N\sum_1^N x_i^2 - \left(\sum_1^N x_i\right)^2} - \sqrt{N\sum_1^N y_i^2 - \left(\sum_1^N y_i\right)^2}}$$

- Use of spreadsheets and/or scientific calculators to calculate the equation of the line of regression and correlation coefficient, e.g. tabulating calculations, using trendline and CORREL() functions in a spreadsheet, or a standard scientific calculator.
- Use of spreadsheets and/or scientific calculators to identify the most appropriate type of regression line, e.g. linear, logarithmic, exponential or variable power.

Probability distributions

- Routine operations involve:
  - normal distribution – shape and symmetry, skew, tables of the cumulative distribution function, mean, variance
  - normal distribution curve – areas under it relating to integer values of standard deviation.
- Non-routine operations involve:
  - confidence intervals for normal distribution and probability calculations.

Statistical investigation

- The use of appropriate mathematical methods to solve the given engineering problem.
- Engineering applications, e.g. inspection and quality assurance, calculation of central tendencies and dispersion, forecasting, reliability estimates for components and systems, customer behaviour, condition monitoring and product performance.
- Reflection on the problem-solving process and the solution obtained, making refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 solve given problems using routine arithmetic and geometric progression operations	**M1** solve given problems accurately, using routine and non-routine arithmetic and geometric progression operations	**D1** evaluate, using technically correct language and a logical structure, engineering problems using non-routine sequence and series operations, while solving accurately all the given problems using routine and non-routine operations
P2 solve given problems using routine power series operations	**M2** solve given problems accurately, using routine and non-routine power series operations	
P3 solve given problems using routine matrices and determinant operations	**M3** solve given problems accurately, using routine and non-routine matrices and determinant operations	**D2** evaluate, using technically correct language and a logical structure, engineering problems using non-routine matrices, determinant and complex operations, while solving accurately all the given problems using routine and non-routine operations
P4 solve given problems using routine complex number operations	**M4** solve given problems accurately, using routine and non-routine complex number operations	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 solve an engineering problem using routine central tendency, dispersion and probability distribution operations	**M5** solve an engineering problem accurately, using routine and non-routine central tendency, dispersion and probability distribution operations, providing an explanation of the process	**D3** evaluate the correct synthesis and application of statistics and probability to solve engineering problems involving accurate routine and non-routine operations.
P6 solve an engineering problem using routine linear regression operations.	**M6** solve engineering problems accurately, using routine and non-routine regression operations, providing an explanation of the process.	

Essential guidance for tutors

Assessment

For P1 and P2, learners must demonstrate the correct use of routine operations (skills and methods) when working with given problems based on sequences and series.

Overall, minor arithmetic and scaling errors are acceptable, as are 'carry through' errors, provided that the basic method is sound. For example, a term in a sequence may be incorrectly calculated but the value used correctly in subsequent calculation of the series, affecting the final value. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For P3 and P4, learners must demonstrate the correct use of routine operations (skills and methods) when working on given problems based on matrices, determinants and complex numbers.

Overall, minor arithmetic errors are acceptable, as are 'carry through' errors, provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For P5 and P6, learners will present the solutions of engineering problems involving measures of central tendency, dispersion and probability distribution. Ideally, they will research their own problems but if this is not possible then they can be given to learners. The solutions may not be complete and there may be some inaccuracies or omissions but there should be evidence of some proficiency of method. Learners will apply the appropriate routine operations (skills and methods) needed to process statistical data. For example, when evaluating sampled dimensional data from a machining operation, learners will present data appropriately and determine routine values such as the mean and standard deviation for a sample but may not compare the values with historical data. They will tabulate measurements and present data in a scatter graph and they may estimate the line of regression graphically.

Overall, the report should be logically structured. It may contain some arithmetic errors that 'carry through', for example the value of the mean of a set of sampled dimensional data from a machining operation may be incorrect, but that value used correctly to find the standard deviation. The methods chosen may not be optimal but the chosen statistical methods should be applied correctly. Minor errors and omissions are acceptable. For example, the axis titles on a scatter graph may be missing units. There will be an appreciation of correct use of units but there may be errors or inconsistency in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For M1 and M2, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on sequences and series.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M3 and M4, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on matrices, determinants and complex numbers.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M5 and M6, learners will present accurate solutions for engineering problems related to measures of central tendency, dispersion and probability distribution, breaking them down into planned stages to obtain solutions. They will apply appropriate routine and non-routine operations (skills and methods) needed to process statistical data accurately. For example, tabulation of data, graphical presentation, accurate calculations of mean and standard deviation comparing measured values with historical data, accurately produced annotated scatter graph (with chart title, axis titles including units and gridlines) and calculation of line of regression and correlation coefficient for a linear relationship and regression line for a non-linear relationship.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor or appropriate for the chosen problems being solved. Solutions will contain an explanation of the process that will be logically structured, and the correct mathematical terminology and relevant units will be used. There may be limited number of minor errors or omissions in non-routine operations. For example, when evaluating sampled dimensional data from a machining operation, learners may determine the mean and standard deviation for a sample and find a degree of correlation between samples, but not draw conclusions from, the values.

To achieve D1, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving sequences and series. Where appropriate to the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to specified numerical precision, as specified by the assessor, through the use of appropriate significant figures.

For D2, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving matrices, determinants and complex numbers. Where appropriate with the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate they are able to work to specified numerical accuracy through the use of appropriate significant figures, as specified by the assessor.

In order to achieve D3, learners will demonstrate mastery in the application of the processing and evaluation of statistical data generated from engineering sources. The identified problems must be sufficiently complex to allow learners to apply both routine and non-routine operations (skills and methods) to their solution. For example, in terms of measures of central tendency and dispersion learners may evaluate one set of measured and four sets of equivalent historical data such as dimensional data from a machining operation or reliability data sourced from products in service. Before starting to process any data, learners will establish that the data sets are large enough to enable reliable analysis to be carried out. For regression, they will propose a theoretical relationship between two variables, collect data, calculate a mathematical relationship between dependent and independent variables using appropriate analytical and graphical methods, and reflect on the accuracy of the initial proposal for a linear and a non-linear relationship.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. There will be correct use of mathematical terminology and the application of relevant units. Learners will work to specified numerical precision, as determined by the assessor or that are appropriate for their chosen problems being solved, through the use of appropriate significant figures or decimal places. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation or standard form.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Sequences and Series to Solve Engineering Problems	An activity requiring learners to solve problems based on sequences and series.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P3, P4, M3, M4, D2	Matrices, Determinants and Complex Numbers to Solve Engineering Problems	An activity requiring learners to solve problems based on matrices, determinants and complex numbers.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P5, P6, M5, M6, D3	Statistical and Probability Techniques to Solve Engineering Problems	An activity requiring learners to solve engineering problems based on statistical data.	An informal report containing the results of learners' analysis and calculation of measured and supplied data; carried out under controlled conditions. Where appropriate, processing of statistical data can be done by spreadsheet.

Essential resources

For this unit, learners must have access to:

- maths support websites, e.g. www.mathcentre.ac.uk/students/topics
- spreadsheet software and/or a scientific calculator such as Casio FX-85GT.

Indicative reading for learners

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A and Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 7: Properties and Applications of Engineering Materials

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to select or specify them for applications in the engineering industry. This unit will give an understanding of the structures, classifications and properties of materials used in engineering and will enable learners to select materials for different applications.

The unit is appropriate for learners engaged in manufacturing and mechanical engineering, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials, some of which learners may not be familiar with initially.

This unit will enable learners to identify and describe the structures of metals, polymers, ceramics and composites and classify them according to their properties. Learners will describe the effects of processing on the behaviour of given materials. Smart materials whose properties can be altered in a controlled fashion through external changes – such as temperature and electric and magnetic fields – are also covered.

Learners will apply their understanding of the physical and mechanical properties of materials, design requirements, cost and availability to specify materials for given applications.

All materials have limits beyond which they will fail to meet the demands placed on them. The common modes of failure will be both demonstrated and explained to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the structure and classification of engineering materials

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

3 Be able to use information sources to select materials for engineering uses

4 Understand about the modes of failure of engineering materials.

Unit content

1 Know the structure of and classification of engineering materials

Atomic structure: element; atom, e.g. nucleus, electron; compound; molecule; mixture; bonding mechanisms, e.g. covalent, ionic, metallic

Structure of metals: lattice structure; grain structure; crystals; crystal growth; alloying, e.g. interstitial, substitutional; phase equilibrium diagrams, e.g. eutectic, solid solution, combination; intermetallic compounds

Structure of polymeric materials: monomer; polymer; polymer chains, e.g. linear, branched, cross-linked; crystallinity; glass transition temperature

Structure of ceramics: amorphous; crystalline; bonded

Structure of composites: particulate; fibrous; laminated

Structure of smart materials: crystalline; amorphous; metallic

Classification of metals: ferrous, e.g. plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous, e.g. aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys, e.g. aluminium-copper heat treatable – wrought and cast, non-heat-treatable – wrought and cast, copper-zinc (brass), copper-tin (bronze), nickel-titanium alloy

Classification of non-metals (synthetic): thermoplastic polymeric materials, e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials, e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics, e.g. glass, porcelain, cemented carbides; composites, e.g. laminated, fibre reinforced (carbon fibre, glass reinforced plastic (GRP)), concrete, particle reinforced, sintered; smart materials, e.g. electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals

Classification of non-metals (natural): e.g. wood, rubber, diamond

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness

Physical properties: density; melting temperature

Thermal properties: expansivity; conductivity

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel

Effects of processing thermoplastic polymers: polymer processing temperature; process parameters, e.g. mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing

Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; de-lamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets

Effects of post-production use: smart materials, e.g. impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity)

3 Be able to use information sources to select materials for engineering uses

Information sources: relevant standard specifications, e.g. British Standards (BS), European Standards (EN), International Standards (ISO); material manufacturers' and stockholders' information, e.g. data sheets, catalogues, websites, DVDs

Design criteria: properties, e.g. mechanical, physical, thermal, electrical and magnetic; surface finish; durability, e.g. corrosion resistance, solvent resistance, impact resistance, wear resistance

Cost criteria: initial cost, e.g. raw material, processing, environmental impact, energy requirements; processing, e.g. forming, machining, casting, joining (thermal, adhesive, mechanical); quantity; mode of delivery, e.g. bulk, just-in-time (JIT); recycling

Availability criteria: standard forms, e.g. sheet and plate, bar-stock, pipe and tube, sectional, extrusions, ingots, castings, forgings, pressings, granular, powder, liquid

4 Understand about the modes of failure of engineering materials

Principles of ductile and brittle fracture: effects of gradual and impact loading, e.g. tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces

Principles of fatigue: cyclic loading; effects of stress concentrations, e.g. internal, external; effects of surface finish; appearance of fracture surfaces

Principles of creep: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress

Tests: destructive, e.g. tensile, hardness, impact, ductility, fatigue, creep; non-destructive, e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual

Degradation processes: on metals, e.g. oxidation, erosion, stress corrosion; on polymers, e.g. solvent attack, radiation and ageing; on ceramics, e.g. thermal shock, sustained high temperature

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material		
P2 classify given engineering materials as either metals or non-metals according to their properties		
P3 explain mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context		
P4 explain the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials	**M1** explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 use information sources to select a different material for two given applications, using the criteria considered in the selection process	**M2** explain the criteria considered in the selection process	**D1** justify selection of an engineering material for one given application
P6 explain the principles of the modes of failure known as ductile/ brittle fracture, fatigue and creep	**M3** explain how two given degradation processes affect the behaviour of engineering materials	
P7 perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material	**M4** explain how one destructive and one non-destructive test procedure produces useful results.	**D2** evaluate the results of one test procedure.
P8 explain a different process of degradation associated with each of metals, polymers and ceramics.		

Essential guidance for tutors

Assessment

Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2 and P3 could be achieved by means of a written assignment following a combination of tutor-led practical and theory sessions and individual research. P2 would require the range of materials given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, an elastomer, one ceramic, one composite, one smart material and one natural material.

Achievement of P4 and M1 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with real engineering applications. For smart materials, they need to consider the effects on the properties of the materials' use after production. Examples here may be related to their change in properties from the effects of external stimuli. For example, when a force is applied to a piezoelectric material it produces an electric charge which can be used to trigger a car's airbag in the event of an accident. In many applications the behaviour is reversible, for example a colour change in response to a change in temperature or a variation in the viscosity of a liquid in response to the application of an electric or magnetic field. To satisfy P5, it is likely that learners would apply the knowledge and understanding gained in meeting criteria P1 to P4. Written responses would satisfy these criteria.

P7 could be met using a combination of practical and research activities involving tutor-led demonstrations of available laboratory tests. Learners could then carry out a series of tests and produce a written record of the test results. A witness statement could confirm the learner's involvement. Depending on available resources, it may be best to carry out the destructive test on the non-metallic material and the non-destructive test on the metallic material. This would allow a wider choice of tests for the latter. To achieve P6 and P8, learners could be given the opportunity to research modes of failure and degradation processes reflected in local conditions, for example a marine environment, or, for employed apprentices, failure and degradation pertinent to their companies' products.

To achieve the merit grade M1, learners will need to explain how the structure and properties of given materials will affect their behaviour in use. This evidence would be best demonstrated by a written task related to the activities carried out to meet P1, P2 and P3. For M2, learners should consider design, cost and availability criteria in their explanation. To satisfy M3, learners could produce a written explanation of the test procedures followed in P7 and the usefulness of the results. In producing evidence for some of this criterion it may be appropriate to include the responses to oral questions. However, centres should ensure that such questions and the responses are recorded for verification and also that they are not the sole source of evidence. M4 could be achieved through an extension of the task given for P8. The processes used in the explanation could be selected to meet local conditions or industrial applications.

To achieve distinction criterion D1, learners need to justify their selection of one of the materials used to satisfy P5, giving reasons why other materials considered for the application were not selected. To satisfy D2, learners are expected to complete a written task to evaluate the results of one of the tests used to meet P7 and M4.

The evidence would depend on the test used but it could include the mathematical results of a tensile test, the values of a hardness test or detailed information gained from a non-destructive test.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Structure and Classification of Engineering Materials	Questions relating to the structure and classification of the range of engineering materials.	A written report containing reasoned answers to the set questions.
P4, M1	Properties of Engineering Materials	Questions relating to the properties and behaviour of engineering materials.	A written report containing reasoned answers to the set questions.
P5, M2, D1	Selection of Engineering Materials	Selection of engineering materials for given applications.	A written report listing selection criteria, information sources and justification for selected materials.
P6, P8, M3	Failure and Degradation of Engineering Materials	Questions relating to the range of failure modes and degradation processes in engineering materials.	A written report containing reasoned answers to the set questions.
P7, M4, D2	Testing Engineering Materials	Carry out and report the results of destructive and non-destructive tests on engineering materials.	A written report containing an explanation of test procedure and evaluation of test results.

Essential resources

Centres will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Centres will also require access to equipment to conduct at least one destructive and one non-destructive test and related materials as specified in the unit content.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Higgins R – *Materials for Engineers and Technicians* (Routledge, 2014) ISBN 9781138778757

Timings R L – *Engineering Materials, Volume 1* (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials, Volume 2* (Longman, 2000) ISBN 9780582404663

Tindell H –*Engineering Materials, Crowood Metalworking Guides* (The Crowood Press, 2014) ISBN 9781847976796

Unit 8: Mechanical Principles of Engineering Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The use and application of mechanical systems is an essential part of modern life. The design, manufacture and maintenance of these systems are the concern of engineers and technicians who must be able to apply a blend of practical and theoretical knowledge to ensure that systems work safely and efficiently. Science underpins all aspects of engineering and a sound understanding of its principles is essential for anyone seeking to become an engineer.

Learners are introduced to the behaviour of loaded engineering materials and the analysis of a range of static engineering systems. They will gain an understanding of dynamic systems through the application of Newtonian mechanics. Finally, they will deal with the effects of heat transfer, the expansion and compression of gases and the characteristic behaviour of liquids at rest and in motion.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to determine the effects of loading in static engineering systems

2 Be able to determine work, power and energy transfer in dynamic engineering systems

3 Be able to determine the parameters of fluid systems

4 Be able to determine the effects of energy transfer in thermodynamic systems.

Unit content

1 Be able to determine the effects of loading in static engineering systems

Non-concurrent coplanar force systems: graphical representation, e.g. space and free body diagrams; resolution of forces in perpendicular directions, e.g. $F_x = F\cos\theta$, $F_y = F\sin\theta$; vector addition of forces, resultant, equilibrant, line of action; conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$)

Simply supported beams: conditions for static equilibrium; loading (concentrated loads, uniformly distributed loads, support reactions)

Loaded components: elastic constants (modulus of elasticity, shear modulus); loading (uniaxial loading, shear loading); effects, e.g. direct stress and strain including dimensional change, shear stress and strain, factor of safety

2 Be able to determine work, power and energy transfer in dynamic engineering systems

Kinetic parameters: e.g. displacement (s), initial velocity (u), final velocity (v), uniform linear acceleration (a)

Kinetic principles: equations for linear motion with uniform acceleration

$v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$

Dynamics parameters: e.g. tractive effort, braking force, inertia, frictional resistance, gravitational force, momentum, mechanical work ($W = Fs$), power dissipation (average power = $\frac{W}{t}$, instantaneous power = Fv), gravitational potential energy ($PE = mgh$), kinetic energy ($KE = \frac{1}{2}mv^2$)

Dynamic principles: Newton's laws of motion, D'Alembert's principle, principle of conservation of momentum, principle of conservation of energy

3 Be able to determine the parameters of fluid systems

Thrust on a submerged surface: hydrostatic pressure, hydrostatic thrust on an immersed plane surface ($F = \rho gAx$); centre of pressure of a rectangular retaining surface with one edge in the free surface of a liquid

Immersed bodies: Archimedes' principle; fluid, e.g. liquid, gas; immersion of a body, e.g. fully immersed, partly immersed; determination of density, e.g. using floatation, specific gravity bottle

Flow characteristics of a gradually tapering pipe: e.g. volume flow rate, mass flow rate, input and output flow velocities, input and output diameters, continuity of volume and mass for incompressible fluid flow

4 Be able to determine the effects of energy transfer in thermodynamic systems

Heat transfer: heat transfer parameters, e.g. temperature, pressure, mass, linear dimensions, time, specific heat capacity, specific latent heat of fusion, specific latent heat of vaporisation, linear expansivity; phase, e.g. solid, liquid, gas; heat transfer principles, e.g. sensible and latent heat transfer, thermal efficiency and power rating of heat exchangers; linear expansion

Thermodynamic process equations: process parameters, e.g. absolute temperature, absolute pressure, volume, mass, density; Boyle's law (pV = constant), Charles' law ($\frac{V}{T}$ = constant), general gas equation ($\frac{pV}{T}$ = constant), characteristic gas equation ($pV = mRT$)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 calculate the magnitude, direction and position of the line of action of the resultant and equilibrant of a non-concurrent coplanar force system containing a minimum of four forces acting in different directions	**M1** calculate the factor of safety in operation for a component subjected to combined direct and shear loading against given failure criteria	
P2 calculate the support reactions of a simply supported beam carrying at least two concentrated loads and a uniformly distributed load		
P3 calculate the induced direct stress, strain and dimensional change in a component subjected to direct uniaxial loading and the shear stress and strain in a component subjected to shear loading		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 solve three or more problems that require the application of kinetic and dynamic principles to determine unknown system parameters	**M2** determine the retarding force on a freely falling body when it impacts on a stationary object and is brought to rest without rebound, in a given distance	**D1** compare and contrast the use of D'Alembert's principle with the principle of conservation of energy to solve an engineering problem
P5 calculate the resultant thrust and overturning moment on a vertical rectangular retaining surface with one edge in the free surface of a liquid		**D2** evaluate the methods that might be used to determine the density of an irregular shaped solid material.
P6 explain Archimedes' Principle	**M3** determine the upthrust on an immersed body	
P7 use the continuity of volume and mass flow for an incompressible fluid to determine the design characteristics of a gradually tapering pipe		
P8 calculate the dimensional change when a solid material undergoes a change in temperature and the heat transfer that accompanies a change of temperature and phase	**M4** determine the thermal efficiency of a heat transfer process from given values of flow rate, temperature change and input power	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 solve two or more problems that require application of thermodynamic process equations for a perfect gas to determine the unknown parameters of the problems.	**M5** determine the force induced in a rigidly held component that undergoes a change in temperature.	

Essential guidance for tutors

Assessment

The criterion P1 requires the solution of a single non-concurrent force system that contains a minimum of four active forces. It will be expected that two of these forces will be set to act in directions other than the horizontal and vertical. This will necessitate the resolution of forces in perpendicular directions, for example the use of $F_x = F\cos\theta$ and $F_y = F\sin\theta$, as the first step in the solution to the problem. A typical problem might be an engineering component under the action of at least four non-concurrent forces whose magnitudes and directions are given. One of the forces might be its own weight but at least two of them should act in directions other than the horizontal and vertical. Learners would be expected to produce space and free body diagrams, resolve forces horizontally and vertically and take moments of the forces about some suitable reference point. The magnitude and direction of the resultant force and the position of its line of action could then be found through vector addition, application of Pythagoras' theorem and consideration of the resultant turning moment.

P2 will use similar skills to those required for P1 but in this case they will be applied to a simply supported beam carrying two point loads, as a minimum, and a uniformly distributed load. These specifications will provide centres with a variety of loading possibilities that can be used for assessment purposes. During the delivery phase for this part of the unit a greater range of loading may be considered but centres need only work with the minimum for assessment purposes. Neither the content nor criteria stipulate that the point loads should be anything other than perpendicular to the beam. During delivery however, it may be useful to demonstrate the resolution of forces applied at an angle to the beam and calculation of the magnitude and directions of the support reactions.

The assessment for criterion P3 will require a task to calculate the direct stress, direct strain and the accompanying dimensional change in a directly loaded component. It will also require a task to calculate the shear stress and shear strain in a component or material subjected to shear loading. Centres should consider how the tasks set for P3 could be extended to incorporate an opportunity to achieve M1. This might involve consideration of the factor of safety in operation for an angled joint that is bolted or riveted such that the fastenings are subjected to both tensile and shearing forces.

It will require the setting of at least three dynamic system tasks to ensure that the range of kinetic and dynamic principles is applied to achieve P4. Centres should not fragment the application of kinetic and dynamic principles to the extent that they over simplify the problems. It is the interrelationships between the kinetic and dynamics principles that are as important as the use of any single equation. The principles applied in P4 can be directly linked to M2, although achievement of M2 will require a further task to be set to consider the impact of a freely falling body. Suitable examples of this type of problem are listed in the delivery section of these guidance notes. A final task to achieve the distinction criterion D1 will be required to enable learners to consider and solve an engineering problem using the two alternative approaches (i.e. D'Alembert's principle and the principle of conservation of energy), and compare the two methods.

P5 may be achieved by calculating resultant thrust and overturning moment on a rectangular retaining surface, examples of which are listed in the delivery section. P6 requires an explanation of Archimedes' Principle.

M3 may be achieved by calculating the upthrust on a totally immersed body using Archimedes' principle. An understanding of fluid principles is needed to achieve D2, which requires learners to evaluate the methods used to determine the density of an irregular shaped solid object.

The criterion P7 examines learners' basic understanding of fluid flow. It may be achieved by considering the design of a gradually tapering pipe to suit given dimensional and flow constraints.

The criteria P8 and P9 have been designed to assess the thermodynamics aspects of the unit. P8 will require tasks to determine the dimensional change in an engineering component that accompanying a change in temperature, and the sensible and latent heat transfer that accompanies a change of temperature and phase in a substance. P9 will require tasks involving the range of thermodynamic process equations applicable to the expansion and compression of an ideal gas. The area of work covered by P8 – the effects of heat transfer – is extended in the merit criteria M4 and M5.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Static Systems	Problems involving engineering components subjected to static force systems.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P4, M2, D1	Dynamic Systems	Problems involving force, work and power in dynamic engineering system.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P5, P6, P7, M3, D2	Fluid Systems	Problems involving hydrostatic thrust and fluid dynamics. Experimental methods used to determine density.	A written report containing an introductory explanation to each step in the sequence of calculations and findings, and an evaluation of the methods used to determine density.
P8, P9, M4, M5	Thermodynamic Systems	Problems involving heat transfer and dimensional change in thermodynamic systems and involving the expansion and compression of gases.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.

Essential resources

As this is a very practical-based unit, centres should provide access to laboratory facilities with a sufficient range of investigation and demonstration equipment wherever possible. In particular, tensile testing equipment, dynamics trolleys, linear expansivity apparatus, apparatus to determine density and apparatus for verification of Boyle's and Charles' laws would be of significant value.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 9: Applications of Mechanical Systems in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Mechanical engineering is a term that covers a wide range of activities. Mechanical systems are found in land, sea and air transport, power generation, manufacturing plant and domestic products. The design, manufacture and maintenance of such systems is the concern of engineers and technicians who must apply a blend of practical and theoretical knowledge to ensure that these systems work safely and efficiently.

Moving parts usually require some form of lubrication and learning outcome 1 examines lubricant types and lubrication systems. Pressurised systems often require seals and gaskets to contain the lubricants and other working fluids. Rotating parts require bearings and mechanical systems incorporate fixing devices to hold the various components in position. A range of seals, bearings and fastenings is examined in learning outcome 2.

A prime purpose of mechanical systems is to transmit motion and power. There are many ways in which this can be achieved and learning outcome 3 examines a range of power transmission systems and components. In learning outcome 4, learners are introduced to a range of plant equipment and systems. This includes an overview of hydraulic and pneumatic systems, steam plant, refrigeration and air conditioning plant and mechanical handling equipment.

The general aim of this unit is to broaden and extend learners' practical knowledge and understanding of mechanical engineering systems and provide a foundation for continuing work in related units.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the purposes and uses of lubricants and lubrication systems

2 Know about the uses and applications of a range of engineering components

3 Understand the operation and uses of mechanical power transmission systems

4 Understand the operation and uses of plant equipment and systems.

Unit content

1 Understand the purposes and uses of lubricants and lubrication systems

Lubricant purposes and types: purpose, e.g. reduction of frictional resistance, reduction of wear, heat dissipation, prevention of corrosion, prevention of contamination; types, e.g. mineral, vegetable and synthetic oils and greases, graphite, compressed gases, cutting fluids

Lubrication systems and maintenance: operation of lubrication systems, e.g. gravity feed, forced feed, splash lubrication, capillary action, grease cups and nipples, grease packing, compressed air/gas bearings; maintenance, e.g. replenishment and renewal of lubricants, safe storage and handling

Applications: e.g. automobile engine, automobile transmission, machine tool, pump, compressor

2 Know about the uses and applications of a range of engineering components

Seals, packing and bearings: seals, e.g. rotary lip seals, mechanical seals, piston rings; packing, e.g. packed glands, gaskets, shims; bearings, e.g. plain journal, thrust, ball, roller (such as parallel or tapered), needle

Fastenings: screwed fastenings, e.g. metric bolts, studs and set screws, self-tapping screws, locking devices; rivets, e.g. snap head, pan head and countersunk heads, bifurcated and pop rivets

Applications: e.g. automobile engine, automobile transmission, other automotive sub-system, machine tool, pump, compressor, other mechanical system involving rotation and fluid containment, component assembly, maintenance and replacement

3 Understand the operation and uses of mechanical power transmission systems

Cams and linkage mechanisms: cams and followers, e.g. radial plate cams, cylindrical cams, face cams, knife edge followers, flat plate followers, roller followers; linkage mechanisms, e.g. slider-crank and inversions, four-bar linkage and inversions, slotted link quick return motion, Whitworth quick return motion

Belt, chain and gear drives: belt drives, e.g. flat, V-section, synchronous, tensioning device; chain drives, e.g. roller (such as single, duplex, triplex), morse rocker-joint, tensioning devices; gear trains, e.g. gear types (such as spur, helical, herring bone, bevel, spiral bevel, hypoid), simple, compound, worm, combinations, epicyclic

Transmission shafts, clutches and brakes: transmission shafts and couplings, e.g. sections (such as solid, hollow), flanged couplings, splined couplings, angle couplings (such as Hooke universal, constant velocity); clutches, e.g. dog, flat plate, conical, centrifugal, fluid couplings; brakes, e.g. friction (such as internal expanding, external contracting), disc, dynamometers (such as friction, fluid, electromagnetic)

4 Understand the operation and uses of plant equipment and systems

Actuation and handling systems: pneumatic and hydraulic actuation systems, e.g. system layout for automated plant and process operations, system components; safety and maintenance; mechanical handling systems, e.g. belt conveyers, roller conveyers, workshop gantry cranes, workstation jib cranes

Steam, refrigeration and air conditioning plant service systems: steam power generation plant, e.g. system layout for power generation and process operations, system components, feed water treatment, safety and maintenance; refrigeration systems, e.g. system layout for vapour compression and absorption systems, refrigerants, system components, safety and maintenance; air conditioning systems, e.g. system layout for full summer and winter cycle air conditioning, system components, safety and maintenance

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the purpose and application of three different types of lubricant	**M1** compare different types of lubrication and explain the benefits and limitations of each	**D1** justify the use of a particular lubricant and lubrication system in a given engineering application
P2 explain the operation and maintenance of three different lubrication systems		
P3 describe the operation of one seal, one type of packing and two different types of bearing, giving a typical application for each one		
P4 describe two different types of screwed fastening and two different types of rivet giving a typical application for each one		
P5 explain the operation of two different types of cam and follower and two different types of linkage mechanism		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain the arrangement and operation of two different kinds of belt drive, two different kinds of chain drive and two different kinds of gear train		
P7 explain the arrangement and operation of two different kinds of transmission shaft and coupling, two different kinds of clutch and two different kinds of brake	**M2** compare different types of mechanical power transmission systems and explain the benefits and limitations of each	**D2** justify the use of a particular mechanical power transmission system in a given engineering application.
P8 explain, with the aid of diagrams, the general layout and operation of a pneumatic actuation system, a hydraulic actuation system and a mechanical handling system	**M3** compare and contrast the operation and use of pneumatic and hydraulic actuation systems.	
P9 explain, with the aid of diagrams, the general layout and operation of a steam power generation plant, a refrigeration system and an air conditioning system.		

Essential guidance for tutors

Assessment

Criteria P1, P2, M1 and D1 could be achieved through an individual assignment. This should contain tasks to explain the purpose and application of three different types of lubricant (P1) and the operation and maintenance of three different lubrication systems (P2). M1 is an extension of P1 involving a comparison of the three lubricants in terms of their benefits and limitations. To achieve D1, learners should fully justify the use of a particular lubricant and lubrication system in a given engineering application. This might be the lubrication system of a vehicle engine or transmission, a machine tool, pump or compressor. Alternatively, a mechanical system required to operate in a hostile service environment such as extremes of temperature may be considered.

A second assignment could be used to assess P3 and P4. This would require learners to describe the operation and application of one type of seal, one type of packing and two different types of bearing (P3). Another task would need to cover two different types of screwed fastener and two different types of rivet (P4). The applications should be general, rather than product specific, to demonstrate an understanding of purpose. Diagrams and sketches could be used to complement the descriptions.

Criteria P5 and P6, which relate to learning outcome 3 on mechanical power transmission systems, could be achieved through a third assignment. This should require learners to explain methods of transmitting/converting motion from one form to another by means of two different types of cam and follower and two different linkage mechanisms. It will also need to include two different kinds of belt drive, two different kinds of chain drive and two different kinds of gear train. As with the previous assessment, learners should be encouraged to illustrate the descriptions with diagrams and freehand sketches.

Criteria P7, M2 and D2 relate to learning outcome 3 and could be achieved through a fourth assignment. This should contain tasks requiring learners to explain the arrangement and operation of two different kinds of transmission shaft coupling, two different kinds of clutch and two different kinds of brake (P7). To achieve M2, learners could compare and contrast the operation of manually operated and automatic friction clutches and fluid couplings. The comparisons should be of a general nature, although they may be accompanied by typical applications to illustrate usage. To achieve D2, learners should fully justify the choice of clutches, bearings, seals, packing and fastenings in a given engineering system. This again might be a sub-system of a vehicle, a machine tool or any mechanical system where rotation and the containment of fluid is involved.

A final time-constrained assignment could be used to assess P8, P9 and M3. This should contain tasks requiring learners to explain, with the aid of diagrams, the general layout and operation of pneumatic and hydraulic actuation systems (P8), a steam generation plant, a refrigeration system and an air-conditioning system (P9).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1 and D1	Applications of Lubricants and Lubrication Systems	Learners need to describe lubricants and the operation of lubrication systems to a new learner.	A series of three written tasks in which learners provide explanations of three lubricants and the operation of lubrication systems. They are also asked to justify the use of a lubricant for a given application.
P3 and P4	Applications of Engineering Components	Learners need to investigate different components in order to find the best to use for a particular application.	A series of three written tasks in which learners describe the application of seals, packing, bearings and fasteners
P5 and P6	Applications of Cams and Drives	Learners need to investigate mechanical power transmission systems.	Two written tasks in which learners explain the use of cams, linkage mechanisms and chains and drives.
P7, M2 and D2	Applications of Brakes and Clutches	Learners need to investigate transmission shafts, clutches and brakes.	Two written tasks in which learners explain the operation of shaft couplings, clutches and brakes, make comparisons and justify the use of one system.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9 and M3	Plant Equipment and Systems	Learners have been asked to produce a report on some new plant equipment and systems that their company is interested in using.	A time-controlled task in which learners produce written explanations and accompanying diagrams of actuation systems and steam, refrigeration and air conditioning systems. They should also carry out a comparison of pneumatic and hydraulic systems.

Essential resources

Centres should have access to a range of engineering components, demonstration equipment and engineering and motor vehicle workshops.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Neale M J – *Lubrication and Reliability Handbook* (Newnes, 2000)
ISBN 10: 0750651547 or ISBN 13: 9780750651547

Unit 10: Organisational Efficiency and Improvement

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

In this unit, learners will gain an understanding of continuous improvement in their sector and identify areas in production where lean working could be used to aid the company. They will learn about quality control methods used in industry and understand the key factors required to remain competitive in the market.

Learners will understand the importance of human resource management in terms of building successful teams and the effect this can have on recruitment and retention of employees.

Note that the use of e.g. in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an e.g. needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand production activities

2 Understand application of quality control and quality assurance

3 Understand organisational improvement techniques and competitiveness

4 Understand personal rights and responsibilities in an organisation.

Unit content

1 Understand production activities

*Types of productio*n: e.g. mass; flow; automated; batch; one-off

Considerations: market requirements; design of product; plant and equipment availability; plant and equipment layout; personnel; production control; quality control; cost

Methods and application of cellular and just-in-time (JIT) production: relation to modern production requirements; application of Push and Pull types of production to meet company and customer needs and expectations

Stages of production planning: scheduling, loading, dispatching (coordination of pre-production activities); requirements, e.g. engineering drawings, technical data, personnel, machinery/tools, components, materials, consumables

*Process chart*s: e.g. flow charts/diagrams, Gantt charts; symbols used in process charts

2 Understand application of quality control and quality assurance

Quality control and assurance: meaning of 'quality control' and 'quality assurance'; fitness for purpose, e.g. meeting customer expectations; purchasing; production planning and procedures for quality assurance; manufacture (process control); final inspection and dispatch; Statistical Process Control (SPC), e.g. measuring quality/performance, document control as an integral part of quality assurance, records of the correct operation; types and the purpose of sampling, e.g. spot check, random sampling, process sampling, batch sampling; mean time between failures (MTBF) in the context of sample size and frequency

*Inspectio*n: checking every stage for deviation from design specification; adjustments that need to be made; stages of inspection, e.g. goods inward, during production (process control), final inspection; role of the inspector in checking compliance with quality standard and procedures; quarantine area to store defective work

BS EN ISO 9001: internationally recognised quality assurance standard; role of the quality manual and process/procedures manual; internal/external audits

Quality manager: relationship with other managers/departments in the company; considerations to be made when developing a quality plan, e.g. quality requirements (customer expectations), allocation of responsibilities (at all levels), the setting up of systems to measure quality and report progress, identification and calibration of quality equipment, ability to take corrective actions where necessary

Total quality management (TQM): main principles and goals; advantages of adopting TQM, e.g. competitiveness in the market, enabling growth and longevity, reducing stress, building teams, partnerships and cooperation

3 Understand organisational improvement techniques and competitiveness

Business Improvement Techniques (BIT): principles of lean manufacture, e.g. removal of waste of all kinds (time, motion, inventory, poor cost of quality etc.), stimulating productivity and quality; use of value-added processes, Kaizen as a philosophy that encompasses continuous improvement; just in time (stockless production or lean production), e.g. manufacturing to order not to stock; Kanban inventory control

Productivity: meaning of the term 'production'; benefits to the company of increasing productivity; company, e.g. multinationals, nationals and regional, Small and Medium Enterprises (SMEs) and sole traders; managing the production process, e.g. layout of the production area, batch production, synchronisation, lead-time

Continuous improvement: meaning of 'continuous improvement'; continuous improvement cycle (plan, do, check, and action); benefits gained; flexible working and multi-skilling; importance in the national and global marketplaces, e.g. multinationals, nationals, SMEs and sole traders

Teamwork: roles in a team, e.g. leaders, doers, thinkers, carers; balance in a team; what individuals bring to a team; team building; communication in the team

4 Understand personal rights and responsibilities in an organisation

Organisational documentation and employment legislation: documentation, e.g. contracts of employment, staff handbook; personnel records, grievance procedures; appraisals; disciplinary procedures; legislation, e.g. Employment Rights, Working Time Regulations, Health and Safety at Work, Data Protection, Equal Opportunities, Human Rights, Equality Act

Development and progression opportunities: company training programmes; apprenticeships; organisational training opportunities; promotion; transfer; higher education; professional qualifications

Roles of representative bodies: e.g. trade unions, professional bodies, employers' organisations (EEF, the manufacturers' organisation); industry training support

Investors in People (IiP) national standard: four key principles – commitment, planning, action and evaluation; how organisations acquire IiP status

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the different types of production	**M1** compare the advantages and disadvantages of different types of production	**D1** justify the selection of a production type for a given process
P2 describe the requirements that need to be considered when selecting a type of production		
P3 describe the different stages of production planning		
P4 explain how to apply typical process charts to production planning		
P5 explain the meaning of the terms 'quality control' and 'quality assurance'	**M2** explain the importance of using a structured approach for quality control and quality assurance	**D2** evaluate a quality management process and make suggestions for improvement
P6 describe the role and stages of inspection activities		
P7 explain the application and content of the BS EN ISO 9000 series of standards		
P8 explain the role and responsibilities of the quality manager		
P9 describe the requirements of quality planning		
P10 describe the principles of total quality management (TQM)		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P11 explain the meaning of the terms Lean Manufacture, Kaizen, just-in-time and Kanban and their overall advantages	**M3** explain the consequences for an organisation of not maintaining continuous improvement standards	**D3** evaluate a production process and identify where improvements can be made to increase productivity and organisational competitiveness.
P12 explain the importance of improving organisational productivity		
P13 describe the need for continuous improvement to ensure organisational competitiveness		
P14 describe the key requirements for managing the production process		
P15 explain the importance of teamwork and the individual's contribution to effective teamwork		
P16 explain the key features of employment legislation in relation to personnel rights and responsibilities	**M4** explain the effects of not adhering to employment legislation in relation to personal rights and responsibilities.	
P17 describe the personnel opportunities for development and progression that are available in the workplace		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P18 describe the role of the representative bodies in the engineering sector that support personnel and organisations		
P19 explain the implications that 'Investors in People' has on an organisation and its personnel.		

Essential guidance for tutors

Assessment

To achieve a pass grade, all the pass criteria must be met. Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2, P3 and P4 could be achieved by means of a written task based upon a given product that needs to be manufactured. For P1, learners need to identify a range of production processes that could be used to manufacture a product and explain the underlying principles behind them. For P2, learners should identify the customer requirements for a given type of product and describe how these requirements will impact on the selection of a specific production method. For P3, learners would identify the key stages in production planning to produce their production plan for the given product. For P4, learners can add in the need and importance of process charts in the plan to identify key stages in the production. This task can also allow learners to achieve M1 through a thorough analysis of the company. Alternatively a case study into quality management of a sample company could be used. At least two possible production types should be compared. D1 can be achieved through justifying their choice of production type in detail.

Achievement of P5, P7, P9 and P10 could use a written task asking learners to identify the terms and roles suitable for accurate quality control procedures and how this can be built into TQM. This could be linked to a case study, based around a company visit if possible. Learners would have to identify the areas where standards such as ISO 9001 are vital in industry and how the companies involved identify the relevant roles for P6 and P8 respectively. As part of this written task, learners can also draw evidence of explaining the importance of structure in the quality procedures to gain M2.

This case study or visit should then allow learners to identify and evaluate the QA procedures in operation and allow them to suggest improvements for D2.

P11 and P12 can be achieved through a written analysis of the different types of production processes and their advantages in improving productivity. This would then lead to a description of the importance of continuous improvement for P13 and also allow learners the opportunity for detailed discussion to achieve M3 at the same time. Learners should describe a given production process and the importance of the management structures present for P14 and then explain the impact effective team building and teamwork has on productivity for P15. Learners can then suggest improvements to this in detail, which would give the opportunity to achieve D3.

The achievement of P16 should be tied to an analysis of learners' own workplace human resources department to produce an explanation of the key features, and also allow the opportunity to discuss why it is important for companies to follow the law, with some examples of the effects for M4. This could be linked to the importance of representation from bodies such as workers' unions for P18.

P17 and P19 can be achieved through research into why companies should continually develop their staff and the effect that Investors in People has on encouraging employment and development.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4 M1, D1	Production Processes and Planning	A company decides to manufacture a product. Learners should analyse the possible types to produce it and identify the most suitable, justifying their selection.	A written task encompassing production and production planning
P5, P6, P7, P8, P9, P10 M2, D2	Investigation into Quality Management	Learners will analyse existing quality management procedures in a company (or their own company if suitable) and use the data found to suggest improvements.	Case study of the company they are working at or a different one if appropriate
P11, P12, P13, P14, P15 M3, D3	Continuously Improving Productivity	Learners identify the most common production methods used by companies (and their own company if appropriate) and analyse the impact that these processes have had on productivity.	A written task, case study.

Criteria covered	Assignment title	Scenario	Assessment method
P16, P18, M4	Employers' Rights and Employment Law	Learners analyse their workplaces' employment contracts and processes, alongside existing cases brought against companies to analyse the importance and effect of the law and union's role in defending workers' rights.	A written task, case study.
P17, P19	Investment in People	Learners will identify the importance of investment in the workforce, how companies obtain IiP and what effect that has on employment.	A written task.

Essential resources

Case study into quality management of a sample company for learners with unsuitable employers to study their own company.

Evidence from previous employment law cases to allow learners to identify the importance of a company abiding by the law.

Indicative reading for learners

Textbooks

Waldock B – *Being Agile in Business: Discover Faster, Smarter, Leaner Ways to Work* (Pearson Education, 2015) ISBN 9781292083704

Hutchinson S – *Performance Management: Theory and Practice* (CIPD, 2013) ISBN 9781843983057

Mullins L J – *Management and Organisational Behaviour*, 10th Edition (FT Publishing International, 2013) ISBN 9780273792642

Journals

Business Review Magazine (Phillip Allan Publishers – see www.phillipallan.co.uk)
The Economist (The Economist Newspaper Group Inc)

Websites

BBC News www.bbc.co.uk/business

National Learning Network www.nln.ac.uk

Unit 11: Electro-pneumatic and Hydraulic Systems and Devices

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

An understanding of how fluid power systems are used to control the operation of machinery and equipment is important for anyone thinking of a career in engineering.

Pneumatic (pressurised air or gas) systems are widely used in manufacturing engineering to operate equipment such as packaging machines, automated assembly machines, clamping and lifting devices. There are many other everyday applications where air operated equipment is found, for example for opening doors on buses. Hydraulic (pressurised liquid) systems are used where greater amounts of power are involved, a good example of this being the linear actuators that move the arms on excavators and other types of earthmoving equipment.

This unit will give learners a broad understanding of the design and safe operation of pressurised fluid systems that use electrical control devices to make them work. This will include reading and producing simple fluid power circuit diagrams, understanding the principles of maintenance, and the use of test routines to identify faults in these systems.

Learners will investigate the impact that current legislation has on the design and safe operation of fluid power circuits, so that when carrying out practical work they are able to work safely. High pressure systems and devices, particularly air-based ones, have hidden dangers. Because hydraulic oil is carcinogenic, learners will be made aware of the regulations covering the handling and disposal/recycling of this substance.

This is followed by a look at a selection of the components used in fluid power systems and how they can be represented using universally recognised circuit diagram symbols. The components studied will include those used to generate a supply of high pressure air or hydraulic fluid, prime movers such as linear actuators (cylinders) and control devices such as valves and sensors.

Learners will be introduced to some of the calculations that need to be carried out before designing and setting up a system. These include some basic pressure and volume calculations involving gases, determination of the correct size of cylinder to produce a specified extending force, and calculation of fluid flow rates needed to keep a system operating effectively. Learners will then investigate how components can be linked together to form systems for a specific purpose.

The final section of the unit looks at how fluid power systems are maintained in service and what happens if they develop faults. The emphasis here is on applying safe working practices, using predetermined systematic schedules and keeping accurate records for future reference.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about the legislation, regulations and safety precautions that apply when working with fluid power systems

2 Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams

3 Be able to apply fluid power principles in the design of circuits

4 Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems.

Unit content

1 Know about the legislation, regulations and safety precautions that apply when working with fluid power systems

Legislation and regulations: legislation, e.g. Health and Safety at Work Act, Employment Act, Factories Act, Fire Precautions Act, Deposit of Poisonous Waste Act, European Conformity (CE marking); regulations, e.g. Employment Equality (Age) Regulations, Management of Health and Safety at Work Regulations, Provision and Use of Work Equipment Regulations (PUWER), Control of Substances Hazardous to Health (COSHH) Regulations, Lifting Operations and Lifting Equipment Regulations (LOLER), Manual Handling Operations Regulations (MHOR), Personal Protective Equipment (PPE) at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Workplace (Health, Safety and Welfare) Regulations, Health and Safety (First-Aid) Regulations, Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations, Simple Pressure Vessels (Safety) Regulations (SI 1994/3098), The Simple Pressure Vessels Directive (Directive 87/404/EEC) (SPVD); Supply of Machinery (Safety) (Amendment) Regulations (SI 2005/831)

Safety precautions: risk assessment of fluid power systems; assembling and testing electro-pneumatic and hydraulic systems and devices, e.g. isolation of services (such as electrical, air, oil), escape of fluids at high pressure which may cause contact injury, hydraulic oil contact with the skin, sudden movement of linear actuators causing entrapment injuries; personal protective equipment (PPE), e.g. safety glasses, gloves, overalls, footwear

2 Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams

Fluid power devices: fluid conditioning, e.g. supply tank, filter, pump, cooler, compressor, dryer, receiver, accumulator; fluid supply, e.g. pipework, fittings, seals, drainage points; electrical supply systems, e.g. mains, low voltage regulated power supply units, AC, DC; fluid control valves, e.g. directional (manual and solenoid), pilot, 4 port, 5 port, pressure reducing, non-return, flow rate; actuators linear, rotary; motors, e.g. electric, air, hydraulic; position sensors, e.g. reed switch, pressure switch, inductive, microswitch; system control, e.g. programmable logic controller (PLC), electro mechanical

Symbols: relevant and current standards, e.g. BS3939, BS ISO 1219-1:2012, European Fluid Power Committee (CETOP); symbols for common components, e.g. fluid conditioning, fluid supply, electrical supply, control valves, actuators, motors, sensors, control

Circuit diagrams: diagrams, e.g. pneumatic, hydraulic, block diagrams, system layout, displacement step diagrams; reference material, e.g. component and equipment data sheets, BS ISO 1219-1:2012, software (such as FluidSIM or Automation Studio)

3 Be able to apply fluid power principles in the design of circuits

Fluid power principles: properties and behaviour of air and hydraulic fluids; gas laws, e.g. Boyle's, Charles', Gay-Lussac's, general gas, dew point; fluid flow, e.g. Bernoulli's principle, volumetric rate, receiver volume, actuator flow requirements; fluid pressure, e.g. units of measurement, Pascal's law, inlet and outlet pressure, pressure drop, actuator efficiency, clamping force; formulae ($P_1V_1T_2 = P_2V_2T_1$, displaced volume = piston area × stroke,

volumetric flow rate = $\frac{\text{displaced volume}}{\text{time}}$,

absolute pressure = gauge + atmospheric pressure,
force = pressure × area, actuator force = pressure × area × efficiency)

Circuits: pneumatic, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell, position and clamp an object using a two-cylinder arrangement, rotary actuator with reversing action; hydraulic, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell and regeneration, hydraulic motor with reversing action

4 Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems

Maintenance: routines, e.g. frequency of maintenance, manuals and reference documentation, keeping of accurate records using paper- or software-based systems; components (electro-pneumatic, hydraulic); systems, e.g. electro-pneumatic, electro-hydraulic

Inspection: functional, e.g. at component level, as a system, performance against specification; keeping of accurate records; report, e.g. component drawing, system circuit diagram, digital images, inspection checklist, record of visual observations made against checklist, conclusions, recommendations

Testing: performance, e.g. against specification, reliability; keeping of accurate records; report, e.g. system circuit diagram, system specification, test schedule, list of test equipment, record test results, record visual observations, compare test results with system specification, recommendations for future actions

Fault finding: identify faults in fluid power systems, e.g. manual diagnosis, visual examination, unit substitution, input to output, injection and sampling, half-split technique, six-point technique, self-diagnostic techniques using programmable electronic equipment, effect of malfunctions; fault-finding aids, e.g. functional charts, diagrams, flow charts, troubleshooting charts, component data sheets, operation and maintenance manuals, specialised equipment; record faults, e.g. paper based, software based, analyse data; report, e.g. system circuit diagram, record test results, record visual observations, compare test results with system specification, record faults and cross reference to circuit diagram, identify type of fault, strategy for rectification of fault

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 list the aspects of health and safety legislation and regulations that apply when working with given fluid power equipment and systems		
P2 describe the safety precautions that apply when working with fluid power equipment and systems		
P3 describe, with the aid of suitable diagrams, the construction and operation of a given electro-pneumatic device and a given electrohydraulic device	**M1** compare the construction and operation of a pneumatic system with that of a hydraulic system	**D1** assess the relevance of current standards, such as CETOP, to the construction and operation of fluid power devices
P4 use standards to identify electro-pneumatic and hydraulic components shown as symbols in given circuit diagrams and reference materials		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 carry out calculations that relate to the fluid power principles used in the design of circuits		
P6 produce a circuit diagram to meet a given electro-pneumatic system specification		
P7 produce a circuit diagram to meet a given hydraulic system specification		
P8 use routines and carry out maintenance on given electro-pneumatic and hydraulic components and a given electro-pneumatic or electro-hydraulic system	**M2** explain the routines used when carrying out maintenance on a given electro-pneumatic or electro-hydraulic system **M3** produce a report of showing findings.	
P9 carry out inspection, testing and fault-finding on a given electro-pneumatic or electrohydraulic system in line with checklists.		**D2** evaluate the use of self-diagnostic techniques to monitor the performance of fluid power systems used in industry.

Essential guidance for tutors

Assessment

It may be appropriate to structure the assessment of this unit as five assignments, using four to cover the pass and merit criteria and the fifth one the two distinction criteria.

The first assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to legislation and, while much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of safety precautions could be generated by giving learners a list of situations/scenarios and then asking them to detail what needs to be done to work safely. This leads into risk assessment and learners could be asked to carry out an assessment for equipment which they will be using later in the unit.

Grading criteria P3, P4, M1 and D1 complement each other and could be assessed through a second assignment that covers the whole of the content for learning outcome 2. P3 asks for information about the construction and operation of equipment and, provided that any written explanation is supported by diagrams there is no requirement for learners to present fully detailed drawings of the devices considered.

To meet the requirements of P4, learners could be given a suitable set of circuit diagrams and manufacturers' reference material for the equipment described for P3. This would determine the amount of components and symbols needed to meet the requirement of P4. Examples of such devices are found in the unit content and delivery guidance. M1 encompasses P3 and P4 and requires a comparison of the construction and operation of the two systems. This comparison can be extended to assess the relevance of standards such as ISO and CETOP to the construction and operation of fluid power devices.

P5, P6 and P7 are linked and could be assessed using a third assignment that will involve calculation and the production of circuit diagrams which meet given design specifications. These can be hand drawn but it is better if learners use a software package so that simulation can be carried out to ensure correct operation of the circuits. This could be evidenced in the form of screen prints consolidated by a witness statement or observation record.

Grading criteria P8, P9, M2 and D2 could be assessed using a fourth assignment. Evidence of learners' competence when carrying out practical tasks will need to be recorded using witness statements, observation records and digital images.

The tasks set to generate evidence for P8 should involve the use of a small range of components and just one fluid power system (i.e. pneumatic or hydraulic). Similarly, when producing evidence for P9, it is only necessary to work with one type of system. Both criteria require learners to keep accurate records and use relevant documentation in addition to carrying out the practical tasks. Learners who built the circuits that they designed to achieve P6 and P7 could work on these when gathering evidence for P8 and P9.

M2 and M3 build on P8 and P9 requiring an explanation and a report showing findings. Finally, D2 requires an evaluation of self-diagnostic techniques to monitor performance. This could include, for example, electronic programmable equipment to carry out the monitoring and an evaluation of its effectiveness.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Legislation and Safety Precautions	Learners to carry out a risk assessment for fluid power equipment in an engineering situation.	A written assignment in which learners detail the legislation and safety precautions that apply to a piece of fluid power equipment that they are going to use.
P3, P4, M1, D1	Construction and Operation of Fluid Power Devices	Use and interpret circuit diagrams to identify and describe the operation of fluid power devices and components.	A written assignment with tasks requiring learners use diagrams to describe fluid power devices and identify components.
P5, P6, P7	Fluid Power Principles and Circuits	Learners have been asked to produce circuit diagrams to meet the requirements of a customer specification in an engineering situation.	A practical assignment requiring learners to produce two circuit diagrams and carry out calculations.
P8, P9, M2, M3, D1, D2	Carrying Out Fluid Power Maintenance, Inspection, Testing and Fault-finding	Learners have been asked by their supervisor to carry this out on fluid power systems.	A practical assignment supported by a logbook/report of activities carried out plus observation records.

Essential resources

To meet the needs of this unit it is essential that centres have access to the following:

- industrial-standard electro-pneumatic and hydraulic equipment and systems
- fluid power circuit design software, e.g. FluidSIM or Automation Studio
- test equipment and measuring instruments
- relevant British and international standards
- health and safety publications.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Kay M – *Practical Hydraulics* (CRC Press, 2007) ISBN 9780415351157

Turner I – *Engineering Applications of Pneumatics and Hydraulics* (Routledge, 1995) ISBN 9780340625262

Zhang Q – *Basics of Hydraulic Systems* (CRC Press, 2008) ISBN 9781420070989

Parr A – *Hydraulics and Pneumatics: A Technician's and Engineer's Guide* (Butterworth-Heinemann, 2011) ISBN 9780080966748

Chapple PJ – *Principles of Hydraulic System Design* (Coxmoor Publishing Co, 2008) ISBN 9781901892154

Unit 12: Engineering Drawing for Technicians

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

It is important that when a product has been designed it is manufactured correctly and to specification. To achieve this, it is crucial that the people making the product in a workshop are provided with well-presented engineering drawings, produced to international standards and conventions. This avoids errors of interpretation that can lead to the scrapping of expensive parts.

An understanding of how graphical methods can be used to communicate information about engineering products is an important step for anyone thinking of taking up a career in engineering. This unit gives learners an introduction to the principles of technical drawings and their applications using hand drawing and computer-aided design (CAD) techniques.

Learners will start by carrying out freehand sketching of simple engineering products using pictorial methods that generate three-dimensional (3D) images. A range of standard components, such as fixing devices, will be sketched together with other solid and hollow items. Learners are then introduced to a more formalised drawing technique that conforms to British Standards and will put this into practice through a number of drawing exercises. A consistent presentation style will be used as learners draw single part components and simple engineering assemblies.

These drawings will contain all the information needed to manufacture or assemble the product, including information such as dimensions, manufacturing notes and parts lists. The use of conventions to represent standard items will be investigated, such as screw threads and springs in mechanical type drawings or circuit symbols such as solenoids and resistors in electrical/electronic type drawings.

Having learned the principles of engineering drawing, learners will then move on to using a two-dimensional (2D) CAD system for the production of drawings using basic set-up, drawing and editing commands. The first task is to produce a drawing template which can be saved to file, as this reinforces the concept of standardisation and consistency of presentation. This is followed by drawing exercises of single-part components, a simple multi-part assembly and circuit diagrams.

Overall, the unit will develop learners' ability to create technical drawings and allow them to compare the use of manual and computer aided methods of producing engineering drawings.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to sketch engineering components

2 Be able to interpret engineering drawings that comply with drawing standards

3 Be able to produce engineering drawings

4 Be able to produce engineering drawings using a computer-aided design (CAD) system.

Unit content

1 Be able to sketch engineering components

Sketches: regular solids, e.g. cube, rectangular block, 900 angle bracket; hollow objects, e.g. circular tube, square section tube; standard components, e.g. nuts, bolts, screws, pulleys; engineering components, e.g. pulley support bracket, machine vice

Sketching techniques: sketching equipment, e.g. paper (plain, squared, isometric), pencil, eraser; pictorial, e.g. oblique drawing (cavalier and cabinet), isometric; orthographic, e.g. single and linked views; sketching in good proportion; dimensions, e.g. overall sizes, detail

Benefits and limitations of using pictorial techniques: benefits, e.g. speed of production, visual impact; limitations, e.g. lengths and shapes not true, not produced to a recognised standard, dimensions difficult to read; consequences of interpretation errors, e.g. incorrect manufacture, incorrect assembly, cost to scrap

2 Be able to interpret engineering drawings that comply with drawing standards

Interpret: obtaining information from engineering drawings, e.g. component features, dimensions and tolerances, surface finish, manufacturing detail, assembly instructions, parts list, circuit operation

Drawing standards: British Standards, e.g. BS 8888, BS 3939, BS 2917, PP 7307; company-standardised layouts, e.g. drawing number, title and issue number, projection symbols (first angle, third angle), scale, units, general tolerances, name of person responsible for producing drawing; line types, e.g. centre, construction, outline, hidden, leader, dimension; lettering, e.g. titles, notes; orthographic projection, e.g. first angle, third angle; views, e.g. elevation, plan, end, section, auxiliary; representation of common features, e.g. screw threads, springs, splines, repeated items; section views, e.g. hatching style, webs, nuts, bolts and pins, solid shafts; symbols and abbreviations, e.g. A/F, CHAM, Φ, R, PCD, M; circuit symbols, e.g. electrical, electronic, hydraulic, pneumatic

3 Be able to produce engineering drawings

Detail drawings of single-piece engineering components: projection method; scale; title block; line work; views; sections; dimensions; tolerances; surface finish; notes

Assembly drawings: line work, e.g. centre lines, construction, outline, cutting plane, sectional view, hatching; representation of standard components, e.g. nuts, bolts, screws, keys; parts referencing, e.g. number referencing, parts list; notes, e.g. assembly instructions, installation features, operating instructions

Circuit diagrams: circuits, e.g. electrical, electronic, hydraulic, pneumatic; components, e.g. transformers, rectifiers, solenoids, resistors, capacitors, diodes, valves, pumps, actuators, cylinders, receivers, compressors

4 Be able to produce engineering drawings using a computer aided design (CAD) system

Prepare a template: standardised drawing sheet, e.g. border, title block, company logo; save to file

CAD systems: computer systems, e.g. personal computer, networks; output devices, e.g. printer, plotter; storage, e.g. server, hard disc, CD, pen drive; 2D CAD software packages, e.g. AutoCAD, Microstation, Cattia, Pro/Engineer, Pro/Desktop

Produce engineering drawings: set-up commands, e.g. extents, grid, snap, layer; drawing commands, e.g. coordinate entry, line, arc, circle, snap, polygon, hatch, text, dimension; editing commands, e.g. copy, move, erase, rotate, mirror, trim, extend, chamfer, fillet

Store and present engineering drawings: save work as an electronic file, e.g. hard drive, server, pen drive, DVD; produce paper copies, e.g. print, plot, scale to fit

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 create sketches of engineering components using a range of techniques	**M1** assess the suitability of the different techniques for the sketches	
P2 describe the benefits and limitations of using pictorial techniques to represent a given engineering component		
P3 interpret the main features of a given engineering drawing which complies with drawing standards	**M2** explain in the importance of working to recognised standards when producing engineering drawings	
P4 produce detailed drawings of three given single-piece components that comply with drawing standards	**M3** explain how the sketches comply with drawing standards	
P5 produce an assembly drawing of a product containing three parts that complies with drawing standards		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 produce a circuit diagram that complies with drawing standards, with at least five different components which use standard symbols	**M4** explain in how a given engineering drawing would be used and the reasons it is suitable for its intended audience **M5** explain the hardware components of a typical industry standard CAD system.	**D1** evaluate the use of different methods of producing engineering drawings including manual and computer aided methods **D2** evaluate the functionality of a CAD software package.
P7 prepare a template drawing of a standardised A3 sheet using a CAD system and save to file		
P8 produce, store and present 2D CAD drawings of a given single-piece component and an assembly drawing of a product containing three parts.		

Essential guidance for tutors

Assessment

Assessment of this unit could be through the use of five assignments. To achieve a pass, learners are expected to show competence in a number of graphical techniques and to be able to apply these to the production of engineering drawings which meet recognised standards.

The first assignment, to cover P1, P2 and M1, could consist of a small portfolio of sketches and written descriptions. Items drawn must include regular solids and hollow objects, standard and engineering components. The techniques used must be valid and involve sketching equipment, pictorial and orthographic representation and sketching in good proportion with the addition of some dimensions (as specified in the unit content). An assessment of these techniques will meet the requirement for M1.

The second assignment, to cover P3 and M2, will need to be carefully structured and should be based on a drawing of a component or assembly rather than a circuit diagram so that the unit content can be properly covered. M2 builds on the evidence presented for P3 and these two criteria could be assessed using a single assignment. The wider issues of standardisation and manufacturing for the global market place should be addressed with learners supporting their explanations with case study evidence.

The third assignment could cover P4, P5 and M3 with the three single-piece components in P4 being used for the assembly drawing in P5. This would then make the assignment more realistic in terms of what happens in industry. M3 would require an explanation of how the sketches in P4 comply with drawing standards.

The fourth assignment could cover P6, M4 and D1, with learners being given a choice of the type of circuit they produce depending on their interest (i.e. from electrical, electronic, hydraulic and pneumatic). The circuit can be drawn by hand but using CAD may be the preferred method if a library of components is available. M4 requires an explanation of the use of engineering drawings to communicate information effectively. D1 could be carried out as a separate task, requiring an evaluation of the various drawing techniques used by learners and link directly with the criteria P1, P5, P6 and P8. To add depth to their evidence, learners could be asked to look more widely at what is used in industry – particularly the use of 3D CAD systems which generate solid models. This would then bring them full circle back to the start of the unit, where they were producing pictorial sketches.

P7, P8, M5 and D2 can be covered by a fifth assignment, which could ask for increased competence in the application of standards when producing drawings. To help authenticate learners' work, additional evidence could be in the form of witness statements, tutor observation records and 'screen dumps' which show the range of commands used during the development of the drawings. M5 and D2 could form a separate task as part of this assignment, requiring an explanation of CAD hardware and an evaluation of CAD software functionality.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Producing Engineering Sketches	Learners have been asked to produce sketches of a range of different objects.	A practical assignment requiring learners to produce a portfolio of engineering sketches with accompanying written descriptions.
P3, M2	Interpreting and Using Drawing Standards	Learners have to read and interpret an engineering drawing in order to report the key features of the component, circuit or assembly to a colleague.	A written assignment for which learners need to produce a short report detailing the main features of a given engineering drawing that complies with drawing standards. A further task would require them to explain the importance engineering standards.
P4, P5, M3	Producing Engineering Drawings	Learners need to produce an engineering drawing of three components and an assembly drawing for use by the manufacturing department of their company.	A practical assignment in which learners produce component and assembly drawings.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M4, D1	Producing Circuit Drawings	Learners need to produce a circuit diagram for use by the manufacturing department of their company.	A practical assignment in which learners produce a circuit diagram.
P7, P8, M5, D2	Producing Engineering Drawings Using CAD	Learners need to prepare and produce 2D CAD drawings for use by the manufacturing department of their company.	A practical assignment in which learners produce 2D CAD drawings of a component and an assembly.

Essential resources

To meet the needs of this unit, it is essential that centres have, or have access to, manual drawing equipment and a CAD system that uses a 2D commercial engineering software package. Centres will also need extracts and illustrations from appropriate drawing standards and conventions.

Indicative reading for learners

Textbooks

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Fane B – *AutoCAD 2014 for Dummies* (John Wiley and Sons, 2013) ISBN 9781118603970

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 13: Computer-aided Drafting in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Computer-aided drafting is fast becoming the primary means of communicating design information in many industry sectors, particularly in engineering and manufacturing. Two-dimensional (2D) CAD drawings and three-dimensional (3D) CAD data can be shared with computer numerical control (CNC) machines using computer-aided manufacturing (CAM) software. 3D models can be rendered to produce photo-realistic representations, or can be animated to produce moving views of products and components as they would appear in service. Additionally, models can be used to analyse features such as mass, volume and mechanical properties.

This unit will enable learners to produce a variety of CAD drawings, from single-part 2D components to complex 3D models. Advanced techniques, such as using pre-prepared symbols to construct circuit diagrams and assembly drawings, will provide opportunities for learners to develop their skills. Learners will investigate the use of CAD in industry, the hardware and software required and the links with other software packages. In doing this, learners will appreciate the advantages of CAD over more conventional methods of drawing production.

Finally, learners will generate 3D models, make comparison with 2D CAD drawings and evaluate the impact of this technology on manufacturing companies and their customers.

The unit as a whole provides an opportunity to carry out practical CAD activities using a full range of commands and drawing environments. In addition, learners will gain an understanding of the use and impact of CAD on the manufacturing industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the national and international standards and conventions that CAD drawings and design need to comply with

2 Understand the advantages of using CAD in comparison with other methods

3 Know about the software and hardware required to produce CAD drawings

4 Be able to produce and interpret CAD drawings

5 Be able to use CAD software to produce 3D drawings and views.

Unit content

1 Know the national and international standards and conventions that CAD drawings and design need to comply with

Requirements of current national and international standards and conventions: engineering drawing practice: BS 8888:2013, BS 5070-3 1988, BS EN 13622:2002, ISO standards

Features of CAD drawings that need to comply with national and international standards: drawing sheet sizes and layouts, projection – first and third angle types of line, lettering and numbering, dimensioning, section cross hatching

Standard representations: welding symbols, electrical symbols, pneumatic/hydraulic symbols, mechanical symbols

2 Understand the advantages of using CAD in comparison with other methods

Advantages of CAD: quality; accuracy; time; cost; electronic transfer of information; links with other software, e.g. CAD/CAM, rendering software, animation software, finite element analysis (FEA)

Other methods: manual drafting; model making

3 Know about the software and hardware required to produce CAD drawings

Software: operating systems; CAD software packages, e.g. AutoCAD, AutoCAD/Inventor, Microstation, Catia, Pro/ENGINEER, Solidworks; minimum system requirements, e.g. hard disk space, memory required, processor, video card

Hardware: keyboard; mouse; other input devices, e.g. light pen, digitiser, joystick, thumbwheel; monitor; printer; other output devices, e.g. plotter, rapid prototyping; storage, e.g. floppy disk, hard disk, memory stick, CD, network

4 Be able to produce and interpret CAD drawings

CAD drawings: orthographic projections; circuit diagrams, e.g. hydraulic, pneumatic, electronic; exploded/ assembly drawing; standards, e.g. BS 8888, BS 3939, BS 2917

Commands: absolute/relative/polar coordinates; features, e.g. linetypes, grids, snaps, circle, text, hatching, dimensioning, layers/levels, colour; viewing, e.g. zoom, pan; inserting other drawings, e.g. symbols, blocks; modifying, e.g. copy, rotate, move, erase, scale, chamfer, fillet

Interpret: determine properties of drawn objects, e.g. list, distance, area, volume

5 Be able to use CAD software to produce 3D drawings and views

3D environment: 3D views, e.g. top, front, side, isometric

3D models: 3D techniques, e.g. addition and subtraction of material, extrude, revolve, sweep, 3D coordinate entry (x, y, z), wire frame drawing, 2D to 3D (thickness, extrusion); surface models; solid models

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the requirements of national and international standards and conventions relating to engineering drawing practice		
P2 explain which features of CAD drawings need to comply with national and international standards		
P3 explain the advantages, compared to other methods, of producing drawings electronically using a CAD package	**M1** explain the relationship between CAD and other software/hardware used in manufacturing	**D1** justify the use of CAD in a manufacturing company
P4 describe the software and hardware that are required to produce CAD drawings		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 produce 2D CAD detail drawings of five components that make up an assembly or sub-assembly to given standards, using appropriate commands	**M2** explain how the range of commands used to produce CAD drawings can impact drawing production	
P6 produce a circuit diagram containing at least five components to appropriate standards, using appropriate commands		
P7 produce an assembly drawing and exploded view of an assembly or sub-assembly containing at least five parts, using appropriate commands		
P8 interpret the properties of an engineering component or circuit from a given CAD drawing		
P9 construct a 3D CAD drawing as a surface and solid model.	**M3** explain how 3D CAD models can be used in the design process.	**D2** evaluate the impact of the use of 2D and 3D CAD models on final design requirements.

Essential guidance for tutors

Assessment

An assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to the national and international standards and conventions. While much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of which features of CAD drawings comply with national and international conventions could be generated by giving learners drawings which highlight the details required for meeting national and international conventions.

The assessment evidence for P3 and P4 could be produced through a case study or through studying the company in which learners may be employed. Typically, it would take the form of a written report or presentation. To achieve P3, learners must demonstrate an understanding of how CAD is used in comparison with more traditional drawing methods, stating its advantages and explaining how CAD systems can be linked with other software. A description of basic hardware and software requirements to operate a CAD system will be required to achieve P4.

The remaining pass criteria could be evidenced through a series of competence-based practical activities. Evidence could be in the form of witness statements, tutor observation records or a portfolio, although it is likely that electronic files will be used for the majority of the assessment. Screen dumps can often be a good source of evidence to show the range of commands used during the development of the drawings. The process evidence for these remaining pass criteria (P5 to P9) could be obtained from further assignments. In the first of these, learners would be required to produce five separate CAD drawings of the components which make up an assembly or sub-assembly. The full range of commands must be used and the drawings should be dimensioned to an appropriate standard, enabling P5 to be achieved. These drawings could then be used to produce an assembly and exploded view drawing (P7).

A further assignment would require production of a circuit diagram to achieve P6. This might reflect learners' occupation or area of interest and should be assembled from symbols previously introduced by the tutor and/or externally sourced. This assignment could also ask learners to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram (P8).

The final assignment would require production of a single 3D model using both surface and solid modelling techniques to enable achievement of P9. This might be a 3D version of one of the part drawings used as evidence for the assembly and exploded view drawing.

To achieve a merit grade, learners will need to look beyond how drawings are produced and evaluate their use and application. This will typically be through looking more closely at the relationship between CAD and other software. Learners should explain how linking CAD to other software/hardware impacts on an organisation (for example improving production, reducing waste, reducing lead times). This will build on the evidence generated for P3 and enable the M1 merit criterion to be achieved.

An explanation of the range of commands for criterion M2 and how they impact on drawing production in terms of efficiency (for example speed, accuracy, repeatability) links with P5, P6 and P7. Similarly, knowledge for the M3 criterion of how 3D models can be used in the design process links with the 3D activity in P9.

To achieve distinction criterion D1, learners should justify the use of CAD and will need to analyse other factors (for example disadvantages, costs, training requirements). This links with P3 and P4 as well as the M1 and M2 criteria. Learners should evaluate the relative merits of using CAD software. This could be as part of the case study outlined as possible evidence for the P3 criterion.

To achieve the D2 criterion learners will need to evaluate 2D and 3D drawings from a customer perspective. This links directly with the P9 and M3 criteria. Learners will need to compare and contrast the impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and P2	National and International Standards Report	Learners to research national and international standards and relate to engineering CAD drawing practice.	A report describing national and international standards and an explanation of CAD features that need to comply with these standards.
P3, P4, M1 and D1	CAD Report	Learners to research and compare the use of CAD with other methods and determine the software and hardware required to produce CAD drawings; in addition an investigation of how CAD links to other software and hardware and a justification of the use of CAD in manufacturing.	A report containing written responses about the use of CAD and alternative methods; in addition the software and hardware requirements of a CAD system should be listed and explained. An explanation of how CAD links with other software and hardware should support a justification of the use of CAD in a manufacturing context.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P7 and M2	CAD Portfolio	Learners to create an assembly drawing of at least five parts and detail CAD drawings of the five components; in completing the task learners should be able to explain how they used a range of commands in the CAD software to efficiently produce drawings.	A portfolio of five component drawings and an assembly drawing containing the five individual parts; in addition a short report containing written responses and/or screen dumps explaining how a range of CAD commands were used to efficiently produce the completed drawings.
P6 and P8	CAD Circuit Diagrams	Learners to produce a CAD circuit diagram containing at least five components to appropriate standards and using appropriate commands. Learners also to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram.	A circuit diagram containing at least five components. In addition, a given detail drawing or circuit diagram, annotated or with a brief summary explaining the information included.

Criteria covered	Assignment title	Scenario	Assessment method
P9, M3 and D2	CAD 3D Models	Learners to produce a single CAD 3D model using both surface and solid modelling techniques, possibly based on one of the part drawings used as evidence for P7. Learners also to research the use of 3D CAD models in the design process, and evaluate the impact of the use of 2D and 3D CAD models on final design requirements.	A 3D model produced using both surface and solid modelling techniques; in addition, a report explaining how 3D CAD models are used in the design process, and evaluating the use of 3D CAD models on final design requirements, including comparing and contrasting impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

Essential resources

Centres will need to have access to a suitably equipped IT facility with access to a printer/plotter. Access to software with 2D and 3D capabilities, such as AutoCAD and Inventor is also required. While general graphics packages would not be suitable, any CAD software capable of generating the evidence required for this unit would be acceptable.

Indicative reading for learners

Textbooks

Ambrosius L – *AutoCAD 2009 and AutoCAD LT 2009: All-in-one Desk Reference for Dummies* (John Wiley and Sons, 2008) ISBN 9780470243787

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Yarwood A – *Introduction to AutoCAD 2012* (Routledge, 2011) ISBN 9780080969473

Unit 14: Advanced Mechanical Principles and Applications

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will build on learners' knowledge of underpinning mechanical principles and the way they affect the design, operation, testing and servicing of machines and mechanisms.

The component parts of a mechanical system are very often subjected to loads and may be used to transmit force. It is essential that they are fit for purpose so that costly breakdowns and accidents are avoided. Design engineers must be able to predict the stresses to which engineering components will be subjected and ensure an appropriate level of safety.

Learning outcomes 1 and 2 will broaden learners' knowledge of stress analysis to include stress due to bending, stress due to torsion and the effects of two-dimensional (2D) and three-dimensional (3D) loading.

Learners sometimes have difficulty with the concepts of resultant and relative velocity. Learning outcome 3 seeks to clarify how these concepts are determined through the techniques of vector addition and vector subtraction. These are then applied to the operation of plane linkage mechanisms to determine the output characteristics for given input conditions.

The aim of learning outcome 4 is to give an understanding of mechanical oscillations in engineering systems. The concept of simple harmonic motion is introduced and expressions are derived for its parameters. These are then applied to freely vibrating systems such as mass-spring systems and the simple pendulum.

The unit as a whole provides an opportunity for investigative, relevant and active study that will enhance learners' ability to solve engineering problems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to determine the effects of uniaxial and complex loading on engineering components

2 Be able to determine the stress due to bending in beams and torsion in power transmission shafts

3 Be able to determine relative and resultant velocity in engineering systems

4 Be able to determine the characteristics of simple harmonic motion in engineering systems.

Unit content

1 Be able to determine the effects of uniaxial and complex loading on engineering components

Uniaxial loading: expressions for longitudinal and transverse strain; application of Poisson's ratio; determination of dimensional changes in plain struts and ties

Complex loading: expressions, e.g. strain in x and y directions due to 2D loading, strain in x, y and z directions due to 3D loading; changes, e.g. dimensional in rectangular plates, dimensional and volume for cubic elements

2 Be able to determine the stress due to bending in beams and torsion in power transmission shafts

Direct stress due to bending: expressions for second moment of area of solid and hollow rectangular and circular beam sections; application of bending equation ($\frac{\sigma}{y} = MI = ER$) to determine stress due to bending and radius of curvature at a beam section; determination of factor of safety in operation

Shear stress due to torsion: expressions for polar second moment of area of solid and hollow circular transmission shaft sections; application of torsion equation ($\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$) and expression for power transmitted (power = $T\omega$) to determine induced shear stress and angle of twist; determination of factor of safety in operation

3 Be able to determine relative and resultant velocity in engineering systems

Resultant and relative velocity: vector addition of velocities; resultant velocity of a body with simultaneous velocities in different directions; vector subtraction of velocities; relative velocity between objects moving simultaneously in different directions; construction of space diagrams and velocity vector diagrams

Plane mechanisms: e.g. slider-crank and inversions, four-bar linkage and inversions, slotted link quick return mechanism, Whitworth quick-return mechanism; construction of diagrams, e.g. space diagram, velocity vector diagram, determination of output motion

4 Be able to determine the characteristics of simple harmonic motion in engineering systems

Simple harmonic motion generation: general equations for simple harmonic motion derived from a consideration of uniform circular motion, e.g. expressions for circular frequency, displacement with time, velocity with time, velocity with displacement, acceleration with time, acceleration with displacement, periodic time, frequency of vibration; application to mechanical systems where output simple harmonic motion is generated by input uniform circular motion, e.g. scotch yoke mechanism; parameters to be determined, e.g. frequency of vibration, periodic time, displacement, velocity and acceleration at a given instant

Vibrating mechanical systems: systems (mass-spring, simple pendulum); expressions for circular frequency in terms of system parameters; application of general equations for simple harmonic motion, e.g. natural frequency of vibration, periodic time, velocity and acceleration at a given instant

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 determine the dimensional effects of uniaxial loading on a plain structural component and 2D loading on a rectangular plate	**M1** determine the dimensional effects and change in volume for a given element of an engineering component when subjected to 3D loading	
P2 determine the maximum stress due to bending, factor of safety in operation and minimum radius of curvature for a simply supported beam carrying a given concentrated load and a uniformly distributed load	**M2** compare the effects on a rectangular section beam's load-carrying capacity of increasing the breadth and increasing the depth by given amounts	**D1** compare the saving in weight and the reduced torque transmission capacity for a hollow power transmission shaft as its internal diameter is increased
P3 determine the maximum shear stress, factor of safety in operation and angle of twist for a mechanical power transmission shaft when transmitting given power at a given speed		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 determine the resultant velocity of an object when moving simultaneously with velocities in two different directions and its velocity relative to a second object moving in the same plane in a third direction	**M3** determine the output velocity of a given quick-return mechanism for given input conditions	
P5 determine the output motion of a slider-crank mechanism and a four-bar linkage mechanism for given input conditions		
P6 determine the periodic time and the displacement, velocity and acceleration at a given instant of the simple harmonic motion generated by circular motion of given parameters	**M4** evaluate the output motion of the slider in a slider-crank mechanism with uniform input motion of the crank, for compliance with the conditions necessary for it to describe simple harmonic motion.	**D2** determine from test data the effective contributory mass of the spring in an oscillating mass-spring system.
P7 determine the circular frequency, the natural frequency of vibration and the maximum velocity and acceleration for a mass-spring system and a simple pendulum with given parameters.		

Essential guidance for tutors

Assessment

Ideally, assessment of this unit will be achieved through applying the mechanical principles covered to relevant engineering settings. This could be achieved through integration with other engineering principles units, practical work that provides learners with opportunities to produce individual evidence for assessment and individual project/assignment tasks. Whichever approach is taken, it is important to ensure that the criteria are achieved autonomously. Where centres consider a test/examination is necessary to achieve authentic evidence, they need to ensure that the test items are set in a way to enable the criteria to be met in full. Centres also need to consider how such an assessment will provide opportunities to meet the merit and distinction criteria and how to provide learners with further learning and assessment should they initially fail to achieve in the test/examination.

If learners make an arithmetic error in the solution to a problem, it is for the centre to decide the significance of such an error, assess the work accordingly and provide suitable feedback. For example, if a learner has chosen the correct approach and manipulated the necessary formulae and data correctly but has made and carried through a minor arithmetic error, then the final 'inaccurate' solution to the problem may be deemed to be good enough to meet the criterion. However, if the final solution to the problem is so obviously wrong that it should have prompted further checks for accuracy, then the solution could be deemed to be unacceptable and reassessment considered. The incorrect application of units and/or dimensions is a typical cause of such major errors, which can lead to relatively large scale errors of the magnitude 103 or greater.

Assuming that the unit is delivered in the order of the learning outcomes, a first assignment could provide an opportunity to achieve the pass criterion P1 by means of tasks to determine the dimensional effects of uniaxial and 2D loading. These could be followed by a task to determine the dimensional effects of 3D loading and corresponding change in volume for achievement of the M1, all to be documented in a short report and authentication of the evidence being presented

A second assignment might contain a task to determine the stress and curvature in a loaded beam (P2) and a task to determine the shear stress and angle of twist in a power-transmission shaft for given operating conditions (P3), suitably documented. A third task, to achieve criterion M2, could be to examine the effects of increasing the breadth and depth of a rectangular beam section on its second moment of area and hence also on its load-carrying capacity. A fourth task to achieve D1 might be to compare the saving in weight and the reduction in torque transmission capacity as the internal diameter of a hollow transmission shaft is increased.

P4 and P5 could be assessed through an assignment containing a task to determine resultant and relative velocities in a system of moving bodies and a task to determine the output motion of plain mechanisms for given input conditions. Both a slider-crank and four-bar chain should be considered, while a third task to achieve M3 could be to determine the output velocity of a quick-return mechanism. In all three criteria, there is an expectation that the response will involve the construction of diagrams to help determine the solution.

A final assignment for P6 and P7 should contain tasks to determine the parameters of simple harmonic motion for a system generated by uniform circular motion, a mass-spring system and a simple pendulum. These could be followed by a task to evaluate the output motion of a slider-crank mechanism for uniform input rotation of the crank to achieve merit criterion M4. The evaluation should conclude that the motion is not simple harmonic but that it may be approached by lengthening the connecting link. A final task to achieve distinction criterion D2 could involve the gathering and analysis of test data to determine the contributory effect of spring mass on the periodic time of a vibrating mass-spring system. The test data may be given in the absence of practical test facilities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Uniaxial and Complex Loading	A suitable engineering situation to set problems involving engineering components subjected to uniaxial loading, 2D and 3D loading.	A written report containing an explanation to each step in the sequence of calculations, experiments or simulations and findings.
P2, P3, M2, D1	Bending and Torsion	A suitable engineering situation to set problems on a simply supported beam and problem on a power transmission shaft Evaluation of load-carrying capacity and power-transmission capacity.	A written report containing an introductory explanation to each step in the sequence of calculations and findings. A written evaluation of the load-carrying capacity of a beam and the power-transmission capacity of a shaft.
P4, P5, M3	Resultant and Relative Velocity	A suitable engineering situation to set problems involving resultant and relative velocity of moving bodies and motion in plane mechanisms.	A written report containing an introductory explanation to each step in the sequence of graphics and calculations.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M4, D2	Simple Harmonic Motion	A suitable engineering situation to set problems involving simple harmonic motion in engineering systems. Evaluation of the output motion of the slider-crank mechanism and analysis of test data for a mass-spring system.	A written report containing an explanation to each step in the sequence of calculations and findings. A written evaluation of the output motion of a slider-crank mechanism. Analysis of test data for a mass-spring system to determine the contributory mass of the spring.

Essential resources

Centres should have access to investigation and demonstration equipment, such as simply supported beam apparatus, torsion test apparatus and apparatus for the investigation of simple harmonic motion.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Bolton W – *Engineering Science* (Newnes, 2006) ISBN 9780750680837

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 15: Engineering Primary Forming Processes

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Almost everything we touch in the world of technology has been created through some technique or process associated with primary forming – the forming of shapes with minimal waste and loss of volume. Without these primary forming processes, the technological world as we know it today would not exist.

Many engineering components are initially formed by moulding, deformation or shaping. Over the years, these processes have been refined to suit the introduction of new materials and the demands of quantity production. In some processes, the shaped component is almost ready for use and requires only a little cleaning and trimming. In others it is produced slightly oversize and, after cleaning and trimming, it is machined accurately to the required dimensions.

The main aim of this unit is to provide a broad understanding of manufacturing processes associated with primary forming. It will give learners a broad understanding of moulding techniques for metals, ceramics and polymers, deformation processes for metals and polymers, and shaping and assembly of composites. The unit will introduce learners to a range of techniques and primary processes but will provide a deeper understanding of the more common processes.

For each technique and process, learners will form an appreciation of the fundamental process requirements, the working techniques used and the relevant health and safety considerations. The use of these primary processes sometimes creates a dangerous environment and knowledge of relevant health and safety and related legislation is very important.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how moulding techniques involving metals, ceramics and polymers are used

2 Understand how deformation processes involving metals and polymers are used

3 Understand how shaping and assembly processes involving composites are used

4 Understand how health and safety issues relate to primary forming processes.

Unit content

1 Understand how moulding techniques involving metals, ceramics and polymers are used

Moulding techniques involving metals: casting method, e.g. sand, die (gravity, pressure), investment, continuous; metal applicable to process, e.g. ferrous (carbon steels, stainless steels, cast iron), non-ferrous (aluminium, copper, brass, zinc, magnesium, nickel, titanium, alloys); form of material supply, e.g. pig iron, scrap, ore, ingots, recycled material, metal composition, trace elements, coke, limestone; mould production, e.g. patterns, cores, dies, moulding parts (boxes, sand, reinforcements, releasing agents, runners, risers, sprues); component removal and finishing, e.g. knock out, ejection, fettling

Moulding techniques involving ceramics: powder metallurgy (blending, compacting); sintering; secondary operations, e.g. infiltration, sizing, coining, machining, impregnation, plating, heat treatment; ceramics applicable to process, e.g. metallic carbides, nitrides, oxides

Moulding techniques involving polymers: techniques, e.g. compression, transfer, injection, rotational moulding, blow moulding; polymers applicable to process, e.g. thermoplastics, thermosetting plastics, polystyrene, polyethylene, acetal, acrylonitrile butadiene styrene (ABS), nylon, polycarbonate, polypropylene; use of additives, e.g. stabilisers, flame retardants, fillers (asbestos, cotton flock, fibres, mica, graphite, wood flour), plasticisers, antistats, colorants, lubricants; mould tools, e.g. two plate, three plate, combination/composite, split, unscrewing; moulding parameters, e.g. temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation

2 Understand how deformation processes involving metals and polymers are used

Deformation processes involving metals: processes, e.g. extrusion (direct, indirect, impact), forging (drop, pressure, upset), rolling (hot, cold), presswork (forming, bending, deep drawing), metal spinning; metals applicable to process, e.g. ferrous (carbon steels, stainless steels), non-ferrous (aluminium, copper, brass)

Deformation processes involving polymers: processes, e.g. vacuum forming, extrusion, calendaring; polymers applicable to process, e.g. thermoplastics, polycarbonate, polysulphon, acrylic, polyvinyl chloride, ABS, thermoplastic sheet; use of additives, e.g. plasticisers, antistats, lubricants, heat stabilisers; features, e.g. double curvatures, shapes (male, female), stiffened mouldings, section shape; parameters, e.g. temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation

3 Understand how shaping and assembly processes involving composites are used

Composite shaping processes: processes, e.g. pre-preg laminating, wet lay-up, moulding; use of fibre (glass, polyethylene, aramid, carbon); use of resin (polyester, vinyl ester, epoxy, phenolic); composite materials applicable to process, e.g. wood, Coremat, foam, honeycomb (Nomex, aluminium), syntactic core, expanding core; design features, e.g. corners (internal, external), surface (concave, convex, return, vertical), double curvature, nett edges, joggle details; types of reinforcement, e.g. roving, braids, tapes, chopped strand, continuous filament, uni-directional, woven, multi-axis

Composite assembly processes: types, e.g. trial, one-off, batch, assembly line; features, e.g. tolerances (loose or close fit), fixing (permanent or non-permanent), shape location, joins (joggle, return or overlap); assembly methods, e.g. fettling, pinning, clamping, trial fitting, aligning, assembly jigs and sequences; joining methods, e.g. thread inserts, fasteners (mechanical, quick release), anchor nuts, rivets; composite components, e.g. trim, panels (closing, body), tubes, structural, aerodynamic, core materials, sections, inserts, housings; non-composite components, e.g. brackets, fixtures, fittings, trim, tapes, memory foam, films

4 Understand how health and safety issues relate to primary forming processes

Health and safety: relevant health and safety legislation and regulations, e.g. Control of Substances Hazardous to Heath (COSHH) Regulations, Provision and Use of Work Equipment Regulations (PUWER), Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) Lifting Operations and Lifting Equipment Regulations, Manual Handling Operations Regulations (MHOR), Personal Protective Equipment (PPE) at Work Regulations, Confined Spaces Regulations, Control of Major Accidents Hazards (COMAH) Regulations, Control of Noise at Work Regulations, Health and Safety (First-Aid) Regulations, European directives, relevant codes of practice; requirements for the use of guards, screens, ventilation; use of personal protective equipment (PPE); manual lifting and handling techniques

Reducing risks: e.g. use of risk assessment methods, avoidance of dangerous conditions, appropriate training, good housekeeping, safe use of tools and equipment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the moulding techniques used to manufacture a metal-based component	**M1** compare and contrast the different moulding techniques used to manufacture products from metals, ceramics and polymers	**D1** justify the use of a specific moulding technique for the manufacture of a given product
P2 explain the moulding techniques used to manufacture a ceramic-based component		
P3 explain the moulding techniques used to manufacture a polymer-based component		
P4 explain the deformation processes used to manufacture a metal-based component	**M2** compare and contrast the different deformation processes used to manufacture products from metals and polymers	**D2** justify the use of a deformation process for the manufacture of a given product.
P5 explain the deformation processes used to manufacture a polymer-based component		
P6 explain the shaping processes used to manufacture a composite-based component	**M3** explain why a composite shaping process is appropriate for a given manufactured product	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 explain the methods used to manufacture a composite-based assembly		
P8 explain the health and safety issues that relate to each of the primary forming processes considered	**M4** suggest improvements that could reduce the risk to the health and safety of a primary forming process operator.	
P9 explain methods of reducing risk for each of the primary forming processes considered.		

Essential guidance for tutors

Assessment

A suitable strategy for this unit would be for learners to carry out detailed investigations into the way given or chosen products are manufactured. A range of products will be required and needs investigated to ensure learners have opportunities to cover the range of primary forming processes listed and the requirements of the assessment criteria.

Criteria P1, P2, P3, M1 and D1 relate to learning outcome 1 and P4, P5, M2 and D2 relate to learning outcome 2. These could be assessed by the first two assignments. These assignments should give learners an opportunity to demonstrate their understanding of the different moulding techniques and deformation processes. The tasks set should ensure that they explain a moulding technique suitable for each of the materials covered by learning outcome 1 (i.e. metals, ceramics and polymers) and suitable deformation processes for both metals and polymers for learning outcome 2. Tasks set in the assignments could require learners to compare and contrast particular moulding techniques (M1) and deformation processes (M2) for products made from the materials listed in the content for learning outcomes 1 and 2 respectively. For the products selected, learners must justify the moulding technique used (D1) and deformation process (D2).

A third assignment could concentrate on composite manufacture (learning outcome 3). A task should be set to explain both a composite shaping process (P6) and a composite assembly process (P7). A further task, or a holistic task, could then ask learners to explain why a particular composite shaping process would be appropriate for a given manufactured product (M3). Care should be taken when selecting a product for this task to ensure that it has all the requirements of the content within the learning outcome, i.e. the use of fibre, resin, design features and types of reinforcement. Likewise, the explanation for P6 should also have these aspects of content covered.

The final assignment should enable learners to achieve P8, P9 and M4. They should be asked to explain the health and safety issues that relate to the processes covered earlier (P8) and to describe risk reduction for one process (P9).

To cover M4, learners could evaluate and suggest improvements to any relevant aspects of legislation or risk within an area of interest to them (for example use of equipment, guards, clothing and handling). The most important aspect of the evidence will be learners' ability to evaluate the situation and come up with some distinct and valid improvements.

The assessment evidence for this unit is likely to be in the form of a number of written responses in a portfolio that may include information and diagrams. Centres need to take care that the evidence used for assessment is learners' own work and that where learners make use of other people's work then this is clearly acknowledged and referenced. Centres may find it helpful to guide learners by providing a recommended structure for their descriptions and in particular a format/system for including references.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Moulding Techniques for Metals, Polymers and Ceramics	An activity requiring learners to carry out research based on actual engineering techniques and suitable roles associated with metals, polymers and ceramics.	A portfolio containing written responses and diagrams showing moulding techniques for each material family type. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P4, P5, M2, D2	Deformation Processes for Metals and Polymers	An activity to investigate, aligned to a suitable role, the processes associated with the deformation of a range of metals and polymers.	A portfolio containing written responses and diagrams showing deformation processes for metals and polymers. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3	Shaping and Assembling Composite-based Products	An activity to investigate the shaping and assembly processes associated with composite product manufacture set within a suitable context.	A portfolio containing written responses and diagrams showing composite shaping processes and assembly processes used to manufacture composite based products. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P8, P9, M4	Improvements to Processes and Health and Safety in Primary Forming	An investigative activity based around a suitable role involving the review of the health and safety issues associated with primary forming processes involving metals, polymers and ceramics. Followed by a case study to improve the primary forming process of a manufactured product and making a safer environment for an operator.	A portfolio containing a written commentary about health and safety and risk reduction. This activity could be supported by an evaluation of a process to suggest improvements to the process and its safe operation. Evidence could also be made available by a PowerPoint presentation.

Essential resources

Centres must have access to a range of cast, ceramic-moulded, polymer-moulded and process-deformed components, along with a range of components made from composites, including both shaped and assembled. Ideally, centres would have facilities to practically demonstrate some of the primary processes covered by the unit content, although this is not essential. However, centres that are unable to do so should consider industry visits or, alternatively, video and other presentation resources. Access to relevant health and safety legislation will be required.

Indicative reading for learners

Textbooks

Black B – *Workshop Processes, Practices and Materials* (Routledge, 2015) ISBN 9781138784727

Bolton W – *Materials for Engineering* (CRC Press, 2006) ISBN 9780849387807

Health and Safety Executive – *Health and Safety in Engineering Workshops* (Health and Safety Executive, 2004) ISBN 9780717617173

Timings R L – *Manufacturing Technology* (Prentice Hall, 1998) ISBN 9780582356931

Unit 16: Engineering Secondary and Finishing Techniques

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

For everyday products and components to be manufactured to a required standard, the machines that produce them need to be operated in an efficient and safe manner. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Machine operators will produce better components if they are aware of a range of finishing and secondary processes that can be used. A secondary process is where raw material or a component is taken for further working, usually involving material removal, and is carried out after a primary forming process.

This unit aims to give learners a detailed knowledge of the use of secondary processing machines, including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods).

The unit gives learners an opportunity to examine a range of secondary processing machines, their design and application. To a lesser extent, they will also identify a range of 'non-traditional' techniques, such as electro discharge and broaching.

Learners will investigate heat treatment processes, which are often used to get a product or component into its final state and ready for use. Without these processes parts would fail prematurely or further manipulation would not be possible on certain materials to create a final component. Learners will also understand assembly methods, including automated techniques that can be associated with computer-aided manufacture and other modern approaches, such as flexible manufacturing systems.

Finally, learners will understand how finishing techniques are used in engineering to add either function or aesthetics to a part component or product. Anodising and plating methods will be discussed, as well as hot processes used to obtain a required finish (such as powder coating or hot dipping) and the associated aspects of health and safety.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how a range of secondary machining techniques are used

2 Know how a range of non-traditional techniques are used

3 Know how heat treatment processes and assembly techniques are used

4 Know how finishing techniques are used.

Unit content

1 Understand how a range of secondary machining techniques are used

Turning: machine, e.g. centre lathe, turret; features of the workpiece, e.g. flat faces, diameters (such as parallel, stepped, tapered), holes (such as drilled, bored, reamed), profile forms, threads (such as internal, external), eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts

Milling: machine, e.g. horizontal, vertical, universal, planer/gantry; up-cut; down-cut; features of the workpiece, e.g. faces (such as flat, square, parallel, angular), steps/shoulders, slots (such as open ended, enclosed/recesses, tee), holes (such as drilled, bored), profile forms (such as vee, concave, convex, gear), serrations, indexed or rotated forms, special forms

Boring: machine, e.g. horizontal, vertical; features of the workpiece, e.g. bored holes (such as through workpiece, to a depth, tapered), holes (such as drilled to depth, drilled through workpiece, reamed, threaded), external diameters, grooves/recesses, chamfers/radii, faces (such as flat, square, parallel, angular, milled), slots, forms (such as indexed, rotated), external tapers

Grinding: machine, e.g. surface (such as horizontal, vertical), cylindrical (such as external, internal), centreless, universal, thread, profile; features of the workpiece, e.g. faces (such as flat, vertical, parallel, square to each other, shoulders and faces), slots, diameters (such as parallel, tapered), bores (such as counterbores, tapered, parallel), profiles forms, thread forms (such as vee, right hand, single start, multistart, internal, external), angular faces

Presswork: machines, e.g. single action, multiple action; features of the workpiece, e.g. blanking, notching, piercing, joggling, cropping/shearing, bending/forming, coiling/rolling, planishing/flattening, first draw, second draw, compound operations, cupping, embossing, coining

Health and safety: appropriate legislation and regulations, e.g. Health and Safety at Work etc. Act, Fire Precautions Act, manual handling, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Provision and Use of Work Equipment Regulations (PUWER), Health and Safety (First Aid) Regulations; use of personal protective equipment (PPE)

Materials: e.g. ferrous, non-ferrous, non-metallic, stainless, special alloys, deep drawing steels

Kinematics: machine tool design; generation and forming of shapes; six degrees of freedom

2 Know how a range of non-traditional techniques are used

Electro discharge: machines, e.g. spark erosion, wire erosion; features of the workpiece, e.g. holes, faces (such as flat, square, parallel, angular), forms (such as concave, convex, profile, square/rectangular), other features (such as threads, engraving, cavities, radii/arcs, slots)

Broaching: machines, e.g. horizontal, vertical; features of the workpiece, e.g. keyways, holes (such as flat sided, square, hexagonal, octagonal), splines, serrations, other special forms

Honing and lapping: machines, e.g. honing (such as horizontal, vertical), lapping (such as rotary disc, reciprocating); features of the workpiece, e.g. holes (such as through, blind, tapered), faces (such as flat, parallel, angular)

3 Know how heat treatment processes and assembly techniques are used

Heat treatment processes for ferrous metals: surface hardening; other processes, e.g. hardening, tempering, annealing, normalising; appropriate health and safety requirements, e.g. Health and Safety at Work etc. Act, requirements relating to chemicals and materials handling (such as Control of Substances Hazardous to Health (COSHH) Regulations, safe disposal of waste materials and components (fluids, hardening materials), manual handling, safe use of electrical and pressurised equipment, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Provision and Use of Work Equipment Regulations (PUWER)

Assembly techniques: manual, e.g. screwed fasteners, locking devices, keys, dowels, circlips; automated, e.g. part feeding devices, transfer and indexing, orientation devices

4 Know how finishing techniques are used

Hot processes: e.g. hot dip treatment (such as molten wax, molten tin to steel, molten zinc to steel, organic coatings), powder coating (such as fluidised bed thermoplastic coating powder, fluidised bed thermosetting powder, electrostatic grade thermoplastic powder, electrostatic grade thermosetting powder)

Anodising: e.g. sulphuric acid, chromic acid, hard anodising

Plating methods: e.g. electroplating (such as copper, gold, silver, cadmium, platinum), electroless nickel, mechanical (such as mechanical zinc, mechanical tin-zinc, mechanical aluminium-zinc), alloy (such as brass, nickel-iron, tin-lead, zinc-nickel, zinc-iron, zinc-cobalt), zinc (such as cyanide zinc, alkaline zinc, acid zinc), nickel and chromium, hard chromium; substrates, e.g. mild steel, stainless steel, brass, copper, zinc based, aluminium

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how five different secondary machining techniques are used safely on a range of materials	**M1** compare and contrast why different secondary machining techniques are used when manufacturing products	**D1** evaluate the effective use of an appropriate secondary machining technique
P2 explain kinematics in secondary machining techniques		
P3 identify appropriate non-traditional techniques for six given products		
P4 describe an appropriate non-traditional technique for a given product		
P5 explain surface hardening and another heat treatment process for ferrous metals	**M2** compare and contrast why different heat treatment processes are used when manufacturing products from ferrous metals	
P6 describe two different manual and an automated assembly technique		
P7 describe a hot process, anodising and plating method when used for finishing on different components		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 explain the appropriate heat treatment processes, secondary, finishing and assembly techniques needed to manufacture four given components.	**M3** from given restrictions and information justify alternative assembly and finishing techniques.	**D2** evaluate a given secondary machining technique and heat treatment process for health and safety risk and impact on the environment.

Essential guidance for tutors

Assessment

It is important that the assessment strategies used are designed to suit the needs of learners. Good assessment strategies are most likely to be supported by proper presentation of appropriate evidence. A portfolio or file of evidence should not contain course notes, research etc. unless it is to become part of the required evidence and assessment.

Work done through the use of case-study material can be used to generate evidence for the portfolio, particularly if industrial visits are well embedded in delivery. It is likely that a range of products will need to be investigated to ensure learners have opportunities to cover the required range of secondary machining techniques and heat treatment processes, together with finishing and assembly techniques.

To achieve a pass, learners need to demonstrate understanding and knowledge of the different processes and techniques, explain or describe their characteristics and how they are used. While learners need to explain what is meant by kinematics in relation to secondary techniques, they only need to show enough knowledge to describe one non-traditional technique. However, they must select appropriate non-traditional techniques for six different products. Learners also need to describe both surface hardening and one of the other processes, such as annealing, and both types of assembly techniques (manual and automated). They should also describe all three types of finishing techniques as listed in the unit content.

This unit could be assessed through three assignments. The first assignment could be a series of written tasks to cover P1, P2, P3 and P4. The task for P1 should have enough detail for learners to cover turning, milling, boring, grinding and presswork. The types of machine they consider from each of these could be left to the learner, as they may have a preference from their place of work. Alternatively, a specific machine type could be given to different learners across the range. This would help centres authenticate each learner's response.

The tasks should also ensure that learners consider the health and safety requirements and cover at least three of the material types listed in the content.

The six products given for P3 must cover the three non-traditional techniques ranged – electro discharge, broaching and honing/lapping. The products should have sensible characteristics, such as type of material, quantity, size, accuracy (tolerances) and surface texture requirements to clearly direct learners towards the correct non-traditional technique. The written task for P4 could be about one of the machines from these techniques. Again, some learners may have preferences based on their workplace. This assignment could also include further written tasks to cover both M1 and D1.

The second assignment could have tasks to explain heat treatment processes (P5) and assembly techniques (P6). Surface treatment must be covered but freedom can be given as to which other process is described. The task should also ask learners about the health and safety requirements. The task addressing P6 must cover two manual and one automated technique.

A further task could be developed to cover M2, which would give learners an opportunity to cover more of the range of heat treatment processes. A comparison between hardening, tempering and annealing would be sensible. Another task in the assignment could cover P7 ensuring that all finishing techniques are covered.

Another task should be given to allow learners to justify alternative assembly and finishing techniques (M3). In doing so, a range of restrictions and information should be given to ensure learners are able to come up with some sensible alternatives. An example is when the modification of an assembled component allows an automatic feeding device to be used, assuming the batch quantity information indicates it would be viable, or a material amendment needs a change of finishing technique.

The third assignment could have a task requiring learners to explain appropriate processes and techniques as listed in P8 for four different components. These components need to be fairly complex to include a requirement for a heat treatment process, a secondary, a finishing and an assembly technique. These requirements must not be given but be suggested by the component characteristics and specification. This can be done by a set of drawings/specifications or by actual products, with a set of notes that would ensure the learners are able to identify the appropriate process and techniques. A final written task could be included to give an opportunity to cover D2.

To achieve a merit, learners need to compare and explain how different machining techniques are used (M1) and how different heat treatment processes are used in manufacturing (M2). They will need to suggest alternative assembly and finishing techniques when given specific restrictions and information (M3).

To achieve a distinction, learners need to confidently evaluate the effective use of secondary machining techniques (D1) for certain circumstances. Learners should show skills in evaluating a given secondary machining technique and a given heat treatment process for health and safety risk and impact on environmental issues (D2).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1 and D1	Secondary and Non-traditional Machining Techniques	An activity requiring learners to carry out research based on actual secondary and non-traditional machining techniques associated with a range of materials.	A portfolio containing written responses and diagrams showing the five different secondary machining and non-traditional techniques for a range of material types, possibly supported by a PowerPoint presentation. Alternatively a case study could be used and presented as a portfolio.
P5, P6, P7, M2	Heat Treatment Processes, Assembly and Finishing Techniques	An activity to investigate the processes associated with the heat treatment of ferrous metals, and the use of hot processes and finishing techniques.	A portfolio containing written responses and diagrams showing heat treatment processes for ferrous metals and descriptions of assembly techniques, hot processes, anodising and a plating method. This activity could be supported by a PowerPoint presentation.

Criteria covered	Assignment title	Scenario	Assessment method
P8, M3 and D2	Secondary Processes and Finishing Techniques Associated with Manufacturing Products	An activity to investigate the heat treatment processes, secondary, finishing and assembly techniques associated with product manufacture.	A portfolio containing written responses to show the processes and techniques used to manufacture four given components, possibly supported by a PowerPoint presentation. Alternatively, a case study could be used and presented as a portfolio.

Essential resources

Centres should have access to as large a range of the machinery and processes outlined in the unit content as possible.

Indicative reading for learners

Textbooks

Health and Safety Executive – *Health and Safety in Engineering Workshops* (Health and Safety Executive, 2004) ISBN 0717617173

Timings R L – *Manufacturing Technology* (Prentice Hall, 1998) ISBN 0582356938

Unit 17: Fabrication Processes and Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Fabrication processes and technology are used in the production of metal structures in a wide range of manufacturing industries. The fabrication of metal structures involves four essential stages: measuring and marking out, preparation of the material for fabrication, forming processes and the assembly of the materials.

This unit gives learners with no previous fabrication experience an understanding of the processes and technologies used throughout the fabrication industry, whilst learning to work in a safe environment. The unit is appropriate for work-based learners or for those who are being prepared for employment in an industrial environment where fabrication is an integral part of the manufacturing process.

Learners will work with ferrous or non-ferrous metals in the form of sheet, plate and sectional materials to construct a fabricated structure. They will learn how to use a range of industrial hand tools and machinery to complete fabrication tasks. The unit will give learners the ability to identify the correct processes and equipment to use, and the tools and equipment appropriate to each stage of the fabrication process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand health and safety legislation, regulations and safe working practices for fabrication activities
2. Know the processes used to mark out and prepare materials to produce fabricated structures
3. Know how materials are formed and assembled to produce fabricated structures
4. Be able to interpret the specification of a fabricated structure and plan and carry out its manufacture.

Unit content

1 Understand health and safety legislation, regulations and safe working practices for fabrication activities

Legislation and regulations: applicable to fabrication activities, e.g. Health and Safety at Work etc. Act, Employment Act, Factories Act, Fire Precautions Act; regulations, e.g. Management of Health and Safety at Work Regulations, Provision and Use of Work Equipment Regulations (PUWER), Control of Substances Hazardous to Health (COSHH) Regulations, Lifting Operations and Lifting Equipment Regulations (LOLER), Manual Handling Operations Regulations (MHOR), Personal Protective Equipment (PPE) at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Working Time Regulations, Workplace (Health, Safety and Welfare) Regulations, Health and Safety (First-Aid) Regulations

Safe working practices: safety in the workshop and on-site; fire prevention; accident prevention and reporting; risk assessment; manual handling; checking conditions, e.g. gas leaks, voltage and amperage, correct fuses, leads, guarding of machinery and power tools; action to be taken when machinery and equipment are dangerous or in poor condition; personal protective equipment (PPE); ventilation and extraction; closing down, e.g. equipment safety, storing equipment, safe disposal of waste materials, use of compressed air

2 Know the processes used to mark out and prepare materials to produce fabricated structures

Marking out: measuring and marking out equipment, e.g. rule, protractor, tee square, set square, tape measure, compass, dividers, trammel, templates, marker pen, scriber, chalk line, laser level; detailed drawing, e.g. dimensions, tolerances; reference points, e.g. datum line, centre line datum; setting out, e.g. radial line, triangulation, projection, true lengths; calculations, e.g. bend allowance, allowance for springback, intersection points, overlap; calibration of equipment

Fabricated structures: examples from local industry; made in a centre's workshop, e.g. equipment storage systems (i.e. tool rack, tool box), work bench, car maintenance equipment (i.e. axle stand, ramp, crawler board), ventilation ducting (i.e. collector hood, reducing section, tee connector)

Preparing materials: obtaining materials, e.g. sheet, bar, plate, section; standard bought out condition, e.g. hot-rolled, cold rolled, standard dimensions, profiles, thickness; metallic materials, e.g. ferrous, non-ferrous; cutting to size and shape, e.g. flame, plasma, powder, water jet, laser, band saw, hacksaw, reciprocating saw; shearing, e.g. hand, bench, rotary, reciprocating; guillotining, e.g. bench, power; nibbling, e.g. hand, power; presswork, e.g. piercing, blanking, punching; material removal, e.g. chiselling, drilling, trepanning, filing, grinding; automated methods, e.g. numerical control (NC), computer numerical control (CNC), direct numerical control (DNC), mechanical copying using templates

3 Know how materials are formed and assembled to produce fabricated structures

Forming: principles, e.g. spring back, bend allowance; forming by hand, e.g. hammer and former, fly press, bench mounted bending machine; forming by machine, e.g. folding machine, press brake; rolling tools (e.g. rolling rolls, pyramid rolls, slip rolls, cone rolls), angle ring-bending; swaging; deep drawing and pressing; web stiffeners; edge preparation; pipe bending; use of templates and patterns; automated methods, e.g. numerical control (NC), computer numerical control (CNC), direct numerical control (DNC)

Fabricated structures: examples from local industry; made in a centre's workshop, e.g. equipment storage (i.e. tool rack, tool box), work bench, car maintenance equipment (i.e. axle stand, ramp, crawler board), ventilation ducting (i.e. collector hood, reducing section, tee connector)

Assembly: trial assembly or 'physical mock up', e.g. offering up, alignment, clamping, dimensional checks, adjustment, modification; workshop clamps, e.g. mitre joint, toggle, G clamp, rivet clamps/skin pins, magnetic clamping devices; joining methods, e.g. spot welding, continuous welding, laser welding, brazing, soldering, structural adhesives, riveting; mechanical fixings, e.g. nuts, bolts, screws, clamps, pipe connectors; web stiffeners; inspect and check against specification

4 Be able to interpret the specification of a fabricated structure and plan and carry out its manufacture

Structure specification: engineering drawing, e.g. assembly, detailed, development; material, e.g. steel, aluminium; material supply forms, e.g. plate of appropriate thickness, hollow section, solid section, pipe, tube; reference points, e.g. edge datum, centre line datum; dimensions, e.g. overall, reference, installation, tolerance; permanent and non-permanent assembly methods, e.g. thermal, adhesive, riveting, mechanical fixings; finish, e.g. paint, polymer coat, electro-plate, polish; quantity, e.g. one-off, small batch, large volume

Plan and manufacture: calculations, e.g. bend allowance, allowance for springback, intersection points, quantity of material required, minimisation of waste material; select suitable equipment, e.g. marking out, preparation, templates, patterns, forming and assembly; mark out; produce manufacturing aids, e.g. formers, jigs, templates; prepare and form individual parts of the assembly, e.g. cutting to size, edge preparation, piercing, bending; assemble the fabrication and join parts together, e.g. trial assembly or 'physical mock up', modification, weld, braze, rivet, fixings; meet the required accuracy as specified, e.g. dimensions, tolerances, finish, visual appearance, joint quality; inspect and check against specification

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the key features of the health and safety legislation, regulations and safe working practices applicable in a fabrication workshop	**M1** explain the effect, including aspects of safety and quality, of using incorrect equipment and processes to produce a fabricated structure	
P2 describe the process of marking out when producing fabricated structures	**M2** explain the factors that influence the assembly methods used in the production of a fabricated structure	**D1** justify the methods used to prepare materials when producing a fabricated structure
P3 describe the process of materials preparation when producing fabricated structures		
P4 describe how materials are formed before they are assembled into a fabricated structure		
P5 describe the assembly process for a given fabricated structure		
P6 interpret the specification of a fabricated structure to plan its manufacture.	**M3** produce a fabricated structure to specification.	**D2** evaluate the quality of manufacture against that specified for a fabricated structure.

Essential guidance for tutors

Assessment

Assessment of this unit could be achieved through the use of four assignments.

The first assignment could cover P1, with learners being asked to produce a written report. Evidence presented for P1 must be specific to fabrication processes and learners will need to be given clear guidelines about what to present. There is a huge amount of generic material that learners will have access to. Care should be taken to ensure that what they present is referenced properly and not directly copied from the internet or any other source. Grading criteria P1 and M1 complement each other and it may be that centres wish to cover them both in the first assignment. However, learners might do better if M1 is assessed later once they have a better understanding of the problems associated with using the wrong equipment and processes. If this is the case then M1 could be assessed through the assignment which addresses grading criterion P5.

P2, P3, M2 and D1 can be assessed through a second assignment. Evidence could be in the form of a written report supported by drawings, diagrams and photographic images of formative practical work carried out by learners as they investigated the various marking out and materials preparation techniques. Records of responses to oral questioning by the tutor may also be appropriate. Learners' evidence should also demonstrate further understanding of what influences the use of assembly methods for M2. D1 requires learners to demonstrate an understanding of the techniques used to prepare materials for fabrication by justifying the use of a selected method.

A third assignment could cover P4 and P5 (and M1 if not already covered in the first assignment). This should follow a similar format as assignment 2, with much of the evidence being based on the practical investigations carried out by learners on forming and assembly techniques. If M1 is covered in this assignment, learners' reports/evidence will also need to evidence their understanding of the consequences of using incorrect equipment and processes.

In P6 and M3, learners will use a given specification to plan and produce a fabricated structure. Care should be taken when designing the assignment brief for P6 and M3 to make sure that it does not just become a test of the learners' practical skills. Due to the time constraints of delivering the unit, it is not reasonable to expect learners to carry out joining processes that require a higher level of skill at an expert level.

There is scope to assess learning outcome 4 as a group activity so that learners can appreciate working as a team to produce a larger fabrication. Each learner could be given a part to work on, although care needs to be taken to ensure that the evidence presented by each learner addresses the whole of the unit content and can be substantiated. Digital annotated photographic images together with witness statements and observation records should be used to consolidate learner evidence of practical competence.

To achieve D2, learners could evaluate the quality of the fabricated structure produced in M3 and report on the quality of the structure compared to that set out in the given specification. This offers an opportunity for learners to evaluate the preparation, forming and assembly techniques they have used and identify where they can develop skills and techniques to improve quality.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Health and Safety for Fabrication Activities	An activity-based assignment that requires learners to research and identify health and safety legislation and safe working practices in fabrication activities.	A report that outlines legislation and safe working practices applicable to fabrication activities. The report should identify and clearly reference all research materials.
P2, P3, M2, D1	Marking Out and Preparing Fabrication Materials	A written assignment that evidences and further investigates the formative practical tasks that have been carried out in a fabrication workshop.	A written report will form a summative assessment that contains drawings, diagrams and photographs to evidence the range of marking out and preparation processes. Learners will justify the methods they have used to prepare materials in a fabrication workshop.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Forming and Assembling Fabrication Materials	A written assignment that evidences the practical investigations that the learner has carried out in a fabrication workshop.	Summative assessment will require a written report that contains evidence of the range of forming and assembly processes used in a fabrication workshop. The report will be supported with diagrams and photographs of their work. The report will examine the possible effects of using incorrect tools and processes. It will also include learners' interpretation of why particular assembly processes have been used.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M3, D2	Manufacturing From a Specification	A practical assignment that requires the learner to plan and make a fabricated structure from a given specification.	Learners will interpret information from a given specification and produce a plan of the processes and fabrication techniques to be used. Having planned the work, and agreed the plan with the tutor, learners will produce the fabricated structure given in the specification. Learners will produce a report which evaluates the quality of their work against the original specification.

Essential resources

Learners will need access to workshop facilities equipped with a range of marking out, forming and assembly tools and equipment, along with a variety of fabrication materials. Access to current health and safety legislation and regulations would also be useful for learning outcome 1.

Indicative reading for learners

Textbooks

Kenyon W – *Basic Welding and Fabrication* (Longman, 1987) ISBN 9780582005365

Robinson A – *The Repair of Vehicle Bodies* (Routledge, 2013) ISBN 9780415534451

Smith B D – *Welding Practice* (Butterworth-Heinemann, 1995) ISBN 9780340614068

Timings R L – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Wakeford R E – *Sheet Metal Work* (Special Interest Model Books, 1987) ISBN 9780852428498

Unit 18: Welding Technology

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning hours: 60

Unit introduction

A diverse range of welding processes is used in the manufacturing engineering industry, including manual, mechanised and machine-based techniques. The selection and application of these joining processes is vital in terms of the weld quality, and the economic viability of the finished product.

Learners will appreciate the need to produce high-quality welded joints in components based on the selection of the most appropriate process. To enable learners to make an informed choice, they will be required to select joining processes to satisfy a given application. The unit is appropriate for work-based learners where their industrial environment utilises welding as an integral part of the manufacturing process. It is also suited to learners who are being prepared for employment in the welding industry.

Learners will perform a range of formative practical tasks that will include planning and preparing for work and ensuring that health and safety legislation and safe working practices are understood and followed at all times. Learners will select and check the condition of appropriate equipment, which is particularly important considering that learners could be working with electric currents, combustible gas mixtures or parts rotating at high speed.

Continuous formative assessment allows learners to develop their practical skills and knowledge, which lead to summative assessments. Assignments will require them to report and record the development of their skills in the preparation and production of welded joints. Learners will inspect their work with reference to relevant quality standards, ensuring that they are capable of producing welded joints and are able to recognise defects.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand health and safety legislation, regulations and safe working practices in the welding industry
2. Be able to prepare for welding operations
3. Be able to produce welded joints to a quality standard
4. Understand how quality inspection processes are applied to welded joints in components.

Unit content

1 Understand health and safety legislation, regulations and safe working practices in the welding industry

Legislation and regulations: legislation, e.g. Health and Safety at Work Act, Employment Act, Factories Act, regulations, e.g. Fire Precautions (Workplace) Regulations, Management of Health and Safety at Work Regulations, Provision and Use of Work Equipment Regulations (PUWER), Control of Substances Hazardous to Health (COSHH) Regulations, Lifting Operations and Lifting Equipment Regulations (LOLER), Manual Handling Operations Regulations, Personal Protective Equipment at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Working Time Regulations, The Workplace (Health, Safety and Welfare) Regulations, Health and Safety (First-Aid) Regulations, Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations, Simple Pressure Vessels (Safety) Regulations

Safe working practices: fire prevention; accident prevention and reporting; risk assessment; manual handling, e.g. materials, safe handling of gas cylinders; checking conditions, e.g. gas leaks, voltage and amperage, correct fuses, circuit breakers, leads, earthing of equipment; personal protective equipment (PPE); ventilation and extraction; closing down, e.g. equipment safety, storing equipment, safe disposal of waste materials; emergency procedures, e.g. within the learning environment and the workplace; hazards associated with welding, e.g. burns, electric shock, radiation

2 Be able to prepare for welding operations

Information sources: safety instructions; job instructions; engineering drawings; quality control documentation, e.g. weld procedure specification (WPS), record and reporting sheets

Tools and equipment: check equipment availability; function and condition relevant to the welding process, e.g. cables, hoses, torches and electrode holders, gas pressure regulators, flow meters; working environment, e.g. workshop, site work, conditions for machinery and plant; assembling welding equipment, e.g. cables, weld return clamps, electrode holders, gas cylinders, regulators, valves, safety devices

Welding parameters: setting and adjusting, e.g.:

- for manual processes: gas pressure, flow rates, voltage, current (either alternating (AC) or direct (DC)), according to electrode or filler size
- for mechanised processes: safety devices, welding speed, other parameters (electrical parameters, flux dispensing and recovery mechanisms, wire feed rate, filler diameter, gas shielding system, mechanical functions (handling, loading, work holding, transfer))
- for resistance welding machines: welding current, welding and squeeze times, electrode pressure cycle, electrode size, welding speed (seam), weld pitch (spot), mechanical functions, electrode diameter and condition

- for laser welding machines: electrical parameters, welding speed, weld alignment and characteristics, beam tracking, beam characteristics (focal spot), gas shielding, mechanical mechanisms for work holding, traversing and transfer
- for friction welding machines: friction and forge cycle time, friction and forge loads (forces), rotational speed or other friction conditions (orbital, frictional burn-off characteristics, forge displacement, braking effort), weld appearance (correct upset)

Welding processes: manual, e.g. manual metal-arc (MMA), metal inert gas (MIG), metal active gas (MAG), metal-arc gas shielded, flux cored wire, tungsten inert gas (TIG), plasma-arc, gas welding; mechanised, e.g. MIG/MAG, cored wire, TIG, plasma-arc, submerged arc; machine based, e.g. resistance welding machines (spot, seam, projection), laser welding machines, friction welding machines

Consumables: appropriate to process, e.g. electrode (rutile, basic, nickel alloy, cellulosic, stainless steel, other electrodes), filler wire, gases (oxygen, acetylene, shielding gases), inert and active gases, flux/agglomerated flux, forms of supply, care when handling flux; safe storage of consumables

3 Be able to produce welded joints to a quality standard

Safety: fire prevention; accident prevention and reporting; using risk assessment; manual handling; equipment maintenance; checking conditions, e.g. gas leaks, voltage and amperage, fuses, circuit breakers, leads; wearing PPE; fumes; using ventilation and extraction; closing down equipment safely after use

Joints/components: e.g.

- for manual processes: butt, fillet, autogenous weld (without filler wire)
- for mechanised processes: two different joint configurations, two different material groups
- for resistance welding machines: two different material thicknesses, two different joint configurations
- for laser and friction welding machines: two different components, two different material groups

Welding positions: to a relevant standard, e.g. British Standard (BS) EN 287 flat (PA), horizontal vertical (PB), horizontal (PC), vertical upwards (PF), vertical downwards (PG), overhead (PE), inclined tube/pipe (H-L045 or J-L045); welding technique, e.g. torch angle, filler angle

Material: forms, e.g. plate (thickness appropriate to process, up to 6 mm for resistance welding), section, pipe/tube, sheet (< 3 mm), other forms; types, e.g. carbon steel, stainless steel, aluminium

Quality standard: minimum weld quality standard equivalent to the level given in the relevant standard, e.g. European/International Standard BS EN ISO 5817, BS EN ISO 10042, BS EN ISO 13919-2; meet the required accuracy as specified, e.g. dimensions, tolerances, weld quality, spot and projection welds are correctly located

4 Understand how quality inspection processes are applied to welded joints in components

Quality standard: safety in the use of test equipment and chemicals; minimum weld quality standard equivalent to the level given in the relevant standard, e.g. European and International Standard BS EN ISO 5817, BS EN ISO 10042, BS EN ISO 13919-2, BS EN 12062; meet the required accuracy as specified e.g. dimensions, tolerances, weld quality, spot and projection welds are correctly located

Testing: non-destructive inspection, e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), pressure tests (hydraulic, pneumatic), fluorescent particle, magnetic particle; destructive, e.g. macroscopic examination, nick break (fracture) tests, bend tests visual inspection; weld gauges, e.g. fillet, leg length, undercut and hi-lo gauges

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain aspects of health and safety legislation, regulations and safe working practices applicable to welding		
P2 use information sources to select a welding process for a given application, and suggest suitable parameters for the welding process	**M1** analyse the effect of using incorrect welding parameters for a selected welding process, including the effects on quality when producing welded components	**D1** justify the selection of a welding process for a given application when producing welded components
P3 produce a list of consumables that are required for a selected welding process		
P4 plan the tools and equipment needed to produce welded components safely, using a selected welding process	**M2** explain the safety issues associated with the selected welding process	**D2** discuss quality standards associated with the selected welding process.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 use appropriate welding positions and materials to produce two welded joints safely with a manual or mechanised welding process	**M3** discuss the advantages and disadvantages of two welding processes considering consumables, equipment, technique and quality for a given welding application	
P6 produce two welded joints/components to a quality standard using a manual or mechanised welding process		
P7 use appropriate welding positions and materials to produce two welded joints safely with a machine-based welding process		
P8 produce two welded joints/components to a quality standard using a machine-based welding process		
P9 explain the results of a destructive and non-destructive test on a given joint/component when welded to a quality standard.	**M4** explain the benefits and limitations of using a non-destructive inspection methods on welded components.	

Essential guidance for tutors

Assessment

Assessment of this unit could be through the use of four assignments.

The first assignment could cover P1 where learners are asked to produce a written report. Evidence for P1 must be specific to welding and the processes used within the industry. Learners will need clear guidelines in respect of what they should present. There is a large amount of generic material that learners will need to access. Care should be taken to ensure that what is presented is properly referenced and not directly copied from the internet or any other source.

A second assignment covering P2, M1 and D1 could be used to demonstrate the information sources to select a welding process. The practical experience will influence learners' ability to answer this task. M1 and D1 can be achieved by analysing the effect of incorrect welding parameters and justifying a selected process for a given welding application. Learners will need to demonstrate their knowledge of both joining processes and the properties of engineering materials.

A third assignment covering P3, P4, M2 and D2 could be used to demonstrate the preparatory requirements for a selected welding process. Evidence could be presented in the form of a written report or by an oral presentation, supported by diagrams and photographs of formative practical work. Learners will need to select and describe a welding process for a given application. The expectation within this task is that all areas of the process will be described and the stated quality standards will be taken into account. M2 and D2 could be achieved with reference to safety and quality standards, as shown in the content, associated with the welding process.

Criteria P5, P6, P7, P8 and M3 could be assessed through a fourth practical assignment. The evidence for the practical investigations will be in a written report format, or may be assessed as part of a logbook or portfolio that records the types of joint, materials and positions used, and the consumables required for the process. This may be supported by witness statements or observation records used to show the evidence required. This will provide evidence of the joints produced using either a manual or mechanised welding process. The choice of whether a manual or mechanised process should be used is left to the centre and may be decided by the pathway that learners are following in their workplace. More freedom of choice may exist with centre-based learners but attention should be given to likely local employment opportunities. Criteria P7 and P8 require joints to be welded using machine-based processes which should be assessed in a similar format to P5 and P6. Care must be taken to consult the content section of the unit to ensure that the range of welding positions, joints, materials and consumables appropriate to the joining process being assessed for the manual, mechanised and machine-based welding processes. M3 can be achieved by learners comparing two processes, which could be the processes used in P6 and P8, and demonstrating further knowledge of the processes. Care will be required when selecting the given application to ensure learners have opportunities to carry out this comparison. Although it is not compulsory to have a manual and mechanised process, this is where opportunities may be maximised during a comparison.

A fifth assignment could be used in assessing P9 and M4, where learners use a report to explain the results of quality standards used for the joints produced in P6 and P8. Learners should include their findings, and refer to the standards, accuracy, destructive and non-destructive tests used. Reference should be made to the original guidelines for the given application and any quality standards that are indicated. This will enable them to explain the benefits and limitations of non-destructive inspection methods (M4).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Safe Working Practices When Welding	Learners need to produce an information report on health and safety requirements and safe working practices applicable to the welding industry.	A written report that explains the legislation and safe working practices used in the welding industry, with clear referencing to appropriate sources of information.
P2, M1, D1	Using Information	Learners have to select a suitable process and welding parameters and identify consumables	A written report could be used to assess the pass criteria using diagrams and photographs of relevant information. Further analysis and justification would assess M1 and D1. It may be considered that an oral presentation, supported with appropriate graphics, may be more suitable in the assessment of all criteria in this assignment. The tutor should consider the method of maintaining evidence of the presentation.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2, D2	Preparing for Work	Plan the consumables, tools and equipment needed for a given welding application (e.g. a number of welded joints to form a simple component).	A written report supported by a logbook or portfolio that records the range of consumables, tools and equipment.
P5, P6, P7, P8, M3	Producing Quality Welded Joints	Learners need to produce welded joints to a required quality standard.	A written report supported by a logbook or portfolio that records the range of joints, materials and welding positions used. Evidence of the weld quality may include photographs, diagrams, witness statements, and quality reports. The report should identify the quality standards used and compliance to that standard. A comparison of two welding processes clearly identifying the processes and the advantages and disadvantages of each process for a given application should be included.

Criteria covered	Assignment title	Scenario	Assessment method
P9, M4	Inspecting Welded Joints	Learners test welded joints that they have previously made in a material or component.	A practical activity evidenced by a report that discusses the quality inspection processes used for the joints produced in P6 and P8 and the results. The report can further investigate the benefits and limitations of using non-destructive testing techniques on welded components.

Essential resources

Centres delivering this unit will need access to appropriate welding equipment, consumables and materials as outlined in the unit. Centres must also have access to appropriate destructive and non-destructive test equipment.

Indicative reading for learners

Textbooks

Davies A – *The Science and Practice of Welding, Volume 1* (Cambridge University Press, 1993) ISBN 9780521435659

Davies A – *The Science and Practice of Welding, Volume 2* (Cambridge University Press, 1993) ISBN 9780521435666

Raj B, Shankar V and Bhaduri A – *Welding Technology for Engineers* (Alpha Science International Ltd, 2006) ISBN 9781842651940

Smith B – *Welding Practice* (Routledge, 1995) ISBN 9780340614068

Timings R – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Weman K – *Welding Processes Handbook* (CRC Press, 2003) ISBN 9780849317736

Zhang H – *Resistance Welding* (CRC Press, 2012) ISBN 9781439853719

Unit 19: Selecting and Using Programmable Controllers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The automation of machines, process control and conveyor lines has resulted in the ever-increasing consistency of quality, speed and cost savings in complex processes. Consumers have come to expect high standards of quality in the manufactured goods they use, but to an engineer these are the challenges that make the profession interesting.

This unit will consider programmable logic controllers (PLCs), control devices which aid the automation of these processes. The capabilities of PLCs have developed over the years, with performance, reliability and operational resilience being key attributes to their continued success. In order to achieve automated monitoring and control, these devices can be used on their own or in conjunction with others through communication systems/links, which are themselves becoming more versatile.

The unit will introduce learners to the use and applications of PLCs, the hardware and software that makes up a PLC and the interaction needed between the component parts. Learners will develop their ability to use programming techniques to produce programs for modern PLCs. They will gain an understanding of the different types of communication media used to link larger numbers of PLCs together, the networking architecture used and the associated standards and protocols.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the selection, hardware and software requirements of a programmable controller

2 Be able to use programming techniques to produce a program for a modern programmable controller

3 Understand complex programmable controller applications

4 Understand data communications media and networks used with modern programmable controllers.

Unit content

1 Understand the selection, hardware and software requirements of a programmable controller

Programmable controller selection: types (unitary, modular, rack-mounted); criteria, e.g. cost, versatility and scanning time; internal architecture, e.g. central processing unit (CPU), arithmetic and logic unit (ALU), flags, registers, memory and types (volatile, non-volatile); scan cycle (self-test, input/logic/output scans)

System hardware and software requirements: manufacturers' specification of input/output (I/O) units (digital and analogue); power supply; use of operating system; configuration of inputs and outputs; number systems, e.g. binary, octal, hexadecimal, binary-coded decimal (BCD); input/output devices; mechanical switch relays (electromechanical and solid state); transducers, e.g. temperature, pressure, flow, smart sensors, simple motors and drives

2 Be able to use programming techniques to produce a program for a modern programmable controller

Programming techniques: e.g. ladder and logic diagrams, statement listing, functional diagrams, graphical programming languages, mimic diagrams, sequential function charts (SFCs)

Produce, store and present program: human-computer interface (HCI), e.g. handheld input pad, personal computer, text, graphical touch screens; use of system software to write, edit, delete, save, restore, create reports, load/unload, search; use of fault diagnostic indicators; print copies of program; storage, e.g. scanning, memory organisation, continuous updating, back-up copies, supervisor control and data acquisition (SCADA)

Instruction types: production of program using relay, bit, branch, timer/counter, comparison, logical, arithmetic instructions; proportional integral derivative (PID) controller loops

3 Understand complex programmable controller applications

Program documentation: hardware considerations (environmental, operational, maintainability); instruction types; documentation for testing, e.g. software debug instructions, diagnostic indicators, data monitors, search, force facilities; complex engineering applications, e.g. machine, process control, conveyor

Health and safety with programmable controller: safe working practices for personnel and with equipment, e.g. tools and equipment risk assessment, job safety analysis (JSA), housekeeping practices for work areas, personal protective equipment (PPE), restriction of non-participants from areas; health and safety standards (local, national, international), e.g. local safety agreements between employees and employers, Health and Safety Executive (HSE), Health and Safety at Work etc. Act, regulations for the use of display screens; avoiding haphazard operations, e.g. risk management, planning considerations, testing (usability, unit, component, acceptance), 'what if' scenarios, commissioning

4 Understand data communications media and networks used with modern programmable controllers

Communication media: selection criteria, description of features, frequency ranges, technology, e.g. analogue, digital, wireless; cable, e.g. twisted pairs, coaxial, fibre-optic, shielded/unshielded, categories, operational lengths; connector, e.g. Bayonet-Neill-Concelman (BNC), registered jack (RJ-45), straight tip (ST), universal serial bus (USB) type A and type B; opto-isolator e.g. photodiode, phototransistor, thyristors, triacs

Network: network architecture (fieldbus, distributed intelligence, 'open' communications networks); network standards/protocols, e.g. International Organisation for Standardisation (ISO), Institute of Electrical and Electronic Engineers (IEEE), Manufacturing Automation Protocol (MAP), Electronics Industry Association (EIA-485), Factory Instrumentation Protocol (FIP)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller	**M1** explain the benefits and limitations of a programmable controller for a specific application	
P2 explain the system hardware and software requirements for a programmable controller application		
P3 use a programming technique to produce, store and present a program that demonstrates the full range of instruction types	**M2** explain the programming technique used and list the instruction types	**D1** justify the choice of a specific programming technique and the methods used to produce, store and present the program
P4 explain the program documentation that has been used for a complex engineering application		
P5 describe the importance of health and safety when working with programmable controlled equipment		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain how one example of each of the three types of communication media would be selected for a specific programmable controller application	**M3** compare two different networks used for a modern programmable controller system.	**D2** compare the current capabilities and limitations of a programmable controller and identify possible areas of future development.
P7 describe a network and relevant standards and protocols used for a modern programmable controller system.		

Essential guidance for tutors

Assessment

PLCs involve a complex mixture of computer technology, communication interfaces and software programming techniques.

The assessment strategy for this unit should consist of a mix of written technical reports and hands-on practical work. Annotated photographic evidence could also be a valuable tool to capture 'on-site' information and support learners' written work.

Where the grading criteria refer to an 'application', this is intended to mean a real-world situation wherever possible. Although a different application could be used for different criteria, it would be reasonable to use the same or closely related applications throughout.

P1 and P2 are closely linked. P1 requires learners to describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller. In doing so, learners need to demonstrate their ability to recognise the different approaches to PLC operational activities. In describing the selection criteria learners should consider things such as cost, versatility and scanning time, together with relevant descriptions of the internal architecture (for example central processing unit (CPU), arithmetic and logic unit (ALU) etc.) and a practical application of each.

For P2, a comprehensive range of hardware and software requirements should be considered. For example, the power supply available may have quite different consequences for an application involving a field monitoring system as opposed to an installation in a factory. The amount of coverage of content for this criterion will be determined by the actual programmable controller application considered, but it is expected that learners should have at least four or five system hardware and software requirements indicated and explained.

P3 requires learners to use a programming method to produce, store and present a program that demonstrates the full range of instruction types. Learners are not expected to be fully competent programmers but their programs should be printed out, annotated where appropriate and stored.

The explanation required for P4 needs to cover all the related unit content, including hardware considerations, instruction types and documentation for testing. A 'complex engineering application' in this context is intended to mean some form of machine, a manufacturing process control operation or a conveyor system based on a real-life situation. Learners will need to provide some details of the complex application and go on to explain the documentation, for example the program instructions, testing documentation and forced facilities etc. associated with it. Ideally this would be a work-based application, although learners could be provided with a case study of a complex application.

P5 requires learners to describe the importance of health and safety when working with programmable controlled equipment. A range of 'what if' scenarios for various applications could be used to cover the full requirements of the unit content.

P6 requires learners to explain how one example of each of the three types of communication media (cable, connector, opto-isolator) would be selected for a specific programmable controller application. The key point here is for learners to recognise the media, understand how each one is selected, describe the main features and consider aspects such as frequency ranges and the technology to which they are being applied.

For P7, there is a possibility that the description of a network and relevant standards and protocols could become overly complex and involve a wide range of issues. Therefore, learners need to be restricted to describing just the general network architecture of perhaps an Ethernet, and provide details of the associated standards and what they generally imply.

M1 builds on the work carried out for pass criteria P1 and P2, as learners need to consider a specific application and apply their understanding of the selection criteria already used. The important point is that they can demonstrate ability in selecting an appropriate PLC type and have knowledge as to why it is an appropriate choice.

M2 can be clearly linked to pass criteria P3 and P4. To achieve M2, learners need to reflect on their choice of programming methods. In their justification (D1), learners should identify why one programming method has been chosen and make it clear why the others have been rejected.

M3 builds on the work undertaken to achieve P6 and P7. It requires learners to compare two different networks used for a modern programmable controller system. This should include details of the networks, standards and key differences. Learners need to demonstrate that they realise the important differences between networks and how they may influence the associated PLC systems.

Finally, D2 requires learners to reflect on the unit as a whole. The comparison could include aspects such as memory capacity, the types of PLC available, the growing development in networking technologies (for example wireless implications), the use of smart sensors and how this may impair the programme and feedback loops, how processor power may influence the programming method etc. Satisfactory achievement of this criterion will require learners to have considered the range of issues covered by the unit content and undertaken some independent research of trends and potential benefits.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Selection and Applications of PLCs	A written assignment requiring learners to demonstrate an understanding of PLC selection and application	A series of three written tasks. Learners provide a description of the selection and application of PLCs and explain hardware and software requirements. Learners are then given an application for which they choose a suitable PLC.
P3, M2, D1	Using Programming Techniques	Learners are required by their employer to produce a program for a specific programmable controller to meet a customer's needs.	A practical programming task. Learners should produce a program, which should be printed out, annotated and stored.
P4, P5	Applications of Programmable Controllers	Learners investigate an industrial application of programmable controllers, and explain the documentation and health and safety considerations that relate to it.	A series of written descriptions/ explanations.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3, D2	Data Communications Media and Networks	Learners investigate the different forms of media, their selection criteria and their applications.	A series of written descriptions/ explanations.

Essential resources

Centres will need access to a range of PLCs, communication media and interface devices. Software packages and tools should also be available to permit programming and implementation of device/applications for circuit performance and debugging. Learners will require access to a range of relevant manuals, reference data and manufacturers' information.

Indicative reading for learners

Textbooks

Bolton W – *Instrumentation and Control Systems* (Newnes, 2004) ISBN 0750664320

Bolton W – *Programmable Logic Controllers* (Newnes, 2006) ISBN 0750681128

Hooper J – *Introduction to PLCs* (Carolina Academic Press, 2004) ISBN 0890893896

Unit 20: Applications of Computer Numerical Control in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

There are three basic principles to CNC machining. These are: positional control of the cutting tool relative to a workpiece using axes coordinates, the setting of cutting speeds and control of other functions such as the application of cutting fluid. To do this, machine tools need to be loaded with a series of instructions which is acted upon in sequence. These instructions are called program code and in this unit learners will be shown how to produce a working program using an industry-standard language.

The unit will consider two aspects of CNC machining. First, learners will investigate machine tools that have an in-built computer system. These are set up by a skilled operator who interprets data taken from an operational plan and converts this into program code.

Learners will then look at machine tools which are downloaded with code generated by a remote computer system running computer-aided design/manufacturing (CAD/CAM) software. The advantage that this type of system has over the stand-alone CNC machine is that a full three-dimensional (3D) simulation of the machining process can be carried out before any cutting of material takes place. This is an important aspect of economic manufacture because incorrect machining of a component will result in lost production and additional costs.

The unit has a high practical content and learners are expected to manufacture actual components. Learners will follow the various steps in the CNC process, starting with interpreting drawings and choosing a suitable machining process, correct cutting tools and work holding devices. They will then write and prove a part program, machine the product and carry out dimensional checking against specification.

The final part of the unit investigates the integration and use of CAD/CAM in the CNC machining process. Learners will be given a drawing file containing details of a component that they will then use to produce a 3D image of the component. Its functionality is confirmed before moving on to the simulation of the machining process using CAM software.

Once the machining operation has been proven and any problems corrected, the data needed to control the movements of cutting tools and other machine operations is downloaded from the computer into the machine's control unit. Machining then takes place, with the program data saved for future use.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of computer numerical control (CNC) and machine structures

2 Be able to interpret a component specification and produce an operational plan for its manufacture

3 Be able to produce a part program and manufacture a component

4 Be able to use a computer aided design/computer aided manufacture (CAD/CAM) software package to generate a part program and manufacture a component.

Unit content

1 Understand the principles of computer numerical control (CNC) and machine structures

CNC principles: system, e.g. machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction; datum points, e.g. machine, component; definition of parameters using numerical coding, e.g. position, movement, spindle speeds, cutting tools, clamping, application of coolant; CNC process, e.g. select machine, select tooling, identify machining sequence, calculate positional coordinates, calculate spindle speeds, programming, post-processing, setup sheet, verify and edit, store for future use

Machine structures: types, e.g. milling, drilling, turning centre, machining centre; designation of axes, e.g. 2 axis, 3 axis, x, y, z; motor and drive units, e.g. spindles, stepless drives, ball screw, stepper motors; transducers, e.g. positional, linear, rotary, analogue, digital, optical encoders, inductive, capacitive, magnetic; tooling, e.g. modular, quick change, turret; tool transfer e.g. automatic, chain magazine, circular magazine; work holding, e.g. pallets, sub tables, rotary work changer, grid plate; swarf removal, e.g. chutes, chip controllers, conveyors; cooling, e.g. cutting fluid, cooling systems; computer hardware, e.g. keypad, display, Central Processing Unit (CPU), storage, cabling links, machine control unit (MCU); computer software, e.g. programming language, CAD/CAM DXF files; safety, e.g. overloading the cutting tool, guards, light barriers, interlocks, operator safety

2 Be able to interpret a component specification and produce an operational plan for its manufacture

Component specification: detailed drawing; material, e.g. steel, aluminium, polymer, other stable material; reference points, e.g. edge datum, centre line datum; dimensional, e.g. external, internal, centres distances, bore diameters, tolerances; surface finish, e.g. R_a, R_z values

Operational plan: zero datums; work holding, e.g. clamps, fixtures, chucks, vices, setting points; changing components, e.g. pallets, sub tables, rotary work changer, grid plate; sequence of operations, e.g. loading, machining, roughing and finishing operations, measurement, unloading; calculations, e.g. cutter path coordinates for intersections, polar centres, arc centres, cutter compensation, cutting speeds, feed rates; use of trigonometric ratios, e.g. sine, cosine, tangent; cutter speed

$\left(\frac{\text{surface speed}}{\pi} \times \text{cutter diameter}\right)$; feed rate

(feed per tooth × number of teeth × spindle speed); grouping of similar operations; canned cycles, e.g. irregular pockets, geometric, hole patterns; tooling, e.g. cutters, drills, reamers; other reference data, e.g. cutting fluids, special requirements relating to specific materials; inspection, e.g. first off proving against specification, on machine measurement; set up sheet and tool list

3 Be able to produce a part program and manufacture a component

Part program: user interface, e.g. menu bar, identification line, tool display window, system status; work/tool relationships, e.g. position, direction, amount of movement; rates of change, e.g. feed rates, spindle speeds; auxiliary functions, e.g. metric/imperial units, tool selection, cutting fluids, workpiece loading and holding, tool changing; CNC codes, e.g. block number, preparatory functions (G codes); miscellaneous functions (M codes); other letter addresses (arc centres, spindle speed, feed rate); dimensional information, e.g. axis coordinates (x, y, z), absolute, incremental; words, e.g. modal, non-modal; block format, e.g. block number, G code, coordinates; special function G codes, e.g. movement system, measuring system, tool compensation, canned cycles, subroutines; M codes, e.g. coolant, tool change, work holding, spindle speed, spindle direction

Manufacture: post-processing, e.g. transfer of files/data between systems, download program to machine tool; pre-manufacture, e.g. run through using graphics display on machine tool, prove program, dry run, load workpiece, stepping, adjust feed rates; run program, e.g. machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor; shutdown

4 Be able to use a CAD/CAM software package to generate a part program and manufacture a component

CAD/CAM package: hardware, e.g. CAD workstation, data storage, hard copy equipment, network system to download data to machine tools; software, e.g. Autodesk Inventor, Esprit, Solid Works, Edge CAM, Denford VR milling/turning; universal formats, e.g. extensions (such as DXF, IGS, AI, EPS, PLT, NC), proprietary formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF)

Part program: e.g. 3D geometric model using CAD software, select machining operations, select tooling, generate CNC program using CAM software, simulation of tool changing and tool paths in the machining process, correction and editing

Manufacture: post-processing, e.g. transfer of files/data between systems, download program to machine tool; manufacturing, e.g. load and clamp workpiece, set tooling, initiate program cycle, machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor; shutdown

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles on which a machine tool operates when controlled by a CNC system		
P2 describe, with the aid of suitable diagrams, the structure of a given CNC machine type		
P3 interpret the specification for a given component and produce an operational plan for its manufacture	**M1** explain the importance of producing an accurate and detailed operational plan for a component that is to be manufactured using a CNC machine tool	
P4 produce a part program for a given component	**M2** explain the importance of correct programming and setting up in order to produce a component to a required specification.	
P5 manufacture a component using a two- or three-axis CNC machine		
P6 use a CAD/CAM package to produce a part program from a given component detail drawing	**M3** test the program explaining how it meets the requirements of the drawing	**D1** compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 manufacture a component on a CNC machine using a post-processed program generated using CAM software.	**M4** explain how the manufactured component meets the requirements of the program.	**D2** evaluate the cost benefits of using CAD/CAM software when programming CNC machines.

Essential guidance for tutors

Assessment

This unit could be assessed through the use of five assignments. To achieve a pass grade, learners need to have an understanding of the principles of CNC and be able to manufacture a component. It is not expected that they should be able to program and set up CNC machines at an expert level, and this should be taken into account when designing assignments.

It is suggested that the first assignment covers grading criteria P1 and P2, with learners being asked to produce a written report. Evidence for P1 should be generic and not specific to a particular type of machine. There is a lot of material that learners will have access to and care should be taken to ensure the validity of the evidence they provide.

P2 relates to a given type of machine, details of which should be specified in the assignment brief. Some learners may be working in a CNC environment and if they have specialised knowledge about a particular machine tool they could use this towards their evidence for P2.

Grading criteria P3 and M1 complement each other and can be assessed through a second assignment. The assignment brief covering P3 should provide learners with hard copy information about the component and a detailed drawing presented in printed form to an acceptable industry standard. The brief could also include a pro forma for setting out the operational plan, although learners working in a CNC environment may wish to use their own style of layout. Care should, however, be taken to ensure there are sufficient aspects of an operational plan covered by the content section for learning outcome 2. It must be remembered that a plan for CNC machining is different from one for traditional machining.

Further evidence in the form of annotated drawings and specification sheets, calculations to support machining decisions such as speeds and feeds and trigonometric ratios to calculate coordinates and intersections will also be needed to support P3. Evidence presented for M1 should make reference to the operational plan produced for P3 but additional evidence drawn from wider sources should be included.

The third assignment could be designed around P4, P5 and M2. It will add realism if the same component is used for both pass criteria. Learners should be given a pre-produced operational plan to work from, although if they wish they could use the one produced for P3, providing it is fit for purpose. The only requirement is that the part program and manufacturing relate to a single component which is significantly more complex that the one looked at in *Unit 22: Computer-aided Manufacturing*. Three-axis machining would be the preferred option, using something like a vertical milling machine. As the assignment involves a lot of practical work, evidence presented for assessment should include screenshots, witness statements, observation records and annotated digital images.

The fourth assignment could cover P6, P7, M3, M4, D1 and D2. Learners who wish to gather evidence for D1 will probably want to use the component specification provided in the third assignment so that they can contrast the effectiveness of the two methods of programming. The starting point for P6 is a detailed drawing and this should be given to learners as a file which can be opened using CAD/CAM software. With the agreement of the tutor, some learners who are taking the CAD unit may wish to use a component that they have previously drawn, but it needs to be in a form that can be easily processed.

Evidence presented for assessment should include screenshots showing tool path simulation, witness statements, observation records and annotated digital images. A written task will need to be given asking learners to compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming (D2). They will obviously need to identify benefits and limitations of each approach and draw valid supported conclusions. The focus of D1 is very specific and some of the evidence presented could relate to the tasks undertaken to achieve P4, P5, P6 and P7. M3 and M4 are logical extensions of P6 and P7 respectively requiring explanations of how the entities produced meet the original requirements.

When writing about their experiences, learners should include an evaluation of their own effectiveness in using the two systems of manufacture. Factors to be considered might include something on how easy it was to learn the software packages, ease of program editing and the lead times needed to produce the components. Discussions with a manufacturing engineer who works for a company using both systems or which has moved from CNC part programming to an integrated CAD/CAM setup could be used as further evidence.

A further task can be included to cover D2, in the form of evaluative writing supported by evidence gathered from published case studies. Learners should consider the effectiveness of CAD/CAM programming in the wider context and not just concentrate on the components that they have manufactured.

Some of the evidence for D2 could be come from work produced for *Unit 22: Computer-aided Manufacturing* and it may be possible to integrate assignments across units. Because there are well documented examples of the cost benefits achieved by companies who use CAD/CAM software to program CNC machines, care must be taken to ensure that what the learner presents as evidence is authentic. Use could be made of experience from *Unit 35: Setting and Proving Secondary Processing Machines*, particularly about work holding and machining parameters. Where appropriate, employed learners should be given the option of using examples taken from their own company.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	CNC Principles and Machines	An assignment requiring learners to demonstrate their knowledge of the underlying principles of CNC machines and CNC machine structures.	Two written tasks for which learners need to produce an explanation of the principles on which machine tools operate and a written description of CNC machine structure.
P3, M1	Component Specifications and Operational Plans for Manufacture	A practical assignment requiring learners to interpret a component specification and produce a plan for its manufacture.	A practical task for which learners are provided with a detailed drawing and information about a component that they need to interpret. Learners produce an operational plan to manufacture the product on a CNC machine. A further written task gives learners an opportunity to explain the importance of an accurate and detailed plan.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, M2	Part Programs for Manufacturing Components	A practical assignment requiring learners to produce a part program and use it to manufacture a component.	Practical tasks in which learners are given a pre-produced operational plan for which they produce a part program and manufacture a component using three-axis machining.
P6, P7, M3, M4, D1, D2	Using CAD/CAM to Manufacture Components	A practical assignment supported by written tasks requiring learners to demonstrate their ability to use CAD/CAM to manufacture a component.	Practical and written tasks. Learners are given a detailed drawing for which they write a part program. Learners then need to use their post-processed program to manufacture the component. Written tasks will ask learners to compare CAD/CAM to CNC part-programming and evaluate the cost benefits of CAD/CAM.

Essential resources

In order to deliver this unit, centres will need to have 2D/3D commercial CAD software and CAM software that integrates with the CAD package used for designing. They will also need to have access to a two- or three-axis CNC machine tool and a two- or three-axis machine tool which can be downloaded with data from a computer system.

Indicative reading for learners

Textbooks

Evans K – *Programming of CNC Machines* (Industrial Press, 2007) ISBN 9780831133160

Smid P – *CNC Programming Handbook* (Industrial Press, 2008) ISBN 9780831133474

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Unit 21: Welding Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The industrial processes used to produce welded joints rely on the application of heat to melt and fuse the materials together. The amount of heat used varies according to the process, but one common factor is that the metallurgical structure of the metal will be changed to some extent by the welding operation.

This unit gives learners an understanding of the effect that the heat input has on a welded component. The unit is suited to welders and those responsible for the specification of the welding process and any post-weld heat treatments. The unit will develop learners' knowledge of the structure of pure metals and the effects of adding alloying elements. Learners will develop an understanding of the effect that heat has on metals and their alloys once they have been welded, and how this influences the performance of a welded component. Learners will also gain knowledge of the post weld heat treatment processes that are available to improve the performance of the structure and relieve stress. The testing of welds is also covered in the unit so that learners appreciate the need for a component to meet a quality standard.

Learners will perform a range of practical and investigative tasks to develop their understanding of different welding processes and the suitability of their application. Learners will prepare materials for welding and the post-welding treatments of welded materials. Identification of defects is vital in ensuring the quality of the finished product and learners will demonstrate their knowledge of the techniques employed in defect detection and the quality standards used in industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the physical features of welding processes

2 Know the effects of welding and select post-weld heat treatments

3 Understand the weldability of metals

4 Be able to use and interpret quality standards and weld testing techniques.

Unit content

1 Know the physical features of welding processes

Welding processes: main processes, e.g. manual metal arc (MMA), metal-arc gas shielded (MAGS), tungsten arc gas-shielded (TAGS), oxy-acetylene; additional processes, e.g. resistance (such as spot, seam), friction, flash butt, laser, electron beam, explosive, exothermic (thermit), capacitor discharge stud welding, friction stir welding; choice of processes; working environment, e.g. workshop, site work, suitability of machinery and plant

Electric arc: alternating current (AC); direct current (DC); heat distribution at the anode and cathode; effect of magnetic fields; applications of AC and DC; consumable and non-consumable electrodes; metal transfer and deposition; plasma-arc

Shielding gases: functions, e.g. atmospheric protection, arc initiation; shielding gases, e.g. inert gases, argon, helium; active gases used in mixtures, e.g. carbon dioxide (CO_2), nitrogen, oxygen; applications, e.g. MAGS, TAGS, plasma-arc

Electrode coverings and fluxes: functions of coverings and fluxes, e.g. atmospheric protection, slag, removal of impurities, alloying, arc initiation; composition, e.g. basic, rutile, cellulosic, iron powder; fluxes, e.g. fused, agglomerated; applications of coverings and fluxes, e.g. MMA welding, submerged arc welding, braze welding

Oxy-acetylene combustion: chemical composition of the inner and outer envelope; heat distribution; applications of flame types, e.g. neutral, oxidising, carburising

2 Know the effects of welding and select post-weld heat treatments

Effects of welding heat input: distortion control, e.g. pre-setting, pre- and post-heating, total heat input, weld deposition (skip and back step) techniques; effects, e.g. distortion (expansion and contraction), expansivity, residual stress; effects of cooling rate, e.g. hardening, grain growth, cracking; structure of the welded joint e.g. heat-affected zone (HAZ), crystal structure (such as equi-axed, columnar), grain growth; heat distribution during welding, e.g. thermal gradients, heat flow, joint configuration (butt, tee, cruciform); use of chills; comparison of processes

Post-weld heat treatments: for ferrous metals, e.g. annealing (full, process), normalising; for heat treatable aluminium alloys, e.g. solution treatment, precipitation hardening

3 Understand the weldability of metals

Weldability: factors, e.g. melting temperature, carbon equivalent, rate of heating and cooling (thermal shock), thermal conductivity, residual stress, degree of restraint (the rigidity of the construction), similar and dissimilar metals; dilution, hardenability, dissolved hydrogen, pre- and post-heat temperature; impurities, e.g. phosphorous (cold shortness), sulphur (hot shortness); mechanical properties, e.g. tensile strength, impact strength

4 Be able to use and interpret quality standards and weld testing techniques

Weld test techniques: non-destructive, e.g. visual (weld gauges, dimensional), radiographic (such as x-ray, gamma ray), ultrasonic, dye penetrant, magnetic particle; destructive, e.g. fracture, bend test, macro and microscopic examination, tensile, fatigue, hardness

Weld defects: visual (surface defects), e.g. undercut, overlap, excess weld metal, leg length of fillets, concavity, cracking (such as cold cracking, hot cracking, crater, transverse, longitudinal, centre-line, HAZ), blowholes, oxidation, restarts; internal, e.g. porosity, inclusions (such as slag, metallic, gaseous), lack of inter-run fusion, cavities

Quality standards: in relation to relevant standards, e.g. British Standard/European Standard BS EN 970, BS EN 1011, BS EN ISO 10042, BS EN ISO 15607, BS EN ISO 15609, BS EN ISO 15614, American Society of Mechanical Engineers (ASME) IX

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 select suitable welding processes for four given applications	**M1** explain the operation of two welding processes for given welding applications, with respect to heat input and the fusion of welded materials	
P2 describe the physical features of an electric arc used in a welding process		
P3 describe the function of two given shielding gases and two electrode coverings/fluxes used in welding processes		
P4 describe oxy-acetylene combustion and its application when using gas welding equipment		
P5 describe three methods of controlling the effects of heat input when using welding processes	**M2** explain how a post-weld heat treatment process will affect the grain structure and properties in two given materials	**D1** explain the advantages and disadvantages of using post-weld heat treatments in a steel or aluminium welded component
P6 describe the effect of heat input, heat distribution and cooling rate on the grain structures of two welded joints		
P7 identify suitable post-weld heat treatment processes for joints in steel and aluminium alloys that have been welded		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 describe the factors that will affect a given metal's weldability	**M3** explain how impurities affect quality in terms of the weldability and material properties of a welded joint.	
P9 use two weld testing techniques to detect surface defects and internal weld defects in accordance with quality standards		
P10 produce a test procedure for a destructive or non-destructive weld test to detect weld defects in welded components.		**D2** analyse the defects found in a component that has been weld tested and identify possible causes in relation to the heat input.

Essential guidance for tutors

Assessment

The learning outcomes of this unit may be linked with those of other units, in particular *Unit 18: Welding Technology*. Written assignments should be supported with appropriate photographs and diagrams.

Pass criteria P1, P2, P3 and P4 could be achieved by learners selecting and describing the functions and features of welding processes and their application in industry. Learners' responses could include both written and oral questioning. The four given applications should include processes across the range of those outlined in the unit content. A further written task to cover M1 should ensure that learners cover the range of processes and physical features identified in the unit content.

Achievement of P5 could be achieved by means of a written task. To enable learners to understand the effects of distortion, it may be appropriate for them to participate in an associated practical task. This could, for example involve measuring the angle between two plates before and after the welding of a tee fillet joint. Evidence for P6 is also likely to come from a written task in which learners are asked to consider two joints that are subjected to extremes of heat input due to the process parameters. One joint could be in thin metal, welded by a process with a high deposition rate (for example MAGS or laser), compared with a thicker metal welded using a slower deposition process (for example MMA or oxy-acetylene welding). A further task covering P7 could require learners to investigate and recommend post-weld heat treatment processes appropriate to welded joints in steel and aluminium alloys. Another written task can then build on this to cover M2.

For P8, a written task could be used based on a range of factors and impurities known to affect the weldability and properties of metals. This could be extended to also cover M3, with learners providing an explanation of how impurities can affect welded joints.

A written task covering P9 should ask learners to produce a procedure for carrying out non-destructive and destructive tests, as identified in the unit content. There is an opportunity to set different procedures for the range of learners or to concentrate on testing techniques that may be found in the learners' workplace, where applicable. P10 could be achieved using a combination of practical assessments and research. Learners could either use welds produced in the welding workshop or commercially produced weld specimens with known defects, to correctly detect surface and internal defects in welds relevant to a given quality standard. Learners should perform this on a range of materials, ferrous and non-ferrous. While this criterion is suitable for assessing by a written report, the assignment may be assessed using an oral presentation where photographs, diagrams and samples should be used.

To achieve distinction criterion D1 learners need to explain post-weld heat treatment processes and discuss the advantages and disadvantages. This will combine the knowledge gained in P1 to P7 as this will depend upon the materials, welding process and the heat input.

Assessment of D2 could be in the form of a written task though this may be better assessed as part of the oral presentation suggested for the assessment of P10. Learners would be expected to demonstrate their knowledge of not only the applications and operation of the weld testing technique, but also that of the quality standards and welding process used.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Welding Processes	An assessment based on learners' knowledge and investigations into the physical features of welding processes.	This assessment will use a written report and oral questions to assess learners' knowledge across a range of welding processes. Learners will need sufficient knowledge to select appropriate processes for given applications. They will also need to know the physical features of those processes. Learners will need to explain welding processes in terms of how the heat is input, and how the fusion of the material takes place to produce the weld.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M2, D1	The Effects of Welding	This assessment requires learners to investigate and report on the effects of welding in terms of controlling distortion, the grain structure and the heat treatment of materials.	A written assessment based on joints or components that learners have investigated in the workshop, these may have been produced by learners, or commercially produced. Those learners who are employed may benefit from applying procedures used in the workplace. The effects of welding should be considered in context with the welding process used. Learners may also explain the effects of welding and analyse these effects further.
P8, M3	Weldability of Metals	An assessment that focuses on the weldability of materials. Learners will report on their research and tutor-led activities.	This written assessment considers the factors that affect the weldability of a material and the effect of impurities on the welded material. An opportunity is given to explain the effect of impurities on a welded joint.

Criteria covered	Assignment title	Scenario	Assessment method
P9, P10, D2	Weld Testing and Quality Standards	This assessment reports on the findings of practical investigations when working to quality standards applicable to weld testing.	This may be assessed in the form of a written report, but would be better assessed by oral presentation (which may utilise ICT to produce a visual presentation). Learners should present a test procedure that has been produced to identify weld defects. Learners should also present information on their use of weld testing techniques and the defects found, comparing them to relevant quality standards.

Essential resources

Centres will require access to welding equipment to allow learners to observe at least one welding process. Weld testing facilities will be required for visual examination and at least one destructive and one non-destructive test. Centres will need samples which are commercially produced which use a range of welding processes.

Indicative reading for learners

Textbooks

Davies A – *The Science and Practice of Welding, Volume 1* (Cambridge University Press, 1993) ISBN 9780521435659

Davies A – *The Science and Practice of Welding, Volume 2* (Cambridge University Press, 1993) ISBN 9780521435666

Smith B – *Welding Practice* (Routledge, 1995) ISBN 9780340614068

Timings R – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Unit 22: Computer-aided Manufacturing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

An understanding of how computer-aided manufacturing (CAM) systems operate in an engineering business is important for anyone thinking of a career in the design and manufacture of products.

This unit aims to develop an appreciation of the use of computer systems in a world-class manufacturing environment and how they are applied to product design and manufacture. Emphasis is placed on the need for a total approach to product development, in particular the interface between the various functions of the design and make process and the use of simultaneous engineering.

Learners will start by investigating how CAM systems are used to increase the profitability of a business by reducing manufacturing costs, improving quality and being more responsive to customer needs. This is followed by a look at how simultaneous engineering is used to bring together the many functions of a manufacturing business so that there is a team-based, multi-disciplinary approach to problem solving. Learners then investigate how simultaneous engineering can be used to meet the demands of a customer-driven economy where people expect an off-the-shelf service for customised products.

The unit covers how newly designed components are modelled using three-dimensional (3D) CAD software so that their functionality can be assessed and any errors corrected before the machining process is simulated using CAM software. Raw materials and the cutting of metal are expensive and getting it right first time is a crucial aspect of economic manufacture.

Learners will investigate how manufacturing processes can be automated by using industrial robots to move materials and components between the machine tools and the workstations that make up a flexible manufacturing system (FMS). Finally, learners will be given the specification for a component, use CAD software to design it and use CAM software to produce a set of instructions for downloading to a machine tool which could be used to make it.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the benefits of CAM and the significance of simultaneous engineering

2 Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process

3 Understand the use of industrial robots and flexible manufacturing systems in engineering

4 Be able to design a simple component and generate a programme for a CNC machine using a CAD/ CAM software package.

Unit content

1 Understand the benefits of CAM and the significance of simultaneous engineering

Benefits of CAM: increased profitability, e.g. reduced machine set-up times, greater flexibility in terms of batch sizes, reduction in lead times, reduction of labour costs, lower unit costs, optimised use of cutting tools, production of complex shapes; improvements in quality, e.g. elimination of human error, consistent accuracy; greater responsiveness to the requirements of the customer; competing in the world market place

Simultaneous engineering: parallel operation of tasks; multi-discipline team-based working, e.g. marketing, design, modelling, rapid prototyping, manufacturing, development; time-based management, e.g. integration of activities, lean manufacturing, total quality management (TQM), shorter development times, faster time to market, right first time, improved communication

2 Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process

CAD/CAM interface: CAD, e.g. product design using industry-standard CAD software, modification of design ideas, production of working drawings; CAM, e.g. generation of part programmes, scheduling of raw materials; specialised linking software, e.g. edgeCAM, Autodesk Inventor/Esprit, SolidWorks; universal formats, e.g. extensions (such as DXF, IGS, AI, EPS, PLT, NC), propriety formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF)

Modelling and simulation: use of CAD/CAM software, e.g. 3D modelling of the product, simulation of tool changing and toolpaths in the machining process, simulation of sequential manufacturing processes, rapid prototyping; benefits, e.g. elimination of machining errors, reduction in scrap rates

3 Understand the use of industrial robots and flexible manufacturing systems in engineering

Robots: applications, e.g. pick and place systems, product handling, product assembly, machine loading, safe operation, codes of practice (Health and Safety Executive (HSE) HSG43, Reducing error and influencing behavior HSG 48, Provision and Use of Work Equipment Regulations (PUWER); advantages, e.g. consistency of performance, 24/7 continuous working, reduced cycle times; limitations, e.g. high standard of maintenance required, precise programming needed, computer systems failure will cause breakdown, new products require complete reprogramming, certain processes still need a skilled operator, complex and expensive equipment

Flexible manufacturing systems: benefits, e.g. production of different parts without major re-tooling, efficient production of customised products, ease of responding to changes in product mix and production schedules, lean manufacture; processing machines, e.g. CNC machine tool, machining centre, flexible cell, welding station, assembly; loading and unloading systems, e.g. material handling, pick and place, fixed position robot, conveyors; coordination of the working schedule, e.g. process monitoring by computer, optical recognition, inspection, TQM

4 Be able to design a simple component and generate a programme for a CNC machine using a CAD/CAM software package

Using CAD/CAM software: hardware, e.g. CAD workstation, data storage, hard-copy equipment, network system to download data to machine tools; software, e.g. 2D/3D CAD, databases, single-component CAD files, part programming, macros, cutter path simulation; post-processing, e.g. transfer of post-processed files/data between systems, download to machine tools, inspection and quality management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how the use of a CAM system can benefit the operation of a manufacturing business	**M1** describe the criteria used to assess the viability of introducing CAM and simultaneous engineering systems into a business	**D1** analyse a current low-technology manual manufacturing system for suitability to move to a CAM environment
P2 describe the strategies used in simultaneous engineering		
P3 explain how the interface between design and manufacture can be integrated using suitable CAD/CAM software	**M2** explain the cost benefits of moving from low-technology manual manufacturing to high-technology automated manufacturing	
P4 explain the reasons for carrying out modelling of a component and simulation before actually cutting metal		
P5 describe the applications, advantages and limitations of industrial robots	**M3** explain the use and operation of robots to move parts between workstations in a flexible machining system	
P6 explain why a flexible manufacturing system will produce productivity gains for a business deploying a range of processing machines, loading and unloading systems and coordinated work schedules		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 use appropriate software to design a simple component and produce a part program which could be post-processed and used to manufacture it on a CNC machine.	**M4** explain the hardware and software used for this process.	**D2** discuss post-processing procedures used.

Essential guidance for tutors

Assessment

Assessment of this unit could be through five assignments.

It is suggested that the first assignment covers P1 and P2, with learners being asked to support their thoughts with evidence taken from published case studies relating to well-known companies (for example Toyota and Airbus Industries). It is important that learners demonstrate a good understanding of the reasons why, in a customer-driven, global market environment, a manufacturing company can survive only if it uses smart systems in the operation of its business. There is scope to expand this first assignment to include M1. A visit to an engineering company which has moved to using world class manufacturing systems would be a good way of gathering research information.

Grading criteria P3 and P4 complement each other and can be assessed through a second assignment. Learners should not be expected to demonstrate proficiency in the use of CAD/CAM software. A visit to a company to look in detail at the way a component is designed and manufactured would be a useful way to gather evidence. This could involve talking to a CAD designer and being shown the processes of design, modelling and manufacturing. There is scope to include M2 in this assignment.

A third assignment could cover grading criteria P5 and P6. Thought needs to be given to structuring the tasks so that learners restrict themselves to just the applications of robots and do not get sidetracked into explaining in great detail their operating principles. As recommended earlier, restricting learners to three applications will be enough to produce valid evidence to meet P5. As criterion M3 builds on P5 and P6 it can be a part of the third assignment.

The fourth assignment could be a practical activity covering P7. The component to be designed should be kept very simple as learners are not required to prove competence in using high-level design skills. As suggested earlier, a simple embossed key fob design which uses the line, arc, diameter and text commands in its design will produce a profile sufficiently complex for a part program and its post-processing. Screen prints could be used as evidence of tool path simulation, supported by witness statement or observation records of learner performance.

M1 builds on P1 and P2. To achieve it there should be evidence of thought having been given to the pressure on design and manufacturing engineers to optimise resources and use business improvement techniques.

M2 links into P3 and P4 but also draws on knowledge from P1 and P2. Explanations should be supported by examples taken from real companies which have successfully moved from low-technology to high-technology manufacturing systems and might include figures for the amounts of cost savings achieved.

M3 requires a greater understanding of how a robot operates and will build on knowledge gained when achieving P5 and P6. Evidence presented should be at a systems (black box) level and the assignment tasks should not be asking for detailed knowledge about, for example, the internal workings of a specific drive or sensor unit within the robot. Tasks based on a scenario which relates to a specific machining system could be used to generate evidence. Learners are not expected to explain how the actual machining functions operate because the criterion relates only to the handling and moving of parts. M4 requires an explanation of the hardware and software used for component design.

Grading criterion D1 builds on content covered in learning outcomes 1, 2 and 3 and could be a very detailed piece of writing based around a scenario. For this reason it might be best covered by a fifth assignment. Learners could assume the role of a manufacturing engineer who has been tasked with presenting proposals to senior management on the implications and suitability of moving from low-technology manufacturing to a CAM environment. There are a lot of well documented examples of how this has been achieved successfully by well-known companies and care must be taken to ensure that what learners present as evidence is authentic. Where appropriate, employed learners should be given the option of analysing their own company. D2 requires a discussion of the post-processing utilised in the component designed in P7.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Using CAM and Smart Systems in an Engineering Business	Learners have been asked by their employer to produce a report on the benefits of using CAM and the strategies used in simultaneous engineering.	A written assignment for which learners produce a report detailing the benefits of CAM to a modern manufacturing business and the use of simultaneous engineering.
P3, P4, M2	CAD/CAM Interfacing	Learners need to provide an explanation of how CAD/CAM software is integrated and the reasons for simulation for a local manufacturer considering moving over to CAM systems.	A written assignment for which learners produce a report into the interface between design and manufacture and the purpose of simulation. A further task would require learners to explain the cost benefits of modern manufacturing systems.
P5, P6, M3	Industrial Robots and Flexible Manufacturing Systems	Learners have been asked by their employer to produce a report on the benefits and limitations of using industrial robots and the use of flexible manufacturing systems.	A written assignment consisting of tasks requiring learners to discuss the applications of industrial robots and explain why a flexible manufacturing system can produce gains for a business.

Criteria covered	Assignment title	Scenario	Assessment method
P7, M4, D2	Using CAD/CAM Software	Learners need to design a component for a client and produce a part program for its manufacture.	A practical assignment for which learners will need to design a component and produce the part program necessary for its manufacture. Evidence is likely to be supported by screen prints and tutor observation records.
D1	Evaluating the Suitability of a CAM Environment	Learners have been asked by senior management to investigate the implications and suitability of moving from low-technology manufacturing to a CAM environment.	A written assignment for which learners produce a report detailing the suitability of moving to a CAM system for a low-technology manual system.

Essential resources

Centres will need to give learners access to 2D/3D commercial CAD software and CAM software which integrates with the CAD package used for designing.

Extracts from appropriate standards and legislation and access to industry-standard CNC machining centres and flexible manufacturing systems are also needed.

Indicative reading for learners

Textbooks

Amirouche F – *Principles of Computer-Aided Design and Manufacturing* (Prentice Hall, 2004) ISBN 9780130646316

Colestock H – *Industrial Robotics: Selection, Design and Maintenance* (McGraw-Hill, 2005) ISBN 9780071440523

Narayan et al. – *Computer-Aided Design and Manufacturing* (Prentice Hall, 2008) ISBN 9788120333420

Unit 23: Electronic Circuit Design and Manufacture

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

A diverse range of techniques is used in the manufacture of electronic circuits. The techniques used for manufacturing prototype electronic circuits are often significantly different from those used in high volume production. This unit provides an introduction to prototype manufacture, as well as the techniques used for the mass production of electronic circuits.

Large-scale electronic manufacture generally involves fully automated assembly techniques using equipment that can produce complex circuits quickly, accurately, at low cost and with minimal human intervention. Alternatively, if only one circuit is to be built (perhaps for evaluation or testing purposes), then a hand-built prototype is much more appropriate.

Computer-aided design (CAD) and computer-aided manufacture (CAM) are widely used in the production of electronic circuits. This unit will introduce learners to the use of modern production methods, including printed circuit board (PCB) layout and computer numerical control (CNC) drilling and mass production.

When an electronic circuit is developed for a commercial application it is usually tested and proved using computer simulation prior to manufacture. This unit will give learners an opportunity to develop and test circuits using SPICE (simulation program with integrated circuit emphasis) software. The unit also gives learners an understanding of the use and application of surface mount technology (SMT) in the manufacture of electronic circuits.

The unit will also enable learners to experience and gain skills in the full cycle of design, manufacture and testing of an electronic circuit assembled on a simple single-layer printed circuit board.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit an learner should:

1 Know the design processes and production methods used in the manufacture of a printed circuit board

2 Understand the use of software techniques and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit

3 Understand the use and application of surface mount technology in the manufacture of an electronic circuit

4 Be able to design, manufacture, assemble and test a prototype printed circuit board for a given electronic circuit.

Unit content

1 Know the design processes and production methods used in the manufacture of a printed circuit board

Design processes: design strategy, e.g. methodology and techniques used in its realisation (build type, number of layers, net rules, track and gap, via size); design tools, e.g. PCB design software, schematic design and capture, creating and modifying component geometries; creating and modifying schematic diagrams; design verification and design rule checking for both tracking and component layout; auto-routing tools; related documents, e.g. parts lists, bills of materials, machine files, component geometries

Production methods: artwork generation; board production, e.g. etching, masking, drilling, silk screening, cutting; automated production techniques, e.g. robotics and automated assembly, CNC drilling and mask production; soldering methods, e.g. wave soldering, automated wave soldering; fabrication and assembly requirements, e.g. placement on one side, placement on both sides, combination of surface mount technology (SMT) and through-hole technology (THC); test strategy, e.g. electromagnetic compatibility (EMC), signal integrity, high frequency requirements; manufacturability analysis

Types of PCB: laminates, e.g. single and double sided, plated through-hole, fibreglass-resin laminate; solder mask over bare copper (SMOBC); tinned; conventional component and surface mount; single, double and multi-layer boards; gold plated contacts, flexible and membrane PCB, chip-on-board (COB)

2 Understand the use of software techniques and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit

Computer-aided design (CAD) software: simulation program with integrated circuit emphasis (SPICE) software; direct current (DC) analysis, alternating current (AC) small-signal analysis; more complex analysis methods, e.g. mixed-mode analysis, transient analysis, pole-zero analysis, distortion analysis, sensitivity analysis, noise analysis, thermal analysis; software integration methods, e.g. export and import data, links with companion software for circuit layout and PCB manufacture

Thermal analysis: heat dissipation methods; thermal ratings of semiconductor devices; thermal calculations, e.g. total power dissipation, thermal resistance, $\theta_T = \theta_{JC} + \theta_{CS} + \theta_{SA}$, junction temperature, $T_J = (P_T \times \theta_T) + T_A$, temperature rise above ambient, $\Delta_T = P_T \times \theta_T = T_J - T_A$, de-rating, correct rating for thermal dissipator/heatsink

3 Understand the use and application of surface mount technology in the manufacture of an electronic circuit

Surface mount technology (SMT): types of SMT device, e.g. passive components (resistors, capacitors, inductors and transformers), active components (transistors, diodes and integrated circuits), connectors and sockets; surface mount device (SMD) outlines, packaging and storage; manufacturers' markings and supporting data; hybrid circuits and multi-chip modules (MCM)

SMT circuit manufacturing: manufacturing methods, e.g. use of solder pastes, flow and wave soldering equipment; SMT quality assurance methods, e.g. batch testing, statistical methods; SMT component reliability and testing of finished SMT assemblies; assembly-level packaging and interconnection

4 Be able to design, manufacture, assemble and test a prototype printed circuit board for a given electronic circuit

PCB design: single-sided printed circuit board for a given electronic circuit design that includes no more than four active devices, e.g. transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits; associated passive components, e.g. PCB mounted resistors, capacitors, inductors, transformers; means of connection, e.g. external controls, connectors, power sources; layout techniques based on the use of electronic CAD to generate PCB master artwork

PCB manufacture: developing, etching, drilling

Electronic circuit assembly: component mounting, soldering

PCB and circuit testing: functional testing using a supplied test specification to determine circuit design inputs and outputs, e.g. test-point voltages, output signals

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the processes used in the design of both a single and multi-layer PCB for electronic circuits of different complexity	**M1** explain the benefits of using automated techniques for the manufacture of an electronic circuit	
P2 describe typical production methods used in the manufacture of both a single and a multi-layer PCB for electronic circuits of different complexity		
P3 explain how computer aided design software is used to analyse an electronic circuit prior to manufacture	**M2** use SPICE software to carry out DC and small-signal AC analysis of a simple electronic circuit	
P4 explain the need for thermal analysis and effective heat dissipation for an electronic circuit	**M3** carry out thermal calculations to solve a range of defined problems	**D1** apply thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain the use of SMT in the manufacture of an electronic circuit and give two examples of the outlines and packages used for surface mounted devices	**M4** evaluate the use of typical quality assurance methods in the manufacture of electronic circuits using SMT	
P6 explain methods used for the manufacture of an electronic circuit using SMT		
P7 design, manufacture and test a prototype printed circuit board for a given electronic circuit to a valid standard.	**M5** justify the design of the printed circuit board with regards to function and suitability for use.	**D2** evaluate the design and manufacture of the prototype PCB and circuit and make appropriate recommendations for mass production.

Essential guidance for tutors

Assessment

P1 and P2 are closely related and evidence could be gathered from either an extended case study or from research and investigation. Case studies and investigations should ideally be based on production techniques and manufacturing processes that are used locally. Learners would benefit from visits to local industry to view the processes in action. An alternative to an extended case study or investigation might be the use of one or more written essay-type questions. However, this approach is likely to be less effective in bringing the topic to life.

To achieve P1, evidence should focus on design strategy, design tools (for example, schematic capture and auto-routing PCB CAD), creating and modifying schematic diagrams (for example, exchanging logic functions), design verification and design rule checking for both tracking and component layout.

It is important that learners demonstrate that they understand the additional processes required to produce multi-layer boards and that they appreciate the need for this type of board in conjunction with more complex electronic circuits. For example, circuits where microprocessor bus systems are realised on different layers or where power and ground connections are separated from signal tracks.

For P2, learners should describe typical production methods used in the manufacture of both single and multi-layer types of printed circuit board for electronic circuits of different complexity.

The explanation of the use of CAD software required for P3 should normally be based on the use of a SPICE package to verify a circuit design before it is manufactured.

For P4, learners should explain the need for thermal analysis and effective heat dissipation in terms of the total power dissipated and the maximum junction temperature ratings for the semiconductor device(s) present. They should explain that the requirements are satisfied by means of appropriately designed heat dissipaters on which the semiconductor devices are mounted.

To satisfy P5, learners should provide a written or verbal presentation of the use of surface mount technology (SMT) in the manufacture of electronic circuits. Learners should state the advantages and disadvantages of SMT and surface mounted devices (SMD) and should describe the typical outlines and packages used for SMD.

For P6, learners should explain the typical methods used for the manufacture of electronic circuits using SMDs. Note that learners are not expected to know how SMDs themselves are manufactured.

For P7, learners should design, manufacture and test a prototype printed circuit board for a given electronic circuit, to a valid standard. The electronic circuit should be supplied, complete with a full component list and component supplier’s references. Learners will be able to use these to determine physical constraints such as lead diameter, pin spacing and package outlines as well as any specialised mounting requirements such as the fitting of a heat dissipater. The circuits chosen should use no more than four active devices (for example transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits) and associated passive components (for example PCB mounted resistors, capacitors, inductors, and transformers). The circuit should have an identifiable function and should be capable of functional testing without specialised equipment.

In order to carry out this task, learners should be supplied with a simple test specification based on test-point voltages, output signal levels etc. Centres are encouraged to provide learners with a standard test-jig in order to carry out these functional checks.

Typical examples of circuits that learners might develop include:

- a variable pulse generator (based on two 555 timers)
- a function generator (based on a single integrated circuit waveform generator)
- an audio amplifier (based on a complementary symmetrical output stage with driver and pre-amplifier stage)
- a regulated power supply (based on a bridge rectifier and a three-terminal fixed voltage regulator).

Note that these last two examples could require learners to undertake some thermal analysis and incorporate appropriate arrangements for heat dissipation (extending the work required for P4 and providing a basis for developing evidence for D1).

Evidence for M1 could be gathered through a written assignment or formal written test. M2 could be assessed through appropriately designed practical activities. M3 could be achieved by carrying out problems related to a case study and M4 by means of an assignment in which learners investigate modern industrial processes used for the high-volume manufacture of electronic circuits. For M5, learners should gather evidence through the evaluation of the design and manufacture of a Prototype PCB and create a written report that includes recommendations.

Learners can achieve D1 by means of an extended assignment involving thermal analysis and the design of a heat dissipator (for example, a heatsink for fitting to a three-terminal integrated circuit voltage regulator).

For D2, the exercise carried out to satisfy P7 could be developed further as learners evaluate their designs and make appropriate recommendations for mass production (based on the understanding that they have evidenced in relation to P1 and P2).

These recommendations will typically include size reduction (including the use of miniaturised or equivalent surface mounted components), the use of multi-layer boards and the use of appropriate interconnecting technologies (for example the use of multi-pole insulation displacement connectors (IDCs) fitted with PCB headers).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	PCB Design and Manufacturing Techniques	Learners investigate the techniques and processes used in the design and manufacture of PCB (including manufacture of both single and multilayer PCB as well as both manual and automated component assembly).	A report containing written responses, including, where appropriate, sketches that describe and explain the techniques and processes used in the design and manufacture of PCB.
P3, M2	Circuit Simulation and Analysis Using SPICE	Learners investigate and use simulation programs with integrated circuit emphasis (SPICE) to carry out a DC and small-signal AC analysis of a simple electronic circuit (e.g. a single stage amplifier with given circuit data, component values and SPICE models).	A report containing written responses, including, where appropriate, sketches that describe and explain the use of CAD software in the analysis of a simple electronic circuit prior to manufacture. Learners should include evidence of their use of a SPICE package to carry out a DC and small-signal AC analysis in the form of screen grabs and/or hard copies of the results obtained.

Criteria covered	Assignment title	Scenario	Assessment method
P4, M3, D1	Thermal Analysis and the Design of Heat Dissipaters	Learners investigate thermal analysis techniques and use them to design an effective heat dissipater for an electronic device (e.g. a TO3 or TAB encapsulated transistor, voltage regulator or other integrated circuit for which electrical and thermal data is supplied).	A report containing written responses, including, where appropriate, sketches that describe and explain the use of heat dissipaters. Learners should include evidence of their thermal analysis including the use of appropriate formulae and relevant calculations of thermal resistance, junction and surface temperature.
P5, P6, M4	Surface Mounting Technology	Learners investigate the use of surface mounting technology (SMT) and surface mounted devices (SMD).	A report containing written responses including, where appropriate, sketches of SMT packages and mounting arrangements.

Criteria covered	Assignment title	Scenario	Assessment method
P7, M5, D2	Design, Manufacture, Assembly and Testing of a Prototype PCB	Learners will design, manufacture and test a prototype electronic circuit. In order to complete this task they will need to design and produce a PCB. The PCB layout should be produced using computer aided design techniques.	A process portfolio containing a circuit diagram, detailed component list, sketches, notes, screen dumps, component and PCB track layout diagrams, test voltages and currents, waveform sketches (as appropriate) together with learners' final prototype electronic circuit. The portfolio should include an evaluation of the design and manufacture of the electronic circuit together with an appropriate set of recommendations for its mass production.

Essential resources

Learners will need access to an electronics workshop with a range of electronic manufacturing equipment sufficient to meet the needs of the grading criteria (for example developing tanks, heated etching baths, PCB drilling equipment, soldering and wiring equipment). Centres will need to provide sufficient electronic test equipment to confirm the functionality of printed circuit boards and provide access to PCs equipped with PCB CAD and SPICE simulation packages. Learners will also need to be provided with relevant personal protective equipment (for example goggles, gloves, protective clothing) when manufacturing circuit boards, handling chemicals, soldering etc.

Indicative reading for learners

Textbooks

Sinclair I – *Practical Electronics Handbook* (Newnes, 2007) ISBN 9780750680714

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Websites

Electronic component suppliers and parts catalogues

Greenweld – www.greenweld.co.uk

Magenta – www.magenta2000.co.uk

Maplin Electronics – www.maplin.co.uk

Quasar Electronics – www.quasarelectronics.com

Electronic CAD, PCB design and SPICE resources

5Spice Analysis – www.5spice.com

Electronics Workbench Multisim – www.electronicsworkbench.com

Matrix Multimedia – www.matrixmultimedia.co.uk

WinSpice – www.winspice.com

Unit 24: Principles and Applications of Electronic Devices and Circuits

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Electronics and electronic devices are used in a huge variety of manufactured products. From everyday popular items such as cameras and thermometers to the robotic welding machines used in industry, the use of electronics is continually growing.

This unit provides a practical introduction to basic electronic devices along with analogue and digital electronic principles. It gives learners an opportunity to investigate the operation of diodes and transistors, two of the most important building blocks in electronic circuits. Learners will then go on to build and test circuits that make use of these devices and will consider the operation of integrated circuits such as the operational amplifier. Logic gates and flip-flops are also investigated both in practice and by using simple electronic principles, such as voltage gain or truth tables.

Finally, the unit will introduce learners to computer-based circuit design and simulation software packages that will allow them to build and test analogue and digital circuits. This will enable learners to recognise the importance of simulation software in the design of electronic circuits.

The overall aim of this unit is to build learners' confidence in their ability to construct and test simple electronic circuits. The emphasis is on prototyping, constructing and measuring. The unit treats systems in terms of their functionality and their input/output relationships.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of diodes, transistors and logic gates

2 Be able to build and test operational amplifier-based analogue circuits

3 Be able to build and test combinational and sequential logic circuits

4 Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits.

Unit content

1 Understand the function and operation of diodes, transistors and logic gates

Diodes: types, e.g. Zener, light-emitting diode (LED), PN-junction; circuit applications, e.g. voltage stabiliser, indicator light, half-wave rectifier

Transistors: types, e.g. NPN, PNP or field-effect transistor (FET); analogue circuit (single-stage amplifier); digital circuit, e.g. comparator, transistor as a switch (automatic vehicle head lights or night light); operation, e.g. analogue (voltage gain, phase inversion), digital (set-point of operation); function of components in circuits

Logic gates: types of gates, e.g. AND, OR, NOT, NAND, NOR, XOR; gate symbols, e.g. British Standards (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI); truth tables; Boolean expressions, e.g. A+B, $\bar{A}$, A • B

2 Be able to build and test operational amplifier-based analogue circuits

Building analogue circuits: method of construction e.g. prototype/bread-board, printed circuit, strip-board; types of circuits, e.g. oscillator, filter circuit, comparator circuit, inverting and/or non-inverting amplifier

Testing analogue circuits: performance against given design requirement; recording actual input and output voltages (tabulating data, plotting graph of results); circuit measurements, e.g. measurement of resonant frequency, cut-off frequency, switching point, gain at mid-frequency, bandwidth

3 Be able to build and test combinational and sequential logic circuits

Building combinational and sequential logic circuits: types of combinational circuit, e.g. at least three gates and three input variables; types of sequential circuit, e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; types of logic family, e.g. transistor-transistor logic (TTL) and complementary metal oxide semiconductor (CMOS); characteristics of chips, e.g. supply voltage, input and output operating voltages, input and output impedance, propagation delay, power

Testing of logic circuits: records of performance against given design requirement; input and output states; use of truth tables; use of test equipment, e.g. logic probe, signature analyser

Minimisation of logic circuits: e.g. use of De-Morgan's theorem; Karnaugh maps

4 Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits

Simulation of analogue circuit: types of circuits, e.g. transistor amplifier, op-amp, active filter, rectifier; types of components, e.g. resistor, capacitor, transistor, diode; instrument simulation, e.g. voltmeter, ammeter, oscilloscope; records of performance against given design requirement, e.g. screen print, input/output waveforms (with scales), gain-frequency response

Simulation of digital circuit: types of circuit, e.g. three input combinational circuit, counter, shift register; types of gates/sequential circuit, e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; instrument simulation, e.g. on/off indicator, logic probe, word generator, logic analyser; records of performance against given design requirement, e.g. screen print, digital input/output waveforms (with scales)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the function of different types of diodes, transistors and logic gates in different electronic circuit applications		
P2 explain the operation of two different types of transistor, one in an analogue and one in a digital circuit		
P3 build two different types of analogue circuit using operational amplifiers, testing appropriately	**M1** modify an existing analogue circuit to achieve a given revised specification by selecting and changing the value of one of the components	
P4 explain the operation of three different logic gates with appropriate gate symbols, truth tables and Boolean expressions		
P5 build a combinational logic circuit that has three input variables, testing appropriately	**M2** modify a digital circuit to achieve a given revised specification by selecting and changing up to two logic gates	**D1** compare and contrast two different types of logic circuits, referencing five key characteristics

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 build a sequential circuit using integrated circuit(s), testing its efficiency	**M3** minimise a three input variables combinational logic circuit containing three gates	
P7 use a computer software package to simulate the construction and testing of an analogue circuit with three different types of components	**M4** explain the benefits and limitations of a computer software package used to simulate the construction and testing of both analogue and digital circuits.	**D2** analyse the effects of changing the values of circuit parameters on the performance of an analogue circuit containing transistors.
P8 use a computer software package to simulate the construction and testing of a digital logic circuit with three gates.		

Essential guidance for tutors

Assessment

The learning outcomes and related criteria can be assessed in any order. The criteria P1, P2 and P3 are related and it would make sense to build a practical assignment or project around them. The focus would be to build two different types of analogue circuit (P3) that would allow learners to explain the operation of two different types of diodes, transistors and logic gates (P1) and the operation of one of the two different types of transistor (P2). Learners would then need to work on another circuit or simply explain the operation of a transistor in a digital circuit.

A second assignment could be used to cover the practical work required for P5 and P6. This could be linked to the explanation of theory that is necessary to achieve P4.

The last two pass criteria, P7 and P8, could be covered by a third assignment, either before the build and test exercise to prove the circuits, or afterwards, to simulate the circuit performance and testing that learners have already experienced.

Opportunities for the achievement of the merit criteria can be set within the assignments suggested above. For example, a task could be set for M1 that requires learners to modify a circuit to produce a different voltage gain from the one used in P3, or for a different resonant frequency for an oscillator.

M2 could be obtained through a task additional to that used for P5, such as to modify the circuit given for P5. M3 simply requires a minimisation (for example using a Karnaugh map). M4 could then be completed as this requires an explanation of the benefits and limitations of a computer software package, essentially encompassing P7 and P8.

To achieve D1, learners need to compare and contrast two different types of logic family, with reference to at least five characteristics. The comparison, which can be partly but not wholly achieved using a table, should consider common logic families such as TTL and CMOS. Where a table is used for comparison, it is expected that the meaning of any terms used (for example sink current) should be clearly explained. The comparison as a whole (table, written explanations, diagrams etc.) must make it clear how one logic family can be differentiated from another.

D2 requires an analysis, using a simulation package, of the effects on the performance of an analogue circuit containing transistors of changing the values of circuit parameters (for example components or component values, input/output voltages or signals). To meet the criterion it would require at least one other parameter to be changed – possibly the supply voltage, or input voltage – and noting how ‘clipping’ can occur. Part of the analysis could be to use calculations to show how the theoretical results align with those actually obtained through simulation.

Again, careful selection of the circuits used for the pass/merit assignment could enable this final step to be a natural development from the work already carried out. Establishing firm links between the pass, merit and distinction criteria in this way will encourage learners to work towards higher levels of achievement and will improve the relevance and coherence of the assessment activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Construction and Operation of Analogue Circuits	Learners have been asked by their employer to build and test analogue circuits to meet a new design requirement.	A practical assignment accompanied by written tasks/oral questioning in which learners construct and test two different analogue circuits, each circuit containing a diode and one containing a transistor. One of the circuits could then be modified to meet a revised specification. Additional tasks would then require the learner to explain the purpose/operation of the diodes and transistor, plus an additional transistor from a further digital circuit.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M2, M3, D1	Construction and Operation of Logic Circuits	Learners have been asked by their employer to build and test logic circuits to meet a new design requirement.	A practical assignment accompanied by written tasks/oral questioning, in which learners construct and test combinational and sequential circuits. Additional tasks would then require the learner to explain the operation of logic gates and compare and contrast different types of logic family.
P7, P8, M4, D2	Using Simulation Software to Construct and Test Circuits	Learners have been asked by their employer to use software to simulate the construction and testing of circuits to meet a new design requirement.	A practical assignment in which learners construct and test analogue and digital circuits using simulation software. They should also be given the opportunity to analyse the effect of changing circuit parameter values.

Essential resources

Centres will need to provide access to an appropriate electronics laboratory with a range of measuring and test equipment, as listed in the unit content. For example, facilities for circuit construction and prototyping, a range of components, logic-tutor boards, hardware and software to support computer-based analogue and digital schematic capture and circuit simulation will be needed. Learners will also need access to publications, reference data and manufacturers' product information to enable them to consider the different types of components listed within the unit.

Indicative reading for learners

Textbooks

Bell D – *Fundamentals of Electronic Devices and Circuits* (Oxford University Press, 2007) ISBN 9780195425239

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Unit 25: Engineering Maintenance Procedures and Techniques

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The correct maintenance of engineering systems results in improved efficiency and can save organisations time and money in relation to system downtime and stoppages in production. This unit introduces learners to a range of commonly used engineering maintenance procedures and monitoring techniques, which may be encountered in any manufacturing, plant or process environment. The unit will also help learners understand how the data gathered from monitoring engineering systems can be used.

Learners will examine the consequences of maintenance and maintenance planning in terms of cost, and the implications for production, personnel, the environment and safety. They will gain an understanding of engineering maintenance and process planning and develop the skills needed to plan scheduled and preventative maintenance activities on engineering systems.

The unit has been designed to reflect the multidisciplinary nature of maintaining manufacturing plant and process engineering systems, rather than being confined to specialist knowledge of a single discipline. Learners will need to produce a maintenance plan for an engineering system involving two or more interactive technologies from mechanical, electrical, fluid power, process control or environmental systems.

Learners will be required to know about the methods, procedures and documentation that must be completed before handing over maintained systems, and how to confirm that the system is ready to run in a safe and operable condition.

Finally, learners will gain an understanding of the basic techniques of condition monitoring and how computerised maintenance systems can be used to capture data and predict specific failure trends in plant, machinery, equipment and systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about the types of maintenance associated with engineering plant, equipment and systems

2 Know about maintenance frequency, the cost of maintenance and its effects on production

3 Be able to produce a maintenance plan for a specific engineering system

4 Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used.

Unit content

1 Know about the types of maintenance associated with engineering plant, equipment and systems

Type of maintenance: types, e.g. planned, total preventative maintenance (TPM), breakdown, scheduled, corrective, emergency, post fault, scheduled servicing, modification to equipment, condition-based maintenance; maintenance activities, e.g. visual examination, monitoring, replacement, sensory, testing, checking alignment, making routine adjustments, removing excess dirt and grime, recording results and reporting defects

Reasons for maintenance: issues relating to higher plant reliability and availability, e.g. longer equipment life, improved product quality, greater cost effectiveness, improved safety, legal requirements; issues relating to health and safety, e.g. statutory regulations and standards, company rules, codes of conduct, reduction in environmental damage

Engineering systems, plant and equipment: systems, e.g. process monitoring and control, mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical; plant and equipment, e.g. gearboxes, pumps, engines, compressors, machine tools, lifting and handling equipment, process control valves, mechanical structures, company specific equipment, electrical plant, motors, starters, switchgear and distribution panels, cardiovascular equipment, medical imaging equipment

2 Know about maintenance frequency, the cost of maintenance and its effects on production

Frequency of maintenance: time, e.g. daily/weekly/monthly/yearly; activities, e.g. data logging and checking, adjustments, tests, routine maintenance, fixed-interval overhaul, equipment replacement, use of computerised techniques; methods for determining frequency, e.g. calendar maintenance, hours run meter

Costs: representative data of cost, e.g. maintenance as a proportion of total expenditure, utilisation of operator (frontline maintenance), maintenance labour, maintenance contracting, lost production, levels of spares and consumables in stores, equipment hire/replacement, safety and environmental effects

Effects on production: e.g. downtime, effects on operating performance, product quality, customer service, financial penalties, effects on associated equipment or plant, higher energy costs, secondary damage

3 Be able to produce a maintenance plan for a specific engineering system

Maintenance plan: maintenance planning, e.g. methods, sequence and timing, frequency, check lists, planned repairs, use of planning techniques, Gantt and Pert charts, team working, computerised methods; resources, e.g. personnel, supporting equipment, tools, manuals, materials, components, facilities, stores spares and consumables; procedures, e.g. safety procedures, risk assessment, Control of Substances Hazardous to Health (COSHH) Regulations 2002 and other relevant safety regulations, safe access and working arrangements for the maintenance area, isolation requirements for plant/equipment, disposal of waste, handover procedures, liaison with other departments

Engineering systems: process monitoring and control, e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging)

Supporting documentation: manufacturers' drawings and maintenance documentation; maintenance logs, databases, records, results and defect reports; plans and schedules; production records; standing instructions; handover documentation

4 Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used

Monitoring techniques: e.g. condition monitoring, scheduled overhauls, routine servicing, planning systems, hazard studies, failure mode and effect analysis (FMEA), teamwork, self-diagnostic and computerised systems

Data collection: collected at identified points; data, e.g. types, operational characteristics, output quality, throughput, environmental operating conditions; interpreting data, e.g. electronic-based data, data recording and presentation

Need for monitoring: physical aspects, e.g. improve safety, reduce environmental hazards, extend equipment life, ensure accurate equipment performance; cost-related aspects, e.g. improve product quality, reduce downtime, reduce costs; other aspects, e.g. produce comprehensive computer database, better communications

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe two types of maintenance	**M1** justify the suitability of particular types of maintenance for specific applications	
P2 describe the reasons for maintaining a specified engineering system		
P3 describe four maintenance activities for a specified engineering system		
P4 identify two items of plant and equipment for a specified engineering system that require maintenance, describing the frequency at which it should be carried out		
P5 describe the effects on production of carrying out maintenance on a specified engineering system	**M2** from a given range of data, calculate the maintenance costs for a specified engineering system in relation to maintenance type, resources and production downtime	**D1** discuss how the frequency of maintenance affects production and costs for a specified engineering system

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 produce a basic maintenance plan for a specified engineering system containing supporting documentation with resource and procedure requirements	**M3** justify planned maintenance for a specified engineered system in terms of system downtime, environmental and health and safety considerations	**D2** produce a comprehensive plan for the maintenance of a specified engineered system containing all supporting documentation.
P7 describe an application of monitoring, the technique used and how the data is collected and interpreted	**M4** analyse given condition monitoring and quality control data to predict specific machinery/plant failure.	
P8 explain the need to monitor the performance and condition of engineering systems.		

Essential guidance for tutors

Assessment

Evidence of achievement could be obtained from investigative assignments, reports of workshop activities or through learners building a portfolio from maintenance operations carried out in the in the workplace.

The unit could be assessed through a mixture of written assignments and practical tasks. Assuming that the learning outcomes are delivered in order, a first assignment with a series of written tasks could be used to cover the criteria associated with learning outcomes 1 and 2. The first task could ask learners to describe two types of maintenance (P1) and four maintenance activities (P3). Learners would then need to describe the need for maintaining a specific engineering system (P2). The system might be mechanical, fluid power, electrical, process control, or an environmental system. This could be extended to cover M1, for which learners must justify the suitability of particular types of maintenance for specific applications. The work produced for M1 should include total preventative maintenance (TPM), scheduled or condition-based maintenance.

A second assignment to cover P4 could ask learners to identify items of plant and equipment that require maintenance and the frequency at which maintenance should be carried out. They will also need to give reasons for carrying out maintenance, for example longer equipment life, improved product quality, greater cost effectiveness, improved safety or legal requirements. The task also needs to ensure that learners cover timing, activities carried out and methods of determining the frequency. It should also ensure that learners have opportunities to give reasons for the required maintenance covering plant reliability/availability and issues relating to health and safety.

A third assignment covering P5 and M2 and D1 could ask learners to calculate from given data the cost of maintenance and describe the effects on production. A further task requiring learners to explain how the frequency of maintenance can affect production and cost would enable M2 to be met.

A well-planned, investigative practical assignment could be used to cover criteria P6, M3 and D2. To achieve P6, learners need to produce a basic maintenance plan for a specified system with accompanying documentation with resource and procedure requirements.

This basic maintenance plan should include at least the following:

- identification of the plant/equipment/machinery to be maintained
- identification of the person with overall responsibility for the maintenance process
- the maintenance procedures to be adopted
- timescales for preparation and implementation of the maintenance activities
- a list of the physical resources required for the maintenance activities (for example lifting equipment, tools, test and measuring equipment)
- details of the administrative support that is to be provided for the maintenance work
- details of the maintenance documentation systems to be provided.

This then needs to be built on in order to achieve D2, where a comprehensive maintenance plan containing all supporting documentation needs to be produced for a specified engineering system. The comprehensive maintenance plan should contain the entire basic plan together with at least the following:

- health and safety procedures
- identification of appropriate types of maintenance compatible with production requirements
- identification of who is to carry out the maintenance (for example in-house labour, contractors, specialists)
- lists of sub-assemblies and spare parts to be held
- the quality control procedures that need to be followed during maintenance activities, together with maintenance tools/equipment control and test instrument calibration
- environmental considerations such as the procedures to be adopted for the disposal of all types of waste material arising from the maintenance activity including the safe disposal of toxic and/or hazardous materials if relevant
- handover documentation.

To achieve M3, the practical activity could be supported by written evidence, showing that learners are able to justify the maintenance plan in terms of system downtime, environmental and health and safety considerations.

The criteria associated with learning outcome 4 could be assessed through a written assignment. Learners need to explain the need for monitoring the performance and condition of engineering systems (P8). This should include the physical aspects, cost related aspects and other aspects as outlined in the unit content. Systems do not need to be given as the task should be tackled as a generic response outlining the need in systems in general. The task also needs to ask learners to describe an application of monitoring, the technique used and how data is collected and interpreted (P7).

To achieve M4, learners need to carry out an in-depth analysis of given condition monitoring and quality control data to predict specific machinery/plant failure. An example would be data produced by vibration analysis for a large motor bearing. The data could come from computer analysers, inspection and test, SPC (Statistical Process Control), or from general product quality control.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Types of Maintenance Activities	Learners need to report to their manager on types of maintenance and maintenance activities and justify particular reasons for maintenance.	A written report relating general maintenance types to specific examples.
P4	Maintenance Needs in a Complex Engineering System	Learners need to write a report on the maintenance of a complex engineering system.	A written report describing the practical needs for maintenance of plant and equipment that also discusses frequency that maintenance is carried out.
P5, M2, D1	Costing a Maintenance Schedule	Using plant data and a maintenance schedule, learners calculate the cost and effect of maintenance on system production.	A written assessment of the plant maintenance data to identify the costs of maintenance and its impact on production and cost.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M3, D2	Maintenance Planning	Learners produce a maintenance plan and justify the maintenance programme.	An investigative practical assignment. Evidence includes a written basic maintenance plan for the specified system with accompanying documentation, and resource and procedure requirements. A comprehensive maintenance plan containing all supporting documentation for the specified engineering system. Additional written evidence justifying the maintenance plan in terms of system downtime, environmental and health and safety considerations.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, M4	Monitoring Techniques	Learners need to describe condition monitoring and how data is used to a new member of staff.	Written explanation of the need for monitoring the performance and condition of engineering systems. Written or oral description of an application of monitoring, the technique used and how data is collected and interpreted. Written analysis of given condition monitoring and quality control data to predict specific machinery/plant failure.

Essential resources

In order to deliver this unit, centres will need to provide learners with access to complex engineered systems or test rigs, relevant data books, manufacturers' specifications, system manuals, functional flow charts and system diagrams. Learners will also need appropriate test equipment and tools and access to maintenance records/documentation from modern factories/plant. Computer software for data logging and self-diagnostics should also be provided.

Indicative reading for learners

Textbooks

Kelly A – *Maintenance Systems and Documentation* (Butterworth-Heinemann, 2006) ISBN 0750669942

Kelly A – *Strategic Maintenance Planning* (Butterworth-Heinemann, 2006) ISBN 0750669926

Mobley R K – *Maintenance Fundamentals* (Butterworth-Heinemann, 2004) ISBN 0750677988

Snow D – *Plant Engineer's Reference Book* (Butterworth-Heinemann, 2001) ISBN 0750644524

Unit 26: Monitoring and Fault Diagnosis of Engineering Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Condition monitoring and quality control techniques are used to detect potential failure symptoms in engineering systems. The methods used by engineering technicians range from fully automated monitoring down to the use of the human senses. This unit gives learners an understanding of the fundamentals of engineering system monitoring and fault diagnosis, and explains the basic concepts of condition monitoring. The unit examines the development of engineering system monitoring and fault diagnosis and how modern technology, quality control and environmental issues have affected current thinking.

The unit will give learners an understanding of the precautions required to protect themselves and others in the workplace, and focuses on the safety measures needed when carrying out monitoring activities, especially those for isolating equipment.

Learners will understand how to use a range of condition monitoring equipment and will develop the skills and knowledge required for the location and identification of faults in engineering systems. Learners will be required to select the appropriate monitoring technique and equipment based on the type of plant or equipment being monitored and the conditions checked.

The unit will enable learners to check and set up monitoring equipment before using it to carry out diagnostic condition monitoring on engineering systems, in accordance with approved procedures. Learners will be expected to use a variety of fault diagnosis methods and techniques, and use a number of diagnostic aids and equipment. From the evidence gained they will then identify the fault and its probable cause.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems

2 Know about system monitoring and reliability

3 Be able to use monitoring and test equipment

4 Be able to carry out fault diagnosis on engineering systems.

Unit content

1 Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems

Legislation: appropriate statutory acts and regulations, e.g. Health and Safety at Work Act, Management of Health and Safety Regulations, Provision and Use of Work Equipment Regulations (PUWER), Control of Substances Hazardous to Health (COSHH) Regulations, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Lifting Operations and Lifting Equipment Regulations (LOLER), Manual Handling Operations Regulations (MHOR), Personal Protective Equipment (PPE) at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Health and Safety (First-Aid) Regulations; specific safety requirements, e.g. company rules, permit to work procedures, risk assessment, environmental issues; health and safety procedures, e.g. response to alarms, use of safety equipment, reporting of accidents, reporting of hazardous items of plant or equipment; personal safety, e.g. appropriate dress, protective clothing, appropriate or protective headgear, protective gloves and footwear, eye protection, face masks and respirators, appropriate use of barrier creams, personal cleanliness, prompt attention to injuries

Hazards and practices: workplace hazards, e.g. compressed air, hydraulic fluid, gases, hot surfaces, electrical equipment, unfenced machinery, toxic substances and fumes, falling objects, liquid spillage, untidy work area, badly maintained tools and test equipment; safe working practices, e.g. isolation procedures, methods of immobilising equipment, precautions to be observed when operating or working on live equipment, permit to work, use of danger tags, warning notices, safety barriers, cones and tapes

Engineering systems: process monitoring and control; fault diagnosis; systems, e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging)

2 Know about system monitoring and reliability

Monitoring terminology: condition monitoring methods, e.g. offline portable monitoring, sampled monitoring, continuous monitoring, protection monitoring, human sensory monitoring; monitoring techniques, e.g. vibration analysis, temperature analysis, flow analysis, particle analysis, crack detection, leak detection, pressure analysis, voltage/current analysis, thickness analysis, oil analysis, corrosion detection, environmental pollutant analysis

Failure and reliability: calculations concerning failure, e.g. degrees and causes of failure, failure rate, failure modes, functional failure, primary and secondary functions, mean time between failures (MTBF), reliability; factors affecting reliability, e.g. design, operation, environment and manufacture, reduction in system/device failure, e.g. routine servicing, adjustments; data, e.g. defects examination, statistical process control (SPC), quality

3 Be able to use monitoring and test equipment

Monitoring and test equipment: use of fixed and portable monitoring equipment for on and offline monitoring including continuous and semi-continuous data recording, e.g. vibration monitoring of bearings, self-diagnostics (such as PLCs/smart sensors, computerised data acquisition, data logging, electrical data, gas analysis); use of handheld instruments, e.g. meters, thermal imaging; test equipment for taking measurements of parameters, e.g. temperature, pressure, viscosity, speed, flow, voltage, current, resistance, sound, vibration

Procedures: practical methods, e.g. crack detection, leak detection, corrosion detection, flow analysis, vibration analysis, pressure analysis

4 Be able to carry out fault diagnosis on engineering systems

Diagnostic terminology and techniques: terminology (definitions and explanations of symptoms, faults, fault location, fault diagnosis and cause); techniques, e.g. six point, half-split, input–output, emergent problem sequence, functional testing, injection and sampling, unit substitution

Diagnostic aids: test and measuring equipment; other aids, e.g. plant personnel, manufacturers' manuals, system block diagrams, circuit and schematic diagrams, data sheets, flow charts, maintenance records/logs, self-diagnostics, software-based test and measurement, trouble shooting guides

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 outline the aspects of health and safety legislation that apply to monitoring and fault diagnosis of an engineering system		
P2 describe workplace hazards and safe working practices relevant to specific monitoring and fault diagnosis situations		
P3 describe a condition monitoring method and technique related to a given engineering system	**M1** explain four factors that influence either failure or reliability in a given engineering system	**D1** analyse the environmental effects on reliability of temperature, humidity, vibration and pressure for a given engineering system
P4 use given data to calculate failure rates for a range of components and equipment	**M2** explain the environmental conditions that affect the reliability of the components in given items of congruent equipment	
P5 describe the factors affecting reliability for a given engineering system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe the monitoring and test equipment used for measuring given system condition parameters	**M3** evaluate the quality of measurements made and the limitations of given items of condition monitoring equipment	
P7 use procedures to carry out system monitoring on two separate engineering systems		
P8 describe the terms and two different techniques related to fault diagnosis	**M4** demonstrate a logical approach to finding faults by identifying and distinguishing between symptoms, faults and causes.	**D2** analyse monitoring/quality control data and information to predict/detect potential failures in given engineering systems.
P9 use diagnostic techniques, test and measuring equipment and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.		

Essential guidance for tutors

Assessment

Evidence of achievement of the learning outcomes and grading criteria may be obtained from well-planned investigative assignments or reports of workshop activities. Alternatively, it may be accumulated by learners building a portfolio from investigations and monitoring and fault diagnosis operations in the workplace or through realistic exercises and tests. In either case, the opportunity should exist for merit and distinction grades to be achieved with relevant and sufficient evidence to justify the grade awarded.

Assuming that the unit is delivered in the same order as the learning outcomes, a first assignment could cover the criteria for learning outcome 1 (P1 and P2). This assignment could be a written or practical task requiring learners to identify appropriate health and safety procedures and personal safety requirements for an engineering system. Such a system might be mechanical, fluid power, electrical, process control or an environmental system (such as fume extraction or air conditioning).

Learning outcome 2 could be assessed through a written or time-constrained assignment requiring learners to calculate, from given data, failure rates for a range of components and equipment. These could be pumps, actuators, compressors, air receivers, accumulators, valves, generators, motors, transformers, switch gear, machine tools, engines or gearboxes (P4). The assignment could contain a task requiring learners to describe factors affecting reliability (P5) and monitoring methods and techniques (P3). A third task could be added to cover M1, requiring learners to identify and describe four factors that influence either failure or reliability in a given engineering system. A further task requiring learners to identify and describe environmental conditions affecting the reliability of components in items of equipment and analyse the effects of the environment on component/asset reliability could enable achievement of M2 and D1. The range of components and equipment should be sufficient to allow these higher grading criteria to be achieved. However, the range required for pass criterion P4 would need to be at least one mechanical type, one electrical type and one fluid type system. Therefore, a range of data for each is required to be given to learners.

Assessment of learning outcome 3 could be by a well-planned practical investigative assignment covering criteria P6, P7 and M3. This would require learners to carry out monitoring activities on two separate engineering systems, such as bearing vibration analysis, temperature, flow, particle, oil, pressure, voltage/current corrosion, environmental pollutant, crack and leak detection. Such systems may be mechanical, fluid power, electrical, process control or environmental systems. This could be supported by written evidence that shows learners are able to describe the use of monitoring and test equipment and evaluate the quality of measurements and the limitations of given items of monitoring equipment. Witness statements and annotated photographs would be suitable evidence to support the use of procedures to carry out system monitoring.

Learning outcome 4 is best suited to practical investigation. For P8, learners need to explain the terms and two different techniques from those in the unit content, such as six-point, half-split, input-output, emergent problem sequence, functional testing, injection and sampling and unit substitution. For P9, they need to use diagnostic techniques, test and measuring equipment (such as dial test indicators, torque instruments, logic probes, multimeters etc.) and aids to locate faults on two separate engineering systems, where two malfunction symptoms are evident on each system. The assignment to cover this could have a task requiring learners to carry out fault diagnosis on a given engineered system. This could be either in a simulated situation or in the workplace using evidence gathered in a logbook containing items such as equipment used, tests carried out and measurements taken. This should be supported by the inclusion of witness statements.

Learners must describe typical fault conditions and find faults independently on equipment, which exhibits symptoms of more than one function failure. For example, a pump can have two functions, one to pump water at a given rate, the other to be free of water leaks whilst pumping. To achieve M4, learners must demonstrate a logical approach to fault finding and be able to distinguish between symptoms, faults and causes. A second task supported by written evidence would enable learners to demonstrate that they are able to analyse data and use this information to predict/detect potential failures in given engineering systems for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Health and Safety in System Monitoring and Fault-finding	An investigation of practical health and safety issues and legislation, relating to system monitoring and fault diagnosis.	A report and risk assessment, identifying and discussing relevant health and safety issues, including the methods used to address them.
P3, P4, P5, M1, M2, D1	System Condition Monitoring and Reliability	Practical and theoretical investigations into the factors affecting component and system reliability, including: failure rate calculations; factors affecting reliability and system and component monitoring techniques, in general and as applicable to a specified engineering system.	A written and/or time-constrained assignment containing learners': calculations of failure rates for specified components and equipment; discussions on reliability; and on system monitoring methods. Supported by learners' engineering sketches and diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3	Performing System Monitoring and Measurements	A practical investigation into the monitoring and evaluation of two different engineering systems.	A report or portfolio of evidence and data describing the monitoring techniques and equipment used, and interpreting the measurements made on the two systems. Supported by learners' engineering sketches and diagrams. Witness statements and annotated photographs.
P8, P9, M4, D2	System Fault-Finding Techniques	A practical investigation into two different techniques across two separate systems (four tasks in total) using diagnostic techniques, test and measuring equipment and aids.	A report containing an explanation and evidence of the investigations and tests performed, and the conclusions drawn. Supported by learners' engineering sketches and diagrams. Witness statements and annotated photographs.

Essential resources

This unit is intended to provide learners with a practical introduction to monitoring and fault diagnosis methods and techniques. Therefore, it is essential that learners have access to:

- actual engineered systems or test rigs designed for monitoring/fault finding
- data books and manufacturers' specifications
- system manuals and functional flow charts and system diagrams
- computer software for data logging and self-diagnostics
- appropriate test equipment and tools
- maintenance records.

Indicative reading for learners

Textbook

Yardley E – *Condition Monitoring: Engineering the Practice* (Wiley-Blackwell, 2002) ISBN 9781860583612

Website

Health and Safety Executive www.hse.gov.uk

Unit 27: Principles and Applications of Engineering Measurement Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

There is now a wide range of systems and methods used to measure performance and operations in engineered systems.

This unit is designed to develop learners' knowledge and understanding of the use of measurement and testing in engineered systems, while giving them opportunities to explore both traditional and modern methods. The unit explains the physical principles used in transducers and shows the way that these principles are exploited in practice across a range of industrial measurement applications.

The selection of correct measurement systems is key to the optimum performance and operation of an industrial plant. The unit gives learners an insight into the main elements of a measurement system and shows how these elements working together provide a required function.

The unit describes recording and display devices and their operational characteristics, so that learners will be able to use and make informed choices between similar devices on technical grounds. Modern display and recording techniques are discussed and learners' are given the opportunity to use and design virtual instrumentation systems using computer software.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the applications of common measurement systems

2 Understand the operation of measurement system components

3 Be able to use testing, recording and display equipment for a measurement application

4 Be able to test and calibrate a measuring system.

Unit content

1 Understand the applications of common measurement systems

Main purpose and elements of measurement: producing or obtaining data; carrying out inspection and testing; monitoring health and safety; checking outputs, e.g. meeting specifications, quality control, condition monitoring; controlling processes; carrying out statistical analysis

Measurement system elements: block diagrams; elements, e.g. transducers, signal conversions, signal conditioning, recording and display, transmission links; common measurement systems, e.g. pressure transmitter, level transmitter, temperature transmitter, flow transmitter

Measurement system performance: performance terms, e.g. accuracy, error, linearity, reliability, repeatability, sensitivity, resolution, range, transfer function, static and dynamic characteristics, electrical noise, calibration

2 Understand the operation of measurement system components

Transducer types: output of common measurement transducers, e.g. temperature, pressure, flow, level, vibration, weight, displacement; physical principles, e.g. resistive, capacitive, piezo-electric, inductive, opto-reflective, static pressure, elasticity

Signal converters: conversion process, e.g. voltage to current, pressure to current, current to pressure, frequency to voltage, analogue to digital (ADC), digital to analogue (DAC); signal converter types, e.g. Wheatstone bridge, V/I converter, P/I converter, I/P converter, F/V converter, ADC, DAC

Signal processors: types, e.g. voltage and current amplifiers, mechanical amplifiers, simple signal filters, multiplexers, decoders; specification requirements, e.g. voltage amplitude, current amplitude, signal frequency, noise reduction

3 Be able to use testing, recording and display equipment for a measurement application

Test equipment: electrical/mechanical types, e.g. multimeters, handheld oscilloscope, signal generator, logic testers, earth loop impedance meter, pressure injector, 4–20 mA loop calibrators, insulation tester, optical alignment; safety; functions and operation; specification, e.g. output, input, range of operation, resolution

Recording and display devices: computer elements in monitoring and recording, e.g. data acquisition, interface cards, software; specification, e.g. acquisition speed, resolution, input type; plotters and chart recorders

Virtual instrumentation: software available, e.g. NI LabVIEW, Visual Basic, Discovery; mimics; trending; alarms

4 Be able to test and calibrate a measuring system

Test and calibrate: calibration parameters (component specification, system requirements); calibration of measurement equipment, e.g. pressure, level, temperature, flow, nucleonic, position, speed

System specification and function: measurement system specifications; characteristics and limitations of measuring systems, e.g. operating range, environment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the main purpose and elements of measurement	**M1** justify the design of a measurement system, ensuring that it meets the required specification	**D1** evaluate the performance of a given measurement system against a required specification
P2 explain the main elements in three given common measurement systems		
P3 explain the performance of a given common measurement system		
P4 explain the operational principles of three different types of transducer		
P5 explain the conversion process that takes place in three given signal converters		
P6 describe the signal processors needed to meet a given specification		
P7 use appropriate test equipment to test the function and operation of a common measurement system against specification		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 use an appropriate recording or display device to meet a given specification	**M2** design a graphic display for a given measurement system	
P9 use virtual instrumentation software to display, record and generate a report on a given measurement system		
P10 test a given common measurement system to meet the requirements of the system specification, calibrating as required to ensure its performance limitations are not exceeded.	**M3** explain the testing methods used and the calibration process.	**D2** evaluate the performance limitations of the calibrated system.

Essential guidance for tutors

Assessment

Assessment evidence for the first six pass criteria (P1–P6) could be produced through a written assignment. After explaining the various purposes of measurement systems (P1), learners could be asked to explain the main elements of three different measurement systems using block diagrams (P2), given manufacturers' data sheets for each of the given systems.

The block diagram could provide learners with a basis to select and explain the functionality and performance of the transducer, signal converter and signal processor elements (P3, P4, P5 and P6). The assignment must include reference to common performance terminology.

A practical workshop assessment could be used to assess pass criteria P7 and P10. Firstly, learners could be given a measurement system and data sheets. They could then be given details of the required output tests that must be carried out to ensure it can be checked for function and operation. Learners will need to select an appropriate test instrument that meets the test requirements, and perform the test(s). A written report should be produced presenting the results clearly, with appropriate conclusions. A witness statement/observation record could be used to confirm the safe use of the test equipment for P7 and that testing and calibration was carried out successfully (P10). This could be extended to include a written explanation of the testing methods and calibration process (M3) and an evaluation of the performance limitations to achieve D2.

The final assessment could be a combined practical and written assignment that asks learners to use a computer with previously produced screen mimics and interfaces to record and display data from the output of a measurement system (P9). Learners could then be asked to compare this display/recording/trending system with alternatives, select an alternative and provide reasons for the selection (P8).

Assessment evidence for M1 is likely to be an extension to the assignment covering pass criteria P1–P6. Learners could be asked to design a new measurement system (block diagram form may be sensible) to meet a given measurement specification. The specification will need to include a transducer, a signal converter and a signal processor. This type of activity could be supported through simulation software to confirm that the specification has been met.

Assessment evidence for M2 could be achieved through an extension to the assignment covering criteria P8 and P9. Learners will need to be given a computer interfaced to the previous measurement system. They could then be asked to design a software graphic, input the measured data and display in an appropriate form to meet a given specification.

Assessment evidence for D1 could be achieved through an extension of the assignment covering criteria P1–P6 and M1. Learners could be asked to evaluate the performance of a measurement system that is measuring a variable within an industrial process plant. This evaluation will consider the operation and performance of the system. Learners could be asked to suggest improvements to the system or suggest an alternative, having identified and discussed advantages and limitations.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, P6, M1, D1	Measurement Systems and System Components	Learners need to produce an information booklet detailing the purpose of measurement and the function of the main elements in a measurement system.	A written assignment, including a task requiring learners to explain the purpose of measurement and a series of descriptions, based on block diagrams, of the main elements within a measurement system.
P7, P10, M3, D2	Testing and Calibrating Measurement Systems	Learners need to use suitable equipment to test and calibrate a measurement system.	A practical assignment supported by observation records and a written report in which learners select equipment, perform tests to meet requirements and calibrate a measurement system.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M2	Recording and Display Equipment	Learners need to record and display data from a measurement system and write a report comparing the system used with alternatives.	A mixed practical and written assignment. Learners are to use a computer with previously produced screen mimics and interfaces to record and display data from the output of a measurement system. They should then compare this display/recording/ trending system with alternatives and select an alternative.

Essential resources

Process rigs and associated measurement and test equipment are essential for the delivery and assessment of much of this unit. Learners should have access to relevant workshop or laboratory facilities, including:

- process plant or system simulators
- measurement and data acquisition software
- measurement and data acquisition hardware (PCs and interface cards)
- data books and manufacturers' specifications
- measurement and test equipment manuals
- appropriate tools.

Indicative reading for learners

Textbook

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004)
ISBN 9780750664325

Unit 28: Electrical Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Electricity is used in a wide range of applications, such as manufacturing, healthcare, transport and entertainment. All of these are reliant on electrical technology in one form or another. For example, for someone to be able to visit a holiday destination, go to a music festival or download the latest track by their favourite performer, numerous electrical activities and concepts must be coordinated.

Electrical technology provides the link between science and its application. It is underpinned by a range of enabling technologies and concepts such as materials science, energy efficiency, environmental impact, geological characteristics and design.

This unit provides an introduction to ways in which electricity is produced, the options we have about how and why we produce it, and the disposal of related by-products. The unit considers how the electricity that has been produced is then moved to where the customer (end-user) needs it. It also examines the materials used and whether alternatives exist or could be found.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the methods used to produce electrical energy

2 Understand the properties and applications of conductors, insulators and magnetic materials

3 Understand the physical arrangements of supply, transmission and distribution equipment

4 Understand how electrical energy is used to support applications of electrical technology.

Unit content

1 Know the methods used to produce electrical energy

Electromagnetic generation: characteristics and principles of operation of alternating current (AC) and direct current (DC) generators, e.g. relative motion between conductors and magnetic fields, production and regulation of AC using field/slip-ring control, production of DC using commutators and brushgear; features of different types of electrical power generating stations and their energy sources, e.g. coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass

Solar panels: developments in photoelectric cells, e.g. photo-electric effect, PN-junction for basic photocell, need for use of converters to convert to alternating current source; small and large scale applications of solar panels, e.g. roadside furniture such as school crossing warning signs, domestic/ commercial roofing

Electro-chemical cells and batteries: construction, applications and disposal; primary and secondary, e.g. lead/acid, alkaline, nickel-iron (NiFe), nickel-metal-hydride (NiMH), nickel-cadmium (NiCad), lithium

2 Understand the properties and applications of conductors, insulators and magnetic materials

Conductors: properties, e.g. conductivity, resistivity, tensile strength, rigidity; electrical applications of solid conducting materials, e.g. copper, aluminium, steel, brass, carbon, soil (for Earth continuity); applications of liquids and gases, e.g. electrolytes, fluorescent and discharge lighting

Insulators: properties, e.g. resistivity, maximum voltage capability, operating temperatures, mechanical strength; applications of solid, liquid and gas insulating materials, e.g. polyvinyl chloride (PVC), butyl rubber, glass, paper, oil, air

Magnetic materials: properties, e.g. retentivity, coercivity, B-H curve, hysteresis, iron losses; electromagnetic applications, e.g. permanent magnets, electromagnets, soft iron, silicon steel, mu-metal, ferrites for use at audio and high frequencies

3 Understand the physical arrangements of supply, transmission and distribution equipment

Electrical generation: energy conversion methods, e.g. generating plant and equipment (coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass, photo voltaic, Gas turbine); by-products (useful and not so useful, $C0_2$ emissions, carbon neutral); speed governing and voltage regulation for supply standardisation

Electrical transmission: use of transformers for feeding into and out of the grid network; construction and operation of power transformers, e.g. double-wound and autotransformers; construction and operation of switchgear and protection systems, e.g. air circuit breakers, oil circuit breakers, fuses, over current and over voltage devices; transmission voltages, e.g. 400 kV, 275 kV and 132 kV and the reasons for using them; cross-channel/intercontinental links for electricity supply

Electrical distribution: ring and radial feeders; sub-stations; use of distribution voltages, e.g. 33 kV, 11 kV; plant and equipment, e.g. isolators, oil breakers, air breakers; three-phase and single-phase distribution systems and voltages (400V and 230V); earthing arrangements

4 Understand how electrical energy is used to support applications of electrical technology

Applications of electrical technology: manufacturing, e.g. automated processes, robotics, control systems; healthcare, e.g. magnetic resonance imaging (MRI) scanners, operating theatre uninterruptible power supplies (UPS); entertainment, e.g. sound and video systems, theme parks, music festivals; transport, e.g. electric trains, inner-city trams, electric cars, solar-powered space travel

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the characteristics and principles of operation of a DC electromagnetic generator	**M1** compare the features of three prime energy sources that are in general use for the production of electricity by mechanically driving an electromagnetic generator	**D1** justify the use of different energy sources, including fuels and renewable sources, to provide a nation's electricity supply
P2 describe the characteristics and principles of operation of an AC electromagnetic generator		
P3 describe the operation and an application of a solar power source		
P4 describe the characteristic features of two different types of electro-chemical cells or batteries		
P5 explain the properties and a typical application of a solid and a liquid or gas electrical conductor		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain the properties and a typical application of a solid and a liquid or gas electrical insulator		
P7 explain the properties and an application of two different magnetic materials commonly used in electrical and electronic engineering		
P8 describe the arrangements and features of an electrical supply system from generation through to transmission and distribution to end users	**M2** explain the reasons for the use of a range of voltages in an electricity supply system	**D2** evaluate an electrical supply system suggesting possible improvements.
P9 explain two different applications of electrical technology and, for each of them, describe how electrical energy is used to enable them to function.	**M3** explain how a practical application of electrical technology could be improved by making effective use of available technologies.	

Essential guidance for tutors

Assessment

Although this unit could be delivered completely in class, the learning and assessment experience is much more relevant if the learners make use of the outside world and visit real applications of electrical technologies.

The pass criteria could be achieved through the use of written assignments and/or illustrated posters with relevant text boxes to describe the concepts covered, for example the characteristics and principles of operation of a DC electromagnetic generator.

For P1 (DC generator) and P2 (AC generator), motor vehicle/motorcycle parts are cheap and are a relatively safe resource that could be investigated and described. The larger items in power stations are just scaled-up models (figuratively speaking) with somewhat larger brush gear and coils, etc. Hence, an assignment could require learners to use such an easily obtainable device to help them describe the principles and operation of electromagnetic generation.

Learners could then use this simple model to illustrate the similarities and differences between these and larger machines when they consider the characteristics of a power station and its energy sources (for example a coal, gas, oil, nuclear, hydro-electric, pumped storage, wind farm, tidal, biomass) used to generate power commercially.

Solar cells (P3) can be found on a range of items, including calculators and street signs, as well as small kits used by many college and school science departments. Learners' description of their operation should be limited to developments in photoelectric cells and a consideration of the action of the atoms in crystal lattice PN-junctions when subjected to illumination. An in-depth atomic theory explanation is not expected.

Cells and batteries take many forms and, although a wide range should be taught, learners only need to select two for P4. Liquid conductors and insulators (P5 and P6) could also be part of learners' response to P4 if a wet cell such as lead acid were to be described. Reference could also be made to the potential hazard of topping up the cell with tap water if living in a hard water, high mineral content region. This would short out the plates and ruin the cell(s), whereas distilled or de-ionised water would not.

There is a wide range of other examples that could be examined for P5 and P6. For example, oil is a good insulator and is used on oil circuit breakers to quench the spark and prevent conduction. Fluorescent lights contain a variety of conductive gases and vapours requiring different arcing voltages and producing a range of colours. Overhead lines are insulated by air and any simple electric switch uses air as an insulator when in the 'off' position.

To cover P7, learners could consider electrical relays, motors, generators or similar devices that rely on electromagnetism. For example the soft iron formers of transformers and motors or a radio tuner's use of ferrite core inductors. Some devices use permanent magnets, which could also be explained to address P7.

P8 requires learners to describe the arrangements and features of an electrical supply system to cover the key aspects of the content. This will include the generation method, transformer construction, types and operation, including single wound (autotransformers) and double wound voltages and distribution method. Learners might also include the finer details of distribution such as an electronics workshop having isolating transformers on bench supplies and reasons why they are used.

P9 provides an opportunity for learners to apply their knowledge by considering complete real-world applications. Examples could include lighting systems, sound systems or systems including motion (ranging from a model containing an electric motor to the electrification of the rail network). The Docklands Light Railway (DLR) and some airport transport systems have no driver and an investigation of these systems could allow learners to work on an area in which they may be interested and learn through the application of electrical technology. This should take learners into such aspects as electromagnetic effects and sensors for control, computer control, or the requirement for emergency or uninterrupted power supplies (UPS).

To achieve a merit, learners should differentiate between the mechanical prime movers of electromagnetic generators (M1), ranging from nuclear, coal and gas to wind and wave power and water storage such as that used at Dinorwic in Wales. Things to compare and contrast could include cost, response time, maximum demand, pollution, environmental issues, including appearance, hazards (and perceived hazards), locality of employees, life span of the project and post-service decommissioning.

While reporting on a supply system (P8), learners could address M2 by explaining why a range of voltages is used such as 15 to 25 kV at the generators and up to 400 kV for transmission, and the reasons for other voltages (for example 33 kV, 11 kV and 3.3 kV down to 400/230 volts) for light industrial and domestic end users.

To address D1, learners need to produce a thorough justification of why a nation might use a range of different energy sources. This could include (as a source and focus for the learner's own justifications) suitably referenced third-party comments from parliamentary reports, Greenpeace opinions, local opposition groups and the projected impacts on national and global economies. Other considerations could include the future of different methods and fuels, lifespan of equipment and the actual fuel, cost of fuel production, hazards and environmental impact assessments.

D2 provides an opportunity for learners to develop the ideas of P8 and M2, electrical supply systems. For D2, learners are expected to provide suggestions for improvements to many aspects of effectiveness and efficiency of a chosen system. The suggestions made, and their explanations and justifications, should be feasible and possible. This could include an evaluation of learners' ideas by a third party/engineer in that chosen industry. Learners could then make effective use of this through further reflection and subsequent development of their own work by following the professional feedback.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, D1	Electrical Energy Production	Learners produce an information poster for learners detailing the main forms of electrical energy production.	A written assignment with a series of tasks requiring learners to describe AC and DC generators, solar power and two different batteries.
P5, P6, P7	Conductors, Insulators and Magnetic Materials	Learners need to produce a report detailing the properties and applications of different conductors, insulators and magnetic materials to determine the best for a particular application.	A written assignment with a series of tasks requiring learners to explain conductors, insulators and magnetic materials.
P8, M2, D2	Electrical Supply, Transmission and Distribution Equipment	Learners produce a report on the electrical supply system.	A written assignment for which learners describe the electrical supply system and explain the reasons for a range of voltages.
P9, M3	Applications of Electrical Technology	Learners have been asked to investigate the use of electrical energy.	A written assignment requiring learners to explain the use of electrical energy in different applications.

Essential resources

Centres will need simple models or alternators/dynamos from motor vehicles to demonstrate AC and DC generation. Because cells and batteries can be hazardous, videos/DVDs or pictures are recommended to illustrate these along with manufacturers' data.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012) ISBN 9780273755104

Kiameh P – *Power Generation Handbook* (McGraw-Hill, 2011) ISBN 9780071772273

Patrick D and Fardo S – *Electrical Power Systems Technology* (Fairmont Press, 2008) ISBN 9781439800270

Unit 29: Electrical Installation

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

We all use electricity, almost without thinking about it. Although we are surrounded by and rely on electrical appliances, most people have little understanding of how electricity arrives at its final point of use.

This unit will give learners an understanding of the circuits regularly found in domestic premises, the components and accessories used, cables, sockets and light switches etc. Learners will gain some practical experience of constructing and investigating some of these circuits and systems. The unit will provide an understanding of installations where there is an increased shock risk, mainly to illustrate the hazards associated with these areas.

Safety and safe working practices are essential to reduce the risks of working with electricity to an absolute minimum. Learners will gain a knowledge of selecting types of cable for their insulation properties, current-carrying capacity and physical strength, and choosing the correct type and rating of protective devices to prevent over-current. Learners will also be introduced to how the design and provision of earth-bonding conductors helps prevent electric shock.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to interpret lighting and power circuits diagrams

2 Understand the methods used to protect circuits

3 Be able to install and test lighting and power circuits

4 Know the statutory and non-statutory regulations relating to the provision of an electrical installation.

Unit content

1 Be able to interpret lighting and power circuits diagrams

Lighting circuits: e.g. one way, two way (loop-in method, junction box, singles)

Power circuits: e.g. fused plug socket outlet, ring circuit, radial circuit, switched fused spur, cooker, immersion heater, heating control

Choice of cables and protection devices: cable calculations, e.g. design current, correction factors, tabulated cable ratings and voltage drops; maximum demand and diversity, e.g. determination and application of maximum demand and diversity (individual householder, small shops/offices, small hotels/guest houses); segregation of circuits; categories of circuit proximity to non-electrical services

Increased risk of electrical shock areas: e.g. inside the main property (rooms containing a fixed bath or shower, sauna, swimming pool), equipment outside equipotential zone (shed, garage, workshop, garden, pond)

2 Understand the methods used to protect circuits

Types of over-current protection device: fuse, e.g. rewireable, cartridge; miniature circuit breakers (MCBs); residual current breaker with overload protection (RCBO)

Circuit protection methods: earthing and bonding, e.g. ADS automatic disconnection of supply, earthed neutral system, system classification (terra-terra (TT) and terra-neutral (TN) with combined (C) and separate (S) variations (TNC, TNS, TNC-S)), earth electrodes, protective multiple earthing (PME), earth fault loop impedance, typical values; protective conductor circuit, e.g. main and supplementary equipotential bonding conductors, earthing terminal; residual current devices (RCDs); other protection methods, e.g. class 2 equipment, class 3 equipment; cable size, e.g. from tables for current loading and thermal constraints; protection from mechanical damage, e.g. armoured cable, cable trunking, cable tracking

3 Be able to install and test lighting and power circuits

Lighting and power circuits installations: use of flexible and non-flexible cable; use of tables to select cable type and size; circuit components (consumer unit/circuit isolation device, light switching, e.g. 1-gang, 2-gang, 1-way, 2-way, intermediate; power socket outlets, e.g. ring, radial, switched fused spur connection units; other types of power circuits, e.g. immersion heater, heated towel rail)

Circuit testing: for compliance with circuit diagram, e.g. operation of switches, circuit continuity, polarity, insulation resistance checks

4 Know the statutory and non-statutory regulations relating to the provision of an electrical installation

Statutory regulations: scope, object, principles and use of relevant parts of statutory wiring, installation and site regulations, e.g. Health and Safety at Work Act, Electricity Supply Regulations, Electricity at Work Regulations, the Building Regulations (particularly Part P), Construction (Design and Management) Regulations, Electrical Equipment (Safety) Regulations, Electromagnetic Compatibility Regulations

Non-statutory regulations: scope, object, principles and use of relevant sections of the wiring regulations, e.g. BS 7671: plus amendments and relevant guidance notes

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 interpret two different lighting circuit diagrams, explaining the function of the circuits and why the cables and protective devices have been chosen for each installation	**M1** carry out calculations to obtain cable sizes, given the power and voltage, taking installation methods and correction factors into account	**D1** analyse the design specification of a domestic installation with at least six circuits, including the use of diversity when determining the final maximum demand current
P2 interpret two different power circuit diagrams, explaining the function of the circuits and why the cables and protective devices have been chosen		
P3 describe the extra considerations required for an electrical installation in an area of increased risk of electrical shock	**M2** explain the steps taken to prevent electric shock by indirect contact	
P4 explain the operation of the three types of over-current protective devices, describing a suitable electrical installation application for each		
P5 describe the function and application of two different circuit protection methods		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 install and test two different lighting circuits in accordance with current wiring regulations	**M3** inspect and test a given electrical installation for compliance with installation instructions and relevant regulations.	**D2** justify the inspection and testing methods carried out for a lighting and a power circuit.
P7 install and test two different power circuits in accordance with current wiring regulations		
P8 describe the statutory and non-statutory regulations that apply to an electrical installation on the inside of a building		
P9 describe the statutory and non-statutory regulations that apply to an electrical installation on the outside of a building.		

Essential guidance for tutors

Assessment

P1 requires learners to demonstrate their ability to interpret two different lighting circuit diagrams, explain the function of each circuit and say why the cables and protective devices have been chosen for each of the installations.

P2 is similar but focuses on power circuit diagrams. In order to satisfy the cable calculation requirements of P1 and P2, learners should perform calculations based on design current. However, to satisfy M1, learners should take into account appropriate correction factors, use tabulated cable ratings and work with voltage drops.

For P3, learners could use diagrams/sketches to help describe a relevant installation inside a property or equipment outside the equipotential zone. This should include the positioning of equipment and any other safety features and reference to appropriate regulations.

For P4, learners must explain the operation of all three types of overcurrent protective device listed in the unit content (fuse, miniature circuit breaker, residual current breaker with overload protection). They will then need to describe a suitable electrical installation application for each device.

For P5, learners need to describe the function and application of two different circuit protection methods (for example earthing residual current devices) or any other protection methods (for example class 2 equipment, class 3 equipment). Learners must refer to issues of cable size (for example from tables for current loading and thermal constraints) and the method used to protect the circuit from mechanical damage (for example armoured cable, cable trunking, cable tracking).

P6 and P7 require learners to install and test two different lighting circuits and two different power circuits in accordance with current wiring regulations. One approach to assessment might be to use these four circuits as the focus for the assessment of all the other criteria. This type of approach to assessment would provide maximum coherence but, by necessity, would fragment the criteria. Therefore centres would need to take care when tracking learner achievement.

Records for each installation would need to be planned carefully to indicate learners have met the relevant criteria and unit content, and only when all four installations have been completed satisfactorily would each criterion be fully achieved.

Evidence for this work could be a mix of tutor observation records, annotated photographic evidence, learners' research and preparation notes, and formal reporting. For example, in addition to the installation, a formal written description of the extra considerations required for an electrical installation in an area of increased risk of electrical shock would be required. The evidence could be brought together as a portfolio record for each installation. The constraint to this approach would of course be the centre's ability to provide sufficient installation facilities to cope with a reasonable group size.

For P8 and P9, descriptions of the statutory and non-statutory regulations that apply to an electrical installation on the inside and outside of a building could also be planned to fit into the above assessment approach. Learners will need to summarise the relevant legislation (statutory and non-statutory) that needs to be considered when electrical installation work is carried out in and around buildings. The list given in the unit content should not be seen as exhaustive and centres should ensure that the most current, relevant and up-to-date legislation is covered.

Less integrated approaches could also be used to good effect where equipment or other constraints apply. However, a circuit should only be deemed to be correctly wired when any single cores of conductors with diameters less than 2.5 mm^2 are terminated into a screwed terminal. Other elements of good practice also need to be demonstrated, all connections must abide by the latest UK/EU colour code standards (or equivalent for other countries), and the circuit must work.

M1 and D1 build on learners' understanding from P1 and P2. For the application of diversity in D1, the circuits could include examples such as upstairs and downstairs ring circuits, upstairs and downstairs lighting circuits, cooker (with or without 13 A socket), immersion heater, or outside supply to a garage/shed.

Having carried out the installations for P6 and P7, learners should be expected, as simply a matter of good practice, to check their own work for compliance ahead of assessment. This can be extended to meet M3, where learners inspect others' work.

In doing this, learners should follow relevant inspection and test procedures using appropriately annotated inspection and testing documentation (such as those illustrated in the wiring regulations or the on-site guide or other centre devised certification). The activity for this could be the supervised assessment of the work carried out by a fellow learner who is presenting their installation as evidence for P6 and P7.

M2 builds on the work carried out for P3, P4 and P5. This will include earthing connections and other means. To differentiate the work at merit from that at pass, it is expected that at this level learners not only know what needs to be done but can explain and justify the actions taken. This should include, why an RCD is needed outside the equipotential zone, and how it operates, why it needs to operate in a certain specified time and the relevance of its current sensitivity to the effects of electricity passing through a human body or livestock.

D2 builds on the inspection work undertaken for M3. Learners are required to explain and justify the inspection and testing methods carried out for one lighting and one power circuit. This should take into account the what, where and how of the inspection process for compliance with circuit diagram, for example operation of switches, circuit continuity, polarity, insulation resistance checks and should give learners an opportunity to demonstrate their understanding of the unit as a whole.

The evidence, which is likely to be a technical report, should clearly explain what learners were doing during the inspection and why. It should also include what they were looking for and why; which test equipment they used, how and why it was 'proved' before and after use and, finally, how well the results show the installations comply with the respective circuit diagrams.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Interpreting Wiring Circuit Diagrams	Learners interpret given lighting and power circuit diagrams, perform calculations of cable size and analyse the given design specification of a domestic electrical installation.	A report, including supporting calculations, engineering sketches and diagrams, and design analysis
P3, P4, P5, M2	Investigating Circuit Protection and Safety Techniques	Learners investigate, inspect and report on different measures for providing protection against circuit overload and the risk of electrical shock.	A report, including descriptions and explanations supported by engineering sketches and diagrams.
P6, P7, M3, D2	Implementing Electrical Installations	A practical activity in which learners install, test and inspect prescribed lighting and power circuits.	A report, including descriptions and evaluations supported by engineering sketches and diagrams.
P8, P9	Non-statutory and Statutory Wiring Regulations	Learners investigate and then describe pertinent wiring regulatory requirements.	A report, including descriptions supported by engineering sketches and diagrams.

Essential resources

Centres will need to provide access to suitably equipped workshops for the installation of electrical circuits (preferably with some installation onto walls or, where necessary boards), together with relevant test equipment to carry out tests to prescribed regulations (for example BS7671 and Guidance Note 3).

Learners will also require access to a range of wiring diagrams, test rigs and wiring boards, electrical tools and components and cabling required for lighting and power installations.

Centres will need to provide appropriate documentation such as statutory and non-statutory regulations, manufacturers' catalogues, data sheets and relevant cable, component and equipment specifications.

Indicative reading for learners

Textbooks

Hinsley A – *Testing Electrical Installations: A Practical Guide for Electricians* (Castleknight Publications, 2006) ISBN 9782952413831

Scaddan B G – *IEE Wiring Regulations: Explained and Illustrated* (Newnes, 2011) ISBN 9780080969176

Whitfield J – *The Electrician's Guide to the 17th Edition of the IEE Wiring Regulations* (EPA Press, 2008) ISBN 9780953788552

Unit 30: Electronic Measurement and Testing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Practical electronic engineering demands the extensive use of electronic test equipment and measurement techniques. These range from basic measurements of parameters such as voltage, current and resistance, to highly sophisticated software-controlled measurements based on advanced mathematical techniques such as Fast Fourier Transformation (FFT).

This unit will give learners an understanding of a variety of electronic measurement equipment such as voltmeters, ammeters, analogue/digital multimeters and oscilloscopes or specialist diagnostic equipment. The unit also examines a range of electronic test equipment such as signal generators, digital counter/frequency meter, alternating current (AC) bridge, logic probe, logic pulsar and current tracer.

Learners will develop an understanding of the function, features and characteristics of electronic measurement and test equipment. They will also gain practical experience of their use when carrying out electronic testing and measurements in a wide range of electronic engineering applications. This will include selecting, connecting and operating different types of test equipment and applying measurement techniques.

Learners will demonstrate that they can apply common testing methods and assess errors inherent in the instruments used. Particular attention is paid to ensure that the test procedure, as well as the test and measurement equipment used is fit-for-purpose and properly calibrated. Learners will be expected to explain the effects of instrument characteristics such as accuracy, display resolution and loading and how these affect the measured quantity.

Finally, learners will be introduced to the use of virtual test instruments and software to make measurements and analyse measurement data. They will examine equipment such as a digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator or logic analyser. Learners will be expected to make measurements using virtual instruments and analyse the captured data using appropriate software.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function, features and characteristics of electronic measurement and test equipment

2 Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit

3 Know the principles of calibration and configuration of electronic test equipment

4 Be able to select and use virtual test instruments and software to make measurements and analyse measurement data.

Unit content

1 Understand the function, features and characteristics of electronic measurement and test equipment

Function of equipment: as appropriate to the measurement and test equipment, e.g. accurate measurement of alternating current (AC) and direct current (DC) voltage and current, resistance, waveform and distortion measurement, accurate measurement of waveform parameters (period, duty cycle, on-time, off-time, rise time, fall time, frequency, pulse repetition frequency (PRF), impedance, logic level)

Features of equipment: as appropriate to the measurement and test equipment, e.g. displays and display technology, input and output connectors, attenuators, manual and automatic range selection (auto ranging), in-built calibration facilities, portability, power sources, external bus interfaces

Characteristics of equipment: measurement and test equipment specifications, e.g. input impedance, output impedance, resolution, accuracy, distortion, bandwidth, input signal range, output level, sample rate, trigger sources

Measurement instruments: meters (voltmeter, ammeter); analogue/digital multimeter; oscilloscope, to include specialist or manufacturer diagnostic/ measuring equipment

Electronic test equipment: signal generator, e.g. audio frequency (AF), radio frequency (RF) and pulse generators, waveform/function generators; digital counter/frequency meter; AC bridge; logic probe; logic pulsar; current tracer

2 Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit

Selection of equipment: selection based on instrument specifications, characteristics and limitations, e.g. output, level, input sensitivity, frequency range, accuracy, resolution and distortion

Measurement techniques: test-point voltage and waveform measurement; supply voltage and current measurement; power, impedance and phase angle measurement using variable loads; frequency and PRF measurement; rise and fall time measurement; distortion and noise measurement (qualitative only); use of test specifications, e.g. in the case of a variable DC power supply, measurement of the actual output voltage delivered at a specified load current when the power supply has been set to a specified voltage under no-load conditions; in the case of an audio amplifier, measurement of the output power delivered to an externally connected load of specified resistance, using a specified test frequency and waveform and at a specified level of distortion

Measurements: use of test points, test leads and probes; minimisation of loading effects; use of appropriate instrument ranges; precautions to be taken when measuring high voltages and currents; precautions to be taken when working on low voltage and computerised systems; effect of DC levels on AC signals and waveforms; effect of signals present at DC test points; effect of drift and temperature; need for calibration; relevant test specification and measurement techniques, e.g. sampling, averaging

Electronic equipment: industrial/consumer electrical and electronic equipment, including low-voltage DC power supplies, e.g. linear, switched-mode types; amplifiers, e.g. AF, RF, small-signal, power; oscillators, e.g. sinusoidal, square wave, crystal controlled; radio equipment, e.g. radio receivers, low-power transmitters and transceivers; digital electronic equipment, e.g. microcontrollers, microcomputers, programmable logic controllers; manufacturer specific equipment; video equipment, e.g. television and video players/recorders

3 Know the principles of calibration and configuration of electronic test equipment

Calibration principles: procedures, e.g. check, adjust, systematically standardise measuring instrument, set-up arrangement; reference standards, e.g. standard resistors, standard inductor; theory, e.g. accuracy, uncertainty; impact of calibration on quality, productivity and safety; applications, e.g. during manufacture, following installation, periodic scheduled maintenance, in response to identified deviation, after repair or change in environment; terminology, e.g. zero shift, range (or span) error, combined zero shift and range error, non-linearity

Health and safety issues: e.g. precautions to be observed when setting and adjusting mains supply voltages, replacing/charging/disposing of batteries, dismantling and reassembling equipment, removal/replacement of external and internal covers, making adjustments on 'live' equipment, continuity of earth (grounding or bonding) of electrical equipment, safety cut-outs and residual current device (RCD), earth leakage circuit breaker (ELCB)

Configuration issues: pre-conditions and checks to ensure that system/equipment is safe to test and instruments safe to use; test equipment set-up, e.g. use of the equipment manufacturer's procedures, using commissioning guides

4 Be able to select and use virtual test instruments and software to make measurements and analyse measurement data

Virtual measurement and test system: e.g. digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator, logic analyser

Measurement techniques, connection, hardware and software: tests carried out on electronic equipment using virtual test and measuring instruments; instrument connection, e.g. external/internal PC interface, instrument connection standards (parallel port, serial port, USB, PCI/PXI bus, IEEE-488, PCMCIA); use of hardware and software to carry out measurements, e.g. voltage, frequency, frequency spectra measurements (for sinusoidal and non-sinusoidal waveforms); measurement software, data storage and data transfer, e.g. to a spreadsheet, automated measurement/data collection techniques

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the function, features and characteristics of a measurement instrument		
P2 explain the function, features and characteristics of three different pieces of electronic test equipment		
P3 select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment	**M1** use a manufacturer's recommended procedure, together with laboratory instruments and standards, to calibrate and configure an item of electronic test equipment	**D1** evaluate the accuracy of own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions
P4 explain the importance of test specifications as an aid to ensuring the validity and consistency of measurements		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 describe the principles and need for the calibration of an item of electronic test equipment	**M2** explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment	**D2** devise and demonstrate a calibration procedure for an item of electronic test equipment.
P6 explain the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing		
P7 use a virtual measurement and test system to carry out a test on a piece of electronic equipment		
P8 describe the measurement techniques, instrument connection, hardware and software used.	**M3** use appropriate software to display and analyse voltage/ time data captured from a virtual oscilloscope.	

Essential guidance for tutors

Assessment

To achieve P1 and P2, learners will need to describe the function, features and characteristics of one measurement instrument and three different pieces of electronic test equipment. The evidence for this could be block diagrams/sketches (with appropriate annotation) and short notes. The actual function, features and characteristics explained will be dependent on the electronic test equipment selected, but examples of the types of things to consider are given in the unit content.

P3 requires learners to select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment. These can be low-voltage DC power supplies, amplifiers, oscillators, radio equipment, digital electronic test, measurement or diagnostic equipment or display equipment. Further examples of each of these are provided in the unit content.

Learners will need to perform practical measurements in an electronic laboratory or electronic workshop. Given a particular measurement requirement (for example to investigate the frequency range of an oscillator), learners should then select the appropriate items of test and measurement equipment to carry out the task. Both the selected item(s) of test equipment and the measuring technique(s) should be appropriate to each measured quantity. For example, an oscilloscope and ×10 probe would not be appropriate for the accurate measurement of the output frequency produced by an oscillator. The three different pieces of electronic equipment should enable as wide a range of test equipment and measuring techniques to be applied as possible. All three pieces could come from one category (for example consumer electrical and electronic equipment) as long as the chosen equipment enables the use of a sufficient range of test equipment and measuring techniques. It is expected that all the content listed under measurement techniques and measurements will have been covered by the time learners have carried out the measurements on all three pieces of equipment.

Evidence for P3 is likely to take the form of tutor observations and learners' records of the selection and use of equipment and techniques employed. Suitably annotated photographic records could also be used (for example a photograph of the equipment being tested, the test equipment and the test set-up, all suitably labelled to highlight the key features of the test/measurements).

For P4, learners should provide a written or verbal presentation to explain the importance of test specifications as an aid to ensuring the validity and consistency of measurement. Centres should ensure that learners have access to a variety of test specifications for common measurements (for example determining the output impedance of a power supply by voltage/current measurement when a suitably rated variable load is applied). The achievement of this criterion could be effectively linked with the practical work in any one of the tests carried out for P3.

P5 requires learners to describe the principles and need for calibration of an item of electronic test equipment. Again, one of the tests undertaken for P3 could provide the focus for this criterion. The description, which is likely to be a written report, must include the electronic test equipment calibration procedures that need to be carried out, the reference standards required and any relevant theory. Examples of each of these and typical applications are given in the unit content. As an aid to understanding the calibration process, centres should demonstrate the calibration procedures for equipment used in the laboratory (for example oscilloscopes, digital multimeters, signal generators, etc.).

For P6, learners must describe the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing. The health and safety issues considered will depend on the equipment being tested. The configuration issues considered must, as a minimum, enable learners to take into account the required pre-conditions and checks to ensure that it is safe to test the system/equipment. For example, the selection of an adequately rated load in terms of both impedance and power rating when testing an audio amplifier or the need to check that an oscilloscope probe is correctly matched to the oscilloscope that it is to be used with. Learners will also need to ensure instruments are safe to use (for example use of a high-voltage probe when measuring DC voltages in excess of 500 V) and test equipment set-up correctly, for example use of equipment manufacturer's procedures, using commissioning guides. Again it would make sense to link this criterion to one of the tests undertaken for P3.

To satisfy P7 and P8, learners should use a virtual measurement and test system to carry out a test on a piece of electronic equipment. They should provide a written or verbal description of the procedure used, explaining the connections made, the software settings, and the measuring techniques used. A typical example would be the use of a virtual digital storage oscilloscope used in conjunction with a personal computer (PC). Learners should connect and configure the instrument in conjunction with the software running on the PC and select, for example, appropriate sampling rates, input ranges and display and data capture settings. Evidence of individual learner's work can most conveniently be presented in the form of a selection of screen dumps that have been suitably annotated by the learner.

For M1, learners are required to calibrate and configure a test instrument (such as a waveform generator), using the manufacturer's recommended procedures and appropriate laboratory instruments and standards. Learners should be supplied with relevant documentation (for example manufacturer's handbook) and laboratory standards (such as a standard frequency or time generator). Evidence is likely to be a logbook record of the calibration exercise or a technical report of the calibration activity. Tutor observation records should be used to support either of these forms of evidence. There is a clear link between this merit criterion and P5.

To achieve M2, learners need to explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment. This could be achieved as a natural extension to one of the tasks carried out for P3.

To satisfy M3, learners should use a virtual storage oscilloscope (using a PC with appropriate interface hardware and software) to display and analyse a waveform. Note that the emphasis should be on the analysis of the waveform rather than its display. A typical example might involve the production of a frequency spectrum for the sampled waveform using FFT techniques. Once again, learners should keep a record of their work in a logbook, supported by tutor observation records. Relevant screen dumps and print outs that have been suitably annotated by the learner could also be incorporated.

Learners' work towards D1 should require them to evaluate the accuracy of their own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions. For example, learners should be aware of the inability of an oscilloscope to accurately display a transient pulse due to the oscilloscope's own finite rise-time and bandwidth. Another example would be the need to be aware of the effects of aliasing on the captured and displayed waveform when sampling a fast waveform.

For D2, learners need to devise and demonstrate a calibration procedure for an item of electronic test equipment. A typical example might be a procedure to calibrate a ×10 oscilloscope probe using a fast-rise time square wave generator, a high-speed oscilloscope, and a matching ×10 probe. Evidence is likely to be in the form of a technical report although it would be beneficial if the devised calibration could be linked into the work done for P5 and M2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Measurement Instruments and Test Equipment	Learners are requested to generate an information booklet and an accompanying report for new staff.	A written assignment.
P3, P4, P5, P6, M1, M2, D1, D2	Selecting, Using and Calibrating Electronic Test Equipment	Learners have been asked to show a new learner how to take measurements from electronic equipment and talk them through the calibration of test equipment and relevant health, safety and configuration issues.	A practical assignment with additional written tasks.
P7, P8, M3	Virtual Testing	Learners have been asked by their employer to carry out tests on a piece of electronic equipment.	A practical assignment.

Essential resources

Centres will need to provide access to an electronics laboratory fitted with a range of electronic test and measurement equipment (such as multimeters, signal generators, oscilloscopes, or specialist manufacturer equipment within industry etc.). A limited number of specialist items of electronic test equipment and calibration sources (for example standard cells and off-air signal sources) should also be available. Specialist items of electronic equipment (such as AC bridges, earth continuity testers, logic analysers, component testers etc.) may be required as appropriate to the needs of local industry.

A small number of computer-based virtual instruments should also be available together with the appropriate hardware and software (for example LabVIEW, DASYLab, DADiSP, MATLAB etc.). Test and measurement applications should be installed on these systems.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012) ISBN 9780273755104

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Tooley M – *PC Based Instrumentation and Control* (Routledge, 2005) ISBN 9780750647168

Unit 31: Features and Applications of Electrical Machines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

All electrical machines use applications of electro-magnetic principles where electric currents create magnetic fields, which either attract or repel each other. This is the basis of all electric motors, whether they operate on alternating current (AC), direct current (DC) or are universal motors that operate on both.

Transformers are devices that also use the principle of electromagnetism. These are generally very efficient and their output power can be almost 100 per cent of the input power, depending on the application.

This unit has been designed to help learners understand the complexities of electromagnetism and its applications to everyday electrical devices, systems and apparatus. Learners will consider a range of machines, their application and their control. In addition, the unit will help learners understand relevant electrical hazards, legislation, regulation and standards.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus

2 Understand features and applications of alternating current (AC) machines

3 Understand features and applications of direct current (DC) machines

4 Know how electrical machine control circuits and systems operate.

Unit content

1 Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus

Electrical hazards: safe working procedures, e.g. isolation (safe isolation, switch off, lock off, display notices, testing for dead with test lamp and proving unit), earthing, interlocking, warning notices, permit to work; risk assessment when working on electrical apparatus, e.g. hazard evaluation and recording of risk, controlling risk; personal protective equipment (PPE), e.g. insulated gloves, mats, tools, barriers

Legislation, regulations and standards: e.g. Health and Safety at Work Act, Electricity at Work Regulations, Personal Protective Equipment at Work Regulations, Electrical Equipment (Safety) Regulations, Machinery Directives, Health and Safety Executive (HSE) publications, e.g. GS38, Codes of Practice, British and International Standards, BS 7671 17th Edition IEE Wiring Regulations

2 Understand features and applications of alternating current (AC) machines

Alternating current (AC) motors: single and polyphase; construction, principles of operation, starting characteristics and torque; types (induction motors, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives); applications of AC motors, e.g. conveyor belt drives, pumps, machine shop equipment, fixed loads, variable loads

AC generator: types, e.g. single-phase, polyphase; construction and principles of operation; applications, e.g. stand-by generators, remote site generators, vehicle alternators with regulation and rectification

Transformers: principles of operation; efficiency and losses; construction of single and double wound; types, e.g. step up, step down, safety isolating transformer; applications, e.g. incoming mains step down, portable transformer for hand tools, safety isolating transformer for electrical test-bench work, machine power supplies

3 Understand features and applications of direct current (DC) machines

Direct current (DC) motors: types, e.g. series, shunt, compound (long and short shunt), brushless; construction, principles of operation, starting characteristics and torque; applications, e.g. motor vehicle starters and window operation, toys and models, industrial drives, crane hoists, fixed loads, variable loads

DC generators: construction and principles of operation; production and control of DC voltages and current; applications, e.g. motor vehicles, speed control/ feedback systems (tacho-generators)

4 Know how electrical machine control circuits and systems operate

Stop/start/retain relay control: relay/contactor with retaining/latching contact; start, stop, overload, 'inch' (non-latching) control; remote stop/start; safety relays for production/manufacturing equipment, e.g. several guards/closed sensors, oil level detectors, temperature sensors, body heat (passive infra-red) detectors; control circuits, e.g. AC machine control (direct on line (DOL), star-delta, soft start and other solid state techniques such as triac, inverter drives, slip ring rotor resistance control, auto transformer, power factor correction), DC machine control (starting methods and speed control such as face plate, solid state systems); emergency stop, e.g. closed contact device to stop the machine/system from running or starting and turn power off under emergency conditions; emergency stopping, e.g. dynamic braking by either DC injection braking or timed phase reversal, solenoid operated mechanical brakes, instantly stopping the machine

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe hazards that may exist when working with two different pieces of electrical apparatus		
P2 describe control measures that should be used to reduce the risk of harm to self and others when working with two different pieces of electrical apparatus		
P3 describe aspects of legislation, regulations and standards that relate to work being carried out on two different pieces of electrical apparatus		
P4 explain the features, characteristics and application of two different types of AC motor	**M1** explain the operational features of a speed control system for an AC machine	**D1** compare the applications of a DC and an AC motor for two contrasting modern electrical installations
P5 explain the features, characteristics and an application of one type of AC generator		
P6 explain the features, characteristics and application of two different types of transformer		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 explain the features, characteristics and application of two different types of DC motor	**M2** explain the operational features of a speed control system for a DC machine	
P8 explain the features, characteristics and an application of a DC generator		
P9 describe the operation and use of a stop/start/retain relay control circuit for an AC or DC machine.	**M3** explain the use of a safety relay system and how its use addresses the issues raised in relevant legislation, regulations and standards.	**D2** compare the construction and operation of two different types of stop/start/retain relay control circuit for either an AC or a DC machine.

Essential guidance for tutors

Assessment

P1, P2 and P3 are linked and are likely to be achieved through investigations based on the same two different items of electrical equipment, for example transformers, isolators, AC and DC motors. Evidence could be presented in the form of a written report or as a presentation to a group using appropriate visual aids.

When describing hazards and control measures for P1 and P2, learners should include all the aspects identified in the unit content.

For P3, learners should include relevant quotes from their sources and specific references, and it is important that these are shown to be specific to the work being undertaken and not just general quotes.

For P4, learners need to carry out investigations based on two different types of AC motor (for example induction, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives, single or polyphase motors). Ideally, these should be combined into one single investigation of two different motors rather than two separate investigations. This will avoid the need to assess the criterion twice before it can be reported as achieved. Learners need to describe the features, characteristics (for example construction, principles of operation, starting characteristics and torque) and a typical application for each type of AC motor considered. Evidence could include written descriptions plus relevant drawings, circuit diagrams, photographs and exploded views (as appropriate), annotated to aid the description.

P5 and P6 require a similar approach. However, it is important to note that while P5 only requires one AC generator to be considered, for P6, like P4 above, learners must describe two different types of transformer (for example step up, step down or safety isolating transformers).

P7 and P8 simply replicate the criteria for P4 and P5 but for two different DC motors (for example series, shunt, compound (long and short shunt), brushless) and one DC generator. As above, P7 should be done as one activity to avoid splitting the criterion.

P9 requires learners to describe the operation and use of a stop/start/retain relay control circuit. This can be an AC or DC machine and can be chosen by the tutor or the learner. The choice of AC or DC control circuit is only limited by the need to draw as extensively as possible from the unit content to cover such aspects as safety relays and emergency stop/stopping requirements. The assignment should be based on a practical investigation if possible and learners should provide a careful description of the circuit that they have investigated. This should include an itemised list of components (together with a description of the function of each component) and should be supported by a suitably annotated circuit diagram.

To achieve M1 and M2, learners should explain the operational features of the speed control systems for an AC machine and a DC machine respectively. Learners will need to consider the speed control aspects of machines in specific applications, which will draw from and build on their knowledge and understanding developed through P4–P8.

For M3, learners need to explain the use of a safety relay system and how the system addresses the issues raised in relevant legislation, regulations and standards. The system considered could be the same as that described for P9. Learners must set the circuit in a particular context or application and demonstrate that they understand the importance of the circuit in that application.

Learners must also have recognised the relationship of such a circuit to the requirements of relevant legislation, regulations and standards. Note that there is a further link from the work undertaken for P9 and M3 to that required for D2 (see notes below) and this might form the basis of a single assignment.

To satisfy D1, learners should show that they can bring together their understanding of P4–P8 by comparing the applications of a DC and an AC motor for two contrasting modern electrical installations. Learners should investigate two sufficiently complex and contrasting installations that enable them to draw from and show that they can apply the understanding that they have gained at pass and merit level. Typical applications might be a variable-speed motor drive for an electric vehicle and a high-torque constant-speed drive used in an industrial conveyor belt.

Learners should justify the type of DC and AC motor, as well as its supply configuration (for example triac speed controller) and output drive systems (for example gearbox or belt reduction system). They should also make reference to the operating principles and actual machine characteristics (for example starting torque, on-load torque, efficiency).

D2 builds on the work undertaken for P9 and M3. As such, the circuit considered for P9 could be one of the stop/start/retain relay control circuits that is used for comparison and against which a second is compared. However, centres may prefer to get learners to consider two completely different relay control circuits to provide them with a wider range of experience.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Electrical Hazards and Legislation and Regulations	A technician has been asked to show potential electrical hazards to a new learner and explain the legislation and regulations with which they need to be familiar.	A written report or a presentation.
P4, P5, P6, P7, P8, M1, M2, D1	AC and DC Electrical Machines	A technician has been asked to write a report explaining and comparing the key features of a range of new AC and DC machines.	A written report.
P9, M3, D2	Machine Control Circuits and Systems	A technician has been asked to describe the operation of a stop/start/retain relay control to a new member of staff.	A written report.

Essential resources

Centres will need a workshop equipped with electrical machines and associated switchgear and control equipment. Learners will require access to a range of AC and DC motors and generators. A selection of different types of transformer (for example step-down, step-up, isolating variable voltage) will also be required. In addition, to permit testing of motor speed controllers, learners will require one or more variable speed controllers (for both AC and DC motors) together with variable loads and machine braking systems.

Learners will also require access to appropriate statutory and non-statutory regulations, health and safety legislation, as well as catalogues, data sheets and relevant equipment specifications.

Indicative reading for learners

Textbooks

Bird J – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications* (Newnes, 2013) ISBN 9780080983325

Schultz G – *Transformers and Motors* (Newnes, 1997) ISBN 9780750699488

Unit 32: Three-phase Motors and Drives

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Three-phase motors are used where greater amounts of power are required and single-phase motors would not be effective. A good example of this is a large compressor where a constant speed is required. The two main advantages of three-phase types over single-phase types are the smoother torque they provide and a higher power to weight ratio, giving smaller frame sizes for comparable power outputs.

This unit will develop learners' knowledge of the design and operation of three-phase motors that use electrical and electronic control devices to make them work. This will include being able to read and produce simple circuit diagrams and understand the principles of installation, commissioning and maintenance. Learners will be made aware of the requirements of a drive and the need for the motor and drive to be matched to the characteristics of the application.

The unit will provide a good foundation for anyone interested in taking up a career in the manufacturing or processing industry, particularly where large motor drives are involved.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how squirrel-cage and wound rotor three-phase induction motors operate

2 Know how three-phase synchronous and synchronous-induction motors operate

3 Understand the function and operation of motor starters and control gear

4 Understand a range of industrial applications for installing, commissioning and maintaining three-phase motors.

Unit content

1 Know how squirrel-cage and wound rotor three-phase induction motors operate

Principle of operation: production of rotating magnetic field, e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, rotor speed; induction motor types, e.g. squirrel cage, wound rotor (slip ring)

Constructional features: cores, e.g. stator, rotor, laminations, spiders, materials; frame, e.g. cast, fabricated, end covers, materials; rotor, e.g. squirrel cage, wound type; stator, e.g. distributed windings, single layer, double layer; enclosure, e.g. cooling/ventilation, open, totally enclosed, drip proof, flameproof; shaft and fittings, e.g. bearings, slip rings, brushes, brush lifting gear enclosure ratings, e.g. Ingress Protection, BS 490, BS 5345

Characteristics and calculations: characteristics, e.g. frequency, poles, speed/load, torque/speed, torque/slip; calculations, e.g. speed, slip, starting current, load, torque, power, efficiency

2 Know how three-phase synchronous and synchronous-induction motors operate

Principle of operation: production of rotating magnetic field, e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, effect of excitation; synchronous motor types, e.g. pony motor, synchronous-induction motor, synchronising; characteristics, e.g. open circuit, v-curves; reasons for calculations, e.g. speed, torque, leading/lagging power factor, power, efficiency

Constructional features: rotor, e.g. cylindrical, salient pole; stator, e.g. distributed windings, single layer, double layer; excitation methods, e.g. DC exciter, AC exciter, brushless

3 Understand the function and operation of motor starters and control gear

Starters: circuit diagrams and operation of induction motor types, e.g. direct on line (DOL), star-delta, autotransformer, soft start, rotor resistance; circuit diagrams and operation of synchronous motor types, e.g. pony motor, synchronous-induction motor, synchronising; effects of reduced voltage starting, e.g. current, starting torque; protection devices, e.g. short circuit, earth leakage, overload, interlocks, trips

Control gear: speed control, e.g. variable frequency, inverters, pulse width modulation (PWM); motor drives, e.g. DC transistor/thyristor, inverter types, braking, soft starting; programmable logic controllers, e.g. simple ladder logic

4 Understand a range of industrial applications for installing, commissioning and maintaining three-phase motors

Load characteristics: load characteristics and demands of machinery, e.g. centrifugal fans and pumps, compressors, machine tools, mechanical handlers, plastic extruders, lifts, hoists, conveyors

Ratings and calculations: electrical parameters, e.g. power, KVA, KVAr, power factor, voltage, current; mechanical parameters, e.g. power, speed, slip, torque, efficiency, gear ratios, volume, pressure, flow

Installation, commissioning and maintaining: installation procedures, e.g. foundations, mountings, insulation checks, rotation, couplings; commissioning procedures, e.g. starting, running, load test, temperature monitoring; maintenance procedures, e.g. rotor/bearing checks, lubrication, brushes, brush gear, control gear, insulation tests

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principle of operation and the constructional features of a three-phase squirrel-cage and a three-phase wound rotor (slip ring) induction motor	**M1** explain the production of a rotating magnetic field from a three-phase supply suitable for three-phase induction motors	**D1** evaluate the speed control methods used for three-phase induction motors and explain the effects of changing speed on torque/slip characteristics
P2 carry out calculations involving frequency, poles, speed, torque, power and efficiency for a three-phase induction motor from given data	**M2** explain the variation of torque and slip for a three-phase induction motor using values from given data	
P3 describe the principle of operation, constructional features and excitation methods of a three-phase synchronous motor	**M3** explain the methods of starting a three-phase synchronous motor and the effects of variation of excitation with reference to the v-curve characteristics	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 explain, with the aid of suitable circuit diagrams, the operation of two different reduced voltage starters for induction motors, one starting method for a synchronous motor, and a protection device for use with a three-phase induction motor		
P5 explain the control gear required for a three-phase induction motor and a three-phase synchronous motor		
P6 explain the characteristics of typical loads for four types of machinery driven by three-phase motors	**M4** justify the selection of a three-phase motor and its drive for a given application, using calculations involving electrical and mechanical parameters.	**D2** analyse an installation, commissioning and maintenance process for a three-phase motor and its drives and suggest possible improvements.
P7 select a suitable three-phase motor for a given application giving details of ratings, starter types and control gear requirements		
P8 explain the installation, commissioning and maintenance procedures for a three-phase motor.		

Essential guidance for tutors

Assessment

This unit could be assessed through the use of four assignments.

The first assignment could be about induction motors and cover criteria P1, P2, M1, M2, D1 and D2. A written task should be given to cover P1. Learners will need to consider the production of the rotating magnetic field when describing the principle of operation. They will also need to consider cores, frame, rotor, stator, enclosure and shaft and fittings when describing the constructional features.

Learners should be given data to use when carrying out the calculations required by P2. This data could be varied for each learner to aid authenticity, or the task could be time-constrained. A further task should be set asking them to explain the production of a rotating magnetic field and the variation of torque and slip using given values to achieve criteria M1 and M2 respectively. Learners' evidence will be written and will include their calculations. For criterion D1, a task should be set that asks them to write a report that shows an evaluation of the speed and control methods, and explain the effects of changing speed on torque/slip characteristics.

The second assignment could cover synchronous motors and cover criteria P3 and M3. A written task could cover the construction, operation and excitation of synchronous motors. A practical exercise or demonstration could be done for starting and variation of excitation. From this information, learners can formulate relevant descriptions and explanations. Starting voltage, current and torque are useful parameters to be measured.

A third assignment on starting and control could cover criteria P4 and P5. While a written task could be used to cover both criteria, it would be more interesting for learners if they could operate starters and drives and take appropriate measurements. Explanation of the control gear could be as a result of stripping down or opening up starters, drives and other control gear. In doing so, it is important that learners also consider the effects of reduced voltage such as current and starting torque.

The fourth assignment on applications could cover criteria P6, P7, P8, M4 and D2. Tasks should require learners to refer to details of typical loads and machinery to be driven (P6). Learners must then consider the types of motor and control gear appropriate for driving different loads and select and describe the features (P7). For M4, choices need to be supported by detailed calculations, with relevant justification of some depth using calculated parameters. The evaluation of speed control (D2) must be linked to the torque/slip characteristics and include details of more than one method, for example thyristor drives and inverter drives. A further written task could ask learners to describe the installation, commissioning and maintenance procedures for a three-phase motor (P8).

Manufacturers' literature and specifications are a useful source of practical information for the above tasks.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Induction Motors	A technician needs to strip down, inspect and report on the operation of induction motors.	A report, including a set of written descriptions, the results of calculations and an explanation of the production of a rotating magnetic field and the variation of torque and slip.
P3, M3	Synchronous Motors	A technician needs to strip down, inspect and report on the operation of synchronous motors.	A written report, including descriptions based on practical demonstration of excitation methods.
P4, P5	Starters and Control Gear	A technician needs to show a new learner the operation of starters and control gear.	A written report.
P6, P7, P8, M4, D2	Applications of Three-Phase Motors	A technician has been asked to produce a report on the three-phase motors used in an industrial application in their workplace.	A written report based on a practical investigation or case study of local industrial applications.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase electric motors, starting/control gear and associated drives. In addition, appropriate and adequate testing instruments and fault-finding assemblies should be provided. European and British Standards, health and safety and other publications should also be available.

Indicative reading for learners

Textbooks

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications* (Newnes, 2013) ISBN 9780080983325

Petruzella F – *Electric Motors and Control Systems* (McGraw-Hill Education, 2009) ISBN 9780073521824

Unit 33: Further Electrical Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Electrical technicians need to apply practical and theoretical principles of electrical engineering to the development, manufacture and servicing of complex electrical and electronic systems.

They can expect to perform technical functions involved in assembling, installing, repairing and maintaining electrical equipment. These could include the calibration, prototyping, modification and general maintenance of electrical equipment in accordance with manufacturers' instructions and company technical procedures.

Other tasks could include using electrical test equipment on various types of instruments, equipment and systems and replacing faulty components and parts using safe working practices and precision instruments.

The unit will extend learners' understanding of simple direct current (DC) circuits that can be solved by Ohm's law and Kirchhoff's laws. This will require learners to apply advanced circuit analysis theorems such as Thévenin's, Norton's and the maximum power transfer theorems for DC networks.

Learners will develop their understanding of DC transients and of series and parallel alternating current (AC) circuits. They will consider series and parallel circuits that include resistors (R), inductors (L) and capacitors (C) in AC circuits.

The unit will also introduce learners to the theory and advantages of three-phase AC systems. This will include power measurements in a three-phase AC system and the construction and principles of operation of a three-phase AC induction motor.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator
2. Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits
3. Be able to apply single-phase alternating current (AC) theory
4. Be able to apply three-phase alternating current (AC) theory.

Unit content

1 Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator

Direct current (DC) circuit theorems: Thévenin's theorem, e.g. application of theorem to a parallel circuit having two sources of electromotive force (emf) and three resistors; Norton's theorem, e.g. application of theorem to a parallel circuit having two sources of emf and three resistors; maximum power transfer theorem, e.g. application of theorem to a series circuit with a source of EMF, internal resistance and a load resistor; application to a more complex circuit where Thévenin needs to be applied first

Direct current (DC) motor: type, e.g. shunt, series, compound; construction, e.g. windings, motor starter circuits, speed control (series resistance in the armature circuit); characteristics, e.g. EMF generated, torque, back emf, speed and power, efficiency; **developments, e.g. digital switched reluctance motors**

Direct current (DC) generator: type, e.g. separately-excited, shunt, series compound; construction, e.g. main frame or yoke, commutator, brushes, pole pieces, armature, field windings; characteristics, e.g. generated voltage/field current (open circuit characteristics), terminal voltage/load current (load characteristic), $V = E - I_a R_a$

2 Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits

Transient behaviour of RC circuit: variation of current and voltage with time when charging/discharging; time constant; graphical determination of growth and decay of voltage and current when charging/discharging; practical RC circuit to demonstrate transient behaviour; demonstrate the effect of the circuit time constant on a rectangular waveform, e.g. integrator and differentiator circuits; calculations, e.g. time constant, growth of capacitor voltage, initial and steady state values of current, decay of resistor voltage

Transient behaviour of RL circuit: variation of current and voltage with time when connected/disconnected to a DC voltage source; time constant; graphical determination of growth and decay of current and voltage when connected/disconnected to a DC voltage source; practical RL circuit to demonstrate transient behaviour; calculations, e.g. time constant, growth of current, decay of induced voltage, current decay

3 Be able to apply single-phase alternating current (AC) theory

Series R, L and C alternating current (AC) circuits: current and phase angle in series combinations of RLC circuits (RL, RC, RLC); construction of phasor diagrams and relationship with voltage and impedance triangles for each of the three types of R, L and C combinations; power factor ($\cos\Phi$) and power triangle, e.g. apparent power ($S = VI$), true or active power ($P = VI\cos\Phi$) and reactive power ($Q = VI\sin\Phi$); conditions for series resonance, e.g. inductive reactance equals capacitive reactance ($X_L = X_C$); Q factor (voltage magnification), e.g. $Q = \frac{V_L}{V}$, $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ and its importance in high and low frequency circuits

Parallel: evaluation of the voltage, current and phase angle in parallel combinations of resistance, inductance and capacitance, e.g. RL, RC, LC and RLC; construction of phasor diagrams for impedance and phase angle; conditions for parallel resonance in an RLC circuit, e.g. supply current and voltage in phase; impedance at resonance, e.g. dynamic resistance $R_D = \frac{L}{CR}$; Q factor (current magnification), e.g. $Q = \frac{I_C}{I} I$; filter circuits, e.g. high pass, low pass, band pass, band stop

4 Be able to apply three-phase alternating current (AC) theory

Three-phase AC theory: principles of single-phase and three-phase supplies, e.g. rotation of a single coil in a magnetic field, rotation of three identical coils fixed 120° apart in a magnetic field; star and delta methods of connection for power distribution systems; three and four wire systems; voltage relationships for star and delta connections under balanced conditions of load; calculation of power in balanced and unbalanced three-phase loads, e.g. $P = \sqrt{3V_L I_L \cos\theta}$, $P = 3I_p^2 R_p$

Power measurements in a three-phase AC system: e.g. delta system – one wattmeter method, star system – two wattmeter method

Three-phase AC induction motor: construction, e.g. stator, rotor, poles; principle of operation, e.g. production of torque, synchronous speed, number of poles, starting methods, characteristics (speed/torque/efficiency versus current curves); concept of a rotating magnetic field, e.g. application of a three-phase supply to the stator windings, flux generated by each phase of the stator winding

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theorems to solve one circuit problem using Thévenin's theorem, one using Norton's theorem and one using the maximum power transfer theorem for DC networks	**M1** explain the need for a DC motor starter and discuss its operation	
P2 explain the construction and characteristics of a DC motor and a DC generator		
P3 explain the transient behaviour of current and voltage in an RC circuit, verifying through calculation		
P4 explain the transient behaviour of current and voltage in an RL circuit, verifying through calculation		
P5 use single-phase AC theory to calculate the current, voltage, impedance, power and phase angle in one of each of the series combinations of R, L and C circuits		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 investigate the performance of two filter circuits experimentally		
P7 use single-phase AC theory to calculate the input current, voltage, impedance and phase angle for a parallel combination of R, L and C	**M2** discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations	**D1** analyse the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit
P8 use three-phase theory to explain the advantages of three-phase systems and star and delta methods of connection	**M3** compare two different methods of power measurement in a three-phase system for both balanced and unbalanced loads.	**D2** evaluate the performance of a three-phase induction motor by reference to electrical theory.
P9 carry out a practical power measurement on a three-phase system		
P10 describe the construction, principle of operation and concept of a rotating magnetic field of a three-phase AC inductor motor.		

Essential guidance for tutors

Assessment

A good deal of the assessment evidence for this unit can be achieved by practical experimentation, with real components and circuits and/or computer-based software packages where appropriate.

Because of the nature of the learning outcomes and unit content, up to six assessment instruments may be required. If a structured programme of practical work and short tests is also used, then the actual total number of pieces of assessed work could be even more than this. However, careful consideration should be given when designing the assessment not to place an unduly high assessment burden on learners or the tutor. Wherever possible, practical work should lead to a final product that can be assessed without further need for report writing.

Practical activities in the laboratory will need careful supervision. Tutors can capture this evidence by using appropriate records of observation and oral questioning for each learner.

For P1, learners will need to solve circuits involving Thévenin's theorem, Norton's theorem and the maximum power transfer theorem. Before attempting this criterion, learners could be introduced to the idea of a constant voltage source and a constant current source by using a suitable practical demonstration. Further development of this could lead to the link between Thévenin and Norton and then on to the use of Thévenin, before applying the maximum power transfer theorem.

P2 involves the explanation and comparison of a motor and a generator. Learners could possibly be shown actual motors/generators and be issued with incomplete diagrams for completion and annotation.

P3 and P4 require learners to explain the transient behaviour of current and voltage in an RC and an RL circuit both practically and theoretically. Use of a simple bread-boarding technique for both criteria would be ideal here.

For both P5 and P7, an in-class assessment involving the evaluation of current, voltage, impedance and phase angle could be utilised. Learners could be given different circuit values and be encouraged to check their answers with a suitable software programme.

The investigation of the performance of two filter circuits (P6) could be achieved by using a signal generator with a low voltage output ($V_{IN} = IV$) connected to an RC network. Learners could then measure the output (V_{OUT}) as the frequency is raised from, for example, 100 Hz to 10 000 Hz.

P8 requires learners to explain the advantages of three-phase systems (for example smaller conductors, two available voltages). The latter of these leads into the two forms of connection (star and delta). Assessment could take the form of an incomplete handout to be submitted at the end of a lecture or film about the advantages and forms of connection.

P9 requires learners to carry out practical power measurements in three-phase systems. A suitable three-phase resistance load bank together with a three-phase, four wire low voltage supply and three wattmeters could be used to enable learners to measure the power using one, two and three wattmeters for the different configurations.

Evidence for P10 is likely to be in the form of an investigative report. Again, it may be helpful to give learners an incomplete diagram for them to complete and annotate. For the principles of operation and concept of a rotating magnetic field of a three-phase induction motor it may be necessary to include a number of key words (e.g. synchronous speed, pairs of poles) and point to one specific type of three-phase induction motor (e.g. squirrel-cage rotor).

All except the smallest of motors require some type of starter to prevent heavy currents being drawn from the supply on starting. M1 is intended to evaluate this requirement in detail and consider the need for a DC motor starter (e.g. DC faceplate starter) and to discuss its operation. It is expected that learners will draw from the work done at pass and produce a referenced technical report, supported by a suitably labelled diagram to aid their discussion of the operation.

For M2, learners need to discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations. These could include reduced cost to the consumer with reference to a practical example. This could follow a practical demonstration of how the supply current reduces on the introduction of power factor correction, but can increase if over-corrected. M3 could be linked to the practical carried out for P9.

The analysis of the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit (D1) builds on and could be linked to P5 and P7. Evidence for D1 could also be provided by considering the difference in resonance frequency, for example when the value of the resistance is varied.

D2 requires learners to evaluate the performance of a three-phase induction motor by reference to electrical theory, for example squirrel cage by reference to electrical theory. This could be achieved practically by using appropriate experimental rigs that allow the learner to compare their results with the known characteristics for specific machines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	DC Circuit Analysis and Generators	An activity requiring learners to complete three tasks that together solve circuit problems, compare a DC motor and generator, and evaluate the performance of a three-phase induction motor.	A report containing solutions to circuit theorems and written responses about DC motor/generator and three-phase induction motor characteristics. Carried out under controlled conditions.
P3, P4	DC Transients	A written activity that requires learners to explain the transient behaviour of an RC and RL circuit with a numerical verification.	A report containing written responses about the transient behaviour of RC/RL circuits supported by numerical calculations carried out under controlled conditions.
P5, P7, M2, D1	AC Single-Phase Series and Parallel Circuits	A written activity requiring learners to carry out calculations relating to the behaviour of series and parallel R, L and C single-phase AC circuits.	A report containing the results of calculations to determine specific parameters of series and parallel R, L and C single-phase AC circuits carried out under controlled conditions.

Criteria covered	Assignment title	Scenario	Assessment method
P6	Filter Circuits	A practical investigation for learners to measure the response of two simple filter circuits.	A report containing written responses and graphical evidence regarding the response of simple filter circuits.
P8, P9, M3, D2	Three-phase AC Theory	A combined written and practical activity requiring learners to explain the advantages of three-phase systems, the star and delta method of connection followed by a practical power measurement with a comparison of two different methods for both balanced and unbalanced loads together with an evaluation of its performance.	A report containing written responses to the advantages of three-phase systems, an illustration of the methods of connection and measurements of the practical work carried out.
P10	Three-phase AC Induction Motor	A written activity describing the construction, operation and concept of a rotating magnetic field for a three-phase (AC) induction motor.	A report containing neat diagrams and descriptions relating to a three-phase (AC) induction motor.

Essential resources

Learners will need access to a well-equipped electrical/electronics laboratory with up-to-date instruments such as digital/analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components as identified in the unit content together with the means to physically construct circuits.

Centres are strongly advised to consider the provision of suitable hardware and software to enable the use of computer-based methods for circuit design and simulation.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Robertson C R – *Further Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687478

Unit 34: Manufacturing Planning

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

There are many new technologies involved in planning the manufacturing of products, parts and components but many smaller companies still operate and work with traditional approaches.

This unit will give learners a good understanding of the basic techniques of manufacturing planning and an awareness of scheduling requirements. It introduces learners to different types of production and will give them an understanding of the stock holding policies that still exist in many engineering companies. Knowledge of the costs associated with holding stock can aid future manufacturing strategies and any related business improvement considerations.

Before learners develop a production plan, they are expected to have an understanding of the general aspects of planning and control and the techniques used to measure efficiency in a product manufacturing system. Some of these techniques could be explored in detail should learners show an added interest in this area.

Learners are required to produce a production plan from a given range of information in a product specification and prepare a production schedule to support the delivery of the production plan. This unit provides underpinning knowledge for a range of other units, particularly those associated with business improvement.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the techniques and policies used to improve product manufacturing efficiency
2. Understand general aspects of planning and control
3. Be able to use a product specification to produce a production plan
4. Be able to produce a production schedule.

Unit content

1 Understand the techniques and policies used to improve product manufacturing efficiency

Types of production: jobbing; batch; cellular; flow; mass; automatic

Stock holding policy: types of inventory, e.g. materials, parts, components, tools, consumables, finished goods; stock holding costs, e.g. ordering/replenishment, holding, obsolescence; buffer stock; re-order levels; storage areas; economic order quantity, e.g. data, $Q = \frac{\sqrt{2C_s r}}{C_C}$ or $Q = \left(\frac{2C_s r}{C_C}\right)^{\frac{1}{2}}$

Appropriate techniques: e.g. method study, value analysis, job design (ergonomics, layout, safety); work measurement

2 Understand general aspects of planning and control

Aspects of planning: capacity measurement, e.g. machine hours, man hours, throughput, department hours; production planning; pre-production planning; other aspects, e.g. information technology, documentation, health and safety, environmental issues

Control: functions, e.g. production control, quality control

3 Be able to use a product specification to produce a production plan

Product specification: aspects relative to manufacturing and not the customer; type of information required for manufacture, e.g. engineering drawings, process description, make and assembly techniques and requirements, materials required, measurements, tolerances and other quality specifications

Production plan: consideration of a product specification and types of production; requirements (processes, materials required, quantities required, tools and equipment, labour required, estimated process times, quality checks)

4 Be able to produce a production schedule

Production schedule: based on the requirements identified within a production plan; presentation techniques, e.g. use of a Gantt chart, critical path network, line of balance technique; data, e.g. completion deadline, customer requirements, capacity available

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the six different types of production	**M1** explain the circumstances in which cellular production would be better than batch production **M2** explain how you determined the economic order quantity	**D1** discuss the relationship between economic order quantities and stock holding costs
P2 explain a stock holding policy for a given type of inventory		
P3 determine an economic order quantity from given data		
P4 explain an appropriate technique used to improve product manufacturing efficiency		
P5 explain the aspects of planning in manufacturing		
P6 explain functions of control used in manufacturing planning		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 use a product specification to produce a production plan	**M3** compare the importance of different types of information in a product specification when producing a production plan and schedule	**D2** evaluate the use of a production plan when preparing a production schedule and the dangers of the schedule not meeting stock holding requirements.
P8 explain the use of a production schedule		
P9 produce a production schedule from a production plan and given data.	**M4** analyse how the use of presentation techniques can be used to overcome capacity and production planning problems.	

Essential guidance for tutors

Assessment

It is important that the assessment strategies used are designed to suit the needs of learners and any local industry requirements. Good assessment strategies need to be supported by the proper presentation of appropriate evidence. The portfolio should not contain course notes, research etc. unless it is part of the required evidence and assessment.

Work done through the use of case-study material can be used to generate evidence for learners' portfolios. An integrated approach to this unit would be a suitable way for learners to gather evidence, particularly for learning outcomes 3 and 4.

To achieve a pass grade, learners should demonstrate knowledge of types of production, stocking policies and understanding techniques used to improve manufacturing efficiency. Learners are also expected to explain general aspects of planning and control and the use of a production schedule. They should then demonstrate the correct development of a production plan when using a product specification, a schedule and other data.

This unit could be assessed using three assignments. The first assignment could cover learning outcome 1 and its associated criteria (P1, P2, P3, P4, M1, M2 and D1), with a task set for each criterion. For P3, a range of data – such as ordering or replenishment costs per order (C_s), holding costs (C_c) and usage rate (r) – should be given to allow an economic order quantity (Q) to be determined. This could then be extended to include an explanation for M2 and a discussion of the relationship between economic order quantities against the costs involved in holding stock (D1).

Criteria P5 and P6 could be set in a second assignment as separate written tasks. A final assignment could be developed to cover P7, P8, P9, M3, M4 and D2. A product specification should be made available to each learner for them to use to develop a production plan. They could then be asked to produce a production schedule when given further data, such as completion time and capacity available. Standard templates for both the plan and schedule can be used as this would be similar to industrial practice.

Another task would then need to be given, asking learners to provide a written response when explaining the use of a production schedule. Further written tasks should also be included to cover M3, M4 and D1.

To achieve a merit grade, learners should explain what parts of the product specification are most important when developing a plan and schedule. A task for M1 could be given to build on the response given to criteria P1 in the first assignment. A task for M3 should be left until all pass criteria have been attempted and therefore be in the third and final assignment about planning and scheduling. They should also be able to analyse how information found in Gantt charts and critical path network documents could be used to identify and help overcome any over-capacity problems and how improvements can be made to the production plan (M4). This criterion requires a written task set in the final assignment.

To achieve a distinction grade, learners should demonstrate a comprehensive knowledge understanding and of manufacturing planning. Learners will confidently evaluate the development of a production schedule when using a production plan and other data in terms of whether that schedule will have an effect on stock holding requirements (D2).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Types of Production in Manufacturing Industries	A written activity requiring learners to look at a case study of real-life production and stock control.	Written responses to case study based questions about the key features of different production types and describing a stock holding policy and the techniques used to improve efficiency.
P5, P6	Product Specifications	A written assignment and oral questioning on developing a product specification for an existing product and designing a common specification template that accounts for control functions in production.	A whole group activity with learners creating a product specification for a real-world product they have access to and explaining product template for use in further assignments that explain planning and control aspects of production.
P7, P8, P9, M2, M3, D1, D2	Product Planning and Scheduling	Presenting a production plan and schedule based on a product specification. Write up report on the presentation and production schedule.	Presentation and accompanying documents that explain the use of a production schedule and other data. Written report on presentation evaluating the use made of the production schedule and the presentation techniques used.

Essential resources

A range of production data and information as described in the unit content is needed for learning and assessment. Ideally, examples and data from industry will be provided and access to manufactured products will be required.

Indicative reading for learners

Textbooks

Slack N, Chambers S and Johnston R – *Operations Management* (Prentice Hall, 2009) ISBN 9780273730460

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Waters D – *Inventory Control and Management* (John Wiley and Sons, 2003) ISBN 9780470858769

Unit 35: Setting and Proving Secondary Processing Machines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

For components to be manufactured to a required standard, the machines that produce them need to be correctly set up by technicians, ready for an operator to use. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Once satisfied that a machine's parameters are correctly set, the technician would then brief the machine operator and the mass production of accurate components can begin.

The aim of this unit is to give learners a detailed understanding of the setting of secondary processing machines, including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods). Learners' ability to set a machine and brief an operator will stem from their knowledge of the machine itself and their ability to select and use the most appropriate work-holding devices and tooling.

The unit provides an opportunity for learners to examine a range of secondary processing machines, their set-up and the best use of work-holding devices and tools. Learners will need to gain an understanding of the features of the component to be made to enable them to effectively set up the machine and hand over to an operator.

Safety is an important issue to be considered when setting and using secondary processing machines. In this unit, learners will gain knowledge about, and demonstrate safe working practices when carrying out activities. They will also carry out checks for component accuracy and demonstrate this accuracy after setting a machine and when handing over to an operator.

With the knowledge and understanding gained from this unit, there are other opportunities for investigation of a wider range of secondary processing machines, their work-holding devices, tools and machine parameters.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how traditional and specialist secondary processing machines function

2 Understand how work-holding devices, tools and machine parameters are set up to produce a range of components

3 Be able to safely set up a secondary processing machine to accurately make a component

4 Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator.

Unit content

1 Know how traditional and specialist secondary processing machines function

Secondary processing machines: basic principles of operation; machine's suitability to manufacture given components; relevant safe working practices for each machine; machine terminology, e.g. cross slide, spindle, head stock, generation of shapes, forming of shapes; traditional secondary machining techniques, e.g. turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), milling (horizontal, vertical, universal), grinding (surface, cylindrical, centreless, universal, thread grinding, tool and cutter grinding, universal or purpose-built machines), drilling (single spindle, multi-spindle); specialist secondary machining techniques, e.g. boring (horizontal, vertical), electro discharge (spark erosion, wire erosion), honing and lapping (horizontal and vertical honing, rotary disc lapping, reciprocating machines)

2 Understand how work-holding devices, tools and machine parameters are set up to produce a range of components

Work holding: devices for traditional secondary machining techniques, e.g. chucks (hard or soft jaws, three or four jaw, collet, power, magnetic), fixtures and other machine specific devices for:

- turning (drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies)
- milling (clamping direct to machine table, pneumatic or magnetic table, machine vice, angle plate, vee block and clamps, indexing head/device, rotary table)
- grinding (centres, face plate, machine vices, clamps, angle plates, vee blocks, works rests, control stops, injector mechanisms, magnetic blocks, pots, arbors)
- drilling (clamping direct to machine table, machine vice, angle bracket, vee block and clamps, drill jigs, indexing device)

Devices for specialist secondary machining techniques, e.g. angle plate, vee block and clamps, other machine specific devices for:

- boring (clamping direct to machine table, machine vice, pneumatic or magnetic table, indexing/rotary device)
- electrical discharge machining (clamping direct to machine table, machine vice, pneumatic or magnetic table, ancillary indexing device)
- honing and lapping (pots, magnetic blocks, face plate)

Tools: materials and form, e.g. solid high-speed steel, brazed tungsten carbide, indexable tips, electrode material, abrasive stone, composite wheels; tools for traditional secondary machining techniques, e.g. for:

- turning (turning tools, facing tools, form tools, parting-off tools, thread chaser, single-point threading, boring bars, recessing tools, centre drills, twist/core drills, solid reamers, expanding reamers, taps, dies, knurling tool)
- milling (face mills, slab mills/cylindrical cutters, side and face cutters, slotting cutters, slitting saws, profile cutters, twist drills, boring tools, end mills, slot drills)
- grinding (soft wheel, hard wheel, cup, flaring cup, straight sided wheel, recessed wheel, double recessed wheel, dish, saucer, disc, segmented)
- drilling (drill bit, flat-bottomed drill, counterboring tool, countersinking tool, centre drill, spot facing tool, reamer, tap)
- Tools for specialist secondary machining techniques, e.g. for:
- boring (boring tool, facing, turning, recessing, chamfering or radii, forming, twist drill, tap, reamer, milling cutter)
- electrical discharge machining (plain electrode, profile electrode, hollow electrode, wire)
- honing and lapping (mandrel, wedge, honing stone, lapping disc/pad)

Machine parameters: position of workpiece; position of tools in relationship to workpiece; cutting fluid/dielectric flow rate; position and operation of machine guards/safety mechanisms; parameters for different traditional secondary processing techniques, e.g. for:

- turning (threading/profile/taper mechanisms, workpiece revolutions per minute, linear feed rate, depth of cut for roughing and finishing)
- milling (linear/table feed rate, milling cutter revolutions per minute, depth of cut for roughing and finishing)
- grinding (linear/table feed rate, depth of cut for roughing and finishing, cross feed, dressing of wheels)
- drilling (tooling revolutions per minute, linear feed rate, swarf clearance)

Parameters for different specialist secondary processing techniques, e.g. for:

- boring (set up and tooling relative to datum, feed rate, cutter/tool revolutions per minute, depth of cut for roughing and finishing)
- electrical discharge machining (electrical conditions, wire tension, wire speed, alignment of electrodes and wire, ventilation and fume extraction, filtration)
- honing and lapping (revolutions per minute or reciprocating speed, stroke length, stroke overrun length, stroke speed, stone or disc pressure)

Features of the component: materials, e.g. ferrous, non-ferrous, non-metallic; holes, e.g. drilled, bored (parallel or tapered), reamed, threaded, blind, through, counterbored, flat bottomed; relevant component features produced using traditional secondary processing techniques, e.g. for:

- turning operations (flat faces, parallel diameters, stepped diameters, tapered diameters, profile forms, external threads, eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts)
- milling operations (flat faces, square faces, parallel faces, angular faces, steps/shoulders, open ended slots, enclosed slots, recesses, tee slots, profile forms, serrations, indexed or rotated forms, special forms)
- grinding operations (flat faces, vertical faces, parallel faces, faces square to each other, shoulders and faces, slots, parallel diameters, tapered diameters, profiles forms, other thread forms, vee-form threads, right-hand threads, single start threads, multi-start threads, external threads, angular faces)
- drilling operations (countersinking, spot facing, holes)

Relevant component features produced using specialist secondary processing techniques, e.g. for:

- boring operations (internal profiles; external profiles, e.g. external diameters, grooves/recesses, chamfers/radii, flat faces, square faces, parallel faces, angular faces, slots, index or rotated forms)
- electrical discharge machining operations (holes; faces – flat, square, parallel, angular; forms – concave, convex, profile, square/rectangular; other features – threads, engraving, cavities, radii/arcs, slots)
- honing and lapping operations (honing holes; lapping faces, e.g. flat, parallel, angular)

3 Be able to safely set up a secondary processing machine to accurately make a component

Set up: machine guards in place; select and set tooling; checking tool/wheel condition; holding components securely without distortion; selection and use of suitable work-holding device(s); set machine parameters to manufacture given component

Safe working: safe set-up of moving parts, e.g. setting stops, preventing tooling clashes; use of machine guards to protect operator and others; choice and handling of cutting fluids/dielectric flow rate; checks for insecure components; facilities for emergency stop and machine isolation; identification of appropriate protective clothing and equipment; housekeeping arrangements (work area clean and tidy); safe working practices relevant to specific secondary processing technique, e.g. for:

- turning (handling turning tools, airborne particles, tool breakage, swarf disposal)
- milling (handling milling cutters, cutter breakage, swarf disposal, backlash in machine slides)
- boring (handling tools and cutters, airborne particles, tool breakage)
- electrical discharge machining (electrical components, handling dielectrics, fumes, handling and storing electrodes and wires)

- grinding (handling grinding wheels, sparks/airborne particles, bursting wheels)
- drilling (handling drills, taps and reamers, tool breakage, swarf disposal)
- honing and lapping (handling and storing stones, airborne particles)

Checks for accuracy: components to be free from burrs and sharp edges; use of appropriate tools and instruments; checks for dimensional accuracy and surface texture; checks relevant to specific secondary machining technique e.g. for:

- turning (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO, surface finish 63 µin or 1.6 µm, reamed or bored holes within H8, screw threads BS medium fit, angles within +/− 0.5 degree)
- milling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 µin or 1.6 µm, flatness and squareness within 0.001 inch per inch or 0.125 mm per 25 mm, angles within +/− 0.5 degree)
- boring (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 µin or 1.6 µm, flatness and squareness within 0.005 inch per inch or 0.025 mm per 25 mm, angles within +/− 0.5 degree, bored holes within H8)
- electrical discharge machining (components to be free from false starts; dimensional tolerance to BS/ISO, surface texture 32 µin or 0.8 µm or 18 VDI; checks, e.g. for parallelism, angle/taper, squareness, profile)
- grinding (tolerance to BS/ISO surface texture 8 µin or 0.2 µm, free from false grind cuts)
- drilling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO, surface texture 63 µin or 1.6 µm, reamed holes within H8, screw threads BS medium fit)
- honing and lapping (components to be free from stone/disc marks; dimensional tolerance equivalent to BS/ISO; surface finish 8 µin or 0.2 µm; honed components checked for parallelism and ovality/lobbing; lapped components checked for parallelism and flatness)

4 Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator

Trial components: to meet the features and accuracy required by the specification

Use of machine: correct use of work holding devices; tools; machine parameters and safety

Handing over: correct set-up; supplies of components and consumables; machine functions correctly; quality requirements; consideration of safe working

Handover procedures: demonstrating operation; explaining the key stages; highlighting critical areas, e.g. safety, specific tolerances, finishes; observing operator and correcting any errors; ensuring operator is working safely and competently before leaving; periodic checks of machine and operator performance

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe how four different secondary processing machines function when machining a given component for each	**M1** explain the effects of using an inappropriate work-holding device when setting up a secondary processing machine	**D1** justify the choice of a work-holding device for a given component when setting up a secondary processing machine
P2 explain how work-holding devices and tools are used on four different secondary processing machines to manufacture a different given component for each machine		
P3 explain how a range of machine parameters are set up to produce required features on components machined on four different secondary processing machines	**M2** explain the importance of setting machine parameters correctly to produce accurate features on a component produced by a secondary processing machine	
P4 set up a secondary processing machine to safely produce a given component		
P5 carry out checks for accuracy of a given component during the set-up of a secondary processing machine		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain how to produce trial components on a secondary processing machine	**M3** explain the impact of producing trial components and correct handover procedures on the operator being able to continuously produce accurate components.	**D2** evaluate the impact that aspects of working safely have on the effectiveness and accuracy of setting up a secondary processing machine.
P7 explain how to hand over a secondary processing machine to an operator, including a description of the handover procedures used.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit is likely to be gained from a mixture of written tasks and practical process evidence (witness statements/observation records).

To achieve a pass grade, learners must demonstrate knowledge of a range of different secondary processing machines and their techniques when carrying out set-up procedures. Both traditional and specialist techniques need to be covered. This means that learners need to know set up procedures for at least one technique from each range and an overall total of four.

Assessment of the procedure of actually setting up a machine, the knowledge required to prove the process by making trial components and handing over to an operator is restricted to one secondary processing machine, which can be either traditional or specialist. Centres and learners should pick the one most suitable for individual needs, considering any work-based learning expectations.

To achieve a merit grade, learners will need to demonstrate that they can explain some of the effects of using an inappropriate work-holding device when setting up a secondary processing machine. This could be achieved through the selection of appropriate work-holding devices for P2, together with learners demonstrating an appreciation of the possible effects of an inappropriate device. In addition, learners are required to explain the importance of producing accurate features on components, M2, that have been produced by a secondary processing machine. They also have to explain the importance of setting machine parameters correctly. For example, if the depth of cut and/or feed rate in a turning operation is not set correctly, then the component is likely to have an out of tolerance surface finish and not be free from false tool cuts.

Finally, learners need to explain the impact of producing trial components and correct handover procedures on the operator being able to continuously produce accurate components. For example, if trial components are meeting the correct accuracy checks then the 'setter' will be confident when demonstrating to the operator the procedures to follow and the correct tolerance and finish requirements explained more easily to the operator. The required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

To achieve a distinction grade, learners will need to justify their choice of a work-holding device for a given component when setting up a secondary processing machine. This machine is likely to be one from their chosen skill route. Judgement needs to be made as to whether the device used would succeed and whether it is likely to meet the needs and features of the component, alignment and use of the tooling and tool-component interface.

They also need to evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine. They need to consider whether the use of the safety equipment hampers the set-up process. Again, the required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

Wherever possible, it is important to maximise the opportunities for assessment through practical tasks. A possible scenario would be to use a total of three assignments. It may be best to set a practical assignment as the first of these. This could be to set up a secondary processing machine (P4) and carry out checks for accuracy (P5). Evidence for these criteria could be in the form of annotated photographs, observation record/witness statement(s), notes and sketches produced by learners that capture the processes carried out. Learners will also need

to maintain a record of all measurements taken and the action taken to correct any errors in the set up to complete the requirements of P5.

Following the practical, learners could then prepare a written report on how this secondary machining process functions and is set up. This could then be used to cover one of the four different machines required for P1, P2 and P3. It may also be the best opportunity to work towards the merit and distinction criteria M1, M2 and D1.

The second assignment could follow on from the practical activities and involve learners preparing a report on the machining process used in assignment 1. They would also need to research and report on three more machines to generate the evidence required for P1, P2 and P3. The tasks undertaken should make it clear what secondary processing machines are to be covered (this could be set by the tutor or could be decided through learner choice).

To meet the requirements of the unit content for outcomes 1 and 2, both traditional and specialist techniques need to be covered. However, as long as at least one of each type is covered then the other two can be either traditional or specialist machines. When choosing from the examples listed in the unit content, for example turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), it would be sufficient to select from any one of the machines listed, for example for a turning machine – use of a single-spindle automatic. This applies equally to the other aspects of unit content where examples are given.

The choice from these lists will be solely determined by the component being machined. For example, work holding devices for turning lists drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies. If the component only requires mounting on a faceplate then this would be sufficient. However, when choosing components centres need to take care to ensure the use of a reasonable range of techniques. For example, if all the components, for all four machines selected could be simply held in a three-jaw chuck to complete all operations, then this would be considered insufficient.

The last assignment could ask learners to explain how trial components are produced (P6) and how to handover a secondary processing machine to an operator (P7). The assignment could also provide an opportunity to explain the impact of producing trial components and the impact of correct handover procedures on the operator being able to continuously produce accurate components (M3). It could also evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine (D2). See earlier examples of what is expected for criteria M3 and D2; remember that the explanation and evaluation are likely to be a consideration of the experience of the practical work carried out in the first assignment.

Although simulated or practical activities would be the preferred means of capturing evidence for P6 and P7, it is accepted that this might not always be possible or realistic for a number of reasons. If a simulation is possible then for P7 it may be best if the tutor takes the role of the operator. For both P6 and P7 process evidence (records of observation and oral questioning) could be used. This process evidence could then be supplemented/supported by the product evidence that will be available from the activities, e.g. the trial components, learners' own preparation notes before handover and their own records of the actual handover process.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Producing Components Using Secondary Processing Techniques	Learners are required to produce a component using a secondary processing machine and check it for accuracy.	A practical assignment evidenced through photographs, tutor observation records and learners' notes.
P1, P2, P3, M1, M2, D1	Investigating Secondary Processing Machines	Learners need to prepare an information leaflet giving details of four different secondary processing machines.	A written report detailing how each secondary processing machine functions, and the work-holding devices, tools and machine parameters associated with each.
P6, P7, M3, D2	Producing Trial Components and Handing Over Secondary Processing Machines	Learners explain to a new member of staff how to produce a trial component and correctly hand over a secondary processing machine.	A written report detailing how to produce trial components and the correct handover procedures for a secondary processing machine.

Essential resources

To meet the needs of this unit it is essential that the centre has, or has access to some if not all of the range of machines specified in the unit content. This should include at least one specialist secondary processing machine. All auxiliary equipment such as that required for measuring accuracy should also be made available.

Indicative reading for learners

Textbooks

Edwards J – *Lathe Operation and Maintenance* (Hanser, 2003)
ISBN 9781569903407

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Kalpakjian, Serope – *Studyguide for Manufacturing Engineering* & Technology (Cram101 Textbook Reviews) ISBN 9789810694067

Unit 36: Business Operations in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Engineers are employed in a range of businesses in the primary, secondary and tertiary sectors. Their knowledge and skills are used to carry out a variety of specific functions that solve the needs of businesses and contribute to their commercial success. By making effective use of their engineers' expertise, organisations can secure competitive advantage, whether they be a small owner-managed company or a large limited company with many shareholders.

For anyone considering a career in engineering, it is important to have an understanding of how an engineering business operates and its position in society. This unit will develop learners' understanding of business, the engineering industry and the effect of engineering on the environment. It will help give learners a firm foundation for employment in the engineering sector and an understanding of the organisational, financial, legal, social and environmental constraints in which an engineering company operates.

The unit will enable learners to examine an engineering company in detail. This could be either the one in which they are employed or one in an engineering sector in which they may look for employment. Learners will understand how the company operates, the factors that impact on the business and the importance of a cost-effective output. This will include an examination of the engineering functions of the company and the importance of communication and information flow in the business. This is set within a study of how external factors and the economic environment impact on the company.

Learners will examine relevant legislation and how it can place considerable constraints on the way that a typical engineering company is required to operate. A company cannot survive if it is not profitable and the unit allows learners to consider the use and implication of costing techniques on the sustainability of a particular engineering activity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how an engineering company operates

2 Understand how external factors and the economic environment can affect the operation of an engineering company

3 Know how legislation, regulation and other constraints impact on the operation of engineering businesses

4 Be able to apply costing techniques to determine the cost effectiveness of an engineering activity.

Unit content

1 Understand how an engineering company operates

Sectors: primary, e.g. oil, gas, agriculture; secondary, e.g. chemical, manufacturing, automotive, aerospace, marine, sports; tertiary, e.g. energy distribution, nuclear technologies, waste management, water services, building services, civil, construction, structural, health, telecommunications

Engineering functions: e.g. research and development (R&D), design, manufacture, materials supply and control, production planning and control, installation, commissioning, maintenance, technical support, technical sales, project planning and management, quality assurance

Organisational types: size, e.g. micro, small, medium, large; status, e.g. sole trader, partnership, public (plc), private (ltd), new, established, charitable, not for profit; structure, e.g. owner-manager, boards, committees, governors, hierarchical, flat, matrix

Information flow: internal systems, e.g. lines of communication, working procedures, e-systems, integrated systems; people involved, e.g. supervisor, other employees, customers, suppliers; types of information, e.g. work instructions (such as operation sheets, engineering drawings, circuit diagrams), work in progress records, stock/orders/sales; work ethics of communication, e.g. confidentiality, integrity, respect

2 Understand how external factors and the economic environment can affect the operation of an engineering company

External factors: factors to consider, e.g. markets, consumers, demographic and social trends, competitive products/services/organisations, customer/client relationships, innovation and technological change, availability of sustainable resources

Economic environment: measures, e.g. gross national product (GNP), gross domestic product (GDP), balance of payments; location, e.g. local economy, regional and national economy (such as Regional Development Agency, local/regional skills targets); economic variables, e.g. interest rates, exchange rates

3 Know how legislation, regulation and other constraints impact on the operation of engineering businesses

Legislation: legislation, e.g. Health and Safety at Work, Employment Act, Factories Act, Fire Precautions Act, Data Protection, Employment Equality (Age) Regulations, Management of Health and Safety at Work Regulations, Provision and Use of Work Equipment Regulations, Control of Substances Hazardous to Health (COSHH) Regulations, Lifting Operations and Lifting Equipment Regulations, Manual Handling Operations Regulations, Personal Protective Equipment at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Reporting of Injuries Diseases and Dangerous Occurrences Regulations, Working Time Regulations 1998, Workplace (Health, Safety and Welfare) Regulations, Health and Safety (First-Aid) Regulations

Environmental constraints: e.g. sustainability, environmental impact, use of renewable energy resources, carbon footprint, recycling, product end of life strategy

Social constraints: e.g. employment levels, workforce skill levels and training requirements, opportunities for self-improvement and progression, motivation, impact of outsourcing

4 Be able to apply costing techniques to determine the cost effectiveness of an engineering activity

Costing techniques: income; expenditure; profit/loss; cost control, e.g. direct cost, indirect cost, fixed cost, variable cost, contribution, marginal costing; assets, e.g. investment and value of fixed assets, depreciation of fixed assets

Make-or-buy decisions: e.g. break-even point, investment appraisal, return on investment, pay-back time, financial risk, development costs

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the functions carried out by different engineering companies in the sectors in which they operate	**M1** discuss how improvements in information flow could enhance the functional activities of an engineering company	**D1** evaluate the information flow through an engineering company in relation to an engineering activity
P2 explain the organisational types of three given engineering companies		
P3 outline how information flows through an engineering company in relation to an engineering activity		
P4 explain how external factors and the economic environment affect the way in which an engineering company operates	**M2** discuss the impact of relevant legislation on a specific operation in a typical engineering company in terms of benefits and limitations	**D2** evaluate the importance and possible effect of the external factors that directly impact on an engineering company.
P5 describe the legislation and regulations that impact on the way an engineering business operates		
P6 describe the environmental and social constraints that impact on the way an engineering business operates		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 carry out costing techniques to determine the cost effectiveness of an engineering activity	**M3** demonstrate how the cost effectiveness of an engineering activity could be improved.	
P8 carry out costing techniques to reach a make-or-buy decision for a given product.		

Essential guidance for tutors

Assessment

It is likely that the assessment evidence for pass criteria P1 and P2 could be produced through the study of three separate engineering companies. One of these could be the company in which the learner is employed, with the others through case study or relevant research of companies chosen either by the learner or the tutor. It is important to ensure an opportunity for activity in all three sectors is given collectively across the three companies studied. Evidence for criteria P3, P4, P5 and P6 could be produced through the study of a single engineering company, again likely to be one chosen by the learner. The remaining pass criteria (P7 and P8) lend themselves to a controlled and time-constrained activity. Although opportunities to carry out costing exercises in a real environment may be used, it may be that issues of business confidentiality will prevent this.

This unit could be assessed using three assignments. The first assignment could assess criteria P1, P2 and P3 together with M1 and D1. Information should be given about three separate engineering companies, real or fictitious, ideally one from each sector (primary, secondary and tertiary). The functions that the companies carry out can be simplified, such as designing a solution to an engineering problem or installing a machine. Other information should be given about the size and structure of the organisations.

Work-based learners may wish to use their own company to satisfy part of each criteria, although they will need data on a further two organisations to fulfil the criteria. Written tasks could be given and the evidence is also likely to be in written format.

For P2, sketches may also help to explain organisational structures. For P3, learners need to be able to explain how functions within a business are able to communicate effectively to support business strategies in relation to an engineering activity (for example the link between design and technical sales, manufacturing and material/component supply). This will link to the content section on information flow, where learners need to explain the internal systems, people involved, types of information and work ethics of communication relevant to a specific activity within an engineering company.

A second assignment should require learners to investigate how external factors and the economic environment (P4), legislation and regulations (P5), and environmental and social constraints (P6) impact on the overall operation of an engineering business. It is sensible to also include criteria M2 and D2 in this assignment.

The evidence for the last two pass criteria (P7 and P8) could be gathered through a third assignment involving a costing exercise based on the engineering activity considered in P3. For example, this could involve the use of costing techniques to determine the cost effectiveness of the product/service and then looking at a make or buy decision for part of or the whole product/service. If this is not realistic or appropriate then separate tasks may be necessary. The engineering activity considered in the criteria P3 and P7 could, for example, be the manufacture of a product or the provision of a service. In either case, centres need to ensure that the relevant data is available to cover all aspects of the content, although the product or service itself does not need to be overly complex. A task could then be set to complete a make or buy decision (P8). Criterion M3 is also best linked to this assignment.

To achieve a merit grade, learners will need to apply evaluative skills to discuss how improvements in information flow could enhance the functional activities of an engineering company (M1). This could be a natural extension to work carried out for P1, P2 and P3. Learners should discuss the impact of legislation on a specific operation in a typical engineering company (M2). This has a link with the criterion P5, which considers legislation in a broader context for the company. For merit, learners need to analytically apply the understanding they have gained at pass level to consider the impact of legislation in terms of benefit (for example reduced risk to employees and therefore improved safety record) and limitations (for example increase in production cycle times and therefore increased costs) for the operation considered. Finally, to achieve the last merit criterion M3, learners should consider the costing exercise carried out for P7 and P8 and explain how the cost effectiveness of the engineering activity could be improved or the make-or-buy decision made more conclusive or even amended.

To achieve a distinction grade, learners should focus on a specific activity and evaluate the information flow through an engineering company in support of it (D1). This links to P2 and P3, where learners described organisational types and explained the information flow for an activity and with M1 their ability to consider improvements. The evaluation for D1 should consider the key aspects of the information flow, how it impacts on the specific activity and other functional activities of the company, plus any issues in terms of problems encountered or opportunities for improvement. As such this could be in the first assignment. To achieve D2, learners should evaluate the importance and possible effects of the external factors that directly impact on an engineering company. Learners will need to use their general understanding of external factors from P4 but at this level begin to take an analytical view of the relative importance and the direct effects on the business.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Types and Operation of Engineering Businesses	An activity requiring learners to carry out research based on actual engineering companies. These companies will be involved in a range of business activities, and have different management structures and operating methods.	A portfolio containing written responses and flow diagrams based on primary and secondary research data. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P4, P5, P6, M2, D2	External Factors and Legislation that Affect the Operation of an Engineering Company	An activity to investigate the external factors and pressures that can affect the profitability of businesses. It involves finding out about economic, legislative and environmental constraints in the context of a given engineering company.	A portfolio containing written responses to a number of defined activities. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation. This assessment could be delivered in two parts – small group research activity followed by a summative test.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, M3	Assessing the Cost and Viability of an Engineering Activity	An investigative activity involving calculation and decision making supported by reflective writing and, where appropriate, verbal presentation.	A portfolio containing spreadsheets and written commentary carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.

Essential resources

For this unit, learners require access to sufficient data on engineering companies. This can be in the form of case studies, industry visits or data available through learners' employers.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Chelsom J, Reavill L and Payne A – *Management for Engineers, Scientists and Technologists,* Second Edition (John Wiley and Sons Ltd, 2004) ISBN 9780470021262

Nicholas J and Steyn M – *Project Management for Engineering, Business and Technology* (Routledge, 2011) ISBN 9780080967042

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 37: Industrial Plant and Process Control

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Modern industrial plant would fail to operate effectively without appropriate process control systems and methods. Engineers play a vital role in designing, installing and operating such systems.

The aim of this unit is to introduce learners to the principles and techniques involved in the control of industrial process plants. The methods of process control are investigated, along with the industrial techniques that are employed to ensure that plant is controlled to meet given specifications.

The unit starts by considering the basic principles of control in terms of open- and closed-loop systems and the elements that are required as part of the loop. Further areas of closed-loop control are discussed and simple analysis techniques are considered.

Having identified a control system, the unit then considers the main controller types that are available. Emphasis is placed on the widely used two-step and three-term controllers. These controllers are examined in some depth with opportunities to extend knowledge of controllers through standard tuning methods.

Modern large industrial process plants are controlled using hierarchical control systems. This unit allows learners to consider hierarchical control strategies such as supervisory control and distributed control systems. The philosophies of these systems are discussed and reference to the physical structure is covered.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the characteristics of process control systems

2 Know about common modes of control and their effect on control system performance

3 Be able to apply tuning methods to three-term controllers to improve control system performance

4 Understand hierarchical and advanced process control systems.

Unit content

1 Understand the characteristics of process control systems

System components: block diagrams; control loops, e.g. open, closed; accuracy and stability; elements, e.g. detecting, measuring, comparing, controlling, correcting

Transfer functions: block diagrams; transfer functions for simple closed-loop systems derived; closed-loop gain determined using derived transfer function; block diagram reduction techniques

System characteristics: inherent regulation; time constant; initial reaction rate; exponential growth and decay, e.g. equations (simple first order) for process systems, curves; lags, e.g. transfer, distance velocity, dead time; measurement of process dead time

2 Know about common modes of control and their effect on control system performance

Two-step control and terminology: applications of two-step control, e.g. temperature control, level control; definition of two-step control; functional attributes, e.g. effect of process lag, overlap, effect of the degree of overlap on process response

Three-term control and terminology: applications of three-term control, e.g. flow rate control, positional control; types of control (proportional (P), integral (I), derivative (D), proportional-integral-derivative (PID))

Three-term control parameters and system response: responses, e.g. under P control, under PI control, under PID control; parameters, e.g. proportional band, proportional gain, integral gain, integral action time, derivative gain, derivative action time

3 Be able to apply tuning methods to three-term controllers to improve control system performance

Tuning methods: methods (process reaction curve, ultimate cycle, frequency response); plant under three-term control, e.g. flow rate control, positional control

4 Understand hierarchical and advanced process control systems

Hierarchical control: pyramid of control, process instrumentation layer, supervisory layer, management layer

Types of hierarchical control systems: applications of distributed control systems (DCS), e.g. petrochemical, nuclear, paper mill; architecture of DCS; multi-loop structure, e.g. plant interfaces, process managers, operator stations, history modules, control networks, management networks; applications of supervisory control and data acquisition (SCADA), e.g. machine control, assembly line production, sequential manufacture; architecture of SCADA, e.g. remote terminal units, programmable logic controllers, control networks, remote input/output, supervisor stations

Advanced control: cascade control; feed-forward control (applications and improvement of response time)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the main system components of a given process control system	**M1** design a block diagram of a single closed-loop process control system to meet a given specification in terms of transfer function and system characteristics	**D1** evaluate the extent to which the design meets the given specification
P2 explain the operation of a given process control system using block diagrams and transfer functions		
P3 explain process control system characteristics		
P4 describe the functional attributes of a two-step controller, using controller terminology for a given application		
P5 describe an application of a three-term controller and the meaning of the four types of control		
P6 record the control system output responses relating to various values of three-term parameters		
P7 use three tuning methods to improve the performance of plant under three-term control		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 explain the pyramid of control for hierarchical control systems	**M2** design a structure for a hierarchical control system, explaining how it meets a given requirement.	**D2** evaluate the performance of a given process control system.
P9 describe two types of hierarchical control system		
P10 explain how two types of advanced control can improve plant performance.		

Essential guidance for tutors

Assessment

Assessment evidence for pass criteria P1, P2 and P3 could be produced through a written assignment. After describing the main components (P1) learners would need to consider a single closed-loop process control system and explain its operation. Block diagrams and transfer function calculations should be used to aid the explanation (P2). The use of simulation software in the assignment should also be encouraged to identify the system characteristics of the single-control loop. Hard copy printouts using the simulation software could form part of the evidence for P3 in the assignment.

Assessment evidence for pass criteria P4, P5 and P6 could be produced through a combination of a practical assignment and written tasks that will enable learners to describe the functional attributes of a two-step controller (P4) through a practical application (e.g. the control of liquid level within a tank). The assessment could then require learners to control liquid flow or shaft position (P5) and record the responses of the system under three term control.

Various three-term controller parameters should be used in the practical activity and context given, and a report produced concluding on the various response results (P6). The practical activity could be extended to include the tuning of a three-term controller to improve the performance of the plant (P7). All three tuning methods should be used and conclusions clearly stated, identifying the most suitable technique in terms of final system improvement.

Assessment evidence for pass criteria P8 and P9 could be produced through a written assignment relating to case studies of hierarchical control systems. The assignment could require learners to explain and describe the operation of given schematics of an industrial SCADA and a DCS. Evidence for pass criteria P10 could also be considered in the same assignment. Learners could be asked to consider a single loop in one of the given hierarchical systems and provide a written explanation of how both feed forward and cascade control can improve the performance of the loop.

Assessment evidence for M1 is likely to be an extension to the assignment that covers P1, P2 and P3. Learners could be asked to design a new control loop in block diagram form to meet a given control specification. This specification can be addressed through the design and identification of control system elements whose transfer functions will contribute to an overall system transfer function. This type of activity could be supported through the use of simulation software to confirm that the specification has been met.

Assessment evidence for criterion M2 could be achieved through the assignment covering P8, P9 and P10. Learners could be asked to design a hierarchical control structure to meet a given specification, in terms of plant size and plant operation. This design may be in the form of a block diagram supported by an explanation for the choice of system and constituent elements.

Assessment evidence for criteria D1 will be an extension of M1, requiring an evaluation of the design in relation to the given specification. D2 is likely to be achieved through an extension of the assignment covering criteria P8, P9, P10 and M2. Learners could be asked to evaluate the performance of a system that is controlling a given industrial process plant. This evaluation will consider the operation and performance of the system and learners could be requested to suggest improvements to both the structure and the selection of control method.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Characteristics of Process Control	Learners need to describe the operation of a control system.	A written report.
P4, P5, P6, P7	Modes of Control	Learners describe the use of controllers and use tuning methods.	A written report and logbook from practical activities supported by witness statements
P8, P9, P10, M2, D2	Hierarchical and Advanced Process Control	Learners explain process control systems.	A written report.

Essential resources

For this unit, learners should have access to a relevant workshop or laboratory facilities, including:

- industrial plant, rigs or system simulators
- control system simulation software
- data books and manufacturers' specifications
- process rig schematics
- appropriate tools.

Indicative reading for learners

Textbook

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004)
ISBN 9780750664325

Unit 38: Industrial Process Controllers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Control engineering plays an important role in ensuring that process plant and machine controlled systems function correctly and with optimum performance. This unit gives learners an opportunity to gain knowledge and experience of the industrial process controllers, which are the main elements in a controlled system.

The unit starts with basic control and the comparison of common control technologies and applications. It then proceeds to examine the traditional three-term controllers that are still widely used in industry and the principles required to tune and set up these controllers.

The unit then develops the knowledge and practical skills that are essential to configure and program a programmable logic controller (PLC). Various instruction types are described and learners will be required to write programs to perform a range of control applications.

Learners will gain knowledge of fault-finding techniques and tools and will write and fault-find PLCs.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about control system types and their applications

2 Know about the operating principles and tuning of three-term controllers

3 Know about the types and operation of programmable logic controllers

4 Be able to write and fault-find programmable logic controller programs.

Unit content

1 Know about control system types and their applications

Control loops: open-loop systems; elements of closed-loop control (controller, error, correction, process, measurement, comparator); signal-flow diagrams (transfer function, calculation of steady state error)

Control system types and applications: sequential control, e.g. component sorting, product assembly; continuous control, e.g. flow, level, temperature, displacement, velocity; batch control, e.g. chemical mixing, bottling plant, manufacturing

2 Know about the operating principles and tuning of three-term controllers

Operating principles: proportional controller (proportional band, gain, steady state error, rise time, overshoot); proportional-integral (PI) controller (Kp, integral action time, integral gain, responses); proportional-integral-derivative (PID) controller (Kp, Ki, derivative action time, responses)

Controller tuning methods: process reaction curve, e.g. level, velocity; ultimate cycle, e.g. flow, displacement; lambda, e.g. paper mill, large holding tanks; adaptive; auto tuning

3 Know about the types and operation of programmable logic controllers

Programmable controller types: unitary; modular; rack-mounted; selection to meet specification, e.g. application, cost, versatility

Operational characteristics: central processing unit (CPU); arithmetic logic unit (ALU), flags, registers); input/output (I/O); memory organisation; scanning

System hardware and software: specification of I/O units, e.g. digital, analogue; power supply; operating system; configuration of I/O; number systems, e.g. binary, octal, hexadecimal, binary-coded decimal (BCD)

External input and output devices: mechanical switches; relays, e.g. electromechanical, solid state; input transducers, e.g. temperature, pressure, flow, smart sensors; output devices, e.g. motors, pumps, valves, audio or visual display

4 Be able to write and fault-find programmable logic controller programs

PLC programs: program applications, e.g. on-off process control, washing machine, traffic lights, conveyor control with component sorting

PLC instructions: ladder relay instructions; bit instructions; branches; timers; counters; logical instructions; arithmetic instructions

Test and debug programs: software debug instructions; diagnostic indicators; data monitors; search and force facilities

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe control loops in terms of their individual elements		
P2 determine transfer functions and values for steady state error from closed-loop signal-flow diagrams		
P3 describe the three different control system types and identify an application for each type	**M1** explain why the control system type is suitable for the particular application	
P4 describe the operating principles of a three-term controller in terms of its three constituent parts		
P5 describe an appropriate tuning method for three different applications	**M2** apply an alternative to a given tuning method so as to improve the performance of a given process controller in terms of its system response	**D1** compare the functionality of adaptive and auto-tuning methods
P6 describe three types of PLC and select an appropriate type to meet a given specification		
P7 describe the four main components that identify the operating characteristics of a PLC		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 select system hardware and software elements that will be required to meet a given specification	**M3** explain why the elements selected meet the requirements of the specification	
P9 describe the four different types of external input and output devices that can be connected to a PLC for plant control or monitoring		
P10 write and document a PLC program using the seven different instruction types that will control a given application		
P11 carry out fault-finding on a PLC program using common debugging tools.	**M4** explain the methods and tools used to carry out fault-finding.	**D2** analyse a given PLC control program and identify improvements that can be made to improve control system performance.

Essential guidance for tutors

Assessment

Assessment evidence for pass criteria P1, P2, P3 and M1 could be produced through a written assignment. The first part of the assessment could ask learners to describe, with the aid of signal-flow diagrams, the difference between an open-loop and a closed-loop system (P1). The second part of this assessment could ask learners to calculate the overall system transfer function of a given closed-loop system (e.g. velocity control) and then calculate the steady error using the transfer function result (P2). The final part of the assessment could look at types of control systems in terms of application (P3). For example a computer-controlled washing machine could be given and learners asked to identify and describe the type of control system and the control processes that will occur. The same example could be used to develop an explanation for its suitability (M1).

Pass criteria P4 and P5 could be assessed through a written assignment, supported by practical formative tasks. This could ask learners to consider a given control system and determine and describe the operating principles of the controller using practical investigations (P4). As a second part of the assessment, learners could be given three different control systems. They could then be asked to select a tuning method for each system (P5).

Evidence for pass criteria P6–P9 could be produced through a short research project. Learners could be asked to research the types of PLC (P6), PLC operating characteristics (P7) and PLC hardware/software (P8) that would be required to meet a given specification. This specification could include information regarding system type, I/O requirement, interface, software requirements and communication system. The project report should include a description of the three types of PLC (unitary, modular and rack mounted) and identify the most appropriate for the given specification (P6).

The response for P7 should include a description of the four component parts listed in the unit content of the operational characteristics (CPU, I/O, memory organisation and scanning). The last part of the report should include the hardware and software requirements to meet the given specification (P8) and include an explanation of the suitability of the elements selected (M3).

A final task in the research project could ask learners to describe a mechanical switch, a relay, an input transducer and an output device (P9) that could be part of the selected solution for the given specification. The given specification needs to be carefully thought through before it is given to learners to ensure that all pass criteria can be evidenced.

A final assignment covering pass criteria P10 and P11 could be in the form of a practical PLC workshop. Learners could be given access to a process rig and be asked to identify the input and output devices found on the rig (e.g. sensors and motors) and connect the PLC to these devices. It is important that these devices include a mechanical switch, a relay, an input transducer and an output device as listed in the unit content. Once the PLC is connected to the rig, learners could be asked to write, document, debug and fault-find a PLC program that will provide rig control (P10 and P11). A witness statement/observation record may be the best way to record the evidence for criteria P10 and P11, supported by annotated photographs and the documented PLC program.

Assessment evidence for M2 is likely to be collected as an extension to the assignment covering criteria P4 and P5. Having selected a tuning method for three different systems, learners could be given a tuned system with an identified tuning method. They could then be asked to select and apply an alternative tuning method that will improve the original system response. The final task of this assignment would involve a comparison of adaptive and auto-tuning methods (D1).

Criterion M4 could be achieved through an extension to the assignment covering criteria P10 and P11. Having written a PLC program to meet a specification, learners could be asked to redesign the program to meet a new specification that identifies the maximum number of lines of code. This will require learners to produce an elegant program structure. The program would still be required to meet specification.

Assessment of D2 could be achieved through an extension of the assignment covering criteria P10, P11 and M4. Learners could be asked to analyse the performance of a given short PLC control program and identify improvements to the program operation in terms of operating speed and memory use. Learners could then be asked to alter the program and measure its performance against the original.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Control System Types and Applications	Learners to produce an information leaflet detailing control systems and their applications.	A written assignment.
P4, P5, M2, D1	Three-Term Controllers	Learners to produce a report describing three-term controllers and identifying the most appropriate tuning method for different applications.	A written assignment.
P6, P7, P8, P9, M3	Programmable Logic Controllers	Learners have been asked to research and produce a report on the different types of PLC.	A written assignment.
P10, P11, M4, D2	PLC Programs	Learners to write and fault-find a PLC program.	A practical assignment supported by observation records and annotated photos.

Essential resources

Centres will need to provide access to process controllers, process rigs, data books and manufacturers' specifications.

Indicative reading for learners

Textbooks

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004) ISBN 9780750664325

Bolton W – *Programmable Logic Controllers* (Newnes, 2015) ISBN 9780128029299

Unit 39: Principles and Operation of Three-phase Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Three-phase systems are used to deliver the great amounts of power required to supply industrial, commercial and domestic demand. These systems can be divided into three main categories – generation, transmission and distribution.

This unit will cover the principles of the basic circuit configurations that are common to all parts of the electricity supply system. Circuits are connected in either star or delta using three wire circuits wherever possible, as four wire circuits are normally only used where division into single-phase distribution is required. The unit also covers the equipment required to protect systems against faults and the procedures used to operate systems safely and legally.

On completion of this unit, learners will have a broad knowledge of the design and operation of three-phase circuits. This will include being able to read and produce simple circuit diagrams, make simple measurements and knowledge of the principles of system operation and maintenance.

This unit provides a foundation for anyone interested in taking up a career in the electricity supply, manufacturing or processing industries. In large factories and processing plants, three-phase systems are used for internal distribution.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits
2. Know about the operation of three-phase supply systems
3. Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads
4. Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment.

Unit content

1 Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits

Three-phase circuit relationships: systems of connection, e.g. 3-wire star, 4-wire star, delta; phasor diagrams

Current and voltage: star connection; delta connection; line and phase voltages; line and phase currents

Power in balanced loads: the power triangle, e.g. real, reactive and apparent power values, relationships; real power, e.g. single-phase equation, phase angle, power factor (PF); three-phase power, e.g. total power relationships from phase and line currents and voltages, calculations involving phase and total power, kW, kVAr and kVA values

2 Know about the operation of three-phase supply systems

Three-phase supplies: diagrammatic representation; system generation, transmission and distribution, e.g. National Grid, schematic diagrams, operating voltages (such as 400 kV, 275 kV, 132 kV, 33 kV, 11 kV, 400 V, 110 V), transformer connections (such as star-delta, star-star, delta-star)

Principle of operation of synchronous generators (alternators): calculations, e.g. emf, voltage, leading/lagging power factor, power, efficiency; production of three-phase emfs, e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, phase sequence, effect of excitation; characteristics, e.g. open circuit, v-curves

Construction of alternators: rotor, e.g. cylindrical, salient pole; stator, e.g. distributed windings, single layer, double layer; excitation methods, e.g. DC exciter, AC exciter, brushless; parallel operation of generators, e.g. conditions for synchronising onto supply system, voltage control

3 Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads

Circuits: calculations, e.g. parameters (such as line and phase voltages, line and phase currents, real power, apparent power, reactive power, power factor, phase angles, 3- and 4-wire circuit currents, line, phase and neutral currents), phasor diagrams (such as sketches, scaled diagrams, determination of values); circuits, e.g. balanced star and delta, unbalanced star and delta

Measurement of three-phase power: parameters from practical measurements, e.g. voltage, current, real power, line and phase voltages, line, phase and neutral currents; measurement methods, e.g. single wattmeter for 4-wire balanced circuits, three wattmeter and two wattmeter methods for unbalanced loads; equipment for practical measurements, e.g. voltmeter, ammeter, wattmeter

4 Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment

Faults and protection: protection equipment, e.g. current transformers, voltage transformers, relays; protection of three-phase generators and transformers; common faults, e.g. excess current, overvoltage, phase to phase, phase to earth; monitoring equipment, e.g. voltmeter, ammeter, wattmeter, frequency meter, PF meter, kVAR meter, kVA meter

Supply considerations: availability of supply, e.g. single-phase, three-phase, voltage; tariff structures, e.g. commercial, industrial, maximum demand, metering and recording arrangements, methods and connection of power factor improvement equipment (such as capacity banks, capacitors on individual machines, synchronous motors operating on leading PF)

Safety: safety precautions when working, e.g. warning notices, labelling, working space, earthing arrangements, interlocking arrangements, personal protective equipment, rubber mats, barriers, insulated tools, test equipment; documentation, e.g. limitation of access, permit to work, sanction for test

Equipment, machines and systems: equipment, e.g. switchgear, protection apparatus, monitoring apparatus; machines, e.g. generators, transformers; systems, e.g. transmission networks, distribution networks

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 demonstrate current and voltage quantities for star and delta connections using three-phase circuit relationships	**M1** explain the operation of the protection system on a three-phase transmission line in the event of a given common fault	**D1** explain, using numerical examples, the need for different voltages for different parts of the generation, transmission and distribution systems
P2 determine real power and three-phase power for both star and delta connections, including the use of the power triangle		
P3 describe the system of three-phase generation, transmission and distribution		
P4 describe the principle of operation of a synchronous generator (alternator) with the aid of calculations	**M2** using practical examples and/or characteristics, explain how the variation of excitation of an alternator can be used to control power factor	
P5 describe the function of the components in an alternator		
P6 carry out calculations relating to line and phase voltages and currents in circuits with balanced and unbalanced three-phase loads		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 measure voltages, currents and real power in circuits with balanced and unbalanced three-phase loads	**M3** explain why it is important to use the correct equipment when measuring three-phase power and the impact this would have on circuit calculations when using any of these measurements	
P8 describe the equipment required to protect three-phase generators and transformers against common faults and the equipment required to monitor supplies	**M4** explain the different tariff structures and how this could lead to the connection of power factor improvement equipment.	**D2** evaluate the benefits to commercial consumers and suppliers of installing power factor improvement equipment on consumers' equipment.
P9 describe the equipment and documentation required for safe working on high voltage equipment, machines and systems.		

Essential guidance for tutors

Assessment

The unit could be assessed using three assignments. The first assignment could be based on circuits throughout the supply system and the reasons for the choice of voltages. This could cover criteria P1, P2, P3, M1 and D1 and ensure diagrams are suitably detailed. Exercises on numerical and phase relationships could be used to achieve P1 and P2. It is important that both line and phase voltages and currents are covered. To ensure authenticity of evidence, data would need to be varied for each learner. Alternatively the tasks for P1 and P2 could be carried out first in a time-controlled environment and then the rest of the assignment carried out in learners' own time.

To achieve P3, diagrams of parts of the supply system for P3 could be coupled with explanations of the reasons for choosing different voltages at D1. At distinction level, such an exercise would require numerical evidence to be analysed to support the principles applied in selecting a voltage. Realistic or measured values should be used at all times. The assignment could be completed with a task to explain the protection system (M1).

The second assignment could cover the major aspects of power in three-phase systems and enable achievement of criteria P4, P5, P6 and M2.

The generation of power and the control of all types of power and power factor throughout the system are the main features of this assignment to ensure the understanding of each component and their purpose. Results from practical tests could be used for part or all of the work, although in this assignment the practical element is not being assessed. Simulation packages and low voltage equipment could be used for the measurements if other methods are not available.

As with the first assignment, data could be varied for each learner or these tasks could be carried out first in a time-controlled environment to ensure authenticity. As well as the requirement for carrying out calculations, the task to achieve P4 should consider the production of three-phase emfs and characteristics.

A written task could then be given asking learners to describe the function of an alternator and in doing so should include rotor, stator and excitation aspects, as well as parallel operation of generators.

A further task could be given to achieve M2. The tasks for P4 and P6 could be done under controlled conditions and P5 and M2 by the learner in their own time, clearly evidencing the components that make up an alternator.

The third assignment could focus on the protection of the system and the techniques of making work on high voltage systems safe. This would cover criteria P7, P8, P9, M3, M4 and D2.

To demonstrate an appreciation of the whole system, learners would need to explain how and why it is important to operate at an economical power factor (D2). The consumer's equipment would be found at the user end of the transmission and distribution networks. For this assignment, a visit to a power station, sub-station or large industrial plant could provide the required background information.

A practical task needs to be set to measure voltages, current and real power (P7), and in the task there should be scope to cover measurement methods and equipment requirements. The evidence for this criterion is likely to be in the form of a witness statement/observation record supplemented by a table of results and annotated photographs.

A written task is required for P8 and P9 and further written tasks for M3 and M4. The task for P9 should ensure that equipment and documentation requirements are considered when working on all three aspects of high voltage. These should include a type of equipment, a type of machine and a type of system as listed in the content section of learning outcome 4.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Three-Phase Circuits	A technician has been asked to look at a range of circuits in the supply system and determine current, voltage and power quantities.	A controlled test to determine current, voltage and power quantities, plus a written explanation/ diagrams of three-phase generation, transmission and distribution, including reasons for choice of different voltages.
P4, P5, P6, M2	Power Generation and Control	A technician needs to determine the operation of three-phase supply systems and line and phase voltages and currents.	A controlled test to determine operation of a synchronous generator line and phase voltages and currents, plus a written description of an alternator.
P7, P8, P9, M3, M4, D2	Protection and Safety Requirements for Three-Phase Power	A technician must show a new learner how to measure voltages, current and real power and explain the use of relevant protection and safety equipment.	Results from practical measurement tasks supported by observation records, plus a written report.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase equipment and systems. Appropriate and adequate testing instruments and measurement equipment should also be provided.

A range of relevant international and British Standards and health and safety publications should be available.

Indicative reading for learners

Textbooks

Bayliss C and Hardy B – *Transmission and Distribution Electrical Engineering* (Newnes, 2012) ISBN 9780080969121

Bird J – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Bird J – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Unit 40: Industrial Robot Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will give learners an understanding of the principles and operation of industrial robots used in modern manufacturing. The unit will cover robot control systems, the operating principles of different types of sensors used and their application in an industrial robot.

Learners will gain an understanding of the programming methods used and will be required to produce a working program for an industrial robot or robot work cell. The unit will give learners an understanding of the health and safety and maintenance requirements associated with modern industrial robots.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating, design and control principles of modern industrial robots and typical robot work cells

2 Understand the operating principles of industrial robot sensors and end effectors

3 Be able to produce a working program for an industrial robot or robot work cell

4 Know the hazards and health, safety and maintenance requirements associated with industrial robots and robot work cells.

Unit content

1 Understand the operating, design and control principles of modern industrial robots and typical robot work cells

Principles of operation: operational characteristics and specifications; types of controller, manipulator, end effector/tooling, e.g. pneumatic suction cup, hydraulic, electrical and mechanical grippers; work space organisation, e.g. feed of work, robot-to-robot work, material flow and logistics

Design principles: manipulator coordinate systems, e.g. cylindrical spherical, jointed, spherical, Selective Compliance Assembly Robot Arm (SCARA) with associated working envelope; wrist articulations, e.g. yaw, pitch and roll, degrees of freedom in terms of translations and rotations; drive mechanisms: mechanical (ball screws, chain/belt, gears), pneumatic, hydraulic, electrical; speed reducers/gearheads, e.g. harmonic, cycloidal, parallel shaft spur gear, planetary

Control systems: on/off and proportional-integral-derivative (PID) control; closed-loop servo controlled systems, e.g. for driving one axis of a robot; input, output and feedback signals, e.g. the sequence which takes place in order to perform a task; control of three axes of a robot

2 Understand the operating principles of industrial robot sensors and end effectors

Sensors: sensor types, e.g. tactile (micro switches/piezoelectric/strain gauge/pressure), non-tactile (capacitive/inductive/light/laser), vision (inspection, identification and navigation); sensor applications, e.g. safety, work-cell control, component/part inspection

End effectors: grippers and tools, e.g. parts handling/transfer, assembly, welding, paint spraying, testing

3 Be able to produce a working program for an industrial robot or robot work cell

Operating program: program selection, start-up, test, alterations and operation; types of programming, e.g. manual, walk through, teach pendant methods; off-line programming; planning robot efficient routes; writing programs using flowcharts; work-cell commands, e.g. wait/signal/delay

4 Know the hazards and health, safety and maintenance requirements associated with industrial robots and robot work cells

Health and safety requirements: relevant regulations, e.g. Health and Safety at Work Act, Electricity at Work Regulations, Health and Safety Executive (HSE) publications; human dangers, e.g. during programming, maintenance and as a result of system faults; safety barriers, e.g. 'dead man's handle', hold and emergency stop buttons, pressure pads/matting surrounding robot, infrared curtains and electromagnetic field barriers

Maintenance: inspection routines, e.g. mechanical condition of all parts, environmental conditions (particulate matter, temperature, ventilation, shock, vibration, electrical noise); spare parts required to sustain continuous operation; relevant maintenance tools and test equipment; set-up and maintenance schedules

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating principles of a given industrial robot or robot work cell	**M1** explain how the design principles of a given industrial robot or robot work cell are reflected in its control and operation	**D1** evaluate an industrial robot or robot work cell installation in terms of its design, operation and control
P2 explain the design principles of a given industrial robot or robot work cell		
P3 describe the control systems, including input, output and feedback signals, used to control the operation of an industrial robot or robot work cell to perform a specific task		
P4 explain the operating principles of three different types of sensors and their relevant application in an industrial robot or robot work cell	**M2** justify the use of a specific sensor/end effector for a given industrial robot or robot work cell application	
P5 explain the relevant operating principles of two different industrial robot or robot work cell end effectors being used to perform a specific task		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 produce an operating program for an industrial robot or robot work cell to enable it to effectively carry out a specific function	**M3** test that an industrial robot or robot work cell conforms to a specification and performs the programmed tasks correctly and safely	**D2** compare two different methods used to program an industrial robot or robot work cell for a specific operation, and justify the choice of one over the other.
P7 describe the health and safety requirements for the safe operation of a given industrial robot or robot work cell	**M4** justify the choice of a safety barrier for a given industrial robot or robot work cell operation.	
P8 describe maintenance procedures on a given industrial robot or robot work cell.		

Essential guidance for tutors

Assessment

One assignment could cover P1, P2, P3, M1 and D1. For P1, learners will need to explain the principles of operation of robots, including types of controller, manipulator, end effector/tooler and work space organisation. This can be linked to P2 so that their explanation also includes robot design principles (manipulator coordinate systems, wrist articulations, drive mechanisms and speed reducers). Learners will need to describe types and applications of control systems suitable for robots (P3). A separate task could be used to combine M1 and D1, which essentially synthesises P1, P2 and P3 and requires an evaluation of a given industrial robot or robot work cell in terms of its design, operation and control.

A second assignment could cover P4, P5 and M2. For P4, learners will need to explain the operation of three different sensors and their different applications. This can be linked to P5 where they will need to provide details of robot end effectors. M2 combines P4 and P5. Learners could select one example used in P4 to justify sensor use and one example from P5 for end effector use or use one example to combine the two.

A third assignment could be used to cover P6, M3 and D2. For P6, a robot must be programmed and the program produced should be tested in order to achieve M3. It is suggested that the program should be centred on industrially relevant tasks. The ability to have used two programming methods and subsequently to evaluate and compare them is also necessary to achieve D2.

A fourth assignment could be used to cover P7, P8 and M4. A clear awareness of health and safety (P7) and maintenance issues (P8) associated with robots should be shown through the assessment tasks. To achieve M4, learners must be aware of safety and choose and justify the choice of a safety barrier in an industrially relevant situation.

Learners must select and interpret from a range of sources of information, such as manufacturers' literature, textbooks and the internet. Learners should require significantly less tutor help or guidance when carrying out assessable practical activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Robot Operation, Design and Control Principles	A technician needs to evaluate the operation, design and control of a robot to see if improvements can be made.	A written report.
P4, P5, M2	Sensors and End Effectors	A technician needs to explain to a new learner the operating principles of robot sensors and end effectors.	A written report.
P6, M3, D2	Producing and Testing Operating Programs for Industrial Robots	A technician needs to produce and test an operating program for an industrial robot.	A practical task supported by learners' written records and records of tutor observation.
P7, P8, M4	Health, Safety and Maintenance With Industrial Robots	A health and safety manager requires a report on health and safety requirements for an industrial robot, along with maintenance procedures.	A written report.

Essential resources

Centres delivering this unit should be equipped with, or have access to, an industrial standard robot or smaller educational-standard robots. Learners are expected to undertake programming exercises and be encouraged to set up robot controlled systems/processes.

Indicative reading for learners

Textbooks

Appin Knowledge Solutions – *Robotics* (Infinity Science Press, 2006) ISBN 9781934015025

Niku S – *Introduction to Robotics: Analysis, Control, Applications*

Unit 41: Vehicle Electronic Ancillary and Information Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Significant technological developments in the motor vehicle industry have resulted in modern vehicles being equipped with a vast array of additional ancillary and information systems. From anti-lock braking systems (ABS) and stability control, to condition monitoring computers and satellite navigation and information, these systems contribute to the overall safety and comfort of the vehicle's occupants.

Through practical investigation, learners will gain an understanding of the function of these systems and their key components. The unit will also focus on how ancillary and information systems interrelate with each other and how they interact with a vehicle's driver or passengers.

Learners will carry out inspections on different vehicle ancillary and information systems to confirm their correct operation and system integrity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating principles and characteristics of vehicle electronic ancillary and information systems

2 Know about the function of key units and components of vehicle electronic ancillary and information systems

3 Know the interrelationships and interaction of vehicle electronic ancillary and information systems

4 Be able to inspect vehicle electronic ancillary and information systems.

Unit content

1 Understand the operating principles and characteristics of vehicle electronic ancillary and information systems

Systems model: use of systems model (input – process – output); characteristics of control strategies employed, e.g. open-loop, closed-loop

Operating principles and characteristics: control systems, e.g. analogue, digital, programmable, non-programmable; main elements of a digital processing system and principal functions, e.g. central processing unit (CPU), memory devices (such as volatile, non-volatile), buses, input/output ports, multiplexing, controller area network (CAN) systems; characteristics, e.g. purpose and applications of the system, operating conditions (such as conditions in which the system is operative or inoperative, 'fail-safe' features), system evaluation to identify benefits, comparative cost, performance, safety, convenience, efficiency

Vehicle electronic ancillary and information systems: electronic ancillary systems, e.g. anti-lock braking systems (ABS), vehicle stability control systems, security and alarm systems, central body electronic systems (such as seat positioning, seatbelt tensioning, secondary restraint systems, cargo/cabin compartment climate control); information systems, e.g. driver information (condition monitoring and trip computers), navigation – global positioning system (GPS), communication systems, entertainment systems, proximity (reversing) sensors and road positioning

Operating principles of sensors and actuators: transducers used in vehicle ancillary and information systems, e.g. electromagnetic, Hall effect, photoelectric, resistive, inductive, capacitive; factors affecting performance and application, e.g. sensitivity, accuracy, linearity and stability; influence of environmental factors, e.g. heat, vibration, moisture, contaminants

2 Know about the function of key units and components of vehicle electronic ancillary and information systems

Key units and components of vehicle ancillary systems: input data, e.g. temperature, speed, position; process data, e.g. mapping to input; output data, e.g. electronic/mechanical actuation; key units and components, e.g. sensors (temperature, speed, position), processors (ABS, electronic climate control unit), actuators (switches, inductive, capacitive, direct current (DC) motors, stepper motors when used for throttle poisoning or ventilation control), solenoids when used on ABS, air conditioning or for multi-position; legal considerations, e.g. modifications to vehicle specification that may affect sensor/system performance (fitment of larger wheels/tyres effect on speedometer accuracy, fitment of passenger airbag isolation switches)

Key units and components of vehicle information systems: input data, e.g. temperature, speed, position, levels, electrical values; process data; visual output, e.g. lights, display screen, gauges; audible output, e.g. buzzer, speaker; key units and components, e.g. sensors (temperature, fluid level, speed, GPS); processors, e.g. satellite navigation, on-board diagnostics when used as comfort computing; output units, e.g. display screen, speakers, buzzers, gauges, lights; legal considerations, e.g. fitment of radar detectors

3 Know the interrelationships and interaction of vehicle electronic ancillary and information systems

Interfacing and signal processing: compatibility between components and systems; characteristics of devices that give rise to the need for signal processing (inductive pick-ups, analogue to digital (A/D), digital to analogue (D/A); control of output devices, e.g. energy transfer, power output stages, buffer circuits

Representational methods: diagrams, e.g. circuit, flow, block, systems; circuit type, e.g. electrical, electronic, hydraulic, pneumatic; connections

Functional interrelationships: location, e.g. units and components in the vehicle, position/location of components relative to others in the system; functional relationships between the elements of the system; effects, e.g. failures on other components in the system, the operation of the system and on external systems (such as effect of speed sensor failure)

System interaction: ways in which the system under consideration interacts with other vehicle systems and functions, e.g. integration of anti-lock braking and stability control (anti-skid), systems, stability control system obtains information from the steering system, ABS system components interacts with the braking and engine control systems

Driver/passenger interaction: driver/passenger influence on the operation and characteristics of the system (such as seat pad recognition); effects of the system on the driver's/passengers' behaviour, comfort and safety (such as temperature effect on stress levels)

Vehicle interaction: ways in which the system affects the vehicle in relation to other vehicles, e.g. proximity detection; external factors influencing the operation/function of the system, e.g. satellite navigation, ground positioning systems

4 Be able to inspect vehicle electronic ancillary and information systems

Inspections: location of systems and key components; means of identification; testing and diagnostic procedures as appropriate to the system under consideration

Safety: relating to the operation, inspection, maintenance and testing of the system

Practical confirmation of system operation and characteristics: observation of the system in operation; examination of system responses to external conditions as appropriate to the system under consideration

Testing considerations: factors affecting performance/reliability and application, e.g. sensitivity, accuracy, linearity and stability; influence of environmental factors, e.g. heat, vibration, moisture, contaminants

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating principles and characteristics associated with the vehicle electronic ancillary and information systems, with the aid of a systems model	**M1** compare the characteristics of two vehicle electronic ancillary and information systems in terms of function, performance, safety and cost	
P2 describe the operating principles of sensors and actuators	**M2** compare two different sensors, with respect to position and environment control	**D1** evaluate the factors that affect the performance and application of sensors and actuators
P3 describe the function of the key units and components of two vehicle ancillary systems		
P4 describe the function of the key units and components of two vehicle information systems	**M3** explain how the malfunction of key units and components can influence the operation of a vehicle electronic ancillary and information system	
P5 describe interfacing and signal processing in ancillary and information systems	**M4** explain the benefits of the interaction of vehicle ancillary and information systems for a chosen application	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 use representational methods to help describe the functional interrelationship and interaction between systems		
P7 describe driver/ passenger and vehicle interactions for one ancillary and one information system		
P8 safely inspect an electronic ancillary system to confirm system operation and integrity		
P9 safely inspect an information system to confirm system operation and integrity		
P10 identify the testing considerations to make when carrying out a practical investigation into inspecting vehicle electronic ancillary and information systems.	**M5** explain the factors affecting performance and reliability of vehicle electronic ancillary and information systems	**D2** evaluate the effect of environmental factors on vehicle electronic ancillary and information systems.

Essential guidance for tutors

Assessment

This unit could be assessed using three assignments.

Learners will need to generate evidence of using a systems model to explain the operating principles and characteristics (P1). This can be extended to make a comparison of the characteristics for M1. Learners can then describe the function of two ancillary systems (P3) and describe the operating principles of sensors and actuators (P2) relating to the two identified ancillary systems, comparing different sensors in respect of position and environment (M2). This can be expanded on to evaluate the factors affecting performance and application of sensors and actuators (D1). All of the above criteria could be combined into one assignment, which is likely to be in written form and may include diagrams and sketches.

A second assignment could cover P4, P5, P6, P7, M3 and M4. Learners would need to describe the function of key units and components of two vehicle information systems (P4). To meet P5, the description of interfacing and signal processing should include compatibility, inductive pick-ups, processing and the control of output devices. The inclusion of an appropriate circuit diagram for each system would meet P6 and would need to include the description of the functional interrelationship and interaction of systems.

Learners could then be asked to describe driver/passenger and vehicle interactions (P7). Further tasks could be set to extend to the information system element of M3 and M4.

A third assignment will need to be based on practical sessions, with learners carrying out inspections on both ancillary (P8) and information systems (P9) to industry standards. A written task could ask learners to identify testing considerations for both types of system (P10). M5 requires factors affecting performance/reliability and application, and could include sensitivity, accuracy, linearity and stability. This can be extended to D2 to include the influence of environmental factors such as heat, vibration, moisture and contaminants.

Evidence should include notes, diagrams, test data, and records of the maintenance and diagnostic procedures carried out. Witness statements/observation records, supplemented by annotated photographs could also form part of the evidence for these practical elements.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Function and Operation of Ancillary and Information Systems and Components	A technician needs to investigate vehicle ancillary systems, sensors and actuators before system testing.	A written report.
P4, P5, P6, P7, M3 and M4	Interrelationship and Interaction of Ancillary and Information System Components	A technician needs to investigate the vehicle information systems, system interfacing and signal processing and the interaction between systems.	A written report.
P8, P9, P10, M5, D2	Inspecting and Testing Electronic Ancillary and Information Systems	A technician needs to inspect vehicle electronic ancillary and information systems to confirm their operation.	A practical assignment evidenced through learners' portfolio and tutor observation records.

Essential resources

A range of components, vehicles and equipment will be required for practical investigation, along with an accompanying variety of data sources.

Indicative reading for learners

Textbooks

Denton T – *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Hillier V – *Hillier's Fundamentals of Automotive Electronics Book 2*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515372

Unit 42: Light Vehicle Suspension, Steering and Braking Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Advances in engine and transmission design mean that modern vehicles have an increased need for suspension, steering and braking technology that can cope with the forces associated with modern vehicle performance.

Some suspension systems have different modes for the driver to select according to personal demands or those of the terrain. The most sophisticated suspension systems can self-level, have yaw control and adjust to the type of terrain being encountered.

Steering systems are now mostly power-assisted, in some cases to counter the effects of wider tyres and suspension that have been set to enhance the vehicle's road holding. Most tyres are now low profile in order to ensure that performance, control and stability are maximised.

Sports vehicles, family saloons, multi-purpose vehicles, off-road vehicles, passenger service vehicles and haulage vehicles all require different things from these systems in order to perform well in the environment for which they are intended. It is vital that these systems interrelate with, and complement, each other to ensure maximum comfort and safety of the driver and passengers.

This unit will develop learners' knowledge of the function and operation of the main suspension, steering and braking system components and their relationship to the efficient operation of the vehicle. Learners will then carry out a range of practical inspection and fault-finding techniques on these systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the function and operation of different types of suspension system

2 Know the function and operation of steering system components

3 Know the function and operation of braking system components

4 Be able to carry out fault-finding procedures on steering, braking and suspension systems.

Unit content

1 Know the function and operation of different types of suspension system

Suspension systems: types of independent front suspension, e.g. unequal length wishbones, transverse link and strut; types of independent rear suspension, e.g. trailing arm, pure and semi, unequal transverse links, transverse link and strut, air suspension; dampers (construction, operation and typical faults); suspension requirements, e.g. sprung weight, unsprung weight; impact of chassis design on suspension type, e.g. ladder, monocoque, space frame, welded shell constructions

Adaptive suspension system main components: Electronic Control Unit (ECU); regulator; solenoid valve; sensors; dampers; system operation

2 Know the function and operation of steering system components

Power-assisted steering main components: hydraulic pump; control valve; power cylinder; reservoir; filter; pressure relief valve; pipes; steering gear; types, e.g. integral, semi-integral, rack and pinion, worm and follower, speed sensitive

Steering characteristics: understeer; oversteer; neutral steer; roll axis; roll centre; centre of gravity

Road wheels: wheel type, e.g. alloy (cast or forged), steel, well based, specialist (such as wire spoke, flat-edge, double hump, divided, detachable flange); rim codes; wheel retention methods

Tyres: types, e.g. belt and brace construction, ply construction; tyre profile and tyre markings, e.g. width, aspect ratio, type of construction, load index, speed index, ply ratings, direction indicators; applications, e.g. high performance, light/heavy vehicles, motorcycle, agriculture, industrial; valve types

3 Know the function and operation of braking system components

Main components: types of system, e.g. single piston disc brakes, multi-piston disc brakes; brake fluid characteristics; brake bleeding componentry; brake pad warning systems; types of brake circuits (construction and operation), e.g. tandem master cylinders, vacuum servo units, pressure apportioning valves

Anti-lock braking system (ABS) components: wheel speed sensors; ECU; system modulator; reservoir; electronic control system

4 Be able to carry out fault-finding procedures on steering, braking and suspension systems

Fault-finding: identification of typical faults and corrective action to be taken for each system; adjustment and servicing of the main components for each of the systems; protection of units against the usual hazards during use or fault-finding; safe working practice

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the function and operation of two independent front and two independent rear vehicle suspension systems, including suspension requirements and the impact of chassis design	**M1** compare the relative advantages and disadvantages of an adaptive suspension system with one other type of suspension system	**D1** evaluate an adaptive suspension system for performance and safety
P2 describe the function and operation of the main components of an adaptive suspension system		
P3 describe the function and operation of the main components of power-assisted steering		
P4 distinguish the range of steering characteristics	**M2** explain the effect of understeer, oversteer and neutral steering characteristics, vehicle roll axis, roll centre and centre of gravity on wheel/tyre function and operation	
P5 describe the functional differences between two different wheel and tyre combinations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe the function and operation of the components found in a given type of braking system	**M3** compare the function and operation of the braking system selected with an anti-lock braking system.	**D2** evaluate two different braking system applications for efficiency and safety.
P7 describe the function and operation of the components found in an anti-lock braking system		
P8 carry out fault-finding on a suspension system to check for satisfactory operation and state corrective actions		
P9 carry out fault-finding on a steering system to check for satisfactory operation and state corrective actions		
P10 carry out fault-finding on a braking system to check for satisfactory operation and state corrective actions.		

Essential guidance for tutors

Assessment

This unit could be assessed through three written assignments and one practical assignment.

The first written assignment could give learners opportunities to meet the requirements of P1, P2, M1 and D1. A task could be set asking learners to describe the function and operation of two main types of independent front and two types of independent rear vehicle suspension design (P1). Different types of rear suspension could be given to different learners from the range listed in the unit content. The task should ensure that learners cover dampers, the suspension requirements and the impact of chassis design.

For P2, a task should be given asking learners to describe the function and operation of the main components of an adaptive suspension system. The main components that need to be covered are listed in the unit content. A further written task could be set asking learners to compare the relative advantages and disadvantages of an adaptive suspension system and one other suspension system (M1). This could be extended to incorporate an evaluation of an adaptive suspension system using performance and safety as the criteria (D1).

A second assignment could be given to meet the requirements of P3, P4, P5 and M2. An initial task, covering P3, could require learners to describe the function and operations of the main components in a power-assisted steering system. Tutors can give different types of steering system to different learners.

A second task in this assignment must ask learners to distinguish between understeer, oversteer and neutral steering characteristics, vehicle roll axis, roll centre and centre of gravity, to achieve P4.

A third task, covering P5, would give learners the opportunity to describe the functional differences between two different wheel and tyre combinations. Consideration should be given to wheel types, rim codes and retention methods, valve and tyre types including profile and markings and applications. A further task could then be set asking learners to explain the effect of steering characteristics on wheel/tyre function and operation (M2).

A third written assignment could be used to meet the requirements of P6, P7, M3 and D2. Initially, learners could describe the function and operation of the components found in braking systems (P6) and anti-lock braking systems (P7). A further task could then be set asking them to compare the braking system with an anti-lock system (M3) and extend this to evaluate two braking system applications for efficiency and safety (D2). Although the components used in the anti-lock braking system are clearly listed in the unit content, tutors can vary what is given to each learner. It is important that the type of system is fully explored and that brake bleeding componentry and brake pad warning systems are considered in the descriptions.

A final practical assignment could be set to meet the requirements of P8, P9 and P10. Learners would need to be given a particular vehicle to carry out a fault-finding exercise on its suspension, steering and braking systems. In doing so, learners will need to establish which components are operating satisfactorily and which are not. At least one fault in each system must be present to allow corrective actions to be identified and stated. A record of hazard protection and safe working needs to be made.

Depending on the resources available, different learners could work on different vehicles. Evidence for this practical assignment is likely to be in the form of a witness statement/observation record, supplemented by annotated photographs and a list of the faults found and suggested corrective actions for each.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Suspension Systems	A vehicle technician needs to describe the function and operation of suspension systems to a new apprentice.	A written report.
P3, P4, P5, M2	Steering System Components	A vehicle technician needs to describe the function and operation of steering systems to a new learner.	A written report.
P6, P7, M3, D2	Braking System Components	A vehicle technician needs to describe the function and operation of braking system components to a new learner.	A written report.
P8, P9, P10	Fault-finding of Suspension, Steering, Braking and Systems	A vehicle technician needs to inspect a vehicle's steering, braking and suspension systems.	Practical activities evidenced by learner record sheets and observation records.

Essential resources

A range of suspension, steering and braking components and equipment will be required for delivery of this unit. Learners will need access to vehicles in order to carry out fault-finding on the different systems.

Indicative reading for learners

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Killingsworth J, Godfrey E and Haynes J – *Suspension, Steering and Driveline Manual* (Haynes, 1998) ISBN 9781563922930

Nunney M – *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 43: Mechanical Measurement and Inspection Techniques

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

In order to produce components that meet the design criteria, manufacturing companies have to know whether the components they make are to the required dimensional and accuracy standards. Companies carrying out maintenance activities also need to know that the components they are working with, repairing or servicing are to the required size and accuracy.

Measurement and inspection play an important role in establishing these needs and support other areas of assuring quality in the products produced. The process of finding out whether a product is accurate and to dimensional standards also needs to be done in an efficient and effective way.

The aim of this unit is to provide a broad understanding of mechanical measurement and inspection techniques that apply to a range of engineering activities in different companies. The unit will give learners an understanding of a range of techniques and equipment commonly used in mechanical measurement and inspection.

Learners will be introduced to principles of measurement and the use of comparators and gauges, along with sampling and statistical process control (SPC). Learners will develop the skills needed to select and use standards, measuring equipment, comparators and gauges. They will appreciate the fundamental requirements of measurement and inspection techniques and apply standards to them.

Learners will have an opportunity to carry out practical measurements using linear measuring equipment and techniques and comparators and gauges. They will also prepare a process control chart for a given process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand principles and applications of mechanical measurement

2 Be able to use measurement equipment and techniques

3 Be able to use comparators and design a gauging system for inspection

4 Be able to apply sampling and statistical process control (SPC) during inspection.

Unit content

1 Understand principles and applications of mechanical measurement

Limits and fits: e.g. concepts of limits and fits, definitions of the types of fits (clearance, transition, interference)

Tolerances: principles, e.g. standard symbols and interpretation, maximum material condition, maximum variation of form, grades of tolerance; hole tolerances, shaft tolerances

Principles of measurement: units; standards, e.g. BS 969, BS 1134, BS 2634, BS 4500; calibration, e.g. national standards, traceability; errors and instruments; kinematics of equipment

2 Be able to use measurement equipment and techniques

Linear measurement equipment: range (verniers, callipers, micrometers); principles involved; scales; types; use in dimensional measurement; specific calibration issues

Further measurement techniques: determining surface texture, e.g. significance to component function, surface texture symbols, roughness average, waviness, finish, amplitude parameters, spacing parameters, instrumentation used for surface texture measurement; determining alignment, e.g. principles of straight edges, measurement of straightness, squareness, flatness and parallelism; determining angular measurements, e.g. concepts of geometry, divided circles, principles of angular measurement, angular scales, methods for angular measurement, taper measurement

3 Be able to use comparators and design a gauging system for inspection

Comparators: types of comparator, magnification, cosine errors, use of angle dekkor, specific calibration issues

Gauge design: principles of gauge design (gauge types, gauge materials, Taylor's principle, principle of go/no-go gauging); slip gauges as references for length standards (classification of slip gauges, multiple slip gauge use, ancillary equipment, care and maintenance required, wringing); slip gauges for instrument calibration (use with dial gauges in dimensional measurement, specific calibration issues)

Simple application: measuring a component containing round (external or internal), linear and angled features, following the use of a high precision manufacturing method such as grinding, e.g. the jaw of a toolmaker's clamp

4 Be able to apply sampling and statistical process control (SPC) during inspection

Sampling: acceptance sampling, 100% inspection

Statistical process control: charts (mean, range); process capability, conformance, cost, process variability; process, e.g. grinding machine, high-volume lathe

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the different types of limits and fits	**M1** analyse the use of the concept of limits and fits	
P2 use tolerancing principles to calculate hole and shaft tolerances for a range of required component fits		
P3 explain the principles of measurement		
P4 use linear measurement equipment to carry out practical measurements for given products	**M2** explain the use of linear measuring equipment when used on given products	**D1** evaluate the use and accuracy of linear measuring equipment when used on given products
P5 use further measurement techniques on given products to establish surface texture, alignment and angular measurements		
P6 use comparators to measure dimensions and angles for a simple given product	**M3** compare different uses of comparators when used to measure dimensional accuracy	**D2** analyse the calibration requirements of comparators and measurement equipment.
P7 design a gauging system for a simple given application		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 explain the technique of acceptance sampling and state when 100% inspection is applicable	**M4** explain process capability in relationship to statistical process control (SPC) for a given relevant process.	
P9 produce control charts for a given process.		

Essential guidance for tutors

Assessment

Four assignments could be developed for the assessment of this unit.

The first assignment could be a time-constrained assignment addressing criteria P1, P2, P3 and M1. A range of data for all three types of fit should be given, allowing learners to apply their knowledge of tolerancing to develop suitable tolerances for each fit. Tasks need to be included that ensure the range of unit content – such as maximum material condition and tolerance grades – are covered (P2). Written tasks should be given for the other criteria, P3 and M1, targeted in this assignment.

For the second assignment, addressing criteria P4, P5, M2 and D1, a range of products need to be made available so that each learner is able to use a vernier, a calliper and a micrometer. It would be useful if the products had both internal and external features to be measured. Obviously the products need to be machined to allow the accuracy that demands the use of this equipment. The instructions should ensure that surface texture, alignment and angular measurements are taken.

Particular care needs to be taken with the choice of product to ensure it is large enough to allow alignment measurements to be taken as ranged in the content. At least two products are required to ensure the range of features and accuracy can be measured and the use of the equipment evaluated. A written task needs to follow the practical activity to address M2. A witness statement/observation record would support the evidence for the use of this equipment, along with a table of measurements taken. D1 will form an extension to the practical work and will require an evaluation of the range of instruments – vernier, a calliper and a micrometer.

The third assignment, addressing criteria P6, P7, M3 and D2, could also be based around a practical exercise. The choice of product for the use of comparators (P6) needs to ensure that there are both dimensions and angles to be measured. No more than two angles are required otherwise the product will be too complex.

Care will need to be taken when planning an assessment activity for the designing of a gauging system (P7). Data or a particular specification should be made available that ensures the principles of gauge design are applied and slip gauges are used. The unit content suggests as an example the jaw of a toolmaker's clamp, so in this case as long as there are external and internal features, linear and angled features the product is suitable. An overly complex product would not be suitable. A written task should be given to provide opportunities for criteria M3 and D2, and could be an extension of the practical work. Again, a witness statement/observation record would support evidence of the use of comparators, along with a table of measurements taken.

The last and fourth assignment could address criteria P8, P9 and M4. Data needs to be given for a process that allows learners to present control charts (P9) for both mean and range and link this to M4. A further written task needs to be set for P8.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3 and M1	Tolerances and Fits	A time-constrained assignment requiring learners to demonstrate their knowledge of tolerances and fits.	A practical assignment requiring learners to calculate tolerances for component fits, supported by written tasks.
P4, P5, M2 and D1	Using Measurement Equipment and Techniques	An assignment requiring learners to use linear measuring equipment and further measuring techniques.	A practical task in which learners use verniers, callipers and micrometers and determine surface texture, alignment and angular measurements on at least two products. A further written task can be used to give learners an opportunity to evaluate the use of linear measuring equipment.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3 and D2	Comparators and Gauges	A practical assignment requiring learners to use comparators and design a gauging system.	Two practical tasks in which learners measure dimensions and angles using comparators. Learners then design a gauging system. A further written task could build on the practical work so that learners can carry out a comparison and analysis for M3 and D2.
P8, P9 and M4	Sampling and Statistical Process Control	An assignment requiring learners to investigate sampling and inspection techniques.	A series of three written tasks in which learners provide an explanation of sampling and inspection techniques. Learners will need to produce control charts from given data.

Essential resources

A range of measuring and inspection equipment as defined by the content is necessary, plus a range of products for learners to measure. Centres will need to provide access to engineering data handbooks, manufacturers' specifications and suitable current British Standards (e.g. BS 969: Limits and Tolerances on Plain Limit Gauges, BS 1134: Method for the Assessment of Surface Texture).

Indicative reading for learners

Textbooks

Drake P – *Dimensioning and Tolerancing Handbook* (McGraw-Hill, 1999) ISBN 9780070181311

Griffith G – *Geometric Dimensioning and Tolerancing: Applications and Inspection* (Prentice Hall, 2001) ISBN 9780130604637

Timings R L – *Fundamentals of Engineering* (Routledge, 2002) ISBN 9780750656092

Unit 44: Vehicle Engine Principles, Operation, Service and Repair

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Although the technology used in modern vehicles is under constant development, the basic principles of the internal combustion engine (ICE) have remained the same for many years. However, advances in design have produced engines that are more efficient, powerful, environmentally friendly and, with the aid of electronics, much more responsive to the needs of the user.

Developments in engine design and materials technology have significantly increased the reliability and durability of engine components and systems and, therefore, minimised failure and the need for subsequent repairs. However, the modern motor vehicle technician still needs to have a working knowledge and understanding of the engine, and associated sub-systems, to enable them to carry out the necessary care, fault diagnosis and repair.

This unit will enable learners to develop an understanding of a range of engines in terms of their operating principles and processes, applications and service/repair. Two and four-stroke cycle spark and compression ignition engines will be considered, together with their related sub-systems – fuel, cooling and lubrication. The unit also examines current and future developments in engine design that make use of alternative fuel and power systems.

Finally, the unit will give learners an opportunity to apply their understanding of engine principles by carrying out engine service and repair work in a vehicle workshop environment. Learners will gain practical experience of using a range of tools and equipment and will work to industry standards relating to vehicle service and repair.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of operation of an internal combustion engine

2 Understand the principles of operation of fuel supply systems

3 Understand the principles of operation of engine cooling and lubrication systems

4 Be able to carry out engine service and repair procedures.

Unit content

1 Understand the principles of operation of an internal combustion engine

Operating cycles: internal combustion engines (ICE), e.g. four-stroke spark ignition (SI) and compression ignition (CI) cycles, two-stroke cycle, Wankel (rotary); pressure-volume diagrams and engine performance diagrams (torque/power), e.g. the Otto cycle, identification of induction, compression, ignition, exhaust strokes, effects of bore, stroke, swept and clearance volume; engine efficiency, e.g. engine timing, pressure charging, compression ratio

Engine configurations and layout: orientation (longitudinal/transverse); position of engine (front, mid and rear); cylinder arrangement, e.g. single cylinder, multi cylinder; cylinder configuration, e.g. in-line, vee, horizontally opposed arrangements; vehicle design and performance, e.g. space saving, arrangements for power transmission, vehicle function (passenger, people carrier, off-road, motorsport), cost, environmental issues

Engine assemblies: engine types, e.g. four-stroke SI and CI, two-stroke cycle, Wankel (rotary); components, e.g. cylinder block (piston, connecting rod, crankshaft and bearings), cylinder head (camshaft, inlet/exhaust valves, valve operating mechanisms such as overhead valve (OHV), single overhead cam (SOHC), double overhead cam (DOHC), variable valve timing); flywheel; inlet and exhaust manifolds

2 Understand the principles of operation of fuel supply systems

Petrol combustion process: fuel principles, e.g. composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio; combustion process, e.g. mixing of fuel/air, flame spread, exhaust emissions; effects of pollutants/causes of undesirable emissions, e.g. weak mixture, rich mixture, oil control problems; symptoms of incorrect combustion process, e.g. detonation, pre-ignition; fuel supply method, e.g. fuel injection, mechanical, electrical; fuel system components, e.g. tank, petrol filter, air filter, supply/pressure pump, pressure regulator, injectors

Diesel combustion process: fuel principles, e.g. composition of diesel, characteristics of diesel, air/fuel ratio; combustion process, e.g. phases, delay, combustion/flame spread, spontaneous/direct burning, pressure/crank angle diagrams, diesel knock; exhaust emissions, e.g. normal, excess air, excess fuel, effects of pollutants; fuel supply method, e.g. rotary, inline, unit injector; fuel system components, e.g. low pressure (tank, filter(s), supply pump), high pressure (in-line pump, governor, injector, cold start arrangements)

Alternative fuel/power: systems, e.g. electric, liquefied petroleum gas (LPG), natural gas, hydrogen, hybrid; adapted/additional components, e.g. batteries, fuel tank, additional modifications, cooling system, management control system, performance; legislation, e.g. emissions, tax, health and safety

3 Understand the principles of operation of engine cooling and lubrication systems

Engine cooling systems: types of system, e.g. air-cooled (cylinder construction, fan, shutters, thermostat), water-cooled (radiator, radiator cap, expansion tank, water pump, viscous/electric/mechanical fans, thermostat, hoses, types of coolant, level indication, anti-freeze protection, effects and prevention of corrosion); cooling control systems, e.g. engine temperature sensor, ambient air temperature sensor, thermostatic control valves (mechanical and electrical), cooling air flow control (air flow control via flap for warm up); engine management system (EMS), e.g. overheating, fuel cut-off

Engine lubrication system: system components, e.g. wet/dry sumps, oil pump, pressure relief valve; engine oil types and filtration methods, e.g. viscosity, Society of Automotive Engineers (SAE) International rating, multi-grade oil; filters, e.g. full flow or bypass; lubrication control systems, e.g. sensors, level indicator (mechanical, electrical); pressure sensors, e.g. absolute and gauge or lamp; low pressure safety system, e.g. EMS fuel cut-off

4 Be able to carry out engine service and repair procedures

Routine engine service: procedures, e.g. changing engine lubricant, filters (air, lubricant, fuel), checking and adjusting engine timing (ignition, camshaft); working to instructions, e.g. manufacturer's service schedules/data, dealership work schedules/job cards; use of tools and equipment, e.g. hand tools, vehicle lift equipment, oil drainer, on-board service indicators; safe working procedures, e.g. personal and vehicle protection (personal protective equipment, vehicle covers, mats); Control of Substances Hazardous to Health (COSHH) Regulations 2002; safe disposal of waste products

Major engine repair: procedures, e.g. strip and inspect bore and crankshaft journals for wear, cylinder head for distortion, valves for seating and damage; working to instructions, e.g. manufacturer's repair manuals, web-based information, dealership work schedules/job cards/supervisor's instructions; use of tools and equipment, e.g. engine crane, chains, slings, torque wrenches, micrometers, dial test indicators (DTI), timing tools, locking devices, cleaning equipment; safe working procedures, e.g. personal and vehicle protection (personal protective equipment (PPE), vehicle covers, mats), manual handling, use of lifting and support equipment, use of cleaning solvents; safe disposal of waste products

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating cycles of two different internal combustion engines	**M1** compare the advantages and disadvantages of the design and performance of two different engine configurations and layouts	**D1** evaluate the suitability of an engine used for a current vehicle application, in terms of its layout, operation and performance
P2 explain the vehicle design and performance implications of an engine's configuration and layout		
P3 explain the function, operation and construction of the components/ assemblies of one type of engine		
P4 explain the effects of different air-fuel ratios on the petrol combustion process and exhaust emissions		
P5 explain the diesel combustion process		
P6 describe an application of an alternative fuel/power supply system	**M2** compare a conventional fuel system with that of an alternative fuel/power source	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 explain the principles of operation and difference between an air-cooled and a water-cooled engine	**M3** compare the advantages and disadvantages of two different engines in terms of their fuel, cooling and lubrication systems	
P8 explain the layout, system components and operation of two different engine lubrication systems		
P9 carry out a routine engine service by following given instructions		
P10 prepare a work schedule for a major engine repair procedure.	**M4** carry out the repair procedure in line with the schedule.	**D2** evaluate the effectiveness of the work schedule.

Essential guidance for tutors

Assessment

Tutors should design a varied assessment strategy that could include research and investigate tasks, set piece service/repair activities and technical reporting.

While assessment methods must reflect the unit content, they should also recognise the need to keep up to date with current components, systems, applications and working practices. The examples given in the unit content reflect current practice but could be replaced with more relevant and up-to-date examples as technology changes, without affecting content coverage. For example, the content for lubrication control systems has the examples 'sensors, level indicator (mechanical, electrical)' but advances in digital/computer-based engine management systems could make mechanical sensors obsolete in the not too distant future.

There are no fixed ways in which the unit should be assessed or the number of assessment instruments that might be used. The maximum number of assignments is likely to be five, one for each of the first three learning outcomes and two for the last. However, there are strong links between all the pass criteria and across the merit and distinction criteria. Tutors should endeavour to make the most of these links to keep the number of assessment instruments to a minimum.

One approach might be to design two project-style assignments that run in parallel to each other. Each project would focus on a particular engine and learners would study the engine's operating cycle, configuration and layout, combustion process, cooling and lubrication systems. They would then carry out a routine service on one engine and a major repair on the other.

To meet all the requirements of the criteria, one engine should use petrol combustion and the other diesel. One allowance on this would be to incorporate an alternative fuel such as LPG. Special considerations in the project brief would need to be applied to P2 and P3, which only need to be covered for one engine (although the configuration and layout of the second engine would need to be considered to achieve M1). Additional tasks would probably need to be included in the project brief to enable learners to achieve P6 (alternative fuel/power supply system) and P7 (differences in operation of an air- and a water-cooled engine). P6 could be achieved through a 'what if' scenario in one of the projects (for example consider an alternative fuel/power supply system for the vehicle being considered). P7 could be achieved by ensuring that one engine is air-cooled and the other water-cooled. However, as this situation is unlikely to occur, a 'what if' scenario could also be set in one of the projects (for example if the water-cooled engine had been air-cooled then explain the principles of operation and differences that would apply).

Running the two projects in parallel would ensure that assessment could follow delivery, and also that the criteria would not need to be fragmented (i.e. visited twice at different times before they could be achieved). Opportunities to achieve the merit and distinction criteria could also be built into the projects with some imagination and careful planning.

Whatever form of assessment is used, the tasks set will need to ensure that for P1 learners are able to explain the operating cycles of two different internal combustion engines (i.e. selecting two from the list of examples in the unit content). For each engine, learners should explain the engine's operating cycle by using suitable diagrams to indicate pressure-volume within the cycle, engine performance (torque/power) and engine efficiencies (for example engine timing, pressure charging and applicable compression ratios).

For P2, learners must explain the vehicle design and performance implications of an engine's configuration and layout. They need to take into account the orientation (longitudinal/transverse), position of engine (front, mid and rear), cylinder arrangement, cylinder configuration, the purpose for which the vehicle has been designed and its expected performance (see examples in the unit content). The key question for learners to address and consider is – why that engine for that vehicle?

To achieve P3, learners need to explain the function, operation and construction of the components/assemblies of one type of engine (for example a four-stroke SI engine or a four-stroke CI engine). Their explanation should include details of the engine's main components and assemblies (i.e. cylinder block, cylinder head, flywheel, inlet and exhaust manifolds).

Criteria P4, P5 and P6 focus on fuel systems. For P4, learners need to focus on a petrol engine and explain the effects of different air/fuel ratios on the petrol combustion process and exhaust emissions. This should include an introduction to fuel principles (for example composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio) the combustion process, effects of pollutants and causes of undesirable symptoms. Learners should also consider the fuel supply method and fuel system components (for example tank, petrol filter, air filter). This could be set within the context of the particular petrol engine/vehicle being studied.

A similar approach is required for P5 but this time learners need to explain the diesel combustion process. Learners should explain diesel fuel principles, the combustion process, exhaust emissions, fuel supply method and fuel system components for either low pressure or high pressure diesel fuel systems.

For P6, learners must describe an application of an alternative fuel/power supply system. This can either be given by the tutor or chosen by the learner.

Learners should describe the system (for example LPG, natural gas, hydrogen, hybrid) and how traditional components have been adapted and/or any necessary additional components. They should also describe the relevant aspects of legislation that apply to these alternative fuel/power supplies. This should be set within the context of a particular vehicle.

P7 and P8 are closely linked and require learners to consider the fundamental differences between common cooling and lubrication systems. They can also be extended through to M3.

For P7, learners need to explain the principles of operation of and the differences between an air- and a water-cooled engine. Learners need to identify the types of system being considered (for example for an air cooled engine the cylinder construction, fan, shutters etc, for a water cooled engine the radiator, radiator cap, expansion tank etc). For each engine, learners will need to consider the cooling control systems used and the relevant aspects of the engine management system with respect to engine cooling.

For P8, learners need to explain the system components, layout and operation of two different engine lubrication systems. This should include the respective system components (for example wet/dry sumps, oil pump, pressure relief valve), engine oil types and filtration methods, lubrication control systems, pressure sensors and low pressure safety system.

P9 and P10 form the focus of the practical assessment for this unit. Learners need to carry out a routine engine service and a major engine repair following given instructions. Examples of typical routine servicing and major repairs are given in the unit content, although these are not exclusive. Other service activities or repairs of an equivalent level of difficulty would be acceptable.

Assessment evidence for P9 and P10 is likely to be in the form of learners' personal log/record of the work undertaken plus relevant tutor observation records. Learners may also wish to use suitably annotated photographic evidence to support both their log/record and tutor observation. The evidence must indicate the service and repair procedures carried out, the instructions followed, the tools and equipment used and the safe working procedures followed, including safe disposal of waste products.

To achieve M1, learners need to further consider the design and performance of two different engine configurations and layouts by comparing the advantages and disadvantages of each.

For M2, learners must compare a conventional fuel system with that of an alternative fuel/power source. This can be linked with the work undertaken for P4, P5 and P6. The comparison should be in terms of the same aspects covered for the pass criteria (for example the fuel/power principles, combustion process, adapted/additional components, effects of pollutants/causes of undesirable emissions, fuel/power supply methods, fuel/power system components, relevant legislation). Again, evidence for this criterion is likely to be in the form of a written report and learners may make use of suitable images, as detailed for D1 below.

To achieve M3, learners need to build on their understanding of fuel, cooling and lubrication systems (P4 to P8) to compare the advantages and disadvantages of two engines with respect to these systems.

For M4, learners need to prepare a work schedule for a major engine repair procedure, carry out the repair and evaluate the effectiveness of the work schedule. Learners are expected to carry out a second (and different) major engine repair to achieve the merit criterion. It is not sufficient for learners just to prepare the work schedule and carry out a single repair in order to achieve P10 and M4. The object of the assessment at pass level is to establish whether learners can competently complete a given major repair under supervision/guidance. However, at merit level they are expected to demonstrate independence and reflection. This can be extended to incorporate an evaluation of the effectiveness of the work schedule (D2).

For D1, learners need to evaluate the suitability of an engine for a current vehicle application. This should be done in terms of the engine's layout, operation and performance. It is expected that the evidence presented will include a detailed evaluation of the particular vehicle's engine (for example type, power, layout, main components, fuel, lubrication systems). Having evaluated the engine in this way, learners should then arrive at a reasoned justification for the manufacturer's choice based on their own findings.

Evidence for D1 is most likely to be in a written format but learners could also include diagrams, photographs or other visual means to illustrate their work. Where images are not learners' own work credit must be given to the originator. Learners should suitably annotate these images to indicate how they support their report.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Principles and Operation of Engines	A technician needs to explain to a new learner the different internal combustion cycles, the design and performance implications of an engine layout and the operation and construction of the components and sub-assemblies.	A written report supported by relevant annotated diagrams.
P4, P5, P6, M2	Fuel Systems	A technician needs to explain the differences between diesel, petrol and alternative fuel systems to a learner.	A written report/presentation supported by relevant annotated diagrams.
P7, P8, M3	Cooling and Lubrication Systems	A learner needs to investigate a vehicle's cooling and lubrication systems.	A written report supported by relevant annotated diagrams.
P9	Routine Engine Servicing	A technician needs to carry out a routine engine service to give the opportunity of vocational tasks in employment.	Workshop practical activity with associated documentary evidence to reflect industrial methods and standards. Observation records and annotated photographs would also be suitable supporting evidence.

Criteria covered	Assignment title	Scenario	Assessment method
P10, M4, D2	Major Engine Repair Procedures	A technician needs to carry out a major engine repair.	Workshop practical activity with associated documentary evidence and a written evaluation, to include data collation aligned to full list of tools and equipment utilised. Observation records and annotated photographs would also be suitable supporting evidence.

Essential resources

Centres will need to provide learners with access to a suitable workshop, equipped to modern standards with live vehicles, test rigs and components that reflect current technology and working practices.

Indicative reading for learners

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney M – *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 45: Vehicle System Fault Diagnosis and Rectification

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Although technological advances have led to increasingly reliable mechanical, electrical and electronic vehicle systems, for a variety of reasons these systems still fail. When a fault develops, it is more important than ever to carry out a quality repair from an operational, safety and often a legal standpoint.

Learners will be expected to diagnose and undertake work on faults in vehicle mechanical and electrical/electronic systems regardless of the manufacturer or vehicle type (for example light or heavy vehicle, passenger carrying vehicle, motorsport vehicles). Learners will identify, select and use a range of diagnostic tools and equipment, checking that they are in a safe and useable condition before use.

For the purpose of this unit, a fault may be considered to be a component failure or system malfunction relating to mechanical or electrical and electronic systems, individually or in combination.

When diagnosing faults, learners will need to work in a logical manner, working to instructions obtained from appropriate sources. Safe working practices and good housekeeping are a recurrent theme throughout the unit.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to identify vehicle system faults

2 Be able to prepare and use diagnostic equipment and procedures to identify and confirm faults

3 Know alternative rectification procedures

4 Be able to rectify faults and confirm system integrity.

Unit content

1 Be able to identify vehicle system faults

Mechanical system: systems, e.g. engine (pistons, belts, chains, bearings, shafts), ancillary systems (fuel, lubrication, cooling), transmission (clutch, torque converter, gearbox, rear axle, differential), steering and suspension, braking; faults, e.g. internal engine component failure, failed head gasket, failed seal, fuel blockage, contamination (oil, fuel, coolant, hydraulic and pneumatic fluid), non-starting, low/high oil pressure, faulty coolant system, clutch malfunction, damaged clutch linkages, bearing failure (engine, clutch, pump, rear axle/differential), selector mechanisms malfunction, gear selection difficult, faulty torque converter hydraulic components, worn gear, worn drive shaft/joint, misalignment (drive shafts, steering/suspension), defective steering/suspension components, inoperative braking system (faulty caliper, worn disc); symptoms, e.g. unusual sounds, noisy bearings, leaks, smoke, metallic particles in lubricants, loss of power, exhaust gas contamination, misfire, engine overheating/overcooling, water contamination, clutch (slip, grab, judder, difficult selection), vibration, unusual tyre wear, poor brake efficiency, brake noise and judder, braking imbalance, excessive brake pedal travel, poor road handling, oversteer, understeer

Electrical/electronic system: systems, e.g. starting, charging, ignition, lighting and auxiliary, control systems (electronic, instrumentation, engine); faults, e.g. starting system sluggish or non-operational, battery faults, alternator malfunctioning, diode faults, electronic control not working, fuse problems, damaged or loose wire, inoperative ignition components, ignition timing faults, inoperative systems, headlamp misalignment, instrumentation malfunction, driver information malfunction, engine management malfunction, chassis control system malfunction (anti-lock braking system (ABS), stability control, transmission control), security and alarm systems failure; symptoms, e.g. noisy operation, no charge, over charging, short circuit, open circuit, misfire, non-starting, incorrect information, inaccurate displays, confused control

2 Be able to prepare and use diagnostic equipment and procedures to identify and confirm faults

Preparation: adherence to regulations, e.g. Provision and Use of Work Equipment Regulations (PUWER), Control of Substances Hazardous to Health (COSHH) Regulations, Lifting Operations and Lifting Equipment Regulations, Manual Handling Operations Regulations (MHOR), Personal Protective Equipment (PPE) at Work Regulations, Confined Spaces Regulations, Electricity at Work Regulations, Control of Noise at Work Regulations, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR), Health and Safety (First-Aid) Regulations, motorsport specific; positioning, e.g. use of ramps, jacks, stands; vehicle protection, e.g. covers, sheeting; component/system access, e.g. removal of bodywork, fairings and covers, removal of excessive oil, dust, grease and dirt, competition/road debris

Diagnostic equipment: mechanical equipment, e.g. dial gauges, micrometers, feeler gauges, pressure gauges, specialist equipment, e.g. auto transmission test equipment, steering geometry and suspension alignment equipment, wheel balancing and brake testing equipment; electrical and electronic equipment, e.g. meters, multimeters, oscilloscopes, diagnostic analysers, data logging/ self-diagnosis equipment, emissions testers, computer systems

Diagnostic procedures: reference to considerations of safety and vehicle/system protection; procedures, e.g. visual, aural, performance monitoring, road and roller tests, procedures used with electrical, electronic and systems diagnostic equipment; assessing vehicle information systems and data in a variety of formats, e.g. workshop manuals, diagnostic information, Dvds, IT-based data retrieval systems and fault code analysers

3 Know alternative rectification procedures

Rectification procedures: e.g.

- dismantling, inspection and assessment: comparison against specifications (manufacturer, vehicle data, auto data, computer-based systems), factors influencing rectification choice (operational, cost, safety and legal requirements)
- adjustments: associated with the range of vehicle systems, manufacturers' specifications (tolerances, operational limits), safety, performance and legal considerations
- replacement: using new, overhauled and factory or third party reconditioned components and units
- repair: in-house or third-party specialist repair options, comparison of cost of replacement/repair including consideration of service life expectancy, reliability and warranty status
- substitution/alteration: use of adapted, redesigned or re-engineered components and/or units and effects of substitution (based on comparisons of specifications, manufacturers' bulletins, safety and service recommendations)

4 Be able to rectify faults and confirm system integrity

Rectify faults associated with mechanical systems: e.g. engine and ancillary systems, transmission, steering, wheels and tyres, suspension and braking systems

Rectify typical faults associated with electrical/electronic systems: e.g. starting, charging, ignition, lighting and auxiliary systems, vehicle instrumentation, driver information, engine management, chassis control (ABS, stability control, transmission control), security, driver information and alarm

Equipment: hand tools; MOT equipment; product specific equipment; for mechanical systems, e.g. measuring equipment, analysers, on-board diagnostics, alignment equipment, balancing equipment; for electrical/electronic systems, e.g. scanning equipment meters

Documentation to confirm system integrity: manufacturers' specifications and data; legal requirements; performance test data

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 diagnose two mechanical system faults on two different vehicles from given symptoms	**M1** justify the use of the equipment chosen to diagnose selected system faults with reference to the expected accuracy of the results obtained	**D1** evaluate the use of diagnostic test equipment
P2 diagnose two electrical system faults on two different vehicles from given symptoms	**M2** compare the advantages and disadvantages of two diagnostic procedures	
P3 prepare two vehicles for fault diagnosis		
P4 use appropriate diagnostic equipment and procedures to diagnose faults on two different mechanical systems on two different vehicles		
P5 use appropriate diagnostic equipment and procedures to diagnose faults on two different electrical systems on two different vehicles		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe an alternative rectification procedure for two faults on different mechanical systems		
P7 describe an alternative rectification procedure for two faults on different electrical/ electronic systems		
P8 carry out rectification procedures on two different faulty mechanical systems, conforming with manufacturers' specifications and safety and legal requirements	**M3** justify the selection of a rectification procedure in terms of safety, cost, performance and legal considerations.	**D2** evaluate one rectification procedure carried out and make recommendations for improvement.
P9 carry out rectification procedures on two different faulty electrical/electronic systems, conforming with manufacturers' specifications and safety and legal requirements		
P10 use appropriate equipment, procedures and documentation to confirm system integrity.		

Essential guidance for tutors

Assessment

This unit is likely to be assessed through a combination of assignments and practical workshop investigations.

It is expected that learners will have carried out practical work on vehicles to support their underpinning knowledge. Evidence will include test data, printouts and records of diagnostic procedures carried out and supported by witness statements/observation records supplemented by annotated photographs.

The emphasis of this unit is on developing practical fault diagnostic and rectification skills across a range of mechanical and electrical/electronic vehicle systems. Learners should be given opportunities to diagnose typical faults, recommend repair strategies and carry out fault rectification. This should be based on diagnostic information and other criteria such as safety, cost, operational and legal requirements. It is expected that learners will be given opportunities to use and compare alternative diagnostic procedures and equipment in practical situations.

To achieve the pass criteria associated with learning outcome 1 (P1 and P2), learners should diagnose faults on two mechanical and two electrical systems on two different vehicles from given symptoms. This means there will be a total of eight faults to diagnose. It is likely that only one symptom for each fault will be sufficient. However it may be beneficial to learners if more symptoms can be given or arranged.

For P3, learners will need to prepare two vehicles for fault diagnostic checking. They will need to diagnose faults on two mechanical systems (P4) and on two electrical systems (P5), on two different vehicles faults prior to rectification. Learners should select and access sources of data to help with the fault diagnosis and also select, prepare and use the appropriate diagnostic equipment to carry out the tasks.

To achieve P6 and P7, learners need to describe an alternative rectification procedure for faults on two mechanical systems and two electrical/electronic systems. Although the rectification procedures described for the two electrical/electronic systems or two mechanical systems need to be different, procedures described for P6 can be used again in P7. The rectification strategies described could relate back to the different faults identified for P1 and P2.

For P8 and P9, learners will apply their knowledge by carrying out the rectification process, conforming to the manufacturer’s specifications, safety and legal requirements, for two different mechanical and two different electrical/electronic systems.

When confirming system integrity for P10, the equipment that could be used is listed in the unit content under learning outcome 4, although other equipment, such as that listed under learning outcome 2 as diagnostic equipment, is also appropriate. Confirmation of system integrity should include comparing results against manufacturers’ specifications and data, legal requirements and performance test data.

Throughout the assignments, it is expected that the faults will be on different systems and may be on different vehicles at different times. The vehicles could, however, be of the same type (for example both goods vehicles and motorsports vehicles if this is appropriate) or different types. The intention is to give learners experience of a diverse range of vehicle system faults across different vehicles so that they have the opportunity to satisfy all the grading criteria with sufficient depth and rigour.

To achieve M1, learners should justify the use of the equipment selected to diagnose system faults, with reference to the expected accuracy of the results obtained.

This should demonstrate learners' ability to progress from knowing how to select and use the equipment to justifying the reasons for using the correct equipment and possible consequences of not doing so.

For M2, learners should compare the advantages and disadvantages of alternative diagnostic procedures, including the use of dedicated test equipment in the context of the fault diagnosis being carried out. Learners should justify the selection of a rectification procedure (M3) in terms of safety, cost, performance and legal considerations. All responses to tasks set for the merit criteria are likely to be in the form of written outcomes.

To achieve a distinction, learners should evaluate the use of diagnostic test equipment giving reasons for the advantages and disadvantages (D1). Learners will also need to evaluate a vehicle rectification procedure and make recommendations for improvement (D2). These criteria can be met through responses to written tasks after all pass criteria have been carried out and data obtained from the practical tasks for D1.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, M1, M2, D1	Identifying and Diagnosing Faults	A vehicle technician needs to diagnose and diagnose vehicle system faults using diagnostic equipment.	Practical work evidenced through records/log of work carried out and observation records.
P6, P7	Alternative Rectification Procedures	A vehicle technician needs to propose alternative rectification procedures to be used for vehicle system faults.	A written task.
P8, P9, P10, M3, D2	Rectifying Faults	A vehicle technician has to rectify faults and confirm system integrity.	Practical work evidenced through records/log of work carried out and observation records.

Essential resources

A range of vehicle types and equipment is needed for delivery of this unit. This will include manufacturer/vehicle-specific equipment (for example for engine management, ABS, security and other advanced systems) and non-manufacturer/vehicle-specific equipment (for example meters, oscilloscopes). A variety of data sources will also be required to support the range of vehicles, systems, equipment and procedures used.

Indicative reading for learners

Textbooks

Bonnick A – *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998) ISBN 9780340706305

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney M – *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 46: Applications of Vehicle Science and Mathematics

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will develop learners' knowledge of mathematical and scientific principles and their application in the vehicle technology environment. This can be in a variety of vocational areas, such as the fine detail needed in the calculations in motorsport or the crucial calculations required when working with large commercial vehicles.

Learners will carry out data collection and manipulation in vehicle-related areas such as speed, acceleration and power. They will complete a variety of practical activities, including carrying out an engine performance test and comparing the outcomes to scientific calculations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to apply mathematical and statistical methods to vehicle-related tasks

2 Be able to apply fundamental algebraic laws and trigonometric ratios to solve vehicle-related tasks

3 Be able to apply scientific principles related to heat, force and machines to solve vehicle-related tasks

4 Be able to carry out engine testing and apply scientific principles to determine vehicle and engine performance.

Unit content

1 Be able to apply mathematical and statistical methods to vehicle-related tasks

Data for vehicle-related tasks: data, e.g. engine speed, stopping distance, miles per gallon, brake pad life, vehicle speed, acceleration, wheel bearing life; sources, e.g. manufacturers, workshop experiments, **diagnostics**, publicly available figures (such as media, internet); considerations, e.g. types of error, accuracy, representation

Mathematical methods: methods, e.g. addition, subtraction, multiplication, division, use of brackets, order, estimation techniques, use of calculators, expressing numbers using standard form and scientific notation, e.g. 5.6×10^5, 12×10^3 W, 12 kW; features, e.g. ratio and proportion, percentage, real and integer numbers, binary systems, vulgar and decimal fractions, ratios, direct and inverse proportion, roots and powers (such as $v = \sqrt{2gh}$, $I = \sqrt{\frac{P}{R}}$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, if $\frac{1}{2}mv^2 = mgh$ find v)

Data manipulation and graphical representation: data represented in graphical format, e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table, variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves; **spreadsheets**

Statistical information: arithmetic mean; median; mode; discrete and grouped data

2 Be able to apply fundamental algebraic laws and trigonometric ratios to solve vehicle-related tasks

Linear equations and graphs: linear equations, e.g. $y = mx + c$; straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph $y = ax^2 + bx + c$

Factorisation and quadratics: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor, e.g. $ax + ay$, $a(x + 2) + b(x + 2)$; by grouping, e.g. $ax - ay + bx - by$; quadratic expressions, e.g. $a^2 + 2ab + b^2$; roots of an equation, e.g. quadratic equations with real roots by factorisation, and by the use of formula

Trigonometric ratios: basic ratios, e.g. sine, cosine, tangent; $\frac{\sin\theta}{\cos\theta} = \tan\theta$

Vehicle-related tasks: algebraic application, e.g. Ohm's law, pair of simultaneous linear equations in two unknowns (two linear or one linear and one quadratic), acceleration 30 to 50 mph, time taken to cover a given distance when subjected to constant acceleration, volume and area of combined shapes, e.g. swept, clearance volume, loading capacity, workshop areas; trigonometric application, e.g. steering and suspension angles, valve timing, wiper motion angles

3 Be able to apply scientific principles related to heat, force and machines to solve vehicle-related tasks

Force: laws of friction; friction in a clutch; stress and strain; Young's modulus; forces in tension/compression; vehicle component subjected to tension/compression, e.g. tie rod, cylinder head bolt, push rod, valve stem, piston, connecting rod, braking components

Heat: gas laws, e.g. Boyle's law, Charles' law, general gas equation $\frac{pV}{T} = c$, ideal gas equation $pV = mRT$; change of dimension, e.g. linear, superficial, cubical, heat dissipation; pressure, e.g. hydraulic, gas; gauge pressure, atmospheric pressure

Machines: ratios, e.g. steering box, gear ratio, final drive ratio, compression ratio; vehicle mechanism, e.g. alternator and power steering, pulleys, winches, levers, brake operation, cylinder, gearbox

4 Be able to carry out engine testing and apply scientific principles to determine vehicle and engine performance

Vehicle performance: equations of motion; Newton's laws; performance, e.g. work, power, velocity, acceleration, retardation

Engine testing: safe use of equipment, e.g. rolling road, dynamometer rig, engine analyser; collection of data, e.g. torque, power (indicated and brake), fuel consumption

Engine performance: performance to report on, e.g. torque, power (indicated and brake), mechanical efficiency, thermal efficiency, volumetric efficiency, specific fuel consumption, brake mean effective pressure, indicated mean effective pressure; presentation within report, e.g. engine indicator diagrams, calculations using data (such as efficiency, frictional loss, temperature variations)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain what should be considered before using data gathered from different sources		
P2 use mathematical methods for different features to manipulate collected data and present statistical information in a graphical format		
P3 solve a linear equation by plotting a straight-line graph, using given experimental data, and use it to deduce the gradient, intercept and equation of the line for a vehicle-related task	**M1** solve a pair of simultaneous linear equations in two unknowns	**D1** solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P4 factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	**M2** solve a quadratic equation by factorisation and one by the formula method	
P5 use trigonometric ratios to solve two vehicle-related tasks		
P6 use the laws of friction to find the friction in a clutch		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 determine Young's modulus for a given tension/compression on a given vehicle component		
P8 use a gas law to determine the change in dimensions of the gas		
P9 describe how ratios help a given vehicle mechanism function properly		
P10 calculate vehicle performance using Newton's laws and the equations of motion	**M3** explain, with examples, the importance of the accuracy of data that is used to solve a range of problems related to engine and vehicle performance.	**D2** compare actual data and calculated data for engine or vehicle performance.
P11 carry out engine testing to obtain data and report on engine performance.		

Essential guidance for tutors

Assessment

For P1, the collation of data should be made vocationally relevant by using vehicle-related subject areas such as engine power to stroke or fuel consumption to capacity. A variety of sources should be used, for example manufacturers' or internet sites. An explanation of the considerations to be taken into account before using the data should be included.

For P2, the methods (for example add, subtract etc.) and features (for example ratio or percentages etc.) need to be completed before graphical presentation. This can be in a variety of formats (for example bar and pie charts, frequency distribution tables). This could be achieved by using computer-based software packages, although care must be taken to ensure authenticity of the evidence provided. Learners need to calculate mean, median and mode for discrete and grouped data. The graphical format used must include at least one from bar charts, pie charts, frequency distributions and frequency table. It should also include a histogram (continuous and discrete variants) and a cumulative frequency curve.

The evidence for P3 could be generated using vehicle speed and timing and the task set should ensure that gradient, intercept and the equation of the line can be presented in the evidence. P4 should also use vehicle-related formulae where possible.

Assessment of M1 and M2 can be linked to that for P3 and P4. If a vehicle context is difficult to apply, then P4, M1 and M2 could be achieved through a purely mathematical context. However, P4 will require a range of tasks that allows expressions with two, three and four terms. Each task is therefore likely to have a different vehicle-related algebraic application or mathematical scenario.

For P5, the use of steering geometry or piston displacement could give vocational relevance when using one basic ratio and $\frac{\sin\theta}{\cos\theta} = \tan\theta$ to calculate angles and length of steering components. This could be integrated with other units that cover vehicle componentry applications.

The evidence for P6 and P7 would naturally link to clutch or brake linings and the use of components for applying loads, such as handbrake cables, to determine Young's modulus.

Assessment of P8 could be integrated with that of other units. The task used should focus on vocational gas applications, such as within engine technology, suspension or brake systems. The task should enable learners to use one of the gas laws outlined in the unit content and must include data on pressure.

Using a system application such as the handbrake, complete with its lever mechanism, would enable learners to generate evidence for P9. There needs to be clear direction to ensure that responses include a description of how mechanical ratios help the system function.

For P10, learners will need to produce evidence of calculating vehicle performance using Newton's laws and the equations of motion. This should be contextualised to their intended vocational area (for example light vehicle, heavy vehicle, motorsport).

For P11, learners will need to complete engine testing to obtain a range of performance data, as set out in the unit content. Assessment of P11 could be linked to that for M3 and D1 and would need to be completed after achievement of P1.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Mathematical and Statistical Methods	A vehicle technician needs to use mathematical methods and gather and manipulate data.	Written responses to set tasks.
P3, P4, P5, M1, M2	Algebraic Laws and Trigonometric Ratios	A vehicle technician needs to use algebraic laws and trigonometry.	Written responses to set tasks.
P6, P7, P8, P9	Heat, Force and Machines	A vehicle technician needs to use the laws of friction, gas laws and ratios.	Written responses to set tasks.
P10, P11, M3, D1, D2	Vehicle and Engine Performance	A vehicle technician needs to calculate vehicle performance and carry out engine testing.	Written responses to set tasks and a report of engine performance based on practical engine testing.

Essential resources

As a minimum, centres will need to provide learners with access to workshop facilities to enable practical investigation and assessment of friction, Young's modulus, ratios, measuring bores and complete calculations linked to gas laws etc.

Indicative reading for learners

Bonnick A – *Automotive Science and Mathematics* (Routledge, 2008) ISBN 9780750685221

Greer A, Fuller A and Taylor G W – *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Twigg P – *Science for Motor Vehicle Engineers* (Elsevier, 1995) ISBN 9780340645277

Unit 47: Electrical and Electronic Principles for Vehicle Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

In this unit, learners will gain an understanding of electrical and electronic principles through the analysis of direct current (DC) motor vehicle electrical circuits. Learners will be introduced to the principles and properties of magnetism as applied to motor vehicle circuit devices.

Learners will examine the concepts of digital electronic principles and microprocessor applications in motor vehicles. They will be introduced to single-phase alternating current (AC) theory as applied to vehicle alternators. They will consider waveform characteristics and determine the values (using phasor and algebraic representation and actual waveform measurements using an oscilloscope) of alternating quantities.

This unit has been designed to encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits
2. Understand the principles, properties and applications of magnetism in motor vehicle technology
3. Know the concepts of digital principles and applications of microprocessors in motor vehicles
4. Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance.

Unit content

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits

DC circuit theory: voltage, e.g. potential difference, electromotive force (emf); resistance, e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source, e.g. battery, stabilised power supply; resistors, e.g. function, types, values, colour coding; diodes, e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae, e.g. $V = IR$, $P = IV$, $W = Pt$; application of Kirchoff's voltage and current laws

DC motor vehicle circuits: circuits to include a DC power source, four components including circuit protection and switching arrangement; vehicle applications, e.g. lighting circuits (side and rear lamp, main and dip headlamp, front and rear fog lamps, stop lamp, reverse lamp, indicator and hazard warning system), auxiliary circuits (horn, window winding, central locking, interior heater, rear screen heater), vehicle security systems, air-conditioning, use of relays, circuit protection devices (DC power source circuit protection fuse and resistors (series/parallel)), operating component(s) such as motor assembly; diode resistor circuit with DC power source, series resistors and diodes, e.g. bulb failure circuit, low oil pressure circuits, alternator rectifier

Measurements in DC motor vehicle circuits: safe use of a multimeter, e.g. setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source); testing a diode's forward and reverse bias

2 Understand the principles, properties and applications of magnetism in motor vehicle technology

Characteristics of magnetic field: field patterns (flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops); ferromagnetic materials; reluctance; magnetic screening; hysteresis

Electromagnetic induction: principles, e.g. induced emf, eddy currents, self and mutual inductance; motor vehicle applications (electric motor/generator, e.g. series and shunt motor/generator, transformer, e.g. primary and secondary current and voltage ratios); motor vehicle applications of Faraday and Lenz's laws, e.g. electrical induction in an alternator, electromagnetic coil

3 Know the concepts of digital principles and applications of microprocessors in motor vehicles

Digital principles: binary system, e.g. binary notation and algebra, bits and bytes, input/output (I/O) voltage levels; logic system, e.g. AND, OR, NOT NAND and NOR gates; truth tables, memory circuits, sequential and clocked circuits, flip flops, read-only memory (ROM)/random-access memory (RAM) structures and organisation; timers; digital to analogue (D/A) and analogue to digital (A/D) converters; types of integrated circuits, e.g. classification, operation, performance characteristics and identification; vehicle applications, e.g. fault diagnosis, code readers, data logging, visual/audio output, speed sensor processing, engine timing control, satellite navigation

Microprocessors: microprocessor system, e.g. programmes, language, I/O interface, memory; construction of microprocessor, e.g. control section, arithmetic and logic sections, register section, memory, I/O section buses, fetch and execute cycle, control by clock pulses; motor vehicle application of microprocessors, e.g. engine management, anti-lock braking systems (ABS), climate control, suspension settings, transmission modes

4 Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance

Single-phase AC circuit theory: waveform characteristics, e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities, e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure resistor (R), inductor (L) and capacitor (C) components

Alternator performance: safe use of an oscilloscope, e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theory to calculate current, voltage and resistance in three different motor vehicle circuits	**M1** use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes and the power dissipated in a load resistor containing two voltage sources	
P2 use a multimeter to carry out circuit measurements in three different DC motor vehicle circuits		
P3 describe the forward and reverse characteristics of two different types of semi-conductor diode		
P4 describe the characteristics of a magnetic field		
P5 explain the relationship between flux density (B) and field strength (H)		
P6 describe how the principles of electromagnetic induction apply to a given motor vehicle application	**M2** explain the application of electromagnetic induction in vehicle motors and generators	**D1** evaluate the performance of a motor and a generator used in a motor vehicle system by reference to electrical and electronic theory.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe two different vehicle system applications of digital principles	**M3** compare the function and principles of operation of two different vehicle applications of microprocessors	
P8 describe the function and operation of two different vehicle system integrated circuits		
P9 describe the function and operation of a vehicle system microprocessor		
P10 use single-phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform	**M4** compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	**D2** analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and resistor.
P11 use an oscilloscope to measure and determine the performance of a vehicle alternator.		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria could be generated through practical experimentation and investigation with real components and circuits and computer-based software packages.

It is likely that at least five assessment instruments will be needed for this unit. If practical work and tests are also used, then the total number of pieces of assessed work could be more. This should be considered carefully so as to not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. Alternatively, practical work could be observed by the tutor/witness and a record of observation used for assessment evidence. Both of these methods will help in ensuring authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Evidence of the use of DC circuit theory to calculate current, voltage and resistance in three different motor vehicle circuits (P1) could be produced by using paper- or computer-based methods. Between them, the three motor vehicle circuits need to be chosen to cover the required aspects of the unit content. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, tutors need to ensure that there is sufficient product evidence of the circuit being used/developed and the formulae selected to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where printouts do not show sufficient detail to meet the criterion.

The ability to use a multimeter to carry out circuit measurements in three different DC motor vehicle circuits (P2) will require process evidence (i.e. it will need to be observed by the tutor or assessor during relevant practical activities on motor vehicle applications). This could be the end product measurement of circuits being assessed for P1. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The description of the forward and reverse characteristics of two different types of semiconductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box. This could be a progression from P1/P2 and could be set up on a vehicle for learners to build, test and compare against data and detail provided.

The characteristics of magnetic fields (P4) could be demonstrated on an overhead projector OHP by using magnets and iron filings. Learners could sketch or be given a handout of the results and then make appropriate comparisons with expected theoretical results. The relationship between flux density and field strength (P5) may be set in the context and use of different materials such as silicon, iron and mild steel use in vehicles examples could include coil, relay and starter operation.

Evidence for P6 will be descriptive and learners will need to consider the movement of a conductor within a magnetic field in vehicle examples such as alternators, starters and solenoids.

For P7, learners need to describe two different vehicle system applications of digital principles. It is expected that one of these will involve the application of a binary system and the other a logic system, including D/A and A/D converters, as appropriate to the particular vehicle application. There is a strong link between P7 and P8, which could be used to good effect if the vehicle system applications of digital principles (P7) enables learners to describe the function and operation of two different vehicle system integrated circuits (P8).

For P9, a practical investigation of a microprocessor application for a selected vehicle system, combined with a descriptive task, could be used. The investigation and report needs to focus on the microprocessor system being applied and its construction. Typical motor vehicle applications of microprocessors could be engine management, anti-lock braking systems, climate control, suspension settings or transmission modes.

P10 requires learners to use single-phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform. This should include waveform characteristics and the determination of values using phasor and algebraic representation of alternating quantities. There is a useful link here with P11 and an assignment could be structured to provide a relevant link between the theory and application of AC to a vehicle.

All the merit and distinction criteria have close links with the pass criteria and tutors should try to design their assignments around these links.

M1 relates to the use of Kirchoff's laws and naturally follows on from learners' use of DC circuit theory to calculate current, voltage and resistance in P1. To achieve M1, learners need to use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes, and the power dissipated in a load resistor containing two voltage sources. Learners should be encouraged to use computer-based simulation to check their calculations.

M2 is an extension of P6 requiring an explanation of the application of electromagnetic induction in vehicle motors and generators.

M3 links to P9 and is designed to encourage learners to take a wider and deeper look at the application of microprocessors in motor vehicles. It is important to keep in mind that the comparison should be based on the original findings for P8 (i.e. the microprocessor system being applied and its construction).

M4 is an extension of P10 and P11, for which learners will have demonstrated an ability to work with a single sinusoidal AC waveform. To achieve M4, learners need to compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram. There are possible links outside of this unit, for example to *Unit 46: Applications of Vehicle Science and Mathematics*.

D1 requires learners to evaluate the performance of a motor and a generator used in a motor vehicle system by reference to electrical and electronic theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines for example alternator output, motor applications such as door or window operating systems.

For D2, learners must analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and a resistor. To achieve this, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of damaging a vehicle's system. This could be achieved using a function generator, alternating voltage or variable power source, along with a small isolating transformer, diode rectifiers (half wave and bridge) and load resistors in circuits such as alternator applications, bulb failure warning systems or data input devices.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	DC Circuit Theory, Measurement and Diodes	A technician needs to complete measurements using a multimeter in a DC network and compare the characteristics of two different types of semi-conductor diode.	Practical assignment evidenced by learner records and tutor observation records.
P4, P5, P6, M2, D1	Magnetism, Transformers and Motor/Generators	A technician needs to explain to a new learner the characteristics of magnetism and help them evaluate the performance of a motor and generator.	A written report containing diagrams, graphs and calculations.
P7, P8, P9, M3	Digital Principles and Microprocessors	A technician needs to describe the vehicle system applications of digital principles, integrated circuits and microprocessors.	Written responses to set tasks, carried out under controlled conditions.
P10, P11, M4, D2	Single-phase AC Theory	A technician needs to consider the characteristics of a sinusoidal AC waveform and use an oscilloscope to determine the performance of an alternator.	A written report based on practical investigations.

Essential resources

It is essential that learners have access to a vehicle workshop equipped with test rigs, vehicles and current electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits. With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software for computer-based circuit simulation and analysis.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Denton T – *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Unit 48: Vehicle Electrical Charging and Starting Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The application of electrical technology in modern motor vehicle systems is under constant development. This has resulted in an ever-increasing electrical load being placed on a vehicle's charging and starting systems. The unit will give learners the opportunity to determine faults in a vehicle's battery, charging and starting systems, identify and confirm the specific component that has failed and undertake suitable rectification procedures.

Learners will investigate the chemical process in a battery and understand how to specify a battery for a particular vehicle. They will gain an understanding of the operation and conversion of energy in the charging and starting systems of a modern motor vehicle. The unit will enable them to apply this knowledge to both charging and starting systems and undertake diagnostic and rectification work on a range of vehicles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to specify a battery for a given motor vehicle application

2 Understand a vehicle's starting system

3 Understand a vehicle's electrical charging system

4 Be able to diagnose and rectify electrical system faults on a vehicle's charging and starting systems.

Unit content

1 Be able to specify a battery for a given motor vehicle application

Different battery types: wet/flooded - consists of all but freely suspended plates that are insulated from each other usually with the negative plate being sealed in a small polythene separator bag; Maintenance Free (MF) battery – normally a wet battery where the design keeps gassing to a minimum and includes a battery box that is sealed to keep the gases in place; Calcium-Calcium – where the antimony on both the negative and positive plates being replaced by calcium alloy; Valve Regulated Lead Acid (VRLA) battery – the battery box is designed as a small pressure vessel with safety valves; Gel – a Gel battery has some elements, usually silicon compounds, added to the acid to ensure it gelatinises and thereby guarantee that no flooded acid can leak out; Absorbed Glass Mat (AGM (Vlies)) – keeps the acid in place by the separator paper that consists of a fibreglass mat operating like a sponge

Chemical processes of lead acid batteries: chemical to electrical conversion, water to electrolyte process, e.g. charge and discharge cycles, use of chemical symbols, changes to specific gravity and components chemical state; health and safety, e.g. gases produced, acid content

Battery performance and construction: performance, e.g. cold cranking amperage, amp/hour rating (10/20 rating); construction, e.g. casing, plates (lead dioxide and spongy lead), separators; connections, e.g. series/parallel, vehicle earthing, corrosion protection; electrolyte, e.g. sulphuric acid, distilled water; battery calculations, e.g. amp/hour system requirement, cold cranking usage, plate area, maximum load; battery specification, e.g. manufacturer's recommendations, type, make, performance; specify battery by comparing system calculations/performance tests to battery capabilities

2 Understand a vehicle's starting system

Starting system: energy conversion, e.g. electrical to mechanical rotation, rotational to linear translation; starter solenoid, e.g. provide mechanical movement by use of Electromagnetic application; ignition key/push button switch, e.g. provide timely electrical supply to starting system; principles of starter motor, e.g. conversion of electrical energy to mechanical movement, creation and use of magnetic effect to create mechanical movement (Fleming's left hand rule)

Starting system components: electrical supply (battery); circuit protection methods, e.g. fuse, immobiliser, key recognition, relay; ignition switch, e.g. key or manual operation; wiring looms; warning system, e.g. visual and audible; solenoid; starter motor assembly, e.g. casing, magnets, armature, brush box, gear, roller clutch drive

Circuit diagrams: switched supply system; permanent feed system; recognition of circuit components/circuit symbols; types of circuit diagrams, e.g. use of workshop manuals, manufacturer's diagrams, wiring diagrams and schematics

3 Understand a vehicle's electrical charging system

Voltage generation, rectification and regulation: function of generator, e.g. alternator to create electro-motive-force using Fleming's right hand rule; system components, e.g. stator, rotor, rectifier, voltage regulator, slip ring, brushes, bearings, cooling fan; warning device; bridge rectifier; drive belts, e.g. single- or multi- 'V' design

Multi-phase electrical output: principles of three-phase electricity, e.g. excitation, magnetic inductance, sinusoidal pattern, full wave rectification; use of oscilloscope to observe wave patterns; AC-DC voltage conversion

4 Be able to diagnose and rectify electrical system faults on a vehicle's charging and starting systems

Battery tests and faults: testing, e.g. relative density, battery capacity, condition testing; equipment, e.g. hydrometer, multimeter, dedicated test equipment, inductive amp clamp; typical battery faults, e.g. dead cell, shorting out, low specific density, failing under heavy discharge, physical damage (overcharged causing heat distortion, corrosion/degradation, mechanical damage/defects)

Starting system tests and faults: system operation; circuit testing, e.g. continuity, feed, voltage drop; component test, e.g. ignition switch, solenoid operation, starter motor operation and internal components (armature, brushes, windings, circuit protection, e.g. relays, overload relay, immobiliser); use of test equipment, e.g. multimeter, dedicated test equipment, oscilloscope, inductive amp clamp; typical starting system faults, e.g. internal short on armature, failed solenoid operation, inhibitor switch failed

Charging system tests and faults: system operation; circuit testing, e.g. continuity, feed, voltage drop; component test, e.g. diodes, bearings, rotor, windings; output test, e.g. voltage, current, waveform; typical charging system faults, e.g. diode failure (indicator light on), faulty voltage control (overcharging), bearing fault (noisy or excessive free play), faulty brush box/rotor (no charge); use of test equipment, e.g. multimeter, dedicated test equipment, oscilloscope, inductive amp clamp

Assessment and grading criteria

In order to pass this unit, the evidence that the learners presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the composition of three types of battery used on vehicle starting systems	**M1** compare the performance characteristics of two different batteries	
P2 explain the chemical processes of a lead acid battery		
P3 perform calculations to select a battery, based on performance and construction, for a given motor vehicle application		
P4 explain the operation of a vehicle's starting system and the function of its components		
P5 use a circuit diagram to identify the electrical components of a vehicle's starting system		
P6 explain the process of voltage generation and regulation for a given vehicle application		
P7 explain the application of multi-phase electrical output in relationship to a vehicle's charging system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 carry out diagnostic tests to identify two different vehicle battery faults	**M2** justify the choice of starting system diagnostic tests and rectification methods	**D1** evaluate the engine electrical systems of two different vehicles in terms of the ease of carrying out diagnostic and rectification procedures.
P9 diagnose and rectify two different vehicle starting system faults	**M3** justify the choice of charging system diagnostic tests and rectification methods.	
P10 diagnose and rectify two different vehicle charging system faults.		

Essential guidance for tutors

Assessment

Assessment evidence is most likely to be gathered from practical work on vehicles and test rigs. Tutors will need to provide or simulate a range of system faults on vehicles to ensure authenticity of individual evidence for large groups of learners. Work-based evidence of the application of theory and fault-finding skills would also be acceptable.

P1 and P2 are linked and should be assessed together. For P1, learners need to describe the composition of any three types of battery from those listed in the Unit content for Learning outcome 1. For P2, learners will need to explain the chemical processes of a lead acid battery. In particular, they should consider the chemical to electrical conversion, water to electrolyte process and relevant health and safety issues when working with a battery.

P3 requires learners to consider the performance and construction of a battery for a given or chosen vehicle application. When considering performance, learners should typically look at the impact of cold cranking, other draws on the power of the battery (for example the demand from modern computer and security systems when the vehicle is idle) and issues such as amp/hour rating. When looking at construction, learners should be considering the battery's casing, plates and separators. They will also need to include how connections are achieved and electrolyte is used. The essential aspect of this criterion will be learners' ability to perform the required battery calculations and establish the required battery specification for the application. It is expected that learners will draw from and make suitable references (for example manufacturer's recommendations, types, makes and performance capabilities) when specifying the battery and use their system calculations/performance tests to determine battery capabilities.

The assignment used for P1, P2 and P3 could be extended to cover M1. This will require learners to compare the performance characteristics of two different batteries. One of the batteries used could be the one already dealt with for P2 and compared against another (completely different) battery.

A second assignment could be used to cover P4 and P5. This will require learners to explain the function of the components and operating principles of a vehicle's starting system (P4). The components to be covered include the battery, circuit protection methods, ignition switch, wiring looms, warning system, solenoid, starter and motor assembly. The explanation should consider the relevant energy conversion methods (for example electrical to mechanical rotation, rotational to linear translation), the operation of the starter solenoid and ignition key/push button switch and the operating principles of the starter motor. In explaining the function of components learners could also identify them using a circuit diagram in order to achieve P5.

P6 and P7 can also be linked, with learners covering the processes involved in voltage generation, rectification and regulation and the application of multi-phase output. For P6, learners will need to provide suitable explanations of the function of a generator, relevant system components and the related drive belts. P7 requires learners to explain the application of multi-phase electrical output in relationship to a vehicle's charging system. This should include the general principles of multiphase electrical output, the use of an oscilloscope to observe wave patterns (screenshots or sketches may be used to evidence the patterns observed under specific conditions), and the application of AC-DC voltage conversion in a vehicle setting.

P8, P9 and P10 will require learners to demonstrate their practical skills with respect to diagnostic tests and rectification for batteries, starter and charging systems. P8 requires learners to carry out diagnostic tests to identify two different vehicle battery faults. Assessment of rectification is not required as this would simply mean replacing the faulty battery. However, P9 and P10 will require learners to carry out both diagnostic tests and rectification of two different vehicle starting system faults and two different vehicle charging systems.

The assessment of P8 could be linked back to P1, P2 and P3. Typical battery faults might include dead cell(s), shorting out, low specific density, failing under heavy discharge or physical damage. Learners will need to select and use suitable equipment when carrying out the diagnostic tests.

For P9 and P10, the diagnostics tests should consider the respective system operation, appropriate circuit testing and component tests. The rectification procedures should be completed and systems checked to confirm integrity. Appropriate work records should also be completed.

It is likely that relevant observation records/witness statements will form the evidence of learners using a range of equipment for each system to confirm diagnosis before undertaking rectification. A short report (or logbook entry) outlining the details of the diagnostic procedures carried out would also be expected. The report does not have to be a full technical report but should reflect industry practice of reporting back to supervisor/customer. To ensure authenticity centres will need to provide a variety of faults so that each learner is able to carry out a series of diagnostic and rectification procedures unique to them.

The practical activities carried out for P9 and P10 will link directly with M2, M3 and D1.

To achieve M2 and M3, learners must justify the choice of starting and charging system diagnostic tests and rectification methods used (on each of the two different vehicle system faults for each criterion), respectively.

For D1, learners should evaluate the engine electrical systems of two different vehicles in terms of the ease of carrying out diagnostic and rectification procedures. The systems considered could be the same ones used for P9 and P10.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Vehicle Battery Systems	A vehicle technician needs to explain to learners the composition and performance characteristics of vehicle batteries.	A written report.
P4, P5	Vehicle Starting Systems	A vehicle technician needs to explain to learners the function and operation of a vehicle's starting system.	A written report.
P6, P7	Vehicle Electrical Charging Systems	A vehicle technician needs to explain to learners the operation of a vehicle's electrical charging system.	A written report.
P8, P9, P10, M2, M3, D1	Diagnosing and Rectifying Faults	A vehicle technician needs to diagnose and rectify faults on a vehicle's battery, charging and starting system.	Practical activities evidenced by record sheets and observation records.

Essential resources

Learners will need access to suitable motor vehicle workshop facilities. This should include equipment for working with dangerous acids, voltage generation equipment and test equipment including oscilloscopes. A range of components and vehicles should be provided as well as a variety of data sources and technical information.

Indicative reading for learners

Textbooks

Denton T – *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 49: Function and Operation of Vehicle Petrol Injection Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Most modern vehicles are fitted with fuel injection systems that enable the engine to work more efficiently and usually result in greater power and cleaner exhaust emissions. These systems work by forcing pressurised fuel through a tiny nozzle that atomises the fuel, allowing it to burn more quickly when mixed with air.

In this unit, learners will study a variety of fuel injection systems in order to understand their operation and the differences between systems. Learners will develop an understanding of the air and fuel supply systems and will gain knowledge of the operation of the engine control systems and components. Learners will also develop knowledge of the equipment and methods used to test, maintain and repair petrol fuel injection systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operational differences of petrol injection systems

2 Understand the function and operation of air and fuel supply components and systems

3 Understand the operation of electronic control systems and components

4 Know the methods used to test, maintain and repair petrol fuel injection systems.

Unit content

1 Understand the operational differences of petrol injection systems

Petrol injection system: principles of fuel combustion, e.g. composition of atmospheric air, calorific value of fuel, mixture strength and the range of combustibility, influence of air/fuel ratio on engine power output; vaporisation of fuel and cooling effects on charge density; injector layout (single point, multi-point, phased and continuous injection); mechanical and electronic control (open and closed loop systems); specification, e.g. technical improvements relative to performance, emissions and costs

Fuel injector positioning: single/multi-point/common rail/direct injectors; positioning of injector within the induction manifold, e.g. up-stream, down-stream or direct into the cylinder; quality of the homogeny of the charge and volumetric efficiency, e.g. requirements for compensatory enrichment, effects of fuel condensation on manifolds walls

Stoichiometric and lean burn technology: phasing of injection, e.g. induction cycle injection (stoichiometric cycle), compression stroke injection (direct injection, stratified engine operation); fuel injection strategies, e.g. continuous injection, intermittent injection, semi sequential and sequential injection, asynchronous and grouped injection; operational conditions, e.g. cold starting, idling, maximum power; thermal efficiency and the formation of pollutants; exhaust gas composition, e.g. composition of the exhaust gases under rich, lean and stoichiometric conditions, legal requirements

2 Understand the function and operation of air and fuel supply components and systems

Air supply system components: air intake tract; air cleaner; air throttle valve (butterfly valve); throttle body; use of an electric throttle; induction manifold and plenum chamber; variable geometry induction manifolds

Fuel supply components: fuel tank construction, e.g. steel with soldered joints, welded joints, moulded plastic, use of internal baffles and swirl pots; electric fuel pump, e.g. vane, roller gear, plunger; valves, e.g. pressure relief, non-return; fuel lines, e.g. accumulator, pipelines, fuel pipe connections, fuel filter; continuous injection mechanical systems; pressure regulator with induction manifold pressure correction; common fuel rail injection (direct injection), e.g. low pressure supply pump, low pressure sensor, high pressure pump, high pressure injectors, high pressure sensor; methods employed to reduce fuel vapour escape, e.g. charcoal canister, purge control valve

3 Understand the operation of electronic control systems and components

Sensors, switches and actuators: sensors, e.g. crankshaft position, camshaft position, coolant temperature, ambient air temperature, fuel temperature, mass air flow (vane type, thermal type (hot wire and hot chip), manifold pressure sensors (manifold absolute pressure (MAP) sensor, exhaust gas oxygen sensor (step response lambda, broad band lambda), engine speed and throttle position sensor; switches, e.g. thermo-time switch, idle speed switch, inertia switch; actuators, e.g. solenoid injectors, variable manifold butterfly actuators, electrical throttle valve actuator

Electronic control unit (ECU): input and output processes; injector driver circuits; fuel mapping; basic programming theory, e.g. use of input parameters to enable the software to calculate correct fuel quantity for injection; software updating, e.g. use of specialised software to change fuel map setting at varying engine/operational conditions; software self-diagnostics; controller area network (CAN) data bus, e.g. single wire, twin wire, fibre optic

Emission control principles and components: exhaust gas oxygen sensing; catalytic converter, e.g. reduction, oxidising, nitrogen oxides (NOx); exhaust gas recirculation (EGR) and components, e.g. outline of the process to reduce NOx formation, operation strategies, EGR valve, vacuum modulator, vacuum sensing valve; air injection and components, e.g. air pump, air injector, pulse air injection, electronic control of EGR and air injection systems; effect of engine operating conditions, e.g. cranking, cold start enrichment, hot start enrichment, cold idle, hot idle, light load, full load, acceleration, deceleration, engine speed limitation

4 Know the methods used to test, maintain and repair petrol fuel injection systems

Diagnostic equipment and tests: exhaust gas analysis, e.g. use of exhaust gas analysers, lambda values, air/fuel ratio, idle speed adjustments; on-board diagnostics (OBD), e.g. fault code reading, data logging, use of break out box to locate faults, data link connection to dedicated code readers; vacuum pump, e.g. induction system leakage, simulation of manifold depression to check fuel pressure regulator; multimeter, e.g. system voltage and circuit tests, circuit resistance, circuit integrity; pressure gauge, e.g. fuel line pressure and regulator settings; injector delivery and spray pattern, e.g. injection quantity, spray pattern and leakage; oscilloscope, e.g. engine/camshaft speed sensor patterns, injection duration, lambda sensor output

Injection systems faults and symptoms: e.g. throttle position sensor, mass air flow sensor, coolant sensor, crankshaft/camshaft speed/position sensor, exhaust oxygen sensor, idle speed control valve

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operation of two different petrol injection systems used on modern fuel injected engines	**M1** compare the relative advantages and disadvantages of port injection and direct injection with reference to timing of the injection process	**D1** evaluate two typical modern petrol injection systems in terms of their legal, environmental and operational requirements
P2 describe the methods used to position the fuel injector for an induction port injection and a direct injection into the cylinder		
P3 describe the principles of stoichiometric and lean burn technology with reference to petrol injection engines	**M2** compare the injection, combustion cycle and exhaust emissions within a stoichiometric air fuel ratio engine and a lean burn stratified charge engine	
P4 explain the function and operation of the air and fuel supply components of a given fuel injection system		
P5 describe the function and operation of four major input sensors, their related switches and actuators and how the electronic control unit uses feedback from these devices to calculate quantity of fuel injected		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain the emission control measures and associated components used for a given fuel injected engine system		
P7 describe the diagnostic equipment required and tests that need to be carried out to check the satisfactory operation of two different fuel injection systems	**M3** compare the diagnostic tests and repair strategies that can be performed on two different modern petrol injection systems, including the equipment that may be used.	**D2** evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on board diagnostic facilities, equipment and software used with modern petrol injection systems.
P8 describe the symptoms associated with three different injection system faults found in modern engines and the repair strategy for each.		

Essential guidance for tutors

Assessment

A variety of evidence could be used to support assessment. For example, a mixture of written tests and practical investigative assignments could be used requiring learners to explain, describe, identify, compare and evaluate as required by the criteria.

For P1, learners need to explain the operation of two different petrol injection systems used on modern fuel injected engines. A task could be developed requiring learners to inspect two different types of system (selected from those outlined in the unit content) in a practical environment. The task should ensure learners explain principles of combustion, vaporisation of fuel and cooling effects on charge density, injector layout, mechanical and electronic control and consider the specifications of each where appropriate. P2 requires learners to describe the methods used to position the fuel injector for an induction port injection and a direct injection into the cylinder. The task should ensure learners consider the quality of the homogeny of the charge and volumetric efficiency. P1 and P2 are closely linked and could be assessed together. The same vehicles could then be used for both criteria.

There are similar close links between P3 and P4. For P3, learners need to explain the principles of stoichiometric and lean burn technology with reference to petrol injection engines. This should include phasing of injection, fuel injection strategies, operational conditions, thermal efficiency and the formation of pollutants, including exhaust gas composition. It is expected that learners will refer to more than one type of petrol injected engine to cover the requirements of the unit content. They will need to demonstrate an understanding of the combustion of fuel in an engine and the differences between the homogenous/stoichiometric charge and the stratified, overall lean mixtures associated with modern direct injected engines. To achieve P4, learners need to explain the function and operation of the air and fuel supply components of a given fuel injection system. The operation and function of all components listed in the content under 'air supply system components' should be explained. The fuel supply components should include the tank, pump, valves, fuel lines etc where applicable in the given system. Learners will, by necessity, need to refer to open- and closed-loop control methods and their relevance to the function, operation and fundamental principles affecting fuel delivery.

For P5, learners need to describe the function and operation of four major input sensors, their related switches and actuators and how the electronic control unit uses feedback from these devices to calculate quantity of fuel injected. This criterion should not be fragmented into sensors, switches, actuators and ECU. One activity should be designed to enable the whole criterion to be covered at the same time. Learners should include, for each major input sensor considered, suitable references to the interrelationships between each of the components within the systems.

P6 requires learners to explain the emission control measures and associated components used for a given fuel injected engine system. Learners should consider exhaust gas sensing, catalytic converter, EGR and associated components and the effect of engine operating conditions on emissions.

P7 and P8 focus on system defects, symptoms and the necessary testing procedures used in maintenance and repair processes. It is likely, although not essential, that the three faults in P8 will be associated with the two systems considered for P7. It is expected that faults associated with more than one system will be considered.

Wherever possible, the descriptions associated with P7 and P8 should be the product of a practical investigation undertaken by learners and should give consideration to exhaust gas analysis, OBD, vacuum pump, multimeter, pressure gauge, injection delivery and oscilloscope. Where centres do not have the equipment to do this, they may wish to consider work-based evidence if practicable.

For M1, learners will need to compare the relative attributes of port injection and direct cylinder injection. They should also clearly define the point at which injection commences relative to the engine cycle.

M2 is linked to P3, P4, P5 and P6 in as much as learners need to explore in more detail the differences in combustion strategy to meet the close limits set by environmental legislation. It is expected that learners will refer to the use of closed loop control and the use of step response and/or broadband (or both) oxygen sensors to enable accurate reduction and oxidation to occur within the catalytic converter.

M3 is linked to P7 and P8. Learners need to compare the effectiveness of the tests that can be used to locate faults and the appropriate repair strategies. This should draw on and bring together the understanding gained at pass level enabling them to demonstrate a coherent understanding of testing and fault finding methods.

For D1, learners need to evaluate two typical modern petrol injection systems in terms of their legal, environmental and operational requirements. For D2, they will need to evaluate the use of diagnostic tests. Emphasis should be placed on the comparison with diagnostic algorithms using standard workshop test equipment and on-board diagnosis (OBD) which require dedicated test equipment. Learners should cite examples of actual testing.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, P6, M1, M2, D1	Electronic Control Systems	A vehicle technician needs to describe the function and operation of sensors, switches and actuators and emission control measures.	Written responses to set tasks.
P7, P8, M3, D2	Maintenance and Repair of Petrol Fuel Injection Systems	A vehicle technician needs to describe the methods used to test, maintain and repair petrol fuel injection systems.	A written report based on practical investigations.

Essential resources

Learners will need access to a range of components, assemblies and rigs and, wherever possible, access to the diagnostic equipment identified in the unit content. Access to suitable vehicles and tools will need to be provided along with a range of relevant information sources and operational manuals.

Indicative reading for learners

Textbooks

Bonnick A – *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998) ISBN 9780340706305

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Hillier V – *Hillier's Fundamentals of Automotive Electronics Book 2*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515372

Unit 50: Diesel Fuel Injection Systems for Compression Ignition Engines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Advances in technology and a tightening of exhaust emissions requirements have led to a considerable improvement in the performance of diesel engines. Once exclusively used in large heavy vehicles, plant or marine applications, diesel engines are now an acceptable alternative to petrol engines in light vehicles.
To compete effectively as an alternative, the light diesel engine must have similar attributes to the petrol engine. Modern fuel injection systems in diesel engines enable improved engine performance and economy and control of emissions, enabling parity with the petrol engine.

In this unit, learners will study a variety of fuel injection systems in order to appreciate their function, their operation and the differences between systems. The unit will develop learners' understanding of air and fuel supply systems and the operation of the engine control systems and components. Learners will also develop their knowledge of the equipment and methods used to test, maintain and repair diesel fuel injection systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operational differences of diesel fuel injection systems

2 Understand the function and operation of air and diesel fuel supply components and systems

3 Understand the operation of diesel engine control systems and components

4 Know the methods used to test, maintain and repair diesel fuel injection systems.

Unit content

1 Understand the operational differences of diesel fuel injection systems

Diesel injection system: principles of diesel fuel combustion, combustion phases, turbulence and the compression of induced air, composition of fuels used in diesel engines, abnormal combustion and its causes; conventional diesel fuel injection systems, e.g. in line, rotary fuel injection pump, high pressure common rail injection system using electronic injector control, low pressure common rail injection system using combined pump and injector, electronic diesel control using conventional fuel injection pump; operational factors, e.g. technical improvements relative to performance and emissions

Diesel fuel supply: fuel supply pumps, e.g. types (diaphragm, gear vane and plunger), multi-stage pressure development, provision for hand priming, single and double pumping action; means of operation, e.g. fuel pump camshaft, engine camshaft auxiliary drives, electrical drives; fuel supply pressure regulating valves (control of fuel flow rates in high-pressure systems); fuel heaters and coolers, e.g. waxing prevention methods, cooling of returned fuel before entering fuel tank; procedures for venting diesel fuel injection systems, e.g. requirements to bleed air from the system, self-venting systems, faults associated with entrapment of air in the fuel injection system; fuel injection system settings requirements to set maximum fuel and maximum speed(mechanical or electronic), methods used to identify injection timing marks/position for refitting to engine, adjustment of plunger travel or torque methods on combined pump and injector types

2 Understand the function and operation of air and diesel fuel supply components and systems

Air supply system components: air cleaners; induction manifold design; use of resonance chambers to improve engine volumetric efficiency; variable geometry induction manifolds and variable geometry turbo chargers

Diesel fuel supply components: fuel tank, e.g. construction, methods used to minimise aeration of the fuel; filtration of the fuel, e.g. requirements to filter the fuel, effects of low temperature wax formation on fine filters, filter placement, effects of water ingress, methods used to trap and remove water, construction and position of primary and secondary filters, effect of blocked filtration system (loss of power, misfire, engine shut down); control valves, e.g. delivery valves with anti-dribble control, manual shut down, solenoid shut down valves and reverse flow valves (used on electronically governed inline pumps to ensure engine shut down), application of electronic control; injector nozzles, e.g. single hole, multi-hole, pintle, pintaux; fuel injection pump, e.g. in-line fuel injection pumps, single and multi-cylinder, drive couplings, mechanical advance/retard system, electronic control of injection timing, firing order control, anti-reverse cams, methods used to meter quantity of fuel injected; high and low pressure pipes, e.g. high pressure injection pipes, factors that govern internal and external diameter, length of high pressure pipes, factors that affect injection timing, size and effects on volume flow rates (low pressure pipes), need for adequate clamping of pipes

3 Understand the operation of diesel engine control systems and components

Sensors and actuators: sensors, e.g. engine speed, air mass, coolant temperature, throttle position, fuel pressure, intake manifold pressure, intake manifold temperature, governor control rod position, throttle position; actuators, e.g. electrical/hydraulic servo units, glow plugs (methods to reduce diesel knock), injectors, fuel pressure regulating valve, rotary injection pumps (distributor type injection pumps, drive methods and engine timing), method to ensure correct firing order

Control systems: common rail, electronically controlled, low pressure systems, e.g. combined pump and injector, drive mechanism for injector, control strategies, operation of the injector on its cycle, fuel supply pump operation pump drive and timing arrangements; common rail electronically controlled high-pressure system, e.g. fuel supply circuitry, operation of the supply pump, fuel rail pressure sensors, pressure limiting valve, construction and operation of the injector, pre-injection phase, main injection phase; diesel fuel injection cold start devices, e.g. retardation of injection timing, excess fuel device (including the legal implications of its use), manifold combustion heaters, heater plugs, ether injection, decompression devices; single, two and variable speed governing, e.g. governor cut in/cut out, maximum speed overrun, hysteresis, over-shoot, speed droop; hydraulic and electronic governors, e.g. components and operation under idling, maximum speed (legal requirement), overrun and variable speed

Electronic control unit (ECU): input and output processes; injector driver circuits; fuel mapping; basic programming theory, e.g. use of input parameters to enable the software to calculate correct fuel quantity for injection; software updating, e.g. use of specialised software to change fuel map setting at varying engine/operational conditions; software self-diagnostics; controller area network (CAN) data bus, e.g. single wire, twin wire, fibre optic

Emission control measures and components: exhaust gas emissions under normal and abnormal running conditions, e.g. methods employed to reduce emissions (exhaust gas recirculation (EGR), urea injection into exhaust using selective catalytic reduction); legal requirements for emissions (EURO specification); effect of diesel engine operating conditions, e.g. cranking, cold/hot start, cold idle, hot idle, light load, full load, acceleration, deceleration, engine speed limitation

4 Know the methods used to test, maintain and repair diesel fuel injection systems

Diagnostic equipment and tests: exhaust gas analysis, e.g. use of smoke meters for exhaust gas opacity, idle speed adjustments and maximum speed settings; on-board diagnostics (OBD), e.g. fault code reading, data logging, use of breakout box to locate faults, data link connection to dedicated code readers; checking common rail operational pressures, effects of low rail pressure on starting and performance; induction system leakage, effects of changes in boost pressure on turbocharged engines, effects of fuel injection quantities of changes in boost pressure; use of multimeter, e.g. system voltage and circuit tests on injector control solenoids, circuit resistance, circuit integrity; pressure gauge, e.g. fuel line pressure and regulator settings; oscilloscope, e.g. engine/camshaft speed sensor patterns and injection duration

Injection system faults and symptoms: removal and refitting of main fuel injection system components, e.g. removal and refitting of injectors, including common rail, removal and refitting of a fuel injection pump; servicing of fuel system, e.g. fuel filters, bleeding and rectification of leaks; checking the operation of the fuel injection system, e.g. in situ adjustments of fuel quantities injected and speed, checking of injection timing, producing fault-finding algorithms; testing of injectors, e.g. safety factors associated with high pressure fluids and vapour, spray patterns, setting pressures, nozzle back leakage, nozzle tip leakage, specialised equipment to test combined pump and injector types; maintenance of fuel systems, e.g. fuel filter condition, condition of pipes and securing clamps, leaks, checking the condition and security of fuel injection pumps and drive couplings, security of maximum fuel and speed seals, check indication of visible vapour from the exhaust; test rectification techniques, e.g. location of misfire on conventional injection system and/or on common rail using dedicated software, poor performance through lack of power, excess exhaust gas opacity, fuel leaks, air ingress, probable causes of black, blue and white smoke; legal implications of defects on diesel fuel injection systems, e.g. excessive smoke, loss of power weight ratio and fuel leaks onto the road surface

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operation of two different diesel fuel injection systems used on modern diesel engines	**M1** compare the relative advantages and disadvantages of a conventional fuel injection system with a high pressure common rail system	**D1** evaluate two typical modern diesel injection systems in terms of their legal, environmental and operational requirements
P2 describe two different types of diesel fuel supply methods		
P3 explain the function and operation of the air and diesel fuel supply components of a given diesel fuel injection system	**M2** compare two governor types used on modern automotive diesel engines in terms of their modes of operation and levels of sensitivity	
P4 describe the function and operation of four major diesel injection system input sensors, the related actuators and their relationship with the engine electronic control unit		
P5 explain the emission control measures and associated components used for a given diesel fuel injected engine system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe the diagnostic equipment required and the tests that need to be carried out to check the satisfactory operation of two different diesel fuel injection systems	**M3** compare the diagnostic tests and repair strategies that can be performed on two different modern diesel injection systems, including the equipment that may be used.	**D2** evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on-board diagnostic facilities, equipment and software used with modern diesel injection systems.
P7 describe the symptoms associated with three different diesel fuel injection system faults found in modern engines and the repair strategy for each.		

Essential guidance for tutors

Assessment

Assessment of this unit could be through a mixture of written tests and practical investigative assignments.

P1 and P2 are closely linked and could be assessed together, using the same vehicles for both criteria. For P1, learners need to explain the operation of two different diesel fuel injection systems used on modern diesel engines. A task could be developed requiring learners to inspect two different types of systems (selected from those outlined in the unit content) in a practical environment. P2 requires learners to describe two different types of diesel fuel supply methods. Ideally, one will be a conventional fuel lift pump with hand priming and the other a two-stage high-pressure pump and flow control valve for a common rail system.

For P3, learners need to explain the function and operation of the air and diesel fuel supply components of a given diesel fuel injection system. This should include an explanation of the principles of induction system design used to improve engine volumetric efficiency. Specifically, this should be the use of acoustic design on normally aspirated engines to aid the induction ram effect and the use of geometrical variable manifolds and turbochargers to improve engine performance characteristics. Learners should also consider the effects of turbo charger boost pressure on fuel quantities injected and emissions, which would enable learners to appreciate the control strategies involved.

For P4, learners need to describe the function and operation of four major diesel injection system input sensors and related actuators used to monitor engine parameters and enable the fuel and timing of injection to be controlled with accuracy through the ECU. P5, for which learners need to explain emission control measures and associated components can be linked with P3 and P4.

P6 and P7 can be linked through a practical assessment during a workshop session or at the learner's own place of work. If work-based evidence is used, care must be taken to ensure may its validity and authenticity.

For M1, learners need to compare the relative advantages and disadvantages of a conventional fuel injection system and the high-pressure common rail system. This is closely linked to P1, P2, P4 and P5.

For M2, learners are required to compare two different engine governing systems such as speed for heavy goods vehicle against performance limitations/ expectations for light vehicles. It is important that the related operational characteristics of these governors are analysed and compared in relation to their operation and levels of sensitivity.

M3 requires learners to compare the diagnostic tests and repair strategies performed on two different diesel injection systems. This builds on the knowledge gained through P6 and P7 and could be built in to the same practical assignment.

For D1, learners need to evaluate two modern diesel injection systems in terms of their legal, environmental and operational requirements.

D2 requires them to evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on board diagnostic facilities, equipment and software used with modern diesel injection systems. Emphasis should be placed on the comparisons with diagnostic algorithms using standard workshop test equipment and on-board diagnosis (OBD), which require dedicated test equipment. Learners will need to give examples of actual testing.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, M1, M2, D1	Air and Diesel Fuel Supply and Engine Control Systems	A vehicle technician needs to explain the function and operation of air and diesel fuel supply and diesel engine control systems to a new learner.	A written report.
P6, P7, M3, D2	Testing and Maintenance of Diesel Fuel Injection Systems	A technician needs to explain to a learner how to carry out testing and maintenance of a diesel fuel injection system.	A written report.

Essential resources

Learners will need access to a range of components, assemblies and rigs and, wherever possible, access to the diagnostic equipment identified in the unit content. Access to suitable vehicles and tools will need to be provided, along with a range of relevant information sources and operational manuals.

Indicative reading for learners

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney M – *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 51: Operation and Testing of Vehicle Electronic Ignition Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Electronic ignition systems have developed in line with the advancement of engine technology and engine management systems. Modern electronic ignition systems have improved vehicle reliability, performance and efficiency of operation. Recent advances in spark plug design, manufacture, operation and longer working life have also improved electronic ignition systems.

It is important that all motor vehicle technicians are aware of these systems and are able to recognise and confirm faults. This unit will enable learners to understand the fundamental operating principles of electronic ignition systems and will give them the knowledge and understanding needed to carry out accurate diagnosis and repair. Learners will develop an understanding of the main components of vehicle electronic ignition systems and their relationship to the efficient operation of the engine unit and sub-systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of conventional ignition systems and their components

2 Understand the operation of programmed electronic ignition and distributorless ignition systems

3 Know about the function and operation of pulse generators and control modules

4 Be able to undertake tests on electronic ignition system to verify system faults.

Unit content

1 Understand the function and operation of conventional ignition systems and their components

Ignition system operation: ignition timing (static and dynamic); dwell (angle, time, variation); ignition scope patterns, e.g. spark kV, primary circuit, secondary circuit, dwell, coil output

Ignition system components: circuits (diagrams, primary, secondary); contact breaker; coil; leads; distributor and cap; rotor arm; spark plugs; mechanisms (mechanical advance, retard, vacuum advance)

2 Understand the operation of programmed electronic ignition and distributorless ignition systems

Programmed electronic ignition: components, functions and operation; electronic control unit; sensors, e.g. manifold absolute pressure, crankshaft, camshaft, engine temperature, knock, air temperature; ignition coil; distributor; ignition switch; reluctor disc; discharge, e.g. capacitor, inductive

Distributorless ignition system: components, functions and operation; transformer; capacitor; ignition coil(s), e.g. waste spark, direct acting; spark plug; sensor, e.g. manifold pressure, crankshaft, camshaft, knock; primary current switching modules, waste spark, direct acting

3 Know about the function and operation of pulse generators and control modules

Generators: Hall effect, e.g. Hall voltage, Hall integrated circuit (IC), vanes, magnet, control module; inductive pick-up, e.g. permanent magnet, inductive windings, trigger wheel; optical pulse, e.g. light-emitting diode (LED), phototransistor

Transistor assisted contacts: transistor operation; Darlington pair; advantages of breakerless systems

Control modules: e.g. pulse shaping, dwell period control, voltage stabilisation, primary switching, pulse processing, secondary output control, ignition amplifier, air gap, electronic spark advance, spark advance map, read-only memory (ROM), erasable programmable read-only memory (EPROM), knock control

4 Be able to undertake tests on electronic ignition system to verify system faults

Testing: equipment, e.g. on-board diagnostics (OBD), test instruments, voltage drop tester, electronic control unit tester; spark advance and retard tester; safe working practice; components and circuits, e.g. fuses, wiring, connectors, coil, spark plug, leads, rotor arm, distributor cap, pulse generator, sensors (such as crankshaft, camshaft, knock), break out box, ignition switch, reluctor air gap; checking for faults, e.g. moisture, dirt, corrosion, fault code reading, gap, data link connection, output and resistance, spark plug leads condition and resistance, rotor arm condition and leakage, distributor cap condition and leakage, dwell angle, spark plug condition, pulse generator module resistance, ignition timing, sensor output, sensor operation

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain, with the aid of appropriate diagrams, the operation of a typical conventional ignition system and the function of its main components		
P2 distinguish between dwell angle, dwell time and dwell variation		
P3 explain the operation of a programmed electronic ignition system and the function of its main components	**M1** compare the relative advantages and disadvantages of a typical conventional ignition system, a programmed electronic ignition and a distributor less ignition system	**D1** explain how the conventional ignition system, programmed electronic ignition system and distributor less ignition system operate in a variety of cold start and acceleration situations
P4 explain the operation of a distributor less ignition system and the function of its main components		
P5 describe the function and operation of a pulse generator		
P6 describe the advantages of transistor assisted contacts		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe the use of two different control modules		
P8 use appropriate equipment to carry out tests on five components/circuits to verify faults in an electronic ignition system.	**M2** suggest methods for dealing with typical faults on the electronic ignition system.	**D2** analyse test results to diagnose defects, wear and maladjustment in the ignition system from given data and symptoms.

Essential guidance for tutors

Assessment

Assessment of this unit will normally be carried out through a combination of assignments, projects and practical investigations. The unit can be linked to other units such as *Unit 46: Applications of Vehicle Science and Mathematics* and *Unit 47: Electrical and Electronic Principles for Vehicle Technology* and it would be appropriate, where possible, to combine assessment. Alternatively, this unit could be assessed using four assignments.

The first assignment could assess P1 and P2, with written tasks for each criterion. For P1 the use of diagrams is essential in the assessment process, and learners should explain both the function and operation of the main components of a typical conventional ignition system. This should include the type of circuit, contact breaker, coil, leads, distributor and cap and rotor arm. For P2, a simple description including the differences between the indicated elements could be assessed at the same time.

A second assignment could cover P3, P4, P5, P6 and M1. This could also provide an opportunity to direct learners to D1. Separate written tasks could be given for each criterion and learner responses are likely to be in the form of a report.

P7 could be assessed independently in a third assignment, or could be linked to the second assignment.

A final assignment covering P8, M2 and D2 could be assessed with the aid of task sheets that track authenticated, reliable and current practical activities on five components/circuits. The structure of this assignment is critical and tutors should ensure that learners have opportunities to diagnose faults (P8), suggest methods for dealing with faults (M2), and analyse test results on defects, wear and maladjustment (D2). The data and symptoms should be given to each learner. The evidence provided must include the test results involved and would typically incorporate printouts from test equipment. A witness statement/observation record would be a suitable form of evidence to show what the learner did and the equipment they used when carrying out tests.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Conventional Ignition Systems	A vehicle technician working on historic racing cars needs to report on the operation of a conventional ignition system.	A written report supported by relevant diagrams.
P3, P4, P5, P6, M1, D1	Programmed Electronic Ignition, Distributor less Ignition Systems and Pulse Generators	A technician needs to explain the function and operation of programmed and distributor less ignition systems and pulse generators to a new learner.	A written report.
P7	Control Modules	A vehicle technician needs to describe the use of different control modules to a mature technician.	A written report.
P8, M2, D2	Testing Electronic Ignition Systems	A technician needs to carry out tests on an electronic ignition system components and circuits as part of professional development.	Practical activities evidenced by record sheets and observation records.

Essential resources

For this unit, learners will need access to vehicle workshops equipped with modern vehicles, rigs, components and appropriate test equipment.

Indicative reading for learners

Textbooks

Bosch R – *Automotive Electrics/Automotive Electronics* (Wiley-Blackwell, 2007) ISBN 9780470519370

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 52: Vehicle Engine Management Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Modern motor vehicles continue to make use of the rapid advances in electronics technology in a wide range of vehicle applications. This unit considers how electronics are used in engine management systems (EMS) and, in particular, the use of engine control units (ECU) that control different aspects of an engine's operation.

As a minimum, a simple ECU may just control the quantity of fuel injected into each cylinder during each engine cycle. However, advanced ECUs also control the ignition timing, variable valve timing, the level of boost maintained by a turbocharger and may also control a range of other engine system peripherals. Increasingly, the EMS also plays an important part in maintaining environmental controls, fuel economy and safety and in ensuring compliance with the various legislative requirements placed on modern engines.

This unit will enable learners to gain an understanding of the systems and operating principles of an EMS. Learners will consider the interaction between the EMS and the functions and performance of a modern motor vehicle engine. They will also carry out a series of EMS tests and will select and use equipment to carry out a diagnostic test to determine EMS faults.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating principles and characteristics of an engine management system

2 Understand the operating principles of engine management system sensors and actuators

3 Understand the interrelationships and interaction of engine management systems and components

4 Be able to carry out tests on an engine management system to locate a system fault.

Unit content

1 Understand the operating principles and characteristics of an engine management system

Operating principles and characteristics: systems modelling, e.g. diagrammatic representation of system input/process/output, characteristics of open- and closed-loop system control strategies used in engine management systems; control systems, e.g. analogue, digital, programmable, non-programmable; main elements of a digital processing system, e.g. central processing unit (CPU), memory devices (such as volatile, non-volatile), buses, input/output ports; principal functions of a digital processing system, e.g. multiplexing, controller area network (CAN) systems; characteristics, e.g. purpose and applications of the system, operating conditions (conditions in which the system is operative or inoperative, 'fail-safe' features), system features (benefits, cost, performance, safety, convenience, efficiency)

Engine management systems: integration developments, e.g. fuel, mechanical to full electronic; interaction between other vehicle systems, e.g. sport mode on gearbox selection; fuel management (spark and combustion ignition) systems; ignition control and combined fuel/ignition control; emission control, e.g. active to reactive such as use of lambda system and knock sensor control; vehicle performance monitoring, e.g. throttle position, driver selection

2 Understand the operating principles of engine management system sensors and actuators

Operating principles of sensors: types, e.g. electromagnetic, Hall effect, photo-electric, resistive, inductive, piezo-electric element effect, capacitive; factors affecting performance and application, e.g. sensitivity, accuracy, linearity and stability; influence of environmental, factors, e.g. heat, vibration, moisture, contaminants

Operating principles of actuators: e.g. ignition components such as coils, high tension (HT) components (individual coils, spark generators), fuel components (idle control valves, cold start devices, electronic injectors), variable valve timing control

3 Understand the interrelationships and interaction of engine management systems and components

Interfacing and signal processing: compatibility between components and systems, e.g. temperature and speed sensors, throttle position/drive by wire actuators; characteristics of devices which give rise to the need for signal processing (inductive pick-ups, analogue to digital (A/D) and digital to analogue (D/A) conversion); control of output devices, e.g. energy transfer, power output stages, buffer circuits

Functional interrelationships: location, e.g. units and components in the vehicle, position/location of components relative to others in the system; functional relationships between the elements of the system, e.g. data input from sensors and electronic control unit (ECU) process to affect actuation; impact of a component's failure on other components in the system, the operation of the system and on external systems, e.g. the effect of speed sensor failure, Lambda sensor fault

System interactions: e.g. integration fuel and emission control and/or vehicle performance control, achieved by common data sources and actuator responses

4 Be able to carry out tests on an engine management system to locate a system fault

Test components/circuits for satisfactory operation: test equipment, e.g. onboard diagnostics, test instruments, voltage drop tester, ECU tester, spark advance and retard tester; safe working practice, e.g. common rail fuel pressures, working with ECU, HT voltage; components and circuits, e.g. fuses, wiring, connectors, injector, coil, ECU, pulse generator, sensors/transducers (such as crankshaft, camshaft, knock), actuators, pressure check (fuel pump), break out box; checking for faults, e.g. moisture, dirt, corrosion, fault code reading, gap, data link connection, output and resistance, condition, ignition timing, sensor output, sensor operation

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating principles and characteristics associated with an engine management system	**M1** compare the relative advantages and disadvantages of two different engine management systems	**D1** justify the use of a specific engine management system
P2 explain the operating principles and application of three different types of engine management system sensor	**M2** compare the performance of three engine management system sensors in terms of their sensitivity, accuracy, linearity and stability	
P3 explain the operating principles and application of three different types of engine management system actuator		
P4 describe the interfacing and signal processing requirements of two engine management system components		
P5 explain the functional interrelationships and system interactions of engine management system units and components		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 explain the effect of different engine management functions during fuel, emission and performance control	**M3** explain the benefits of an integrated management control system on engine performance	
P7 use appropriate equipment to carry out tests on five different engine management system components/ circuits to establish their serviceability		
P8 carry out a diagnostic procedure to locate an engine management system fault.	**M4** explain the benefits of dedicated diagnostic equipment and procedures employed with engine management systems.	**D2** evaluate an engine management system diagnostic procedure and suggest possible improvements.

Essential guidance for tutors

Assessment

This unit could be assessed using three assignments and evidence is likely to be in the form of written work and tutor observation of practical work.

The first assignment could be designed to cover the requirements of P1, P2, P3, M1, M2 and D1. Evidence should show that learners can explain both the operating principles and characteristics associated with an engine management system (EMS). The task should ensure inclusion of systems modelling, the control system used and their principal functions and characteristics. The evidence should also show that learners have understood the relevant aspects of the EMS being considered. This should include integration developments, the interaction between other vehicle systems, fuel management systems, ignition control and combined fuel/ignition control, emission control and vehicle performance monitoring. The assessment task could also include a natural link to M1 by asking learners to consider two different EMS. Having compared two systems in M1, learners could come up with reasons for justifying the use of one specific system (D1).

Learners could then consider relevant EMS sensors to cover P2 (engine sensors/transducers such as engine temperature, speed and position) and actuators to cover P3 (such as idle control or ignition components). It would be natural to put the sensors/transducers (input) and actuators (output) in three different vehicle contexts (possibly across the two different engine management systems). Learners' evidence should identify, for each specific application, the type of sensor/transducer being used (for example electromagnetic, Hall effect, photoelectric, resistive, inductive, piezoelectric element effect, capacitive), the factors that may affect its performance and application and the influence of environmental factors. It would be possible to generate evidence for P2 and P3 through a practical investigation of the outputs and inputs from sensors/transducers and actuators using scanner/oscilloscopes or other dedicated equipment. For the actuators, learners must show an understanding of the principles of how individual actuators operate, such as spark generation and idle control valve (for example, include how the electromagnetic effect is used to create linear movement). Learners should be given opportunities to link the work carried out for P2 with the requirements of M2.

A second assignment could be used to cover P4, P5, P6 and M3. This will need to include a task requiring learners to describe the interfacing and signal processing requirements of two EMS (P4) and explain the functional interrelationship and system interaction of one of these (P5). A separate task could then require learners to explain the effect of different engine management functions during fuel, emission and performance control (P6). A task to explain the benefits of an integrated control system on engine performance would cover M3. Finally, a task to substantiate the comparative benefits of dedicated diagnostic equipment and procedures employed with EMS (M4) could also incorporate an evaluation of an engine management system diagnostic procedure (D2)

The third assignment will require learners to carry out practical activities to cover P7 and P8. It would also provide the best opportunity to cover M4 and D2.

For P7, learners will need to use appropriate equipment to carry out tests on five different EMS components/circuits to establish their serviceability. The evidence for this criterion should be gathered over time and collected together in a portfolio/report, including results of the tests, relevant descriptive work and tutor observation/oral questioning records. The evidence should include the results of tests on both components and circuits, and clearly identify which system(s) and components are affected and are serviceable.
The evidence for P8 may also be used for some (or all if appropriate) of the testing carried out for P7. Although this would be ideal in terms of integration, it would need to be managed carefully to ensure full coverage of both criteria.

It is expected that all the tests and procedures are completed to relevant standards and within health and safety guidelines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3	Interrelationships and Interaction of Engine Management Systems	A vehicle technician has been asked to explain the interrelationships and interaction of engine management systems and components, and substantiate comparative benefits of dedicated diagnostic equipment and procedures employed with engine management systems to a new learner.	A written report.
P7, P8, M3, M4, D2	Engine Management System Testing and Fault Location	A vehicle technician needs to locate an engine management system fault to aid work-based development.	A practical assignment evidenced through learners' portfolio and tutor observation records.

Essential resources

A range of components, vehicles, diagnostic equipment and software will be required for delivery of this unit. This will need to include manufacturer/vehicle specific maintenance and test equipment and non-specific equipment such as measuring instruments, meters and pressure gauges. A variety of data sources will also be required for the vehicles, systems and procedures used.

Indicative reading for learners

Textbooks

Bonnick A – *Automotive Computer Controlled Systems* (Routledge, 2001)
ISBN 9780750650892

Bonnick A – *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998)
ISBN 9780340706305

Denton T – *Advanced Automotive Fault Diagnosis* (Routledge, 2011)
ISBN 9780080969558

Unit 53: Operation and Maintenance of Light Vehicle Transmission Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit covers the conventional aspects of light vehicle transmission systems, their function, principal components and operating principles. This will include a detailed examination of the three major systems – a vehicle's clutch mechanism, gearbox and the driveline and final drive systems.

Learners will be introduced to the most recent developments in the use of electronics for the control and operation of transmissions systems in both standard production vehicles and motorsport applications. These developments are now frequently integrated into the overall electronic management of the vehicle and can provide significant improvements in terms of driveability, economy and performance. Learners will appreciate the fundamental operating principles of these developments, their integration in transmission systems and their significance in the maintenance of a vehicle's transmission system.

Finally, learners will carry out specific tests and checks to identify transmission system faults such as clutch slip, gearbox linkage problems and failing constant velocity joints. Learners will use these tests and checks, together with on-board diagnostic (OBD) equipment, to maintain a vehicle's transmission system. This will include the maintenance requirements relating to driver/passenger safety and component reliability.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operation of a vehicle clutch mechanism and the function of its principal components

2 Understand the operation of a vehicle gearbox and the function of its principal components

3 Understand the operation of a vehicle driveline system and final drive and the function of its principal components

4 Be able to maintain a vehicle's transmission system.

Unit content

1 Understand the operation of a vehicle clutch mechanism and the function of its principal components

Principal clutch components: pressure plate, disc, flywheel (including bearings and bushes); release bearings; release systems, e.g. production vehicles (hydraulic, mechanical and cable), motorsport vehicles (push/pull and electrohydraulic actuating mechanisms)

Types of clutch mechanisms: e.g. production clutches (coil and diaphragm spring, single plate, wet and dry types), automatic clutches (torque converter, fluid flywheel, one way clutch), motorsport clutches (paddle, slipper and multiplate)

Operating principles of clutch: constructional design and use of materials (linings, drive plates and friction surfaces, springs); engagement and disengagement of clutch (single and multiplate, one way clutches and automatic clutches); provision for adjustment/self-adjustment; torque calculations and coefficient of friction; power flow; common faults, e.g. wear, misalignment; fault symptoms (slip, drag, judder, overheating); fluid flywheels

2 Understand the operation of a vehicle gearbox and the function of its principal components

Principal gearbox components: gear design (spur and helical); bearings, shafts, casing, selector and sealing arrangements; gear locking and interlock mechanisms; gear speed synchronisation and engagement mechanisms, e.g. sliding mesh, synchromesh and dog type

Types of gearboxes: e.g. manual (single stage, double stage, sliding mesh, constant mesh), automatic (epicyclic gear train, hydraulic control systems); layout, e.g. transverse, longitudinal and transaxle

Operating principles of gearbox: manual gearbox – gear ratios, power flow, e.g. constant mesh single and double stage; torque and speed calculations; gear ratio characteristics and number of available gears; selection and engagement methods, e.g. synchromesh and dog type, selector forks, interlocks and linkages, remote control mechanisms, motorsport (sequential, electro-hydraulic); automatic gearbox – torque converters (lock-up mechanism); epicyclic gear trains (simple and compound); brake bands; multi-plate and unidirectional clutches; power flow paths; function of key hydraulic components (pump, governor, actuators, servos, regulator and shift valves); electronic control system including mode selection; electronic selection of conventional gear arrangements; lubrication, e.g. method (splash and pump assisted); oil requirements and types (mineral, synthetic); seals and sealing arrangements (static and dynamic types)

3 Understand the operation of a vehicle driveline system and final drive and the function of its principal components

Principal components of driveline system: propeller shaft arrangement, e.g. single, divided; driveline arrangements, e.g. front, rear and four wheel; universal joints, e.g. Hooke type and rubber; constant velocity joints, sliding joints; drive systems, e.g. two-wheel, four-wheel (transfer box, centre differentials, viscous couplings, differential locks, automatic and manual)

Principal components of final drive: axle types and support arrangements, e.g. transaxles, live and independent; final drives, e.g. bevel, spiral and hypoid; differentials, e.g. sun and planetary gears, crown wheel and pinion, limited slip systems; axle types, e.g. semi, three quarter and fully floating; bearings

Operating principles of driveline: universal joints (Hooke type and rubber); constant velocity joints (angular limitations and conditions required to achieve constant velocity, basic consideration of balance requirements, alignment and torque capacity of hollow and solid shafts); suspension and transmission characteristics giving rise to the requirement for sliding joints and centre propshaft bearings

Operating principles of final drive: gear ratio, speed reduction and torque multiplication in the final drive; final drive arrangements for transaxles; driving thrust and torque reaction; differential (effects on torque/speed at the driven wheels, limited-slip differentials); lubrication methods (final drive and rear axles); oil requirements and types (mineral, synthetic); oil seals and sealing arrangements (static and dynamic)

4 Be able to maintain a vehicle's transmission system

Transmission system faults: e.g. clutch (slip, drag, judder, loss of drive, excessive noise, wear, misalignment, operating mechanism faults), gearbox (gear selection, oil leaks, linkages and fittings), driveline and finals drives (prop/drive shafts, universal and CV joints, bearings, gaiters and seals), use of on-board diagnostic (OBD) equipment, reporting methods (inspection records, oral report to supervisor)

Maintenance operations: working to manufacturers' maintenance and service procedures, e.g. manuals, job cards, direct supervision; maintenance operations, e.g. clutch adjustments/alignment, gearbox oil change, gear selection linkage repair, driveshaft gaiter condition check/replacement, security of mountings and fittings; context of the maintenance operations, e.g. routine maintenance, repair or adjustment due to a system failure, alternative service procedures for adverse condition (vehicles operating in dry, dusty environments, race/rally vehicles and vehicles working in extreme temperature environments)

Critical safety considerations: procedures relating to maintenance operations carried out, e.g. materials handling (protection against dust, oil and chemical exposure), vehicle and system protection (application of four-wheel drive diff locks, lifting and supporting vehicles), personal protective equipment (PPE), Control of Substances Hazardous to Health (COSHH) Regulations, component and environmental waste disposal

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the function of the principal components of two different types of clutch mechanism	**M1** compare two different vehicle clutch types in terms of their principal components and operating principles	**D1** justify the use of a specific clutch type for two different vehicle applications in terms of purpose, function and performance
P2 explain the operating principles of one type of clutch		
P3 describe the function of the principal components of one type of gearbox	**M2** explain the advantages and disadvantages of increasing the number of available gears in a gearbox	
P4 explain the operating principles of two different types of vehicle gearbox		
P5 describe the function of the principal components in a vehicle driveline and final drive	**M3** compare two different vehicle driveline and final drive arrangements.	**D2** justify the use of a specific type of driveline and final drive arrangement for two different vehicle applications in terms of purpose, function and performance.
P6 explain the operating principles of a vehicle's driveline and final drive arrangement		
P7 inspect a vehicle's transmission system		
P8 report faults and attribute symptoms to the faults identified		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 carry out a maintenance operation on a vehicle's transmission system		
P10 follow relevant safety procedures when inspecting and maintaining a vehicle's transmission system.		

Essential guidance for tutors

Assessment

This unit provides opportunities for assessment evidence to be generated from a combination of assignments, projects and practical work. Although most of the pass criteria require descriptive evidence, it is not expected that tutors only use tests to achieve this. The unit lends itself to an investigative, practical approach and this should be reflected in the assessment strategy wherever possible. The range of evidence presented could include notes, diagrams, investigative test data and the records of the maintenance and diagnostic procedures carried out.

To achieve a pass, learners will need to describe the function of the principal components of two types of clutch mechanism (P1), one gearbox (P3) and a vehicle's driveline and final drive (P5). In addition, learners need to explain the operating principles of one of the clutches (P2), two types of gearbox (P4) and one vehicle's driveline and final drive arrangement (P6). The unit content for each of these areas provides a range of choices through the examples listed. For clutches, this includes production, automatic and motorsport, and within these groupings there are further examples. Tutors are expected to cover as wide a range of these as possible during delivery but need only select one or two of these, as indicated by the criteria, for assessment purposes. This will enable tutors to concentrate on a specific specialisation as the main focus of assessment (for example motorsport paddle clutch).

Where a criterion requires learners to consider two types, this is to ensure that coverage is sufficiently varied so as not to limit learners' employment potential. For example, while a centre may specialise in motorsport, it is important that learners are equally aware of a production vehicle's clutch or vice-versa. The range of choices available could mean that each learner could be considering the function of the principle components for a different type of vehicle and clutch. This can be beneficial when considering the authenticity of learners' evidence.

At pass level, learners should inspect a vehicle's transmission system (P7), identify and report faults aligned to the symptoms that are attributed to the findings (P8), and carry out a routine maintenance operation (P9) while following relevant safety procedures (P10). P7, P8, P9 and P10 would be best assessed through investigation and practical examination of a live vehicle layout and configuration. P10 should be an integral part of the assessment for P7 and P9.

A suitable transmission system fault may need to be simulated for P7 and P8 and learners given the typical symptoms of the fault, as would be reported by a driver of the faulty vehicle. Assessment is likely to consist of a written inspection record completed by learners at the time of the inspection, a verbal report back to the supervisor/customer (tutor record of oral questioning/observation) and tutor observation of the process (for example use of logical and efficient diagnostic techniques, safe working).

The main assessment evidence for P9 would be the final product – the completed maintenance task. However, tutor observation will also be necessary to cover the process aspects of the task (for example working to the manufacturer's procedures, correct and safe working). The final link is with P10 and the safety procedures relating to the maintenance operation being carried out. For example, tutors will need to observe learners handling materials correctly, using relevant system protection, using appropriate PPE, working to COSHH regulations and correctly disposing of waste, as required by the task being undertaken.

To achieve a merit, learners need to compare the constructional differences of two different clutch types (for example production diaphragm spring versus motorsport paddle or production wet versus production dry types). The two clutches could be the same as those considered for P1, or if tutors wish to encourage learners to have wider experience then one or two completely different clutches could be used. The focus of the comparison should be based on the understanding developed through P1 and P2. Learners must also explain the advantages and disadvantages of multiple gear ratio applications (for example 3 speed versus 4 speed, 5 speed versus 6 speed). Finally, they need to compare two different vehicle driveline and final drive arrangements (for example longitudinal, in line versus transverse or rear engine, rear wheel drive versus rear engine four wheel-drive). Again, one of these could be the driveline and final drive considered for P5 and P6.

To achieve a distinction, learners need to justify the use of two different clutch types and two different types of driveline and final drive arrangements for differing applications (for example production, fast road, motorsport track, motorsport rally), in terms of purpose, function and performance. Once again, these could be the same clutches, driveline and final drives that learners have been working with through the pass and merit criteria.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	Vehicle Gearbox Operation	A vehicle technician has been asked to explain the operation of a vehicle gearbox to a new learner.	A written task under controlled conditions or oral questioning.
P5, P6, M3, D2	Vehicle Driveline and Final Drive Operation	A vehicle technician has been asked to explain the operation of a vehicle driveline and final drive to a new learner.	A written task under controlled conditions or oral questioning.
P7, P8, P9, P10	Maintaining Vehicle Transmission Systems	A vehicle technician has to safely inspect, diagnose and repair a transmission system.	A practical maintenance task supported by observation records and a written inspection record.

Essential resources

For this unit, learners will need access to a range of transmission types (clutches, gearboxes and driveline/final drives) and their components. A variety of information and data sources specific to the transmission systems will also be required. The necessary special tools and equipment will be needed for investigation and routine maintenance of the selected transmission systems as defined in the unit content and grading criteria.

Indicative reading for learners

Textbooks

Denton T – *Advanced Automotive Fault Diagnosis* (Routledge, 2011) ISBN 9780080969558

Heisler H – *Advanced Vehicle Technology* (Elsevier, 2002) ISBN 9780750651318

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology Book 1*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 54: Operation of Vehicle Chassis Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Modern vehicles are highly developed machines that involve sophisticated and complex systems. Engines now provide more power, leading to higher torque and greater speeds than in the past, which drivers have to handle and control. This involves controlling power to the road wheels, stopping the vehicle when needed and directing it in a particular direction. In addition, the vehicle must be comfortable to travel in and be able to cope with the many forces that act on it.

This unit will introduce learners to the layout, function and operation of systems and components found in the main vehicle chassis systems. Learners will develop an understanding of the operating principles of a range of transmission, steering, suspension and braking systems.

The unit will also support further development of apprentice knowledge in areas such as fault diagnosis, specialised transmission systems, steering, suspension and brakes.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the layout and operation of a transmission system and its components

2 Understand the layout and operation of a steering system and its components

3 Understand the layout and operation of a suspension system and its components

4 Understand the layout and operation of a braking system and its components.

Unit content

1 Understand the layout and operation of a transmission system and its components

Transmission layout: drive method, e.g. front-wheel drive, rear-wheel drive, four-wheel drive; power path, e.g. flywheel, clutch, gearbox, drive/prop shafts

Transmission operation: function (clutch, gearbox, prop shaft, drive shaft, universal joint, final drive, differential); factors affecting torque transmitted by clutch, e.g. number of plates, diameter, friction; gearing arrangements, e.g. ratios, simple and compound gear trains

Transmission components: clutch, e.g. single plate spring, diaphragm; release mechanisms, e.g. linkage, cable, hydraulic, pneumatic, electrical; gearbox (input shaft, lay shaft, main shaft, idler); types of gear (straight cut, helical); universal joints, e.g. Hooke's type, constant velocity type; final drive–crown wheel and pinion (bevel, hypoid and helical gears), differential (sun and planet gears); drive shafts (hollow and solid); axles, e.g. semi, three quarter, fully floating; wheel hubs, e.g. taper, roller bearings; transmission lubricant, e.g. hypoid, multi-grade

2 Understand the layout and operation of a steering system and its components

Steering system layout: steering method, e.g. rack and pinion, recirculating ball; position adjustment

Steering operation: Ackerman layout, toe out on turns, wheel alignment, camber, castor, swivel pin inclination, negative offset; oversteer and understeer behaviour; steering arrangement, e.g. two-wheel steering, four-wheel steering systems

Steering components: steering wheel and steering column (bearings, bushes, mounting); universal joint (mounting methods, gaiters); steering linkage and joints for single steer vehicles, e.g. track rod, drag link, drag link ends; steering arm, tie rod (bushes, joints); steering box (seals, bearing)

3 Understand the layout and operation of a suspension system and its components

Suspension systems layout: suspension method, e.g. beam axle, independent front suspension (IFS), independent rear suspension (IRS); vibration and damping methods, e.g. metal, rubber, hydraulic, hydro-pneumatic

Suspension operation: interaction of components, e.g. vehicle loaded/unloaded, cornering, 'bump' reaction

Suspension components: spring systems, e.g. leaf, coil, rubber, hydraulic; fittings and mounting, e.g. shackles, U-bolts, saddle, tie bar; hydraulic/hydro-pneumatic systems, e.g. fluid supply, storage, actuation, control; suspension damping, e.g. oil, gas, friction; tyres, e.g. type (radial, cross-ply, markings) and impact on vehicle suspension system

4 Understand the layout and operation of a braking system and its components

Layout: braking methods, e.g. disc brakes, drum brakes; braking circuit, e.g. hydraulic circuit, split braking circuits

Braking system operation: application of mechanical forces, e.g. pedal force, transmission of force (fluid pressure, piston sizes); brake shoes/pads; heat dissipation, e.g. mechanical to heat energy, vented brake arrangement; brake efficiency, e.g. vehicle testing, axle efficiencies, brake balance; leading and trailing brake shoe action

Components: hydraulic circuit components, e.g. single/tandem circuit, master/slave cylinders (machined surfaces, seals, pistons, springs), brake lines (fixed and flexible piping); brake servo, e.g. diaphragm, spring, valve; pressure limiting valve, e.g. seal, actuation; brake adjuster, e.g. manual, automatic; brake discs/drums, e.g. machined surface, vented, solid; callipers/actuators, e.g. piston(s), seals, mounting; brake shoes (leading, trailing, springs); brake drums (machined surface, mounting); handbrake mechanism (actuation), e.g. mechanical linkage, cables, electronic control systems

Assessment and grading criteria

In order to pass this unit, the evidence that the apprentice presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe with the aid of sketches the layout of a vehicle's transmission	**M1** compare two different types of transmission systems	**D1** evaluate and justify the choice, in terms of layout and operation, of the transmission, steering, suspension and braking systems used for a current vehicle application.
P2 explain the operation of a transmission system and its components		
P3 describe with the aid of sketches the layout of a vehicle's steering system	**M2** compare two different types of steering systems	
P4 explain the operation of a steering system and its components		
P5 describe with the aid of sketches the layout of a vehicle's suspension system	**M3** compare two different types of suspension systems	
P6 explain the operation of a suspension system and its components		
P7 describe with the aid of sketches the layout of a vehicle's braking system	**M4** compare two different types of braking systems.	
P8 explain the operation of a braking system and its components.		

Essential guidance for tutors

Assessment

Assessment of this unit might be best achieved through four separate assignments supported by sketches, each covering one of the listed systems (i.e. transmission, steering, suspension and brakes).

The assignments need to be constructed in such a way as to ensure sufficient coverage of the grading criteria and related unit content. Opportunities to meet the pass and merit criteria that relate to each system should be provided, for example to be able to describe a vehicle's transmission layout (P1), explain its operation and components (P2) and compare it with another different type of transmission (M1). The comparison for the merit criterion should also cover the different systems' layout, operation and components.

The assignment could direct learners to investigate a given or chosen system (for example transmission) and then prepare their descriptions. Learners should be encouraged to research and use a range of resource materials during their investigation. Tutors should provide guidance on how such material can be referenced and used as part of learners' own work so as not to infringe guidelines on authentic evidence, for example annotation of images, diagrams used to support/clarify own text. Development of these research and presentation skills may also provide suitable evidence for functional skills attainment.

Guidance should be provided, during the early formative assessment period, on the type of evidence and amount of detail required, to ensure that it is sufficiently concise, clear and relevant to the unit criteria and content.

To achieve a pass, learners will need to produce a suitable description of each system's layout. This could be achieved through the production of drawings or sketches that illustrate the relevant aspects of the content (for example for P1, a transmission's drive method and power path). The drawings should then be suitably labelled and/or annotated to provide a sufficient description of the layout (for example to clearly identify the path taken by the power between the flywheel and the driven road wheels). In addition, for each system a suitable explanation of its operation and components is needed. Again, drawings or sketches can be used to good effect to support any written evidence (for example for P6, drawings that show the interaction of components during a 'bump' reaction of a suspension system, together with suitable labelling of the key components that play a part in the suspension of the vehicle under such conditions).

These could also be supplemented with evidence from practical activities carried out in other units or from work experience (for example steering geometry test report, braking efficiency tests). The use of such practical work would provide a vocational context to what could be seen as an overly theoretical unit.

To achieve the merit criteria, learners will need to compare two different types of system for each of those covered by the pass criteria (i.e. transmission, steering, suspension and brakes). One could be the system already examined for pass. The second could be chosen by the apprentice or set by the tutor, but it should be sufficiently different to provide scope for comparison. The comparison should consider the differences and similarities in terms of each system's layout, operation and components. It should also consider the differences in terms of how the components of each system interrelate with one another.

To achieve the distinction criterion, learners will need to choose, or be given, a current vehicle to investigate and evaluate in terms of the layout and operation of the four systems considered at pass level.

It is expected that tutors will supervise the final choice of vehicle so that learners are exposed to systems different to those already covered through the pass and merit criteria (for example if two-wheel drives have been the main focus at pass/merit, then learners should consider a four-wheel drive vehicle for D1). This will give learners both variety in their study and exposure to a greater range of systems. The evaluation and justification should take into account the intended use and therefore design of the vehicle. It should also consider the interrelationships between the systems, for example the impact of the type of suspension on the steering and handling of the vehicle.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Transmission Systems	A vehicle technician needs to explain the layout and operation of a transmission system to a new learner.	A written task supported by relevant drawings/ sketches.
P3, P4, M2	Steering Systems	A vehicle technician needs to explain the layout and operation of a steering system to a new apprentice.	A written task supported by relevant drawings/ sketches.
P5, P6, M3	Suspension Systems	A vehicle technician needs to explain the layout and operation of a suspension system to a new apprentice.	A written task supported by relevant drawings/ sketches.
P7, P8, M4	Braking Systems	A vehicle technician needs to explain the layout and operation of a braking system to a new apprentice.	A written task supported by relevant drawings/ sketches.
D1	Evaluating Vehicle System Applications	A vehicle fleet operator has asked a technician to evaluate the suitability of a possible new fleet vehicle	A written report

Essential resources

Centres need to provide learners with access to vehicle components (e.g. bevel, hypoid and helical gears), demonstration rigs (e.g. sectioned clutches, gearboxes, steering boxes) and vehicles. A range of suitable reference material (e.g. manuals and manufacturers' data) relating to the systems covered is also essential.

Indicative reading for apprentices

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney M – *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 55: Further Mechanical Principles and Applications

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

All machines and mechanisms consist of interconnected parts working together to produce a desired output. Engineers involved in the design, testing and servicing of mechanical systems need to have a firm grasp of the underpinning principles in order to appreciate the choice of components, the forces acting on them and the way that they relate to each other.

The study of stationary structures and their components is often referred to as 'statics'. The first two learning outcomes cover the mechanical principles that underpin the design of framed structures, simply supported beams and structural components. The aim is to give learners the means to evaluate the integrity and safety of engineering structures and to lay the foundation for structural analysis at a higher level.

A great many engineering systems are designed to transmit motion and power. These include machine tools, motor vehicles, aircraft and a range of domestic appliances. The study of the motion in mechanical systems is known as 'kinematics' and the study of the forces at work and the power they transmit is known as 'dynamics'. Learning outcomes 3 and 4 aim to extend learners' knowledge of the mechanical principles associated with these studies. Learning outcome 3 aims to provide a basic knowledge of rotational motion and the effects of centripetal force in simple rotating systems. In learning outcome 4, learners are introduced to simple machines used as lifting devices. An understanding of the mechanical principles involved in the operation of these devices and mechanisms will provide a foundation for the analysis of more complex power transmission systems at a higher level of study.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to determine the forces acting in pin-jointed framed structures and simply supported beams
2. Be able to determine the stress in structural members and joints
3. Be able to determine the characteristics of rotating systems
4. Be able to determine the operating characteristics of simple lifting machines.

Unit content

1 Be able to determine the forces acting in pin-jointed framed structures and simply supported beams

Pin-jointed framed structures: solution, e.g. graphical (such as use of Bow's notation, space and force diagram), analytical (such as resolution of joints, method of sections, resolution of forces in perpendicular directions ($F_x = F\cos\theta$, $F_y = F\sin\theta$), vector addition of forces, application of conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$)

Forces: active forces, e.g. concentrated loads; uniformly distributed loads (UDL); reactive forces, e.g. support reactions, primary tensile and compressive force in structural members

Simply supported beams: distribution of shear force and bending moment for a loaded beam, e.g. concentrated loads, UDL; types of beam arrangement, e.g. beam without overhang, beam with overhang and point of contraflexure

2 Be able to determine the stress in structural members and joints

Single and double shear joints: fastenings, e.g. bolted or riveted joints in single and double shear; joint parameters, e.g. rivet or bolt diameter, number of rivets or bolts, shear load, expressions for shear stress in joints subjected to single and double shear, factor of safety

Structural members: members, e.g. plain struts and ties, series and parallel compound bars made from two different materials; loading, e.g. expressions for direct stress and strain, thermal stress, factor of safety

3 Be able to determine the characteristics of rotating systems

Rotating systems with uniform angular acceleration: systems, e.g. simple (such as rotating rim, flywheel, motor armature, pump or turbine rotor), complex (such as systems where combined linear and angular acceleration is present, hoist and vehicle on an inclined track); kinetic parameters, e.g. angular displacement, angular velocity, angular acceleration, equations for uniform angular motion ($\omega_2 = \omega_1 + \alpha t$, $\theta = \omega_1 t + \frac{1}{2}\alpha t^2$, $\omega_2^2 = \omega_1^2 + 2\alpha\theta$, $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$); dynamic parameters, e.g. radius of gyration, moment of inertia ($I = mk^2$), inertia torque ($T = I\alpha$), friction torque, application of D'Alembert's principle, mechanical work ($W = T\theta$), power (average power = $\frac{W}{t}$, instantaneous power = $T\omega$), rotational kinetic energy ($KE = \frac{1}{2}I\omega^2$), application of principle of conservation of energy

Rotating systems with uniform centripetal acceleration: systems, e.g. simple (such as concentrated mass rotating in a horizontal or vertical plane, vehicle on a hump-backed bridge, aircraft performing a loop), complex (such as centrifugal clutch, vehicle on a curved track); kinetic parameters, e.g. expressions for centripetal acceleration ($a = \omega^2 r$, $a = \frac{v^2}{r}$); dynamic parameters, e.g. expressions for centripetal force ($F_c = m\omega^2 r$, $F_c = \frac{mv^2}{r}$)

4 Be able to determine the operating characteristics of simple lifting machines

Parameters of lifting machines: kinetic parameters, e.g. input motion, output motion, velocity or movement ratio, overhauling; dynamic parameters, e.g. input effort, load raised, mechanical advantage or force ratio, law of a machine, efficiency, limiting efficiency

Lifting machines: lifting machines, e.g. simple (such as inclined plane, screw jack, pulley blocks, wheel and axle, simple gear train winch), differential (such as differential wheel and axle, Weston differential pulley block, compound gear train winch)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 illustrate graphically the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	**M1** analyse the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	**D1** determine the values of distribution of shear force and bending moment and locate a point of contraflexure for a simply supported beam with overhang carrying at least two concentrated loads and a continuous uniformly distributed load
P2 determine the values of distribution of shear force and bending moment for a simply supported beam without overhang carrying at least three concentrated loads		
P3 determine the values of required parameters for a single shear lap joint and a double shear butt joint for given service conditions	**M2** determine the values of induced stresses and dimensional changes that occur in the materials of a series connected compound bar and a parallel connected compound bar when subjected to direct loading	
P4 determine the induced direct stress, dimensional change and factor of safety values in operation for a rigidly held plain structural member when subjected to a combination of direct and thermal loading		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 determine the outcomes of applied torque, work done and power dissipated in a uniformly accelerated simple rotating system to overcome the effects of inertia and friction	**M3** determine the performance value of a complex rotating system due to the effects of centripetal acceleration	**D2** determine the applied torque, work done and power dissipated outcomes in a uniformly accelerated complex rotating system in which both linear and rotational motion is present, to overcome the effects of inertia, friction and gravity.
P6 determine the centripetal acceleration and centripetal force values in a simple rotating system		
P7 determine the outcomes of kinetic and dynamic parameters of operation of two different simple lifting machines from given data.	**M4** evaluate the kinetic and dynamic parameters of operation of a differential lifting machine.	

Essential guidance for tutors

Assessment

Ideally, assessment of this unit will be achieved through application of the mechanical principles covered to the relevant engineering settings. This could be achieved through integration with other engineering principles units, practical work that provides learners with opportunities to produce individual evidence for assessment against the criteria, and individual project/assignment tasks. Whichever approach is taken, it is important to ensure that the criteria are achieved autonomously. Where centres consider a test/examination necessary to achieve authentic evidence, they need to ensure that the test items are set in a way to enable the criteria to be met in full. Centres also need to consider how such an assessment will provide opportunities to meet the merit and distinction criteria, and how to provide learners with further learning and assessment should they initially fail to achieve in the test/examination.

If learners make an arithmetic error in the solution to a problem, it is for the centre to decide the significance of such an error, assess the work accordingly and provide suitable feedback. For example, if a learner has chosen the correct approach and manipulated the necessary formulae and data correctly, but has made and carried through a minor arithmetic error, then the final 'inaccurate' solution to the problem may be deemed to be good enough to meet the criterion. However, if the final solution to the problem is so obviously wrong that it should have prompted further checks for accuracy, then the solution could be deemed to be unacceptable and reassessment considered. The incorrect application of units and/or dimensions are a typical cause of such major errors, which can lead to relatively large scale errors of the magnitude 10^3 or greater.

It is possible to assess the criteria P1, P2, M1 and D1 through an assignment requiring the graphical and analytical solution of a given pin-jointed framed structure and the analysis of given simply supported beams. The magnitude and nature of the framed structure support reactions and internal forces may be illustrated graphically (P1) and confirmed analytically (M1). Learners should make use of Bow's notation in their analysis.

The simply supported beam for P2 should contain at least three concentrated loads and be supported at its free ends. The simply supported beam for D1 should overhang one of its supports and contain at least two concentrated loads and a continuous uniformly distributed load. Learners should be required to adopt an analytical approach to locate the point of contraflexure.

A second assignment could assess the criteria P3, P4 and M2. The first task might be to determine the parameters for a single shear lap joint and for a double shear butt joint (P3) for given service conditions. This might involve calculation of the rivet/bolt diameter required for a given load or the safe working load for a particular joint. The joints should contain at least three rivets/bolts (six in total for the butt joint).

A second task might be to calculate the direct stress induced in a rigidly fixed member due to direct loading and temperature change (P4). A further task could involve evaluation of the stresses and dimensional changes occurring in series and parallel connected compound bars (M2) when subjected to direct loading.

A third assignment could be used to assess the criteria P5, P6, M3 and D2. The first task might involve consideration of a simple rotating system, such as a flywheel, which is accelerated against the effects of inertia and friction (P5). A second task might involve consideration of a more complex system such as a hoist or a vehicle on an incline in which both linear and angular motion is present (M3).

The third task might be to determine the centripetal acceleration and centripetal force present in a simple rotating system (P6). A final task would require learners to determine effects of centripetal acceleration and force in a more complex rotating system (D2). This might involve determining the speed of engagement and power transmitted by a centrifugal clutch. Alternatively, learners could evaluate the active and reactive forces on a vehicle travelling round a curved level track, maximum safe speed and the banking angle required for no tendency to side-slip at a given speed. The term performance in the criterion is therefore relevant to the particular rotating system given/used.

A final assignment containing two tasks could be used to achieve the P7 and M4 criteria. The first task would involve determination of velocity ratio, mechanical advantage and efficiency of two simple lifting machines for given input conditions (P7). Exemplar machines are ranged in the unit content.

In a second task, the M4 merit criterion could be achieved by means of a practical or simulated investigation of a differential lifting device. This should involve the determination of velocity ratio and the gathering of a sufficiently wide range of load and effort values for analysis of the machine performance. Graphs of load versus effort and load versus efficiency can then be plotted from the manipulated and tabulated test data. The law of the machine can be derived from the load versus effort graph and the theoretical value of the limiting efficiency obtained. An evaluation of this limiting value can then be made by comparison with that indicated on the load versus efficiency graph. An evaluation can also be made as to the likelihood of overhauling. Again, exemplar machines for this task are ranged in the unit content.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Forces and Moments in Static Systems	Analysis of pin-jointed framed structures and simply supported beams.	A written report containing required graphics and an appropriate introductory explanation to each step in the sequence of calculations and findings.
P3, P4, M2	Stress in Static System Components	Determination of parameters for riveted joints and determination of stress in plain and compound structural members.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.
P5, P6, M3, D2	Dynamic Systems	Determination of dynamic system parameters and performance.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.
P7, M4	Lifting Machines	Determination of the parameters and performance of simple lifting machines.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.

Essential resources

Centres could provide access to laboratory facilities with a range of equipment for investigation and demonstration purposes wherever possible. In particular, flywheels or other rotor systems for the determination of moment of inertia and radius of gyration, turntable apparatus for the investigation of centripetal acceleration and force and a range of simple lifting machines.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Bolton W – *Engineering Science* (Routledge, 2006) ISBN 9780750680837

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 56: Electrical and Electronic Principles in Engineering

Level:	**3**
Unit type:	**Optional; pathway mandatory in Medical Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The modern world relies on electrical and electronic devices – from mobile telephones to jet aeroplanes, these devices have had an enormous impact on the way we live today. Without early engineers such as Faraday and Lenz, who studied the then new concept of electricity, many of the inventions we now take for granted would not have been developed.

The unit starts by developing and extending learners' understanding of fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners are then taken through the various properties and parameters associated with capacitance and inductance, before finally considering the application of single-phase alternating current (AC) theory. The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

For learners wishing to follow an electrical/electronic programme, this unit is an essential building block that will provide the underpinning knowledge required for further study of electrical and electronic applications.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

2 Be able to apply the concepts of capacitance in DC circuits

3 Know the principles and properties of magnetism

4 Be able to use single-phase alternating current (AC) theory.

Unit content

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

DC circuit theory: voltage, e.g. potential difference, electromotive force (emf); resistance, e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source, e.g. cell, battery, stabilised power supply; resistors, e.g. function, types, values, colour coding; diodes, e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae, e.g. $V = IR$, $P = IV$, $W = Pt$, application of Kirchhoff's voltage and current laws

DC networks: networks with one DC power source and at least five components, e.g. DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement; diode resistor circuit with DC power source, series resistors and diodes

Measurements in DC circuits: safe use of a multimeter, e.g. setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source, testing a diode's forward and reverse bias)

2 Be able to apply the concepts of capacitance in DC circuits

Capacitors: types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function, e.g. energy stored, circuits (series, parallel, combination); working voltage

Charging and discharging of a capacitor: measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants

DC network that includes a capacitor: e.g. DC power source with two/three capacitors connected in series, DC power source

3 Know the principles and properties of magnetism

Magnetic field: magnetic field patterns, e.g. flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis

Electromagnetic induction: principles, e.g. induced electromotive force (emf), eddy currents, self and mutual inductance; applications (electric motor/ generator, e.g. series and shunt motor/generator; transformer, e.g. primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws

4 Be able to use single-phase alternating current (AC) theory

Single-phase AC circuit theory: waveform characteristics, e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities, e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components

AC circuit measurements: safe use of an oscilloscope, e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values); circuits, e.g. half and full wave rectifiers

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theory to calculate current, voltage and resistance in DC networks	**M1** use Kirchhoff's laws to determine the current in various parts of a network having four nodes and the power dissipated in a load resistor containing two voltage sources	
P2 use a multimeter to carry out circuit measurements in a DC network		
P3 describe the forward and reverse characteristics of two different types of semiconductor diode		
P4 describe the types and function of capacitors	**M2** explain capacitance, charge, voltage and energy in a network containing a series-parallel combination of three capacitors	
P5 carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 calculate the charge, voltage and energy values in a DC network for both three capacitors in series and three capacitors in parallel		
P7 describe the characteristics of a magnetic field		
P8 describe the relationship between flux density (B) and field strength (H)		
P9 describe the principles and applications of electromagnetic induction	**M3** explain the application of electromagnetic induction in motors and generators	**D1** evaluate the performance of a motor and a generator by reference to electrical theory
P10 use single-phase AC circuit theory to determine the characteristics of a sinusoidal AC waveform	**M4** compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	**D2** analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors.
P11 use an oscilloscope to measure and determine the inputs and outputs of a single-phase AC circuit.		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and circuits and computer-based software packages, where appropriate.

It is likely that at least five assessment instruments will be required for this unit. If practical work and tests are also used, then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Clearly, the ability to safely use a multimeter (P2) will require process evidence, i.e, it will need to be observed by the tutor during relevant practical activities. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The assessment of the use of circuit theory to calculate current, voltage and resistance in DC networks (P1) could be achieved by using a paper-based or computer-based method. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, centres need to ensure that sufficient product evidence is available of the circuit being used/developed and the formulae selected/used to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where print-outs do not show sufficient detail to meet the criteria.

The description of the forward and reverse characteristics of two types of semi-conductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box.

For P4, learners will need to describe the full range of types of capacitors (electrolytic, mica, plastic and paper, ceramic, fixed and variable), including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages.

P5 requires learners to carry out a laboratory experiment to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500 μF electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor. Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

P6 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel.

The characteristics of magnetic fields for P7 could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. For P8, learners need to explain the relationship between flux density (B) and field strength (H) with particular emphasis on BH curves and the use of different materials such as silicon iron and mild steel.

The evidence for P9 will be descriptive and requires learners to provide basic explanations of the principles and concepts of electromagnetic induction such as the movement of a conductor within a magnetic field.

P10 and P11 could link AC theory and practice with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit. This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and rms values.

M1 relates to the use of Kirchhoff's laws and here again learners should be encouraged to check their results by using a computer software package and/or practical experiment. This criterion naturally follows on from the work on resistors in series and parallel in DC circuits and, as such, could perhaps be incorporated into an assignment covering P1, P2 and M1.For M2, learners need to explain capacitance, charge, voltage and energy for specific capacitors in a series parallel combination. This extends the understanding from the pass grade criterion and could naturally form a next step in an assignment/assessment activity devised for P6.M3 is an extension of P9 requiring an explanation of the application of electromagnetic induction in motors and generators. M4 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. This criterion could be linked to *Unit 3: Mathematics for Engineering Technicians* and, once learners have been taught the sine and cosine rules, could be used to provide evidence for both units.

D1 requires learners to evaluate the performance of motors and generators by referencing electrical theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines.

For D2, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

As suggested earlier, and illustrated in the assignment grid, it would be appropriate to use a five-assessment model to assess this unit.

The first is a theoretical assignment under controlled conditions could assess P1 and M1.

A second practical assignment could be used to assess P2 and P3, again possibly under controlled conditions.

Assignment 3 is to assess P4, P5, P6 and M2 and could be a mixed assignment, preferable not done under controlled conditions.

The fourth assignment could again be a mixed assignment to assess P7, P8, P9, M3 and D1.

Finally, assignment 5 assesses P10, P11, M4 and D2, and could be of a practical nature carried out under controlled conditions.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	DC Circuit Theory/Resistor Networks and Kirchhoff's Laws	An activity requiring learners to complete two tasks, one for each criterion. Task 1 involves learners evaluating current, voltage and resistance in a DC network. Task 2 uses Kirchhoff's laws to determine the current and power dissipated in a load resistor.	A report containing the results of calculations to evaluate current, voltage, resistance and power for a DC network using DC circuit theory and Kirchhoff's laws. Carried out under controlled conditions.
P2, P3	DC Circuit Theory/Measurement and Diodes	A practical activity requiring learners to complete measurements using a multimeter in a DC network for task 1 and compare the forward and reverse characteristics of two different types of semi-conductor diode for task 2	For both tasks, learners will be required to complete pre-prepared response sheets with their measurements and make required responses, together with a brief conclusion. Carried out under controlled conditions

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M2	Capacitors	A mixed activity comprising of four tasks. The first being of a descriptive nature to describe the types and function of capacitors. Second, an experiment to determine the relationship between voltage and current for a charging and discharging capacitor. The third and fourth involve the learner carrying out calculations to evaluate capacitance, charge voltage and energy in DC networks.	A written report containing written responses to the descriptive task, tabulated results and graphs for the practical, together with calculations for the DC networks.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, M3, D1	Magnetism, Transformers and Motor/Generators	A mixed activity comprising four tasks. The first three are to describe the characteristics of a magnetic field, explain the relationship between flux density and field strength, and describe the principles and applications of electromagnetic induction. The final task is to evaluate the performance of a motor and generator.	A written report containing labelled diagrams illustrating magnetic fields, graphical plots of BH curves and diagrams with descriptions to illustrate principles and applications of electromagnetic induction. For the distinction criteria it would be envisaged that comprehensive answers to pre-prepared response sheets together with diagrams, graphs and calculations need to be submitted.
P10, P11, M4, D2	Single Phase AC	A practical activity requiring learners to complete four tasks. First, using single-phase AC theory to consider the characteristics of a sinusoidal AC waveform and second, use an oscilloscope to evaluate the inputs and outputs of a single-phase AC circuit. Third, to compare the results of the addition and subtraction of two sinusoidal AC waveforms. Fourth, to analyse the operation of a power supply.	A written report using pre-prepared response sheets and graph paper carried out under controlled conditions.

Essential resources

It is essential that learners have access to a well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9781466501096

Robertson C R – *Fundamental Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687379

Unit 57: Helicopter Gas Turbine Engines, Transmission, Rotors and Structures

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will broaden learners' knowledge and understanding of helicopter engines and transmission systems and how single rotor and twin rotor systems interact for control and stability during flight. Learners will look at the construction of a turbo-shaft engine and the systems used to monitor its performance. They will analyse the component parts and arrangement of a helicopter power train, before looking at methods used to assemble and align helicopter structures. This unit will not only be of benefit to learners studying at BTEC National level, but also those following a modern apprenticeship in helicopter manufacture or maintenance, as well as those undergoing aircraft training with the armed forces.

Learning outcomes

On completion of this unit a learner should:

1 Know the principles and construction of a helicopter turbo-shaft engine

2 Understand the principles and construction of helicopter main and tail rotor transmission systems

3 Know about helicopter structures and their assembly methods and alignment techniques

4 Know about the function and construction of helicopter flight control systems.

Unit content

1 Know the principles and construction of a helicopter turbo-shaft engine

Arrangement and operation: constructional arrangement and operation of the turbo-shaft engine, mechanical engine control, electronic engine control and fuel metering systems (FADEC)

Engine monitoring systems: e.g. exhaust gas temperature (EGT), turbine temperature, engine speeds (N1, N2, Ng, Nf), oil pressure, oil temperature, fuel pressure (temperature and flow), engine oil system, engine fuel system

Principles: e.g. potential energy, kinetic energy, Newton's law of motion, Brayton cycle; compare relationships, e.g. force, work, power, energy, velocity, acceleration

Modules of a turbo-shaft engine: inlet, e.g. compressor inlet ducts, effects of various inlet configurations, ice protection; compressors, e.g. axial, centrifugal and mixed, constructional features, operating principles, applications, fan balancing; causes and effects of compressor stall and surge; methods of air flow control, e.g. bleed valves/bands, variable inlet guide vanes, variable stator blades; combustion section, e.g. constructional features, principle of operation; turbine section, e.g. operation and characteristics of different turbine blade types, disc attachment, nozzle guide vanes, causes and effects of turbine blade stress and creep; exhausts, e.g. constructional features and principles of operation; free power turbine and main engine output shaft and gearbox arrangement and principle of operation

2 Understand the principles and construction of helicopter main and tail rotor transmission systems

Rotor operation: types of main rotor head (rigid, semi-rigid, fully articulated); gearboxes; main rotor; intermediate/angle; tail rotor; transmission systems; clutches; free wheel units (such as ramp and roller and spragg); rotor brake drive shafts (such as main engine output, intermediate and tail rotor drive)

Components: used to obtain main and tail rotor drive, e.g. ancillary equipment (tail rotor hub, gimbal ring/ carden ring, flexible couplings), systems for fold and spread of main rotor, systems for tail pylon fold, ACSRs, bearings (radial, axial), seals (static, dynamic), lubrication types and applications

3 Know about helicopter structures and their assembly methods and alignment techniques

Helicopter structures: structures, e.g. monocoque, semi-monocoque, truss; constructional features, e.g. ties, struts, stringers, longerons, frames, formers, bulkheads, sub division of airframe; classification of structure, e.g. primary, secondary, tertiary

Assembly: assembly methods, e.g. types of fasteners, jigs and fixtures, airframe rigging, symmetry checks; alignment techniques

4 Know about the function and construction of helicopter flight control systems

Function of flight control systems: cyclic control, e.g. rigging, operation, swashplate; collective control, e.g. rigging, operation; yaw control, e.g. anti-torque, tail rotor, NOTAR technology, bleed air, main rotor heads achieving control, e.g. features (such as design, operational), blade dampers (such as function, construction), rotor blades (such as construction, attachment), tail rotor blades (such as construction, attachment), trim control (such as fixed stabilisers, adjustable stabilisers), system operation (such as manual, hydraulic, electrical, fly by wire)

Construction of flight control systems: components, e.g. cables and pulleys, turnbuckles, brackets, levers, linkages, pivots, valves, micro-switches, locks, connecting rods, stops, jacks, dampers, yaw pedals, cyclic pitch lever, collective pitch lever, auto pilot systems, AFCS, series and parallel actuators, mixer units; types of controls and respective axes about which they provide control; collective, cyclic, yaw pedals, flying control components, e.g. push pull tubes, torque tubes, bell cranks, gradient unit, control boosts

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the constructional arrangement and operation of a turbo-shaft engine	**M1** explain the working cycle of a turbo-shaft engine and identify the various modules, including the axial and centrifugal compressor and the reason for including a free power turbine	**D1** analyse two different helicopter transmission systems used to drive both the main and tail rotors and determine how speed, torque and power train alignment is achieved
P2 describe the function of engine control and fuel metering systems	**M2** explain the operation of a turbo-shaft engine lubrication and fuel system	**D2** carry out a real or simulated rigging operation on a helicopter main or tail rotor flying control system using the appropriate tools and manuals.
P3 identify four engine monitoring systems and describe the information each one is indicating	**M3** remove, examine, refit and align main and tail rotor transmission components in a real or simulated environment	
P4 state the principles of a turbo-shaft engine and compare relationships in the gas flow through the engine	**M4** explain how airframe alignment is maintained during manufacture or repair and how a symmetry check is carried out.	
P5 describe the construction of the main components of a turbo-shaft engine		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 identify the three types of main rotor heads and describe the operation of a fully articulated head		
P7 describe the components used to obtain main and tail rotor drive and their arrangement on a typical helicopter		
P8 describe helicopter structures, their constructional features and classification		
P9 identify the assembly methods and alignment techniques used in helicopter structures		
P10 identify the three helicopter controls used during flight and describe how they achieve control about the three axes		
P11 identify the main components and types of controls and components used in the construction of flight control systems on a typical helicopter.		

Essential guidance for tutors

Delivery

Delivery of this unit should be designed to give learners a thorough understanding of rotary wing aircraft engines, controls and airframes.

When delivering the unit content associated with aircraft engines tutors should concentrate on the turbo-shaft engine, as this is the most common engine in use on helicopters. The operation and control of the engine should be covered in sufficient detail that learners are aware of how power is taken from the engine along with the methods used to control and monitor the operation of the engine. Learners will need to be given access to gas turbine engines so that the construction of components and sections can be examined and explored. Single and double or even triple engine layouts should be considered when looking at the control and monitoring of engines.

The main rotor controls for a single main rotor helicopter have many common components. The general layout of the controls and the subtle differences between the spider arms, swashplates and non rotating components should be examined so that learners will feel confident when faced by either type or system. There should be sufficient access to main and tail rotor controls on a helicopter to allow real or simulated rigging procedures to be undertaken on them. These should also be used to demonstrate how lift is generated and manipulated to give directional flight and the interaction required from all three controls to gain controlled flight.

The layout of the transmission system from the engine(s) to the main and tail rotor gearboxes and to the blades should be investigated by comparing two different helicopters with sufficiently differing layouts. For this reason it may be preferable to use a single engine and a twin engine helicopter where possible. One of the examples used should be available for real or simulated work so that fitting work on the systems may be carried out. This should also ensure that one type of main rotor head will be available for examination so that learners can determine how the final run of the control system is connected to the blades, how lift and thrust forces produced are carried back through to the airframe and how undesirable forces are resolved. All aspects of the transmission system (power train) should be explored so that the learner will develop a thorough understanding of the requirements of the systems.

The construction of the airframe as a support for the transmission and flight control systems along with its purpose of carrying a payload should be considered holistically to integrate all the system requirements. Emphasis should be placed on the load carrying ability of the various airframe constructions and the need to fit transmission components and flying control components in positions that ensure the integrity of the systems. The interaction of the airframe, control systems and transmission systems should be stressed to reinforce the necessity of design with learners. The layout and construction of the main rotor gearbox due to the interaction of the control system used or vice-versa and the necessity of flexibility within the transmission system (power train) and rigidity within the control system should be explored. This will enable the learners to understand the complexity of the helicopter as a fully integrated collection of independent systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Whole-class teaching: • introduction to unit content, scheme of work and assessment strategy • in an aircraft environment, explain and familiarise learners with helicopters, engines, transmissions (power trains), flying controls and structures • in an aircraft maintenance environment demonstrate the constructional arrangements of engines and differing engine controls (FADEC) • explain construction of engine monitoring systems, EGT, N1, N2, EGT, Ng, Nf and engine oil and fuel systems • explain Newton's law, Brayton cycle, force, work, power, energy and velocity of gas flows • compare compressor designs, ice protection, stalling and surging and airflow control, variable inlet guide vanes, bleed bands etc • compare combustion designs, principles and turbine designs, stress and creep. Examine gearbox arrangements. *Individual activity*: • investigate (using manuals and related documents) engine layout and construction comparing different engines where available.
Prepare and carry out Assignment 1: Helicopter Turbo-shaft Engines (P1, P2, P3, P4, P5, M1, M2)
Whole-class teaching: • identify and compare different rotor head designs and features. Examine and compare gearboxes and powertrains, speeds of shafts and rotors • a real or simulated drivetrain component removal, fit and installation. *Group activity*: • view a helicopter to examine powertrains and various components within transmissions and gearboxes.
Prepare for and carry out Assignment 2: Helicopter Rotor Transmission Systems (P6, P7, M3, D1)
Whole-class teaching: • identify helicopter structures, constructional features and explain classification of structures • explain the assembly methods and alignment techniques used for the construction of helicopter structures. *Industrial visit*: • view helicopter structure assembly methods.

Topic and suggested assignments/activities and/assessment
Prepare for and carry out Assignment 3: Helicopter Structures (P8, P9, M4)
Whole-class teaching: • demonstrate the three flying controls and functionally move all controls to reflect the actions on the rotors • explain use of inverted airfoils (elevators) to aid reduction of airframe drag and re-positioning of tail rotor gearbox angle to improved C of G range and overall lift component, e.g. Blackhawk • detail and identify control components within flying controls and how they interact with other controls. *Individual activity*: • in a real or simulated environment carry out rigging operations on main or tail rotor controls using appropriate tools and manuals.
Prepare for and carry out Assignment 4: Helicopter Flight Control Systems (P10, P11, D2)
Feedback on assessment and unit review.

Assessment

This unit could be assessed through the use of four assignments incorporating a practical exercise or simulation.

The criteria covering learning outcome 1 (P1, P2, P3, P4, P5, M1 and M2) are probably best assessed using a formal written assignment. This assignment would require learners to describe a turbo-shaft engine in terms of its layout and operation and the function and operation of the engine control and fuel metering systems (P1 and P2). They should then develop this to explain the full working cycle of the engine with reference to the engine modules and the free turbine (M1). They should include the gas flow relationships at all stages through the engine (P4), whilst considering lubrication systems (M2) and the monitoring systems employed on the engine (P3).

P5 is concerned with the physical layout of the engine in relation to its attachment to the first part of the transmission system and the free turbine take off position. Learners' descriptions will need to include inlet, compressor, combustion section, turbine section and exhaust components and free turbine and main engine output gearbox arrangements.

This can link to learning outcome 2 (P6, P7, M3 and D1) which is concerned with the transmission of the power from the engine to the main and tail rotor hubs and how the transmission is installed and aligned on the helicopter. Evidence for this outcome is likely to come through a written assignment. Learners will need to be shown the three types of main rotor head but should concentrate on the fully articulated head (P6) as this is the more complex and requires a greater amount of servicing. The description given for P7 should include any relevant ancillary systems, systems for rotor spread and fold, bearings, seals and lubrication.

An examination of more than one helicopter type will be necessary for learners to compare transmission (powertrain) layouts and power transmission (D1). Practical work or simulated work on at least one helicopter type will allow learners to display their ability to fit and align various transmission components as necessary (M3).

The main rotor head construction will provide a link to the control systems at learning outcome 4 and the fitting of most of the transmission components will provide a link to learning outcome 3.

Learning outcome 3 (P8, P9 and M4) should be integrated with the other outcomes to enable learners to understand the structural requirements and classification of the airframe (P8), especially at the mounting points for the engine, transmission components and flying control components. Learners need to understand alignment requirements and methods used (P9) to achieve the correct orientation of aerodynamic surfaces and transmission components and be able to explain how this is achieved and checked (M4) during manufacture or repair.

Learning outcome 4 is intended to cover the construction, layout and operation of the main flying controls rather than the aerodynamics of flight, apart from the basic directional control about the flight axes (P10). Learners will be able to cover the main components and types of control (P11) by means of a formal assignment that investigates the layout of the control system on one aircraft type. A sufficiently complete control system must be available to allow learners to carry out practical or simulated rigging activities (D2). This does not have to be a full rig of the flying controls but should reflect the amount of rigging that is required after various maintenance procedures.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, M1, M2	Helicopter Turbo-shaft Engines	A written explanation of the principles of the turbo-shaft engine.	Written response to set tasks.
P6, P7, M3, D1	Helicopter Rotor Transmission Systems	A formal written assignment and a practical/ simulated task.	Written response to set tasks with a practical task for M3. Witness statements will be required for practical task.
P8, P9, M4	Helicopter Structures	A formal written assignment where access to a helicopter will be most beneficial.	Written response to set tasks.
P10, P11, D2	Helicopter Flight Control Systems	A formal written (assignment) and practical/simulated tasks where access to a helicopter or part control system is required.	Written response to set tasks with a practical task for D2. Witness statements will be required for practical work.

Essential resources

Access to the following resources is considered essential to meet the learning outcomes:

- a range of helicopter components, particularly power plants, transmission (powertrain) components, main rotor heads and tail rotors
- relevant data books and manufacturers' specifications, aircraft publications and manuals and quality control procedures
- real or training centre helicopter, in a real or training helicopter maintenance environment.

Indicative reading for learners

Textbooks

Kroes M, Watkins W and Delp F – *Aircraft Maintenance and Repair* (McGraw Hill, 2007) ISBN 9780077231545

Wagtendonk W J – *Principles of Helicopter Flight* (Aviation Supplies, 2007) ISBN 9781560276494

Other publications

Air Publications – 101 Series of manuals and aircraft engineering publications (Military)

ATA 100 Series, specialist publications sanctioned by EASA (European Aviation Safety Agency)

Unit 58: Aircraft Flight Principles and Practice

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Large, modern passenger and transport aircraft can weigh more than 500 000 kg when they fly fully laden, yet this mass is lifted into the air with apparent ease. Light aircraft and military jet fighters are designed to be very manoeuvrable.

In this unit, you will gain an understanding of the atmosphere in which aircraft fly and the mechanical and fluid principles associated with their flight. Then you will explore, through practical experimentation, the effects of airflow over aerodynamic surfaces, as well as how lift and drag are generated and how they interact during flight. Finally, you will gain an understanding of the nature of stability and control, and the methods used to stabilise and control fixed-wing aircraft.

If you want to work in the aircraft industry then understanding how aircraft lift is achieved and how aircraft are controlled and stabilised is essential. Studying this unit will help you progress to aircraft engineering technician roles in aircraft manufacture, maintenance, component overhaul and repair. It will also help you progress to higher education to study aerodynamics or flight mechanics or, alternatively, assist with gaining entry to other aeronautical engineering degrees.

Learning outcomes

In this unit you will:

A Examine the atmospheric, mechanical and fluid principles affecting flight

B Explore safely the lift and drag force generation and interaction that create aircraft flight

C Investigate the nature and methods used to stabilise and control aircraft.

Summary of unit

Learning outcome	Key content areas	Recommended assessment approach
A Examine the atmospheric, mechanical and fluid principles affecting flight	**A1** The atmosphere, the International Standard Atmosphere (ISA) and its effect on flight **A2** Fluid flow and mechanical principles **A3** Application of mechanical principles to aircraft flight	A report covering the atmosphere, the analysis of atmospheric parameters, mechanical and fluid principles and their effect on flight and continuing airworthiness.
B Explore safely the lift and drag force generation and interaction that create aircraft flight	**B1** The nature and effects of subsonic airflow over aerofoil sections **B2** Aircraft lift, drag and their interaction	A portfolio of results gathered by experimentation when investigating airflow over aerofoil surfaces, and lift and drag generation and interaction. Supported by images, observation records, graphs and mathematical analysis.
C Investigate the nature and methods used to stabilise and control aircraft	**C1** Fixed-wing aircraft stability **C2** Fixed-wing aircraft control	A report covering the operation of flight control devices, the nature of stability and the implications and justification for the methods used for fixed-wing aircraft control and stabilisation.

Unit content

A Examine the atmospheric, mechanical and fluid principles affecting flight

A1 The atmosphere, the International Standard Atmosphere (ISA) and its effect on flight

- The atmosphere:
  - composition of the air in the Earth's atmosphere
  - layers of the Earth's atmosphere to include the troposphere, stratosphere, mesosphere, thermosphere and exosphere
  - changes to the atmospheric air pressure, density and temperature
  - danger to flight due to severe atmospheric events, including:
    - lightning strike and the methods used to mitigate the effects
    - severe air turbulence and the possible effects on the aircraft
    - bird strike, hail strike
    - frost and ice accretion and their effects on aerodynamic performance.
- The International Standard Atmosphere (ISA):
  - the need for and functions of the ISA
  - define pressure (barometric, atmospheric, absolute), temperature (Kelvin, Centigrade, Fahrenheit, absolute), density, density ratio, dynamic viscosity, kinematic viscosity and sonic velocity
  - significance of and numerical values for the tropopause, temperature lapse rate, the temperature in the stratosphere
  - standard ISA values for the properties of air at ground level and their changes with altitude, to include pressure (P), density (ρ), temperature (T) dynamic (absolute) viscosity (μ), kinematic viscosity (v) sonic velocity (a)
- define the characteristic gas constant (R), the specific heat capacity of a gas at constant volume (Cv) and constant pressure (CP), the ratio of constant volume (C_v) and constant pressure (C_P), the ratio of specific heats $\gamma = \frac{C_P}{C_V}$
  - numerical values of R, CV, CP and γ, for air, under standard conditions
  - the use of the ideal gas laws and characteristic gas equation in mass form $pv = mRT$ to solve numerical problems on the density, pressure, mass and temperature of air, under differing conditions
  - the use of ISA tables to find changes in pressure, density, absolute viscosity, kinematic viscosity and sonic velocity, for varying altitudes
  - the density ratio (σ), and its relationship to the equivalent airspeed (EAS) and true airspeed (TAS) at varying altitudes
  - the use of the temperature lapse rate equation ($T = T_0 - Lh$), the sonic velocity approximation $a = \sqrt{\gamma RT} = 20.05\sqrt{T}$ and the density ratio, to determine properties of air at varying altitudes.

A2 Fluid flow and mechanical principles

- Newton's laws, including:
  - second law and its relationship to forces generated by aircraft acceleration
  - third law and its relationship to flight forces and to the generation of aircraft lift.
- Continuity equation for laminar constant incompressible steady flow, volume flow rate given by $Q = A_1v_1 + A_2v_2$ and for unsteady variable density flow, the mass flow rate is given by $\dot{m} = \rho_1A_1v_1 = \rho_2A_2v_2$

- The Venturi principle and the nature of flow through a Venturi tube.
- The Bernoulli equation for incompressible steady flow:

  $\rho g h_1 + \frac{1}{2}\rho v^2{}_1 + p_1 = \rho g h_2 + \frac{1}{2}\rho v^2{}_2 + p_2$ also for total energy in a steady stream

  $p + \frac{1}{2}\rho v^2 = c$
- Centripetal and centrifugal accelerations where $a = \frac{v^2}{r}$ and resulting forces where

  $F = \frac{mv^2}{r}$
- Couples and turning moments where torque $T = F \times r$
- Principle of moments and balancing forces.
- Pressure measurement (mercury and aneroid barometer, manometer).

A3 Application of mechanical principles to aircraft flight

- Flight forces:
  - position and equality of lift, weight, thrust and drag forces for straight and level flight
  - flight force couples (lift/weight and thrust/drag), action about centre of gravity (CG) and centre of pressure (CP)
  - balancing aerodynamic force from tailplane
  - using the principle of moments, determine balancing forces needed to maintain aircraft in static equilibrium.
- Flight forces in steady manoeuvres:
  - diagrammatic arrangement for system of forces and their components during gliding flight, diving flight, climbing flight and turning flight where $L\sin\theta = \frac{mv^2}{r}$

    and $\tan\theta = \frac{v^2}{gr}$
  - the definition and significance of load factors
  - analytical solution of flight force parameters, during flight manoeuvres
  - the effects of excessive manoeuvre loads on airframe structure, including pulled rivets, skin buckling, fuel and oil leakage, visual structural cracking, symmetry of structure
  - methods used to prevent the loss of aircraft structural integrity in the event of overstressing damage, including: failsafe, safe life and on-condition structure, redundancy, radiation shields, planned maintenance, maintenance frequency
  - post-flight checks after flight through severe atmospheric events, including: examination of aircraft structure for damage, symmetry, examination for lightning and high intensity radiation field (HIRF) damage, instrument damage and degaussing, controls freedom of movement.

B Explore safely the lift and drag force generation and interaction that create aircraft flight

B1 The nature and effects of subsonic airflow over aerofoil sections

- The nature of subsonic airflow, including streamline, laminar and turbulent flow, compressibility effects at higher subsonic speeds.
- Aerofoil terminology, including aerofoil profile, camber, upper, lower and mean camber lines, chord line, leading and trailing edge, thickness/chord ratio or finess ratio, angle of attack (AOA), angle of incidence (AOI).
- Viscosity effects and the boundary layer, including resistance to motion, velocity gradient, shear rate, boundary layer separation (transition point, separation point).
- Flow over aerofoil sections, including free stream, laminar and turbulent flow, relative airflow, up and down wash, stagnation point, separation.
- Pressure and flow changes at low, medium and high angles of attack and aerofoil stall effects.
- Airflow and aerodynamic shape, including aerofoils (flow over thin, medium, thick and symmetrical aerofoil sections), wings (aspect ratio, generation of tip vortices).

B2 Aircraft lift, drag and their interaction

- Lift:
  - factors affecting lift, including aerofoil shape, lift coefficient, angle of attack, air density, airspeed and stall
  - centre of pressure and lift force
  - parameters and use of the lift equation, $L = C_L \frac{1}{2} \rho v^2 S$
  - wing plan form designs for aircraft subject to low subsonic, high subsonic and transonic speed airflows
  - effects that wing plan forms have on the generation of lift
  - use and types of wind tunnel apparatus, e.g. air blowers, lift and drag balances, open and closed section tunnels, flow visualisation equipment, airflow pressure and speed-measuring devices, aerofoil sections and whole aircraft models
  - measurement of lift forces using wind-tunnel apparatus
  - significance and interpretation of pressure plots for varying angles of attack and airspeed.
- Drag:
  - types of drag, including total, induced (trailing vortex), profile skin friction, profile form, interference
  - factors affecting drag, including aerofoil shape, angle of attack, drag coefficient, airspeed, streamlining, damage to lift producing surfaces, ice and frost accretion
  - drag reduction methods, including polished surfaces, fairings
  - parameters and use of the drag equation $D = C_D \frac{1}{2} \rho v^2 S$
  - significance and interpretation of profile, induced and total drag plots verses airspeed
  - measurement of drag forces using wind tunnel apparatus
  - theoretical determination of drag forces.
- Lift and drag interaction:
  - significance and interpretation of lift and drag plots
  - polar plots of lift coefficient against drag coefficient and their interpretation
  - plots of profile drag and induced drag (total drag) against airspeed
  - minimum drag, the lift/drag ratio and aerofoil efficiency
  - optimum angle of incidence (AOI).

- Interpretation of aircraft model wind tunnel test results for lift, drag and pitching moment.

C Investigate the nature and methods used to stabilise and control aircraft

C1 Fixed-wing aircraft stability

- Nature of stability, including reaction to a disturbance for stable, unstable and naturally stable bodies, static and dynamic stability.
- Definitions for lateral, longitudinal and directional stability.
- Longitudinal static stability, including trim and stability, centre of pressure and aerodynamic centre movement, use of tailplane, CG position and limits for stability, effect of loading of stores and cargo.
- Lateral static stability, including yawing stability (yawing motion or weathercocking, use of fin, keel surface and wing dihedral), rolling stability (use of high wings and sweepback), use of anhedral.
- Nature of dynamic stability, including longitudinal stability (short period pitching oscillations and damping, phugoid motion and damping) and lateral stability (roll damping, spiral mode, Dutch roll and the effect of the fin and side slip on damping).

C2 Fixed-wing aircraft control

- Purpose and operation of primary controls, including ailerons, elevators, rudder.
- Secondary controls including canards, stabilisers, elevons, tailerons and flaperons.
- Purpose and operation of control tabs, including trim, aerodynamic balance and anti-balance, balance panels, servo, spring, mass balance.
- Lift augmentation devices, purpose, operation and interaction, including flaps (plain, split, slotted, fowler, multi-slotted fowler, Krueger), slots, slats, vortex generators, wing fences, winglets.
- Purpose, operation and interaction of drag inducing devices, including spoilers (lift dump and roll), airbrakes.
- Control and stability interaction and aircraft design features for flight at transonic speed, including use of anhedral, sweepback, wing fences, delta wings, area ruling.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Pass	Merit	Distinction
Learning outcome A: Examine the atmospheric, mechanical and fluid principles affecting flight		
A.P1 Calculate the atmospheric changes due to varying altitudes and conditions, explaining the effects of these changes on aircraft flight. **A.P2** Explain the mechanical and fluid principles that enable flight. **A.P3** Explain the nature of the loads and loading parameters imposed on the airframe during flight manoeuvres.	**A.M1** Analyse the dangers to flight caused by altitude and severe atmospheric events, identifying the nature of possible damage and appropriate mitigation methods. **A.M2** Analyse the forces that result from aircraft flight, identifying the nature of structural damage that may occur from the aircraft being subject to excessive loading.	**A.D1** Evaluate, using language that is technically correct and of a high standard, how the structural design of an aircraft mitigates the impact of excessive flight forces and how post flight checks identify defects.

Pass	Merit	Distinction
Learning outcome B: Explore safely the lift and drag force generation and interaction that create aircraft flight		
B.P4 Conduct experiments safely to determine the lift and drag forces produced from steady state air at two different speeds flowing over two different aerofoil sections set at three angles of attack. **B.P5** Explain, using theoretical calculations and experimental results, the lift and drag forces produced from steady state air at two different speeds flowing over two different aerofoil sections set at three angles of attack.	**B.M3** Conduct experiments accurately to determine the lift and drag forces produced from variable state and variable speed air flowing over different aerofoil sections set at three angles of attack. **B.M4** Analyse, using theoretical calculations and experimental results, the lift and drag forces and lift/drag ratios produced from variable state, variable speed air flowing over different aerofoil sections set at three angles of attack.	**B.D2** Evaluate the lift and drag forces and lift/drag ratios produced from variable state, variable speed air flowing over aerofoil sections under three angles of attack, comparing the results from safely conducted experiments and theoretical calculations.
Learning outcome C: Investigate the nature and methods used to stabilise and control aircraft		
C.P6 Explain the nature and operation of aircraft primary controls and secondary controls, lift augmentation and drag inducing devices. **C.P7** Explain the nature of stability and how aircraft are stabilised about their axes of rotation.	**C.M5** Analyse aircraft control and stabilisation methods, including how they interact.	**C.D3** Justify the methods used to control and stabilise modern aircraft that fly at high subsonic and transonic speeds.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. There is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning outcomes and criteria is:

Learning outcomes: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.D1)

Learning outcomes: B (B.P4, B.P5, B.M3, B.M4, B.D2)

Learning outcomes: C (C.P6, C.P7, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- mechanical laboratory equipment, such as centripetal acceleration/force apparatus, Venturi and Bernoulli apparatus, Newton's cradle/Newtonian demonstrator, or similar apparatus to verify these principles
- flow visualisation apparatus, such as a smoke tunnel or a wind tunnel and prepared aerofoil sections with streamers
- an open- or closed-section wind tunnel, with lift and drag measurement equipment, speed and pressure measurement equipment. Please note that wind tunnels with manometers would be more suitable for experimental work than those with digital read-out equipment
- standard aerofoil sections, such as NACA 12 and others with known geometric parameters and pressure measurement plumbing
- workshop barometer and thermometer or other pressure and temperature measurement equipment.

Essential information for assessment decisions

Learning outcome A

For distinction standard, learners will produce evidence that includes a balanced evaluation of the structural design features and post-flight procedures used to ensure continuing airworthiness, including those problems presented by structural degradation. The evidence will include an accurate analysis of the aerodynamic forces acting on the aircraft during all phases of flight as well as the dangers and atmospheric effects on flight through extreme weather events and their combined adverse effect on the aircraft during flight. In addition, there will be an evaluation of the structural design methods used to mitigate adverse effects and the post-flight procedures used to identify the defects resulting from adverse conditions.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. For example, the evidence will be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will provide evidence for each severe atmospheric condition of one area of damage that has been identified and the corresponding mitigation methods considered.

The quantitative analysis of forces that occur during all phases of flight should include taxiing, climbing, cruising, turning and diving manoeuvres. There should be clear evidence presented that identifies the nature, and considers the likely cause of, the structural damage that may occur from excessive loading during all phases of flight.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will include in their evidence a series of calculations to determine the properties of atmospheric air at differing altitudes. Explanations may be limited to the more obvious changes that occur with altitude, such as the drop in temperature, pressure and density of the air in the troposphere and their effects on lift forces. Learners' explanations should also connect these changes with one or two of the more obvious atmospheric events. For example, they could explain how a drop in temperature and precipitation conditions increases the risk of frost/ice accretion and the effects this may have on aerodynamic performance and controls handling.

Evidence should demonstrate the relationship between the Venturi principle, Bernoulli's theorem, Newton's second law and the generation of aircraft lift forces. Aerodynamic forces that occur during aircraft manoeuvres, including gliding, climbing, pulling out from a dive and turning flight, should be explained using vector diagrams.

Overall, the explanations should be logically structured, although basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology, such as confusing dynamic viscosity with kinematic viscosity or using the term 'transition point', when they are really talking about the separation point. Also, the calculations may contain some minor arithmetic errors.

Learning outcome B

For distinction standard, learners will produce a balanced evaluation of at least two experiments undertaken with two different aerofoil sections and under different conditions, for example angles of attack. There should also be theoretical calculation of lift and drag forces and lift/drag ratios based on the airflow over at least two aerofoil sections.

The evaluation should include a comparison of the results obtained through safe experimentation and theoretical calculations, and explain why the variations occur, for example from experimental error and also from the limitations of the theoretical equations and the aerodynamic effects of wind tunnel testing when compared with real aircraft flight. Also, for example, there are the limitations with Bernoulli's theorem, when used experimentally with both steady streamlined and unsteady/turbulent airflows.

Overall, the experimental evidence, for example a report, should be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will conduct accurate experimental work to include setting up the measuring equipment and recording results methodically. The practical work will also involve running the experiments under different airflow conditions, for example to conduct the experiments under steady streamlined and unsteady/turbulent airflows.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Theoretical calculations of lift and drag forces and lift/drag ratios must be accurate and conform to accepted conventions.

For pass standard, learners will safely and correctly set up and carry out a series of experiments and obtain results. A minimum of two experiments, each with a different aerofoil section will be used to determine the effects on lift and drag across them at low, medium and high angles of attack. There may be some minor inaccuracies in the recording of the results, estimating lift and drag forces, and relating to the engineering terminology used.

Overall, learners' explanations will be logically structured and clearly identify the changes to airflow over the aerofoil sections at different angles of attack up to the stall, explicitly commenting on their effect on lift and drag. The explanation of each experiment will include scale diagrams that are annotated with relevant figures, for example lift and drag forces. Theoretical calculations will also be included, but there may be minor numerical and diagrammatic errors.

Learning outcome C

For distinction standard, learners will comprehensively cover in their evidence the nature of aircraft stability, control and interaction of aircraft flying within the subsonic and transonic range. Well-reasoned arguments should justify the methods used to damp longitudinal phugoid motion as well as the use of sweepback, large fins, anhedral and area ruling stability and control methods.

Overall, the evidence will be logically structured and use the correct technical engineering terms.

For merit standard, learners will analyse the way in which aircraft are controlled and stabilised accurately and cover the interaction between aircraft controls, aircraft stabilising devices or both. For example, in the case of aircraft lateral role control the reasons for and the interaction between the ailerons and drag inducing devices should be explained. Also, an explanation of lateral and longitudinal dynamic stability motion and the methods used to damp such motion should be included.

For pass standard, learners will be clear in their explanations for the methods of primary control about the lateral, longitudinal and normal (directional) axes, together with the types and operation of secondary controls. For example, including lift augmentation and drag inducing devices in their explanation.

A clear explanation of the nature of stability and for the methods used to stabilise conventional sub-sonic aircraft about their three axes of rotation should be given.

Overall, the explanations should be logically structured, although basic in parts and they may contain minor technical inaccuracies relating to engineering terminology. These may include being unable to differentiate between the terms 'neutral dynamic stability' and 'dynamic stability' or using the term 'fin' when they mean 'keel surface' or using the term 'leading edge flap' when they clearly mean 'leading edge slat'.

Links to other units

This unit links to:

- Unit 59: Airframe Construction and Repair
- Unit 60: Airframe Mechanical Systems
- Unit 61: Aircraft Electrical and Instrument Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local aeronautical organisations with expertise in aircraft flight
- contribution of ideas to unit assignment/project materials.

Unit 59: Airframe Construction and Repair

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Modern commercial aircraft are required to carry as many passengers or as much freight as possible to distant destinations safely and reliably. The airframe is the mechanical structure of an aircraft and it comprises the fuselage, wings, empennage (tail) and undercarriage (the last component is not covered in this unit). To achieve this, the aircraft manufacturer must make use of innovative airframe design and construction methods. For example, 50 per cent of the airframe of the Boeing 787 is built from composite materials yielding a 20 per cent weight saving compared to more traditional designs.

In this unit, you will gain an understanding of the structural components and methods used to build an airframe. You will then explore the inspection and repair procedures needed to ensure that the aircraft airframe remains airworthy. Finally, you will develop your practical skills by performing an aircraft structural inspection and repair activity in a workshop environment.

As an aeronautical engineer, it is important that you understand the construction of an airframe and develop practical skills to inspect and repair them. This unit will help to prepare you for an aircraft engineering apprenticeship, as well as aircraft engineering technician roles in aircraft manufacture, maintenance and repair. Alternatively, the unit will help to prepare you for higher education and progression to other aeronautical engineering courses.

Learning outcomes

In this unit you will:

A Examine the construction and protection methods used to ensure airworthiness of airframe structures

B Examine how inspection and repair methods are used in the maintenance of composite airframes and components

C Carry out processes to inspect and repair safely an airframe composite structure or components that will help to ensure airworthiness.

Summary of unit

Learning outcome	Key content areas	Recommended assessment approach
A Examine the construction and protection methods used to ensure airworthiness of airframe structures	**A1** Construction and assembly of major airframe structures **A2** Structural considerations for airworthiness	A report covering the construction and assembly methods of major airframe structures, such as the fuselage and wings. Also, the structural concepts and corrosion protection methods to ensure airworthiness.
B Examine how inspection and repair methods are used in the maintenance of composite airframes and components	**B1** Adhesives and sealants **B2** Bonding methods **B3** Defect types and inspection **B4** Repair procedures **B5** Safe working practices for repairing airframe composites	A report covering the inspection and repair procedures used for the maintenance of aircraft composite structures and components.
C Carry out processes to inspect and repair safely an airframe composite structure or component that will help to ensure airworthiness	**C1** Inspection of airframe damage **C2** Structural repair manual **C3** Preparation procedures for the repair of airframe composite structures **C4** Airframe composite structure inspection and repair processes	A practical workshop task to safely undertake the inspection and repair of damage to a composite airframe structure. Evidence will include finished repair, observation records/witness statements, annotated photographs and drawings and a completed record of the quality control measures needed to complete the repair process.

Unit content

A Examine the construction and protection methods used to ensure airworthiness of airframe structures

A1 Construction and assembly of major airframe structures

- Assembly of fuselage structures, including:
  - skin
  - frames, formers and longerons
  - pressure bulkheads
  - fuselage sections
  - wing, stabiliser, pylon, arrestor gear, and undercarriage/landing gear attachments.
- Assembly of wing structures, including:
  - stressed skin
  - stiffeners, spars, ribs, milled, etched, integral
  - wing boxes, torsion boxes
  - integral fuel tanks
  - composite bonding
  - assembly of landing gear attachment, pylon, control surfaces and high lift/drag devices.
- Assembly of empennage structures, including:
  - fin – vertical stabiliser and rudder
  - tailplane – horizontal stabiliser and elevators.
- Assembly methods including riveting, bolting and bonding.

A2 Structural considerations for airworthiness

- Airworthiness requirements for structural strength to include: structural classification of primary, secondary and tertiary, as defined in the aircraft structural repair manual.
- Zonal and station identification systems, including:
  - the zone system used to identify different areas of the aircraft
  - station identification systems used to locate structural elements on the aircraft relative to a reference point of station 0.
- Design concepts, including:
  - failsafe, safe life and damage tolerant structures
  - drains and ventilation provision to protect against deterioration, including weathering, corrosion and abrasion
  - lightning strike protection provision for airframe, fuel and avionics.
- Airframe symmetry and alignment checks that are generally made after hard landings, abnormal loads or certain maintenance procedures to ensure airworthiness, e.g. wing dihedral angle, wing incidence angle, symmetry check.
- Corrosive protection measures, including:
  - materials selection to inhibit corrosion to include: galvanic action, active and
    passive materials
  - jointing compounds
  - drain holes
  - stringer design
  - protection methods, including chromating, anodising, painting and surface cleaning.

B Examine how inspection and repair methods are used in the maintenance of composite airframes and components

B1 Adhesives and sealants

- General types of adhesive, including thermoset and thermoplastic polymers, elastomers, epoxy resins, phenolic resins and redux.
- Adhesive safety and service conditions as defined in the material safety data sheet (MSDS).
- General types of sealant, including silicones, bedding sealants, Thiokol (PRC), room temperature vulcanising (RTV) sealants, Proseal PR 1440.
- Use and characteristics of adhesives and sealants, including heat activated, solvent activated, impact activated, solvent cement.

B2 Bonding methods

- Pre-treatments and surface preparation, including:
  - moisture removal by heating
  - potting surface of adherents
  - solvent wipe for cleaning to remove contaminants
  - surface roughening to improve adhesion.
- Curing, including moisture curing, ultraviolet light, anaerobic reaction and anionic curing (cyanoacrylates).
- Bonding safety and service conditions as defined in the MSDS.

B3 Defect types and inspection

- Cause and identification of typical defects, including structural impact, foreign object, surface, delamination, disband, void, contamination and water ingress.
- Inspection methods and procedures, including:
  - tap test for detection of delamination problems
  - visual inspection to identify damage, e.g. dent, penetration, abrasion
  - non-destructive inspection, e.g. thermography, acoustic emission, ultrasonic, radiography (x-ray or gamma-ray).

B4 Repair procedures

- Non-patch and patch repairs, including:
  - resin injection (potting or filling)
  - delamination injection, heat treatment
  - surface coating bonded external patch
  - bonded scarf
  - bonded flush
  - repair curing using the hot bonder or autoclave
  - bolted external patch.

B5 Safe working practices for repairing airframe composites

- Key features of health and safety regulations, or other relevant international equivalents, including:
  - Control of Substances Hazardous to Health (COSHH) Regulations and amendments; e.g. requirements on the safe storage and use of hazardous substances, manufacturers' safety data sheets, hazard symbols, ventilation, protection from contact with hazardous substances (e.g. methyl-ethyl-ketone, acetone)
  - Personal Protective Equipment (PPE) at Work Regulations and amendments, e.g. employer responsibility to provide appropriate equipment; e.g. eye protection, barrier creams, disposable gloves, protective clothing, dust masks, respirators
  - Manual Handling Operations Regulations (MHOR) and amendments – avoid the need for manual handling, types of hazard, assess risk of injury when manual handling is required, control and reduce the risk of injury, training in use of aids
  - Procedures, hazards and precautions when working at height (Working at Height Regulations and amendments) and working in confined spaces, e.g. under mechanical systems.
  - Other safe working practices, including material data sheets, health and safety procedures, reporting of hazardous items of plant or equipment, and emergency procedures
  - Safety hazards, including dust, solvents, handling materials (e.g. composite sheets and resins), ultraviolet light and high temperatures.

C Carry out processes to inspect and repair safely an airframe composite structure or component that will help to ensure airworthiness

C1 Inspection of airframe damage

- Structural classification of damaged component, e.g. primary, secondary.
- Approved repair information, e.g. structural repair manual, authorised repair drawings.
- Preliminary survey of damage to determine size/depth of area needing repair.
- Removal of damaged materials.
- Repair report detailing the results of the survey and scope of damage.
- Damage classification (as defined in the Structural Repair Manual for the target aircraft), including:
  - allowable, where the damage is within the limits defined in the Structural Repair Manual and the aircraft may return to service until a permanent repair is made,
    e.g. removing dents, stop-drilling cracks, polish scratches
  - repairable by patching, e.g. skin or fuselage repair
  - repairable by insertion, e.g. potting repair
  - repairable by replacement, e.g. honeycomb core repair
  - repair limits for cracks, skin panting, bow and dents.
- Procedural points and safety issues to be considered during repair work, including:
  - inspection of rivet/bolt holes for elongation or deformation
  - inspection before closing work
  - repair material compliance
  - removal of swarf and burrs
  - need for jury rigging.
- Assessment of composite structures for damage and damage limits.

C2 Structural repair manual

- General familiarity and limitations.
- ATA 100 specification.
- Numbering system (chapter, section, subject, figure).
- Use of the manual (identification of limits of damage, restricted/non-restricted areas, repair classification A, B, C, use of flow charts).

C3 Preparation procedures for the repair of airframe composite structures

- Consulting information sources to determine airframe composite structure inspection and repair processes, including standards.
- Identifying and selecting, from information sources, all required consumables and hardware components for designated composite structure inspection and repair activity.
- Complying with laid down processes, including tests and inspection checks for designated composite structure repair activity.

C4 Airframe composite structure inspection and repair processes

- Safe working practices, e.g. the use of personal protective equipment (PPE).
- Carry out repair using processes identified from information sources.
- Repair of minor damage, e.g. scratches, pits, dents, small blisters and minor delamination.
- Typical multi-lamination repairs and repairs to honeycomb core and one or both skins.
- Curing repairs.
- Quality control checks, including:
  - repair activities in compliance with information sources procedure
  - inspection checks, including visual, physical; e.g. tap test and non-destructive tests (e.g. ultrasonic).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning outcome A: Examine the construction and protection methods used to ensure airworthiness of airframe structures</td><td rowspan="2">A.D1 Justify, using language that is technically correct and of a high standard, the construction, assembly and structural considerations used on major airframe structures, considering how they interrelate to help ensure airworthiness.</td></tr>
<tr><td>A.P1 Explain the typical construction and assembly methods used for major airframe structures.
A.P2 Explain what airframe structural considerations apply to an aircraft, helping to ensure airworthiness.</td><td>A.M1 Compare the typical construction and assembly methods used for major airframe structures and explain the structural considerations that apply to them, helping to ensure airworthiness.</td></tr>
<tr><td colspan="2">Learning outcome B: Examine how inspection and repair methods are used in the maintenance of composite airframes and components</td><td rowspan="2">B.D2 Justify the inspection and repair methods chosen for the detection and repair of damage to a given airframe composite structure or component.</td></tr>
<tr><td>B.P3 Explain the procedures for the inspection of damage to composite structures and components.
B.P4 Explain the procedures and related safety precautions for patch and non-patch repairs to composite structures and components.</td><td>B.M2 Analyse what inspection and repair methods would be effective for the detection and repair of damage to a given airframe composite structure or component.</td></tr>
</table>

Pass	Merit	Distinction
Learning outcome C: Carry out processes to inspect and repair safely an airframe composite structure or component that will help to ensure airworthiness		
C.P5 Inspect a composite airframe structure or component for damage; classify the type of damage; and identify an appropriate repair method. **C.P6** Complete the preparation activities to repair a damaged composite airframe structure or component effectively. **C.P7** Repair a damaged composite airframe structure or component safely, including appropriate inspections, checks and tests.	**C.M3** Complete the repair of a damaged airframe composite structure or component safely and accurately, including appropriate inspections, checks and tests.	**C.D3** Refine, during the process, the repair to a damaged airframe composite structure or component safely to ensure airworthiness and integrity, including appropriate inspections, checks and tests.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. There is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning outcomes and criteria is:

Learning outcome: A (A.P1, A.P2, A.M1, A.D1)

Learning outcome: B (B.P3, B.P4, B.M2, B.D2)

Learning outcome: C (C.P5, C.P6, C.P7, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

Please note that the required physical resources may not necessarily be directly available at the centre delivering this unit, but could be made available on the premises of a partner organisation.

For this unit, learners must have access to:

- a range of aircraft airframe composite structural components
- physical examples of corroded airframe structures or structural components
- aircraft adhesives, sealants, composite materials and composite airframe components
- specialist repair manuals, maintenance manuals and related inspection procedures and other documentation.

Essential information for assessment decisions

Learning outcome A

For distinction standard, learners will provide in their evidence a balanced and thorough justification for the construction and assembly of airframe mechanical structures and of structural considerations that apply. For example, the Airbus A380 centre wing box is a major airframe structure which will weigh around 8.8 tonnes of which 5.3 tonnes is composite materials and provides the link between the wings and fuselage.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms and will be of a high standard of written language, for example it will be grammatically correct.

For merit standard, learners will compare in their evidence the construction and assembly of major airframe structures, demonstrate a clear understanding of the assembly processes. For example, the horizontal stabiliser on the Airbus A320 tail-plane is constructed from composite materials because of the high strength and relatively low weight of the materials, but it could equally have been made from metallic materials. Learners will also explain the structural considerations that apply to major airframe structures, for example the Airbus A340 rear pressure bulkhead.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will provide in their evidence an explanation of the construction and assembly of major mechanical airframe structures. For example, the fuselage of an A320 is constructed from composite materials and assembled in sections and joined together with rivets. The explanation will cover the main components, construction and assembly methods used in a typical airframe.

Learners will explain the key structural considerations for airworthiness. For example, learners will explain why galvanic protection is important for mating metal structural components and which type of metals can be in contact with each other.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example making general statements about the assembly methods for airframe structures, and may contain technical inaccuracies or omissions, such as an assembly method described as riveted when bolted is correct.

Learning outcome B

For distinction standard, learners will clearly support in their evidence the selection of inspection methods for the given damaged structure. For example, the considerations that need to be taken into account when making the choice between a bonded or bolted patch repair for impact damage to a composite skin panel, pre-repair inspection to determine the extent of damage and post repair inspection to ensure airworthiness. Learners will also provide a detailed, technically accurate justification of the repair method.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will clearly analyse in their evidence the effectiveness of the available inspection and repair methods in detecting and repairing damage in the given airframe composite structure or component. For example, a visual inspection of the extent of impact damage to a composite skin panel, leading to a bonded/bolted patch repair and final post repair visual and non-destructive testing inspection.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will include in their evidence an explanation of the procedures for the inspection and repair of damage to airframe composite structures and components. For example, that a tap test can be used to detect delamination of a composite structure and a patch repair would normally be required to ensure the airworthiness of the structure with this type of damage.

Overall, the explanations will be logically structured, although basic in parts and they may contain minor technical or diagrammatic errors. For example, the explanation of a scarf patch repair may omit the number, type of layers and/or steepness.

Learning outcome C

The centre can adjust the type of repair to fit with their local needs and resources.

For distinction standard, learners will refine what they are doing, throughout the inspection and repair process, to ensure the airworthiness and structural integrity of the airframe or component. The airworthiness and structural integrity will be determined by inspecting the finished airframe structure or component for dimensional accuracy and effectiveness of the process. For example, the repair should meet the specification defined in the Structural Repair Manual (SRM). In the case of a bolted repair all fasteners and the patch itself should be sealed to prevent water/moisture intrusion, galvanic corrosions or fuel leaks.

Overall, the evidence will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer. There will be a comprehensive record of the safety and operational procedures followed, together with accurately and correctly completed documentation for each of the maintenance operations completed.

For merit standard, learners will complete the repair process safely and accurately. The required accuracy of the inspection and repair will be determined by the standards. For example, correct location of the patch over the damaged area, layout and number of fastener holes as defined in the SRM, correct finish (such as sanded, primed, and painted), and lightning protection mesh installed if required.

Overall, the evidence should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will inspect a damaged composite airframe structure or component, classifying the type of damage and identifying the appropriate repair method. For example, visual and/or non-destructive test inspection to determine the extent of impact damage to a composite skin panel leading to a patch repair of the damaged area.

Learners will prepare for the repair by researching the appropriate procedure and selecting appropriate consumables and hardware components. Learners will repair the damaged airframe structure or component using the correct procedure. For example, to repair impact damage to a composite skin panel, learners will follow the procedure defined in the SRM. If this is not available the basic steps would be: remove damaged material, select appropriate personal protective equipment, prepare surface for either bolting or bonding, apply patch ensuring adequate ventilation, inspect and document repair.

Overall, the correct repair procedure will have been followed but there may be minor errors in accuracy of the finished structure or a void or inclusion may be detected during the final inspection process.

Links to other units

This unit links to:

- Unit 58: Aircraft Flight Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local organisations involved with airframe construction and repair
- contribution of ideas to unit assignment/project materials.

Unit 60: Airframe Mechanical Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

When aircraft take off, they require an undercarriage; wheels and brakes to accelerate along the runway until they are airborne. Once in flight, aircraft are manoeuvred using flight controls, fuel is continuously supplied to the engines, people are kept safe and comfortable in a pressurised air-conditioned cabin and safe flight is maintained no matter what the weather or emergency situation. These essential services help ensure the safety of the aircraft and passengers in flight.

In this unit, you will apply skills and understanding to the function and operation of airframe mechanical systems. You will explore hydraulic power supplies and the power they provide for the operation of aircraft-landing gear and flight-control systems. You will examine the pneumatic, cabin-conditioning, pressurisation and protection systems that control the cabin environment. You will examine the construction and operation of the airframe fuel system that ensures a continuous supply of fuel to the engines. Finally, you will examine the construction and operation of ice-protection and fire-protection systems.

This unit will help to prepare you for an aircraft engineering apprenticeship; it can also help you to find work as an aircraft technician. Alternatively, you could choose to continue your studies in higher education.

Learning outcome

In this unit you will:

A Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight

B Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew

C Examine how the operation of airframe fuel, ice- and fire-protection systems contribute to safe flight.

Summary of unit

Learning outcome	Key content areas	Recommended assessment approach
A Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight	**A1** Hydraulic-power systems and components **A2** Landing-gear systems and components **A3** Mechanically and hydraulically powered flight control systems	A report based on inspections of systems and research, covering the function and operation of aircraft-hydraulic power, landing-gear and flight-control systems as well as components and their contribution to safe flight.
B Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew	**B1** Cabin environmental control systems and components **B2** Cabin protection systems	A report covering the, operation of cabin environmental control and protection systems as well as components and their contribution to the protection of passengers and crew.
C Examine how the operation of airframe fuel, ice- and fire-protection systems contribute to safe flight	**C1** Airframe fuel systems and components **C2** Anti-icing and de-icing systems **C3** Fire detection and extinguishing systems and components	A report covering the operation of airframe fuel, ice- and fire- protection systems as well as components and their contribution to safe flight.

Unit content

A Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight

A1 Hydraulic-power systems and components

- Hydraulic transmission, including:
  - transmission of fluid pressure, fluid force and Pascal's law
  - fluid types and properties, including vegetable, mineral- and ester-based oils, fluid identification, sources and consequences of fluid contamination
  - fluid-system requirements, including direction and flow control, fluid storage, conditioning and filtration.
- Hydraulic power-supply systems and components:
  - power source function and layout, including:
    - hand pumps, engine-driven pumps, electric pumps
    - emergency provision, e.g. multiple-system provision, Ram Air Turbine (RAT) driven pumps, standby pumps
  - identification, function and layout of fluid storage, control, conditioning and actuation components, including:
    - reservoir safety features and fluid conditioning components, diaphragm and piston accumulators
    - fluid plumbing, pipes (rigid and flexible), hoses, seals and fittings
    - directional control valves, restrictor valves, non-return valves, cut-out valves
    - temperature and pressure control valves, heat exchangers
    - linear and rotary actuators
  - operation of hydraulic power supply systems, including:
    - the provision of a supply to the hydraulic services, under normal and emergency conditions
    - the nature of the hydraulic panel indications and warnings under normal and emergency supply conditions.

A2 Landing-gear systems and components

- Identification, function and layout of landing gear and retardation components, including:
  - single- and multi-bogies, doors, fairings
  - oleo and liquid spring shock absorbers, hydraulic actuators
  - wheels, bearings and tyres
  - brake unit, liners, adjusters, rotors, stators
  - anti-skid devices, e.g. hydro-mechanical, hydro-electronic
  - steering mechanisms and actuators.
- Function and operation of extension/retraction system, including:
  - hydraulic directional control and sequencing, e.g. relief valves, shuttle valves, sequence valves
  - cockpit/cabin indications and warnings
  - emergency provision, e.g. blow-down, hand pump, multiple hydraulic supplies, accumulators.

A3 Mechanically and hydraulically powered flight control systems

- Function and operation of mechanical flight control systems and identification, function and layout of system components, including:
  - control rod and cable systems for operation of primary controls, trim and balance tabs, controls rigging
  - control rods and cables, eye and fork end fittings, bell-crank levers, cable pulleys, fairleads, tension regulators and spring feel units.
- Function and operation of hydraulically powered flying-control systems and identification, function and layout of system components, including:
  - primary controls, aileron, tailplane, elevator, rudder
  - lift augmentation systems, flap and slat
  - lift-reduction systems, lift dumper, spoiler, speed brakes
  - ancillary systems, e.g. artificial feel, Mach-corrected trim, stall control protection and warning, rudder limiter and gust locks.

B Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew

B1 Cabin environmental control systems and components

- Pneumatic-supply systems:
  - function of pneumatic supplies, including air-conditioning and pressurisation, thermal anti-icing, engine starting, hydraulic reservoir pressurisation, door and canopy sealing, pitot-static system
  - identification, function and layout of supply system components, including:
    - gas turbine engine and auxiliary power unit (APU) bleed air supplies
    - piston engine air compressor, blower and receiver supplies
    - ram air supplies
    - ground cart
    - supply control via ducts, louvres, channelling, trunking, check valves, pressure control valves.
- Cabin air-conditioning and pressurisation systems and components:
  - identification function and layout of cabin conditioning components, including:
    - mixing and plenum chambers and ducting
    - filters, humidifiers, water separators, diffusers, recirculation fans
    - conditioning pack, pre-cooler, cold-air unit, intercooler
    - mixing valves, duct stats, temperature control valves
  - operation of air-conditioning system, including supply, temperature and humidity control and recirculation of conditioned air
  - identification, function and layout of cabin pressurisation components, including:
    - pressure controllers, e.g. pneumatic, electrical and discharge valves
    - inward and outward relief valves, warning and indicating devices
  - Operation of cabin pressurisation system, including:
    - cabin pressure control cycles (e.g. pneumatic, electrical)
    - cabin air discharge methods
    - emergency provision, warnings and indications.

B2 Cabin protection systems

- Function and operation of aircraft oxygen systems, including:
  - crew and cabin therapeutic walk-round oxygen bottles
  - cabin and crew oxygen storage, distribution and regulation
  - emergency drop-down masks control and provision, e.g. pilot control, altitude switches, bottles, ring main supply, chemical generation.
- Identification, function and layout of cabin and crew equipment, including:
  - safety equipment, e.g. harnesses, seat belts, parachutes, personal equipment connectors
  - emergency equipment, e.g. cabin emergency notices and warning signs, doors and exits, air-stairs, lighting, inflatable passenger slides, smoke detectors, life jackets.

C Examine how the operation of airframe fuel, ice- and fire-protection systems contribute to safe flight

C1 Airframe fuel systems and components

- Fuel types and properties, including:
  - aviation gasoline (AVGAS)
  - JET A1 (AVTUR) an aviation jet turbine kerosene fuel
  - JET B (AVTAG) a wide-cut jet turbine gasoline/kerosene fuel
  - fuel flash point temperature, auto-ignition temperature and density.
- Type and function of fuel additives, including ice and corrosion inhibitors, antioxidants, anti-static agents.
- Fuel system component identification and function, including:
  - fuel-storage tanks, rigid, integral, flexible
  - booster and transfer pumps
  - transfer, non-return and vent valves
  - fuel plumbing, heat exchangers
  - fuel quantity sensors, e.g. float, capacitance probes, solid state
  - fuel gauges, warning and indicating devices.
- Fuel-tank layout, e.g. wing inboard and outboard tanks, fuselage tanks, ventral tanks, longitudinal balance fuel system and trim tanks.
- Fuel system operation, including:
  - fuel engine feed, pressurisation and inerting
  - fuel jettison, venting, refuelling and defuelling
  - fuel transfer, e.g. engine and auxiliary power unit (APU) feed, inter-tank, re-fuel and de-fuel.

C2 Anti-icing and de-icing systems

- Ice formation, rim ice, glaze ice and Hoar frost, effects of ice and snow.
- Ice detection, e.g. probes, vanes, electronically activated, mass activated.
- Function and operation of pre-emptive anti-icing systems, including:
  - electrical, e.g. pitot probe, fuel vent and windscreen electrical heaters, propeller graphite electrical resistance heaters
  - hot air, e.g. wing slat, engine intake and cowling
  - chemical, e.g. aircraft wing, flying controls and windscreen ground anti-icing.
- Function and operation of reactive de-icing systems, including:
  - pneumatic, e.g. inflate/deflate wing leading edge de-icer boots
  - electromagnetic-impulse, e.g. wing, tail leading edge impulse ice removal
  - chemical, e.g. weeping wing and tail system, propeller slinger ring system.

C3 Fire detection and extinguishing systems and components

- Fire detection:
  - fire-detection zones, including engines, auxiliary power unit (APU), jet pipes, cargo compartment, toilets
  - function and operation of fire/overheat detector systems, including:
    - unit-detector systems, e.g. thermal switch, thermocouple, inertia switches, crash switches, detector circuit, alarm circuit, test circuit
    - continuous loop detector systems, e.g. Fenwal and Kidde resistance-sensing systems, dual-loop systems, pneumatic sensing systems, fire-detection control unit
  - function and operation of smoke-, carbon monoxide- and flame-detection systems, including:
    - smoke and carbon monoxide detectors, e.g. light refraction, ionisation, electronic, chemical colour change
    - flame detectors, e.g. optical infrared, optical ultraviolet
  - nature of flight-deck and cabin-fire warnings, including location indicators, red lights, claxons, overheat indicators.
- Fire extinguishing:
  - classes of fire, including Class A fires involving ordinary combustible materials, Class B fires involving flammable liquids, Class C fires involving energised electrical equipment, Class D fires involving combustible metals
  - use of on-board system and hand-held extinguishing agents, including carbon dioxide, halon 1211, halon 1301, hydrofluorocarbon HFC-125, water
  - layout and function of on-board fire extinguishing system components, including extinguisher bottles, discharge valves, cartridges, extinguisher plumbing, two-way check valves, bottle pressure and thermal discharge indicators
  - pilot and automatic operation of extinguishing actuation system.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning outcome A: Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight</td><td rowspan="2">A.D1 Justify, using the findings from safe inspection and research, the function and operation of hydraulic-power, landing-gear and flight-control systems and their components, assessing the contribution made by each to safe flight.</td></tr>
<tr><td>A.P1 Inspect one hydraulic-power, landing-gear and flight-control system safely.
A.P2 Explain, using the practical findings and research, the operation of hydraulic-power, landing-gear and flight-control systems and their components, identifying their contribution to safe flight.</td><td>A.M1 Analyse, using the practical findings from the safe inspection and research, the operation of hydraulic power, landing gear and flight control systems and their components, identifying their contribution to safe flight.</td></tr>
<tr><td colspan="2">Learning outcome B: Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew</td><td rowspan="2">B.D2 Evaluate, using language that is technically correct and of a high standard, the function and operation of cabin environmental control, oxygen, safety and emergency equipment systems and components, assessing their contribution to the protection of passengers and crew.</td></tr>
<tr><td>B.P3 Explain the function and operation of cabin environmental control systems and components, identifying their contribution to the protection of passengers and crew.
B.P4 Explain the function and operation of oxygen, cabin safety and emergency equipment systems and components, identifying their contribution to the protection of passengers and crew.</td><td>B.M2 Analyse the function and operation of cabin environmental control, oxygen, safety and emergency equipment systems and components, identifying their contribution to the protection of passengers and crew.</td></tr>
</table>

Pass	Merit	Distinction
Learning outcome C: Examine how the operation of airframe fuel, ice- and fire-protection systems contribute to safe flight		
C.P5 Explain the function and operation of airframe fuel systems and components, identifying their contribution to safe flight. **C.P6** Explain the function and operation of airframe ice- and fire-protection systems and components, identifying their contribution to safe flight.	**C.M3** Analyse the function and operation of airframe fuel, ice- and fire-protection systems and components, identifying their contribution to safe flight.	**C.D3** Evaluate the function and operation of airframe fuel, ice- and fire-protection systems and components, assessing the contribution to safe flight.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. There is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning outcomes and criteria is:

Learning outcome: A (A.P1, A.P2, A.M1, A.D1)

Learning outcome: B (B.P3, B.P4, B.M2, B.D2)

Learning outcome: C (C.P5, C.P6, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to the following specialist physical resources:

- a functional aircraft hydraulic supply system, either on-aircraft or in the form of a test rig
- an aircraft hydraulic landing gear complete with wheel and brake assembly, doors and fairings and with access to hydraulic retraction/extension system and system components
- a complete functional mechanical or hydraulic flying control system, with access to identify and view the layout of system components
- sight of a cabin-conditioning and pressurisation environmental control system and components
- sight of an airframe de-icing/anti-icing system and components
- sight of a fire-detection and suppression system and components
- sight of cabin or cockpit safety and emergency equipment, as detailed in the content section.

Please note that some or all of the required physical resources identified above may not necessarily be directly available at the centre delivering the unit but may be available at the premises of a partner or related organisation. Ideally, the resources will be available on a training aircraft.

Essential information for assessment decisions

Learning outcome A

The inspection must be completed on one hydraulic-power, one landing-gear and one flight-control system. The subsequent justification must be based on the findings of the inspection and further research to ensure that the function and operation of both mechanical and hydraulically-powered flying-control systems have been justified, in accordance with the content section.

For distinction standard, learners will provide a justification based on the findings from the safe inspection of one hydraulic-power supply, one landing-gear and one flight-control system, which will be based on further research on these systems. Learners could do this, for example, by considering alternative hydraulic supply sources and component type and layout required for all the essential hydraulic services under emergency conditions.

Learners will assess the contribution to safe flight of hydraulic-supply, landing-gear and flight-control systems. For example, when considering the operation of a landing-gear system, the interaction between pilot throttle settings, airspeed, weight switches, landing-gear extension/retraction, and the maintenance of safe flight will be assessed.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. The evidence will be logically structured, use correct engineering terms and will demonstrate a high standard of written language. In particular, the well-reasoned justification will cover concisely and consistently the function and operation of the systems and their components under normal and emergency conditions.

For merit standard, learners will draw on findings in their analysis from the safe inspection of one hydraulic-power supply, one landing-gear and one flight-control system and on further research of these systems. For example, the analysis of an aircraft's hydraulic-power-supply system should consider the types of power source, control valves, fluid plumbing and multiplex supply feeds it provides to the aircraft hydraulic services.

Learners will identify the contribution to safe flight of hydraulic-supply, landing-gear and flying-control systems. For example, by considering the normal and emergency operation of the landing gear, they will identify how the hydraulic systems contribute to the safe operation of the landing gear during the taxi, take-off, cruise and landing phases of flight.

Overall, the evidence should be logically structured, technically accurate and easy to understand. In particular, analysis will cover the function and operation of the systems and their components accurately under normal and emergency conditions.

For pass standard, learners will, in order to understand their function and operation, safely inspect one hydraulic-power, one landing-gear and one flight-control system. For example, the inspection of a hydraulic supply system will be used to determine the identity, layout and function of the system and its power source(s), oil-storage components, fluid plumbing, control valves and feeds to the hydraulic services.

Learners will use the findings of inspections and further research to explain the function and operation of hydraulic-power, landing-gear and flight-control systems and their components, identifying their contribution to safe flight. The explanation will include the operation of the system under normal and emergency conditions; for example, explaining how the aircraft's landing gear may be lowered using an alternative supply, an accumulator or blown-down facility in an emergency-supply situation; and identifying the contribution made to safe flight by the landing-gear system under these conditions.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example it may be missing some constructional detail on the wheel and brake assembly when explaining the layout of the alighting gear system.

Learning outcome B

For distinction standard, learners will evaluate the function and operation of pneumatic, air-conditioning and pressurisation, environmental control subsystems and components. For example, the operation of the systems and function of system components responsible for the safe passage and conditioning of the air – from the engine bled and ram air supplies into the pressurised cabin, under normal and emergency conditions – will be evaluated and the contribution of each to the protection of passengers and crew will be assessed.

Learners will evaluate the function and operation of oxygen, safety and emergency equipment systems and components, under both normal and emergency conditions and the assessment of the contribution made by each system to the protection of passengers and crew. For example, when examining the operation of a ring main oxygen supply system and a chemically-generated oxygen supply system to the cabin drop-down oxygen-mask units, the emergency cabin conditions that lead to activating the oxygen supply, the method and system components used to deliver the oxygen to the masks and the relative merits of the two different oxygen-supply systems and components, will be evaluated and their contribution to crew and passenger safety will be assessed.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. The evidence will be logically structured, use correct engineering terms and will be of a high standard of written language.

For merit standard, learners will analyse the function and operation of pneumatic-, air-conditioning and pressurisation, environmental control subsystems and components. For example, when examining the function and operation of the cabin-pressurisation system and components, the actions of the cabin-pressure controller and discharge valves under normal and emergency conditions will be analysed and the contribution to the continuing safety of passengers and crew of these component actions will be identified.

Learners will analyse the function and operation of oxygen, safety and emergency equipment systems and components, under both normal and emergency conditions and identify the contribution made by each system to the protection of passengers and crew. For example, when examining the operation of a ring main and a chemical oxygen supply to the cabin drop-down oxygen-mask units, the emergency cabin conditions that lead to activating the oxygen supply, as well as the method and system components used to deliver the oxygen to the masks, will, in both cases, need to be analysed and their contribution to crew and passenger safety identified.

Overall, the evidence should be structured logically, technically accurate and easy to understand. In particular, analysis will accurately cover the function and operation of aircraft fixed and walk-round oxygen systems and components, as well as the function of cabin safety and emergency equipment.

For pass standard, learners will explain the function and operation of pneumatic, air-conditioning and pressurisation, environmental control subsystems and components. For example, when examining the function and operation of the cabin air-conditioning system, learners will explain how the bled and ram air supplies are mixed and conditioned before entry into the cabin, and how the quality of cabin air is maintained. Learners will identify how the air-conditioning system contributes to the continuing safety of passengers and crew.

Learners will explain the function and operation of oxygen, safety and emergency equipment systems and components, under both normal and emergency conditions, and identify the contribution made by each system to the protection of passengers and crew. For example, when examining the operation of a ring main and a chemical oxygen supply to the cabin drop-down oxygen-mask units, the method of delivery of oxygen to the masks for both systems will be explained and the cabin emergency conditions needed to activate oxygen flow to the masks and the systems' contribution to passenger and crew protection will be identified.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example it may miss some construction detail when explaining the operation of the cabin air re-circulation system used to maintain the quality of cabin air.

Learning outcome C

For distinction standard, learners will evaluate the function and operation of airframe fuel systems and components, assessing their contribution to safe flight. The evaluation will include an analysis of fuel types and additives and the operation of fuel-system components during fuel-feed, jettison, refuelling and defuelling modes. For example, when examining an engine fuel system in the fuel-feed mode, the operation of the fuel-flow pumps and transfer valves, will be evaluated and the contribution to safe flight of the fuel system and these components will be assessed.

Learners will evaluate the function and operation of de-icing, anti-icing and fire-detection and extinguishing systems and their components and assess their contribution to safe flight. The evaluation will include the function and operation of ice detection, anti-icing/de-icing systems and components, fire-, heat- and smoke detectors, flight-deck and cabin-fire warnings, fire-extinguishing systems and the nature and use of extinguishing agents. For example, when examining a fire-detection and extinguishing system, the operation of the particular type of fire-detector and flight-deck warning system, together with the manual and automatic actuation of the extinguisher bottles, must be evaluated and the contribution of the system and components, assessed.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct engineering terms.

For merit standard, learners will analyse the function and operation of airframe fuel systems and components, identifying their contribution to safe flight. The analysis will include the operation of the fuel system and its components for engine fuel-feed, fuel-jettison and refuel/defuel modes.

For example, when examining the operation of an aircraft fuel system, in the refuelling/defuelling mode, the operation of refuel-valve and fuel-tank isolation valves will be analysed and the contribution of the system and valves to the aircraft and to ground safety will be identified.

Learners will analyse the function and operation of de-icing, anti-icing and fire-detection and extinguishing systems and their components, and identify their contribution to safe flight. The analysis will include the function and operation of ice-detection, anti-icing and de-icing systems and components, fire-extinguishing agents, and fire-detection, warning and extinguishing systems. For example, when examining the function and operation of a hot-air, pre-emptive, anti-icing system, the operation of the ice-detector sensor and its control of the blown hot-air system will be analysed, and the contribution of the detector and its associated control and warning system to safe flight, will be identified.

Overall, the evidence should be logically structured and be technically accurate and easy to understand. In particular, the analysis will cover accurately fuel types and additives, fire types and extinguishing agents, as well as the function and operation of fuel-, anti-icing, de-icing, fire-detection and extinguishing systems and components.

For pass standard, learners will explain the function and operation of airframe fuel systems and components, identifying their contribution to safe flight. The explanation will include the operation of the fuel system and the function of fuel-system components for engine fuel-feed, fuel-jettison and refuel/defuel modes. For example, when explaining the operation of an aircraft fuel system in the fuel-jettison mode, the function in the system of the fuel-transfer and fuel-jettison valves will be explained and the contribution to safe flight of the fuel system and valves will be identified.

Learners will explain the function and operation of de-icing, anti-icing and fire-detection and extinguishing systems and their components, and will identify their contribution to safe flight. The explanation will include identification of de-icing chemicals, the function and operation of ice-detection, anti-icing and de-icing systems, together with the nature of fire-extinguishing agents and the function and operation of fire-detection and extinguishing systems and their components. For example, when examining the function and operation of a chemical weeping wing, de-icing system, the nature of the chemical de-icer and the layout and function of the components in the system must be explained, and the contribution to safe flight of the system and its components must be identified.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, such as failing to identify all of the functions for a particular type of anti-icing- or de-icing system.

Links to other units

This unit links to:

- Unit 61: Aircraft Electrical and Instrument Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local organisations with expertise in aircraft mechanical systems
- contribution of ideas to unit assignment/project materials.

Unit 61: Aircraft Electrical and Instrument Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Electrical and instrument systems are fundamental to the safe operation of aircraft. Aircraft need to be safe with reduced environmental impact and with the ability to operate more efficiently. This leads engineers to find new ways of increasing electrical power generation, which is required for increasingly complex modern aircraft operation.

In this unit, you will apply practical skills and understanding to the construction and operating principles of a range of modern electrical components and instruments, as well as to their associated systems. You will look at the technology and characteristics of electrical generators and learn how power is managed and distributed to where it is needed, helping to ensure the safe operation of the aircraft. You will learn about the function and operation of electrical motors and actuators, loading, control and warning systems and their contribution to safe flight. Finally, through practical work, you will explore the construction and operation of aircraft air data and gyroscopic flight instruments.

This unit will help to prepare you for an aircraft engineering apprenticeship and for employment in an aircraft technician role. The unit will also help you to progress to higher education.

Learning outcomes

In this unit you will:

A Examine how electrical power generation and distribution systems support the safe operation of aircraft

B Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight

C Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight.

Summary of unit

Learning outcomes	Key content areas	Recommended assessment approach
A Examine how electrical power generation and distribution systems support the safe operation of aircraft	**A1** Aircraft electrical power generation **A2** Aircraft electrical power distribution	A report covering the operation, including construction, principles, control and protection of aircraft generators and power distribution components and systems.
B Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight	**B1** Electrical motors and actuators **B2** Electrical loading systems **B3** Electrical control and warning systems	A report covering the function, layout, operation and aircraft application of electrical motors, actuators, loading, control and warning systems.
C Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight	**C1** Air data instruments and systems **C2** Gyroscopic principles and instruments	A series of practical tasks to safely explore the function, construction and operating principles of air data instruments and systems and gyroscopic instruments. Evidence will include observation records/witness statements, annotated photographs and/or drawings and procedural details.

Unit content

A Examine how electrical power generation and distribution systems support the safe operation of aircraft

A1 Aircraft electrical power generation

- Operation and construction of direct current (DC) generators, including:
  - type, including shunt wound, series wound, compound wound, voltage regulation
  - protection and control, including reverse current, over/under voltage, position sensing and temperature control
  - load sharing and paralleling.
- Operation and construction of alternating current (AC) single-phase and multiphase brushed and brushless generators, including:
  - constant frequency (CF), variable frequency (VF), variable speed constant frequency (VSCF), three-phase star and delta connections, voltage regulation, generator paralleling
  - protection control, including over/under voltage, excitation and frequency, differential current and correct phase rotation.

A2 Aircraft electrical power distribution

- Function, system operation and layout of primary and secondary power sources, including single and multiple DC and AC generator systems, integrated drive generators (IDG), auxiliary power unit (APU), ground power.
- Aircraft electrical services provided by the essential, non-essential and vital services bus-bar feeds.
- Function, types and system operation of emergency power source components, including:
  - main and emergency batteries, e.g. nickel/cadmium, lead acid, sealed
  - Ram Air Turbine (RAT) emergency electrical power generator, standby generators.
- Function and operation of power conversion and protection components including DC to AC inverters, AC to DC transformer rectifier units (TRU), circuit breakers and relays.

B Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight

B1 Electric motors and actuators

- Operation, including construction, principles and application of the following types of DC and AC motors, including:
  - DC brush types, e.g. shunt wound, series wound, compound wound, need for heat dissipation, speed and torque characteristics and control methods
  - DC brushless types, e.g. electronically controlled switching of rotor coils, rotor position sensor, speed, torque and operating temperature characteristics, comparisons with brushed motors
  - AC single phase, e.g. split phase, capacitor start, shaded pole, need for field windings, types of starter circuits, currents on start-up, speed torque characteristics
  - AC three phase, e.g. squirrel cage, synchronous, wound rotor, reduction of power losses, speed torque characteristics, comparisons with single phase motors
  - miscellaneous motors types, operating principles and aircraft use, e.g. servo motors, stepper motors, and linear motors.
- Aircraft electrical actuators:
  - motor-driven actuator types, construction and operation, including gearing mechanisms, rotational and linear movement parameters and working cycle and power requirements
  - aircraft actuator applications, including the operation of rotary and linear shut-off valves, temperature control valves, flap drives, motor-driven pumps, engine starters, air-conditioning fans and blowers.

B2 Electrical loading systems

- Function and operation of airframe loading systems, including:
  - external lighting, e.g. navigation lights, high intensity strobe lights, landing and taxiing lights, inspection lights, emergency exit lights
  - internal lighting, e.g. cockpit and flight deck, passenger information, bay lighting for cargo areas, equipment lighting, emergency/evacuation lighting and indicators
  - electrical anti-icing and de-icing, e.g. intake cowls, windscreen, propellers, spinners, probe and drain heating.

B3 Electrical control and warning systems

- Function and operation of electrical fire control and warning systems, including:
  - electrical fire detection and warning, engine and jet pipe overheat thermal detectors, switches and fire wire
  - electrical control of fire suppressants and extinguishing systems
  - fire warning lights and audible alerting devices.
- Cockpit or cabin, centralised and configuration warning panels and indicators, including information displayed, types of warning given.
- Stall warning systems, including stall detectors, cabin warning indicators, stick shakers.
- Engine health monitoring and indicating systems, e.g. exhaust gas, manifold, engine turbine temperatures and pressures, rotational engine speed, fuel flow, torque, thrust, oil pressure, vibration measurement.
- Cabin environmental control, e.g. temperature and pressure warnings.
- Aircraft landing gear, e.g. indications, use of weight-on switches.

C Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight

C1 Air data instruments and systems

- Operation, including principles and construction of air data instruments, including:
  - altimeters, ambient static port, aneroid capsule pressure sensor, gearing and altitude setting knob
  - vertical speed indicator (VSI), operation during level, diving and climbing flight
  - airspeed indicator (ASI) pitot-static data inputs, instrument, pressure, compressibility and density errors
  - Machmeter, use of capsules for altitude corrected airspeed.
- Function and operation of pitot-static systems, including pressure heads, static vents, pipelines, pitot-static leak checks.
- Air data computer (ADC), including functions, block schematic, total temperature, static and pitot pressure inputs, outputs, e.g. true air temperature, auto-throttle, VSI, autopilot, cabin pressure computer.

C2 Gyroscopic principles and instruments

- Gyroscopic principles, including gyroscopic rigidity and precession, laws of gyrodynamics, Sperry's rule, gyroscopic wander, electrically and pneumatically powered gyroscope spin.
- Function, construction and operation of gyroscopic instruments, including:
  - artificial horizon, gyroscopic tumbling, directional and rate gyroscopes and degrees of freedom, direction indicators
  - turn and slip indicator and turn coordinators, gyroscopic action in banked turn, differences between indicators and coordinators
  - laser gyroscopes, principles of interferometry (superimposing waves), benefits of strap-down (no moving parts) technology over electromechanical counterparts.
- Flight instrument panel layout, information and indications, including:
  - basic six grouping, e.g. ASI, altimeter, direction indicator, gyro-horizon, VSI, turn and bank indicator
  - basic T grouping, e.g. combined airspeed indicator, altitude direction indicator, horizontal situation indicator, altimeter, radio magnetic indicator and VSI.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning outcome A: Examine how electrical power generation and distribution systems support the safe operation of aircraft</td><td rowspan="2">A.D1 Evaluate, using vocational and high quality written language, how DC and AC electrical power is generated and distributed under normal and emergency conditions, prioritising the electrical services needed for safe flight.</td></tr>
<tr><td>A.P1 Explain how DC and AC electrical power is produced and controlled, for safe flight.
A.P2 Explain how DC and AC electrical power is distributed and converted within an aircraft under normal and emergency conditions for safe flight.</td><td>A.M1 Analyse how DC and AC electrical power is produced, controlled, distributed and converted under normal and emergency conditions for safe flight.</td></tr>
<tr><td colspan="2">Learning outcome B: Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight</td><td rowspan="2">B.D2 Evaluate the operation, indications and application of aircraft electrical motors, actuators, and loading, control and warning systems, analysing the contribution made by each to safe flight.</td></tr>
<tr><td>B.P3 Explain the operation, application and contribution to safe flight of aircraft electric motors, actuators and loading, control and warning systems.</td><td>B.M2 Analyse the operation, indications and application of aircraft electric motors, actuators, and loading, control and warning systems, identifying the contribution made by each to safe flight.</td></tr>
</table>

Pass	Merit	Distinction
Learning outcome C: Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight		
C.P4 Assemble one gyroscopic and two air data instruments safely, after investigating their operation. **C.P5** Explain, using the practical findings and research, the operation of one gyroscopic and two air data instruments to help ensure safe flight. **C.P6** Inspect one pitot-static system and one flight instrument display safely. **C.P7** Explain, using the practical inspection findings and research, the function and layout of one pitot-static system and one flight instrument display, identifying their contribution to safe flight.	**C.M3** Analyse, using practical findings from safe assembly of instruments and research, the operation of one gyroscopic and two air data instruments to help ensure safe flight. **C.M4** Analyse, using the findings from safe inspection of instruments and research, the function and layout of one pitot-static system and one flight instrument display, identifying their contribution to safe flight.	**C.D3** Justify, using the practical findings from safe assembly and inspection and research, the operation, function and layout of air data and gyroscopic instruments and their associated pitot-static and flight instrument display systems, assessing their contribution to safe flight.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. There is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning outcomes and criteria is:

Learning outcome: A (A.P1, A.P2, A.M1, A.D1)

Learning outcome: B (B.P3, B.M2, B.D2)

Learning outcome: C (C.P4, C.P5, C.P6, C.P7, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to the following specialist physical resources:

- a range of aircraft electric motors, actuators and actuator driven components, on or off aircraft, capable of being dismantled inspected and assembled
- an air data or pitot-static system and an aircraft instrument display panel complete with a series of flight instruments; these may be on-aircraft or in the form of a mock-up
- sight of electrical generators (AC or DC) to allow learners to view the hardware in order to enhance theory
- a training aircraft to view conventional electrical loading, protection and warning systems.

Access to the above resources, in particular a training aircraft or realistic mock-ups, may be on-site or off-site in conjunction with appropriate training or an industrial partner.

Essential information for assessment decisions

Learning outcome A

For distinction standard, learners will evaluate the operation, including principles and characteristics, construction and application of DC and AC generators. Learners will establish how electrical power is produced by these generators and how the quality of their output is controlled to ensure a regulated electrical supply for safe flight under normal and emergency operating conditions. For example, when evaluating the modern brushless AC generator, the use and operation of the constant speed drive unit and voltage regulator will be included. Learners will show how these components control the quality of the electrical output to the AC services busbar and how paralleling (load-sharing) of multi-generator aircraft electrical systems maintains a regulated AC supply in the event of a single generator failure.

Learners will evaluate how the distribution, control and protection of electrical power is directed and prioritised to the electrical services under normal and emergency conditions, for both single- and multi-engine aircraft. For example, in the event of complete failure of the main generators on a multi-engine aircraft, learners will show how the electrical supply from the emergency generator and/or battery system is directed, converted and supplied to both the DC and AC vital services.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured, use correct engineering terms and demonstrate a high standard of written language. In particular, the balanced evaluation will concisely and consistently cover the production of DC and AC aircraft electrical power and the control, regulation, distribution and prioritisation of electrical power under normal and emergency situations.

For merit standard, learners will analyse how DC and AC electrical power is produced and controlled under normal and emergency conditions for safe flight. For example, when analysing the production of electrical power from a self-excited DC generator, the relationship between the type, i.e. shunt, series and compound wound generators, and their operating characteristics should be taken into account when considering their selection for aircraft electrical power production.

Learners will analyse how electrical power is distributed and converted under normal and emergency conditions for safe flight. For example, learners will analyse the distribution and conversion of the 28 volt DC supply from the main generator to the non-essential and essential services DC bus bar under normal operation and the continued supply of DC power to the essential services bus bar, in an emergency when the main DC generator is faulty or off-line.

Overall, the evidence should be logically structured, technically accurate and easy to understand. The evidence will include details of the ways in which aircraft DC and AC power is controlled and converted at key component level; for example, detailing the function and operating principles of an inverter and a transformer rectifier unit (TRU) in the electrical supply system.

For pass standard, learners will explain how DC and AC electrical power is produced and controlled for safe flight. The explanation will include the operating principles and control of the electrical output from both DC and AC aircraft generators. For example, learners will explain clearly the constructional arrangement, function and operation of the fixed windings, armature and commutator in a DC machine, and explain how the quality of the output voltage and current is controlled within limits, using regulators.

Learners will explain how DC and AC electrical power is distributed and converted in an aircraft under normal and emergency conditions for safe flight. The explanation should detail the distribution and nature of electrical power from the supplies – including the batteries – to the non-essential, essential and vital services and busbars under normal and emergency operating conditions. Only the function and electrical inputs and outputs from the conversion components such as TRU and inverters, need to be included.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example omitting or incorrectly identifying the thermostatic switch or damper windings when explaining the operation of a complex brushless AC aircraft generator.

Learning outcome B

For distinction standard, learners will evaluate the function, operation, construction and application of electric motors and actuators and analyse how they contribute to safe flight. When evaluating the application and contribution to safe flight of aircraft electric motor-driven actuators, their characteristics and use in engine starter systems, valve operation, air-conditioning fans and blowers and flying controls will be analysed.

Learners will evaluate the function, operation and contribution to safe flight of aircraft loading systems, including lighting, anti-icing and de-icing systems. For example, when evaluating anti-icing and de-icing systems the contribution to safe flight of air-intake heater mats and pitot-static probe heaters will be analysed.

Learners will evaluate the function, operation and indications given for aircraft control and warning systems. The evaluation should include an analysis of the contribution to safe flight of fire suppression and protection, stall warning, engine health monitoring, cabin environmental control and landing gear systems.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be structured logically and use correct engineering terms. In particular, the balanced evaluation will also include an analysis of the contribution made by the motors, actuators and loading, control and warning systems in maintaining safe flight. For example, when considering electrical fire detection and warnings, the exact nature of the detector and circuitry will be analysed to identify the type and location of the overheat causing the warning.

For merit standard, learners will analyse the operation, indications and application of aircraft electric motors, actuators, loading, control and warning systems, identifying the contribution made by each to safe flight. It will include an analysis of the operation and application of different types of DC and AC electric motors and actuators, lighting, anti-icing and de-icing systems, as well as the operation and indications given for fire, stall, engine health, cabin environment and landing gear, control and warning systems.

Learners will identify the contribution made by electrical actuators and loading, control and warning systems to safe flight. For example, in the event of an engine bay overheat warning from the fire detection system, the types and form of the indications and warnings given to the pilot and the subsequent actions that are taken automatically by the system or manually by the pilot will be analysed, and their effect on safe flight identified.

Overall, the evidence should be logically structured, technically accurate and easy to understand. The depth of evidence will include details on the function and operation of all the different types of DC and AC electric motors and actuators, and loading, control and warning systems laid out in the content. This will be in addition to evidence that identifies the contribution made by each function and operation to safe flight.

For pass standard, learners will explain the operation, application and contribution to safe flight of aircraft electric motors, actuators, and loading, control and warning systems. The explanation will include details on the construction, operating principles and characteristics of the types of DC motor identified in the content, together with at least one example of a single-phase and a multi-phase AC motor. The explanation will also cover the operation and application of the linear and rotary actuators that use these DC and AC motors as their power source.

Learners will explain the function and operation of aircraft loading, control and warning systems, identifying their contribution to safe flight. For example, when considering an engine health and monitoring system, they will explain the nature of the warning indications on the instrument panel such as engine temperatures, oil pressure and vibration measurement and identify the effect they have on maintaining safe flight.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example omitting a particular indication of engine health such as torque when explaining the nature of the warning indications given by an engine health monitoring system.

Learning outcome C

For distinction standard, learners will provide a reasoned justification of the construction, function, operation and layout of aircraft, air data and gyroscopic instruments and their associated pitot-static and flight instrument display systems, assessing their contribution to safe flight.

The justification will draw on findings from the safe dismantling, inspection and assembly of one gyroscopic and two air data instruments and further research on air data and gyroscopic instruments. For example, when inspecting a Machmeter, the function of the altitude capsule, as well as the airspeed capsule will be analysed and related to the measurement of airflow at varying altitude. A justification will be given for the use of this instrument on high-speed aircraft, rather than using a simple airspeed indicator. Learners will also explore one aircraft pitot-static system and one cabin flight display panel safely and use the findings to justify their function, layout and indications to the pilot and, to assess their contribution to safe flight. The justification will include both electric and pneumatically powered air-data instruments and the use of strap-down technology for gyroscopic instruments. For example, when considering strap-down technology such as a laser gyroscope, its advantages and disadvantages need to be assessed and a case made justifying its use over its mechanical counterparts; and assessing its contribution to safe flight.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct engineering terms.

For merit standard, learners will assemble one gyroscopic and two air data instruments safely and use the findings from the practical exploration together with those from research to analyse the operation and identify their contribution to safe flight. For example, when exploring a gyro-instrument, learners will be able to recognise the difference between a directional gyroscope and a rate gyroscope and will be able to determine the function and operation of the instrument.

Learners will inspect one pitot-static system and one flight instrument display safely and use findings to analyse their function and layout and to identify their contribution to safe flight.

Overall, the evidence should be structured logically, technically accurate and easy to understand. For example, when exploring the operation of a flight instrument the evidence will include accurately labelled drawings and/or photographs of its construction, internal components and display, to accompany the written analysis.

For pass standard, learners will assemble one gyroscopic and two air data instruments safely to explore their operation. For example, learners will dismantle an unlabelled instrument such as an airspeed indicator (ASI), vertical speed indicator (VSI) or Machmeter, with the screen masked or removed. They will investigate the arrangement of the capsules and gearing and input/output ports to determine the function and operation of the instrument. They will sketch or take photographs of the internal components and gearing to aid their explanation. After completing the exploration, the instrument should be safely assembled and returned to the state in which it was presented.

Learners will explain, using the practical findings and research, the operation of one gyroscopic and two air data instruments to help ensure safe flight. For example, they will research air data and gyroscopic instruments to confirm the correct identification and function of the instrument being investigated and provide a detailed explanation of its operation. As a minimum, the flight instrument display being explored should contain an airspeed indicator, altimeter, gyro-horizon, direction indicator, (VSI) and a turn and bank indicator or any combination of these instruments for analysis.

Learners will inspect one pitot-static system and one flight instrument display safely, and use findings to explain their function and layout, identifying their contribution to safe flight. For example, when exploring a pitot static system, they will determine the layout of the pitot-static feeds, vents and associated piping to the pitot-static instruments and establish their function. Learners will also identify the contribution to safe flight of each of the instruments in the system. If the pitot-static system being explored uses an air data computer (ADC), only the inputs to and outputs from this device need to be determined.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, such as missing some detail when explaining the layout of the gearing between the capsules and display of a pitot-static instrument.

Links to other units

This unit links to:

- Unit 58: Aircraft Flight Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local aeronautical organisations
- contribution of ideas to unit assignment/project materials.

Unit 62: Shipbuilding Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will develop learners' understanding of the design features, types, forms and major components of ships, to prepare them for work in the shipbuilding/ship repair industry.

Working with modern ships requires a range of skills, whether for building new ships or repairing existing vessels. The nature of ships is such that there are vast differences between the structures and forms of vessels depending on their use, be that cargo, passenger or military.

This unit will develop learners' understanding of the drawings, plans and tables that are used in the building and repair of ships. This will include conventions and abbreviations along with the terms used to describe features of ships. Learners then explore the form and structure of different types of ship, considering the various components and methods of construction that are used. This is complemented by investigations into the structural components of ships.

Finally, learners will examine the ways in which ships are assembled, considering lifting processes, the assembly of prefabricated sections and ways in which accuracy is maintained throughout the process.

Learning outcomes

On completion of this unit a learner should:

1 Understand technical drawings and computer aided engineering as used in shipbuilding

2 Know design features, major components and different ship types

3 Know the principal structural components of a ship

4 Understand how ship parts are assembled and erected.

Unit content

1 Understand technical drawings and computer aided engineering as used in shipbuilding

Terminology used in shipbuilding technical drawings: outboard of; inboard of; in way of; scantlings; length (overall, between perpendiculars and on summer load waterline); forward and after perpendiculars; breadth and depth (moulded and extreme); draught; freeboard; freeboard marks; displacement; deadweight; rise of floor; camber; flare; bilge; bilge radius; bilge keel; flat of bottom; tumblehome; superstructure; forecastle; tank top; stringer; floor; bulkhead; shell; frame/frame station; deck; deckhead; longitudinal; transverse; butt seam; gross; net and displacement tonnage

Use of drawings, plans and tables: shipbuilding drawings (detail, assembly and location); plans (block plans, listed plans, body plans, lines plans, sheer profile); off-set tables; relationship between listed plans and tables

Abbreviations used on drawings: PSFA; LOA (overall length); LBP (length between perpendiculars); LWL (load waterline length); (L); FP (forward perpendicular); AP (after perpendicular); B (beam/breadth); D (draft); SLWL (summer load waterline); TF (tropical fresh waters); F (fresh waters); T (tropical waters); S (summer); W (winter); WNA (winter North Atlantic)

Lines plans and offset tables: lines plan; displacement stations; frame stations and their relationship; tables of offsets to produce ship shapes; illustrating fairing of form in three dimensions: frames, waterlines, buttocks; shell expansion plans; draught and freeboard markings

Mould loft: full scale lofting, scale lofting, numerical control (computer) lofting

Use of templates: avoidance of repetitive marking and measuring, material optimisation, checking angles, contours etc; guidance for repetitive profile cutting; nesting; materials suitable for templates

Computer aided engineering: computer aided design, computer aided draughting, computer aided manufacture; industrial robots - productivity, quality, competitiveness, profit, storage space, impact upon working practices, impact on society, security of data

Application of computer aided engineering in mould lofts: purpose, benefit of computer aided lines fairing, various stages in the production of tapes to control cutting and forming machinery, benefits of numerical control compared to the production and use of templates

2 Know design features, major components and different ship types

Types of ship: cargo, e.g. general, bulk carrier, oil tanker, container, liquefied natural gas, refrigerated; naval vessels, e.g. aircraft carrier, troop carrier, submarine, fleet oiler; passenger vessels, e.g. passenger liner, ferry, cruise liner, roll on–roll off; service craft, e.g. oil support vessel, tug, ice breaker

Design features: cargo, e.g. double bottom arrangements, decks, bulkheads, engine room space, cargo spaces, fore and after peaks, accommodation spaces; naval vessels, e.g. watertight sub–divisions, accommodation spaces, armament and equipment spaces, operations area; passenger vessels, e.g. loading and unloading arrangements, accommodation areas, recreation areas, crew accommodation, access routes; service craft - divisions for: engines, operations, crew, storage

Major components of ships: cargo space; double bottom tanks; peak tanks; engine rooms; accommodation spaces; deep tanks; cofferdams; pump rooms; chain locker; cargo access arrangements; cargo handling equipment

Fore and after end construction:

- fore peak construction - collision bulkhead, floors, types of stem, bulbous bows, deep tanks: construction and usage, chain locker and hawse pipes, bow thrust units and supporting structure, access and egress from fore peak
- after peak construction - types of stern construction, flats, floors and wash plates, steering gear flat, construction and supporting structure, stern frame connections, function, construction and operation of rudders, types of rudder

3 Know the principal structural components of a ship

Principal structural components: double bottoms, tank top, framing, bulkheads, transverses, shell, pillars and girders, superstructure, decks and deckhouses, forecastle, bridge, poop, workshop flats; transverse, longitudinal and combined framing systems of ships

Components of transverse and longitudinal framed double bottoms: watertight, plate and bracket floors, bottom and tank top stiffening and connections, centre and side girders, margin plate, tank top shell structure for transversely and longitudinally framed ships, connections to deck and bottom structure; components of deck structure, pillars and girders, deck openings; rudders; constructional features of different types of transverse and longitudinal bulkheads

Function and method of construction of hatches and doors: deck openings and supporting structure, side and end hatch coamings, hatch closing arrangements, oil tanker hatches, watertight hatches and doors fitted in naval vessels

Bulwarks and guard rails: constructional features and methods of attachment to the hull of bulwarks and guard rails

Factors influencing the strength of a ship's structure: main forces acting on a ship's structure; the variation of liquid pressure with head and its effect on a ship's structure; forces on submerged surfaces; reaction of the ship to applied forces (hogging and sagging, panting, racking); methods of obtaining continuity of strength, the avoidance of abrupt changes in contour

Calculations related to structural components: internal loads from cargo, fuel oil; external loads from sea

4 Understand how ship parts are assembled and erected

Accuracy and alignment: structure; methods of avoiding accumulation of error; personal responsibility for accuracy; checking alignment using levelling equipment (laser, dumpy level)

Inspection: function of a datum surface and datum line; standard measuring equipment; tolerances; methods of checking accuracy of dimensions, alignment, form, squareness and freedom from twist or distortion

Erection: equipment and instruments necessary for fairing, joining, plumbing and levelling; use of datum lines; procedure for the assembly of plates and sections; reasons for assembling thick plate fabrications on a level surface; preparing a level surface; reasons for part assemblies and trial erections; sequence of erection and methods used to temporary fasten and maintain shape, e.g. logical sequence of erection for ship construction, methods used to avoid twist and distortion, use of assembly jigs and fastening devices, use of tack bolts and tack welds; need for continual alignment checks

Lifting procedures and safety precautions for shipbuilding: lifting large fabricated units - centre of gravity, safe working loads, swinging loads; importance of determining centre of gravity of regular and irregular shaped units; problems associated with the lifting of large units; health and safety hazards associated with the lifting of large fabricated units; use of self-propelled modular transporters (SPMT), e.g. types, capacity, loadings, operation, communication, power

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 define terminology used on marine industry specifications and drawings	**M1** explain the use of templates and the mould loft in the production of drawings for the marine industry **M2** explain how computer aided engineering (CAE) techniques are applied in shipbuilding	**D1** evaluate the use of computer aided engineering (CAE) in shipbuilding compared to conventional drafting techniques
P2 interpret abbreviations used on marine industry technical drawings and data		
P3 interpret shipbuilding technical drawings, plans and tables		
P4 describe design features and major components of different types of ship	**M3** explain fore and after end construction in shipbuilding	**D2** compare and contrast ship types in terms of forms, profiles and applications
P5 describe the principal structural components of a ship	**M4** analyse the factors influencing the strength of the structure of a ship	
P6 describe how quality is maintained throughout the ship's construction cycle		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe the lifting procedures and safety precautions for fabricated units in shipbuilding	**M5** explain the purpose and operation of self-propelled modular transporters (SPMT) in shipbuilding	**D3** analyse the structural behaviour of assemblies and sub-assemblies, evidenced from shipbuilding case studies and historical records
P8 describe the main procedure for lifting and erecting sections in shipbuilding		
P9 describe the methods used to secure the sections in the initial position in shipbuilding		

Essential guidance for tutors

Assessment

Evidence can be collected from case studies, assignments and projects which should enable learners to explore the principles of shipbuilding, including the use of drawings, plans and tables.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require evidence that demonstrate additional depth and/or breadth of understanding of concepts.

To achieve a pass, learners must demonstrate an understanding of shipbuilding technical drawings, plans and tables. They will need to describe the key design features of ships. They will have an understanding of the structure of ships and structural components. Learners will need to demonstrate their understanding of the processes used to construct ships, including quality control checks and approaches to safe working.

This unit could be assessed through four assignments. The first assignment could comprise a series of written tasks assessing learners' understanding of methods used to produce and present ship designs. The first task could ask learners to research and then define the terminology used on marine specifications and drawings, with at least two examples of each of position, dimension, design features and structural components (P1). Learners could then be provided with a selection of technical drawings, plans, tables and data from which they should interpret at least ten different abbreviations, along with four features each from at least two technical drawings, two plans and two tables (P2 and P3). A further task could ask learners to explain how drawings are produced using templates and the mould loft (M1) and how computer aided engineering is used in the production of drawings (M2), before evaluating these two alternative approaches, including consideration of the benefits of using numerical control compared to the production and use of templates (D1).

A second assignment could be an illustrated report addressing P4, M3 and D2. The first task could require learners to produce annotated drawings or illustrations of one example of each type of ship (cargo, naval, passenger and service craft). Learners should describe the design features and components of each type of ship (P4). A second task could address the merit criterion, with learners being asked to explain the design details of fore and after end construction (M3). Finally a third task could ask learners to compare and contrast examples of each type of ship, potentially those considered for P4, in terms of their forms, profiles and applications. This could again be supported by annotated diagrams and drawings.

A third assignment could evidence learners' understanding of the structure of a given type of ship. An initial task could require learners to describe principal structural components of ships, referencing components of transverse and longitudinal framed double bottoms, along with hatches and doors (P5). A second task could then require learners to explain the factors that influence the strength of the structure of a ship, using calculations that consider internal and external loadings.

A final assignment could then focus on the assembly of ships, considering the approaches used to fabricate parts whilst also maintaining quality. One task could address each of the pass criteria, with learners being asked to describe lifting procedures that are used with large fabricated assemblies and how safety is maintained (P7) along with approaches used to lift, erect and secure sections in place during the assembly process (P8 and P9). The final part of the task would require learners to describe how quality is maintained throughout construction, considering accuracy, tolerances and inspections (P6). A second task would then examine the purpose and operation of self-propelled modular transporters in the construction of ships, using examples to illustrate (M5). The final task would be to evaluate the structural behaviour of given assemblies and sub-assemblies, based on information from case studies and other historical sources (D3).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Drawings, Plans and Tables	A written activity requiring learners to interpret and explain the features of shipbuilding drawings, plans and tables and investigate the use of computer aided engineering in shipbuilding.	A report containing written responses about the terminology, abbreviations and features of documents used in shipbuilding, and approaches to produce drawings within a relevant context for the learner.
P4, M3, D2	Identification of Types of Ship	An illustrated report that considers examples of each of the four types of ship.	A report containing written responses, diagrams and illustrations that reference the design features of different types of ship, their construction and use.
P5, M4	Structural Components	A written report requiring learners to describe structural components of a given ship, using calculations related to loadings to support explanations.	A report containing written responses and calculations that investigates structural components of a given ship, with calculations to support explanations of methods of providing strength to the structure of the ship.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, P8, P9, M5, D3	Assembling Ships	A written report that focuses on the safe and accurate assembly of a ship from both fabricated sub sections and individual components.	A report containing written responses about the safe assembly of ships that considers the lifting of fabricated sub-assemblies, methods of ensuring quality and the use of SPMTs with the assembly process.

Essential resources

For this unit, learners must have access to:

- drawings, plans and tables as listed in the unit content
- case studies.

Indicative reading for learners

Textbooks

Eyres D, Bruce G – *Ship Construction* (Butterworth-Heinemann, 2012) ISBN 9780080972398

Forrest Pease F – *Modern Shipbuilding Terms, Defined and Illustrated* (Forgotten Books, 2018) ISBN 9780331902730

House D – *Elements of Modern Ship Construction* (Brown, Son & Ferguson, 2010) ISBN 9780851748146

Websites

Shipbuilders & Ship repairers Association	www.ssa.org.uk
Article exploring the use of CAE in shipbuilding	www.marinelink.com/article/shipbuilding/mapping-the-future-design-693

Unit 63: Utility System Maintenance

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will give learners the opportunity to develop the skills and the underlying process technology required for maintaining or installing an industrial utility system. Learners will gain some experience of compressed air, steam and electricity, however they do not need to consider boilers.

Modern industrial plants have a range of different utility systems that combine to ensure that machines and equipment function correctly. To make this happen the utility systems need to be maintained in good working order, so that the chances of failure are kept to a minimum.

This unit will develop learners' understanding of the components that come together to form each type of utility system, including the ways in which the systems operate and why component parts are selected. With this underpinning knowledge, learners will then plan for and carry out a maintenance activity on a given utility system.

Finally, learners will recommission or restore the system to full working order, having replaced any components that need replacing.

Learning outcomes

On completion of this unit a learner should:

1 Understand how utility systems function

2 Be able to plan, prepare and set-up for maintenance of utility systems

3 Be able to inspect and maintain utility systems

4 Be able to reinstate utility systems.

Unit content

1 Understand how utility systems function

Compressor: performance capability in terms of pressure and volumetric output of free air delivered (FAD); types of compressor (single stage and multi-stage piston, screw, centrifugal); basic component parts and layout of each type of compressor; intercoolers and aftercoolers construction and layout; air receivers (function, associated essential equipment fitted to receivers, legal requirements for installation, inspection and testing); air dryers (absorption, adsorption, refrigerant types, super dryers)

Air systems: compressed air hazards; relationships between force, area and pressure and how to use them for calculations; relative humidity and its relationship with air pressure and temperature

Air pipework and systems: factors affecting pressure drops and flow rates and the relationships between these and pipe sizes; use of nomograms; pipework materials and applications; connection methods and supports for different forms of pipework with respect to access and vibration; mains layouts – methods of isolating, draining (including slope) and 'take off' arrangements; costs associated with air leaks; service units – filters, pressure regulators and lubricators

Steam systems: hazards; heat transfer principles and the applications to heat exchangers; calculation of heat flows (temperature difference x surface area x heat transfer coefficient); heat content of steam, relationships between pressure and temperature (use of steam tables); types of steam (saturated, dry saturated, superheated); applications of types of steam

Steam pipework and systems: materials and applications; connecting methods for HP and LP systems - flanged joints (screwed and welded), pipe support systems to allow for expansion and vibration, jointing materials (fibre based, corrugated metallic and spiral wound); lagging and insulation; causes and prevention of water hammer; drainage methods; manual cocks and steam traps; functions and main features of drain coolers; condensers and condensate return systems; types and main features of steam valves used for (system isolation and safety, pressure reduction and control, flow control); uses of LP and exhaust steam for fan heaters, calorifiers and economisers

Electricity: meaning of common electrical terms and state their units and relationships as applicable - voltage, current and resistance (Ohm's law); power, voltage and current; relationship between electrical and mechanical power; heating and magnetic effects; AC and DC voltages - differences and applications

Electrical systems: electrical supply systems and their applications and limitations - supply from grid, 3 phase 4 wire, single phase, 12V and 24V requirements and use; types and uses of transformers (fixed and portable); isolation and control methods - isolators and circuit breakers, switchgear and distribution panels, fuses, no-volt release and residual current detectors; methods of electrical distribution - cable forms and selection (size, insulation, including IMS and screened); cable protection methods - conduit and armoured, bus bars, extension reels (heating effects on coiled cable), meters for testing continuity, voltage and resistance

2 Be able to plan, prepare and set-up for maintenance of utility systems

Planning and preparation: emergency shut down and evacuation procedures for the work; methods of isolation (isolating switches, removal of fuses, closing and 'locking off' of valves, removal of valves and blanking of pipes); procedures for de-pressurising and testing systems to make sure they are in a safe condition; procedure for safe draining and disposal of oil or other such substances; procedures for spillage and contamination, fire, personal injury, disposal of toxic waste and other such substances as defined by COSHH and Environmental Protection Acts

Health and safety: working at heights; working in confined spaces; electrical installations and testing of equipment and appliances according to the IEE and Electricity at Work Regulations; methods of lifting, supporting, or otherwise making system components safe; interaction with other systems or production facilities; use of Personal Protective Equipment (PPE), e.g. breathing apparatus; procedures to be followed in cases of - fire, personal injury; disposal of toxic waste and other such substances as defined by COSHH and Environmental Protection Acts

Tools, materials, equipment and information: use of specialist tools and equipment applicable to the task; specific implications of statutory regulations, codes of practice related to installing or maintaining systems; special considerations as prescribed by the manufacturer

3 Be able to inspect and maintain utility systems

Dismantling: dismantling to allow for reassembly; identification of parts (layout of parts); use of identification (witness) marks on components; label and safely storage of parts that have been removed; methods to avoid distortion and damage to, or leakage from, pipework (disconnecting, aligning, connecting); precautions needed to avoid danger from, or damage to, components whilst dismantling - misalignment, use of wrong tools, excessive force, uncontrolled release of springs, scoring of surfaces; protection of dismantled components from contamination (blanking off open ports, use of correct cleaning agents and lint-free cloths)

Inspecting: checking of bearing surfaces; erosion and pitting; split or worn seals; signs of overheating (discolouration); condition of filters - signs of metallic or other particles, indications of emulsions or oil deterioration; correctly labelling re-built components; checking oil for signs of oxidation and acidity; testing - bench testing, pressure testing pipework and pressure vessels; presenting information that can be used to appraise the outcome of a maintenance or installation activity; electrical continuity tests; electrical insulation tests

Reassembling: sequence for tightening bolts and applying specified torque, application of lubrication to seals, precautions to be taken when refilling systems with specified oils, methods of safely bleeding systems to eliminate air locks and avoid spillage, how to remove; fit and replace: bearings, seals, springs, circlips, keys, brushes; prepare or make new gaskets or joints (including preparation of surfaces and/or housings) and repack glands; reassemble in correct order for recommissioning of the system; testing of parts and system to establish effectiveness of repair/replacement; precautions needed to avoid danger from, or damage to, components whilst installing, dismantling and assembling from: misalignment, use of wrong tools, excessive force, uncontrolled release of springs, scoring of surfaces

4 Be able to reinstate utility systems

Re-commissioning systems: refilling, recharging or re-pressurising systems; opening up the system to the sources of pressure; methods to safely drain; bleeding and purging systems to avoid undue leakage or contamination; set up and testing of - interlocks, sensors and limit switches; sequence of bringing systems back to the specified working conditions - removal of protective covers and blanks, opening appropriate valves or switches, operating the system under gradually increasing pressures or loads; methods of securing pipework and safety fittings - guards, handrails; methods of replacing insulation, lagging and other protective coverings; applying identification markings to different parts of a system, e.g. colour identification of pipework to BS 1710, using appropriate and approved coding for electrical connections and components

Restoring work areas: removal of unused consumables; cleaning the work area; putting tools and equipment into safe storage; identification of waste materials - hazardous, recyclable; reporting damage caused by the maintenance or installation activity where additional restoration work may be needed; informing all interested parties of changes that may affect the operation of the system, or of any new conditions that could exist in the work area; work termination documents or reports that may be required are completed and passed on to an authorised person, e.g. termination of permits to work

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe different types of air compressor and their performance	**M1** justify the use of a specific type of air compressor for a given application	
P2 describe the nature and behaviour of steam and air under pressure		
P3 describe the features of pipework and systems used for supplying compressed air and steam		
P4 describe the nature and effects of electricity and the applications of electrical systems	**M2** analyse, using calculations, the relationship between electrical and mechanical power	**D1** evaluate the selection of cables and cable protection methods for a given electrical installation
P5 describe the type and extent of maintenance work to be carried out on a given utility system	**M3** explain how safety is maintained during maintenance activities on a utility system	**D2** justify control measures used to ensure safe working on a utility system
P6 produce a detailed plan for carrying out a maintenance activity on a utility system		
P7 prepare to carry out a maintenance activity		
P8 dismantle and inspect the components of a utility system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 reassemble a utility system and check for effective operation on completion		
P10 describe reasons for repairing or replacing components within a utility system		
P11 re-commission to operation a utility system		
P12 close down a work area to a clean and safe condition on completion of maintenance or recommissioning of a utility system		

Essential guidance for tutors

Assessment

Evidence of criteria can be collected from case studies, assignments and practical activities which should enable learners to explore utility systems and the approaches used in their maintenance.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require evidence that demonstrates additional depth and/or breadth of knowledge and understanding.

To achieve a pass, learners must demonstrate an understanding of compressed air, steam and electrical systems. They will need to be able to plan for, and carry out, maintenance operations on utility systems. Learners will need to demonstrate safe working and be able to restore utility systems to working order.

This unit could be assessed through four assignments. The first assignment could have a series of written tasks assessing learners' understanding of compressed air, steam and electrical utility systems. The first task could require learners to investigate each of the different types of compressor listed in the unit content and then describe the features of each and their performance (P1). A second task could ask learners to research and then describe the nature and behaviour of steam and air under pressure, including the use of calculations to demonstrate the relationships between factors (P2). This could be linked to a third task that requires learners to describe features of pipework, to include materials used, methods of jointing and other key factors that influence the design of the pipework for both compressed air and steam systems (P3). A fourth activity (P4) could then task learners to examine electrical systems, including the nature and effects of electricity and its application in electrical systems. Again this could be supported by calculations related to Ohm's law and power. Learners will need to show evidence of a range of supply voltages and both AC and DC systems.

To achieve M1 learners will need to justify the use of a specific type of air compressor for a given application, for example the provision of compressed air in a chemical processing plant (M1). For M2 learners need to use calculations to analyse the relationship between electrical and mechanical power. For D1 learners will need to evaluate the selection of cables and cable protection methods, including cable size and insulation for a given electrical installation (D1).

Assignment two will focus on the planning process for a maintenance activity on a given utility system. Learners will need to provide contextualisation for the task, including describing the nature of the maintenance work that is to be completed, in terms of its type and also extent (P5). Learners will produce a detailed plan for the maintenance task that should include a risk assessment, methods of securing the area and isolating equipment, along with an estimation of the tools, materials, equipment and consumables that will be needed (P6). Learners are then required to collate the resources that they need to carry out the maintenance task, and to make the work area safe (P7). For the higher criteria learners will need to provide written evidence that explains how safety will be maintained throughout the process, considering safe working practices and any applicable legislation (M3) along with a justification of the control methods used (D2).

Assignment three is mostly practical in nature and requires learners to dismantle, inspect and then re-assemble a given utility system. Learners will need to demonstrate a logical sequence of working, showing due care to avoid damage when completing each part of the task (P8 and P9). Learners should keep notes and annotated photographic evidence of components that they disassemble and describe reasons for repairing and replacing components as part of the process (P10).

The final assignment would address P11 and P12, with learners being required to complete the recommissioning of the utility system following maintenance. This could include refilling, recharging, re-pressurising or re-energising the system and ensuring that each aspect functions and operates as expected. Learners should complete any required documentation to confirm safe operation (P11). The working area should then be made safe and tidied, with waste being appropriately dealt with, before handover of the system (P12). Learners should keep notes and annotated photographic evidence.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	Investigating Utility Systems	A written activity requiring learners to look at examples of real life compressed air, steam and electrical utility systems.	Written responses to case study based questions about the key features of different types of utility system, describing and evaluating the use of compressors and selection of system components.
P5, P6, P7, M3, D2	Planning for Maintenance Activities on a Utility System	A practical activity to prepare a plan for carrying out a maintenance activity on a given utility system. The report should identify control measures and their justification.	A practical activity to prepare a plan for a maintenance activity, which will include health and safety, tools and equipment that will be used and consumables that may need to be repaired or replaced. This would be supported by learner observation records to confirm that the maintenance activity has been correctly set up.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, P10	Dismantling, Inspecting and Re-assembling a Utility System	A practical activity where learners will systematically disassemble a given utility system to carry out a maintenance activity.	A practical activity that will be assessed though the use of annotated photographs, observation records and written reports. Evidence will need to show that each aspect of the disassembly, inspection and reassembly has been carried out to an appropriate standard.
P11, P12	Recommissioning a Utility System	A practical activity where learners will recommission the utility system that they have been working on, and make safe the area before handover of the system.	A practical activity that will be assessed though the use of annotated photographs, observation records and written test reports.

Essential resources

For this unit, learners must have access to:

- a compressed air, steam, or electrical utility system to perform maintenance activities on (training rigs are acceptable)
- tools, equipment and testing equipment appropriate to the utility system being maintained
- formal testing and commissioning documentation.

Indicative reading for learners

Textbooks

Elliott B – *Compressed Air Operations Manual* (McGraw Hill Professional, 2010) ISBN 9780071491846

Gill P – *Electrical Power Equipment Maintenance and Testing* (CRC Press, 2016) ISBN 9781420017557

Health and Safety Executive – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Websites

Health and Safety Executive – information on current and forthcoming legislation	www.hse.gov.uk/legislation

Unit 64: Operations Management and Costing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

One of the key drivers for business success in manufacturing organisations is how their Operations function is organised in order to maximise efficiency and control costs.

It is vital that engineering organisations are structured so that all the functions required to perform an engineering activity (e.g. carrying out a maintenance procedure, an installation or the manufacture of a product) join together and support each other seamlessly. From preparing design drawings and specifications to planning sequences of operations right the way through to ensuring the quality of the final outcome, each stage is vital. Communication between the key roles within Operations must be reliable, accurate and timely. Most organisations rely heavily on ICT systems to help process the large amounts of data required to coordinate complex manufacturing requirements and control costs.

In this unit you will consider how an engineering organisation is structured before focussing on what is required to carry out the Operations function effectively. You will plan an engineering activity and generate the necessary information and documents to coordinate its completion. Whilst working through this process you'll also be asked to consider the importance of effective communication and the impact of ICT on how engineering activities are organised. In addition you will perform cost calculations for an engineering activity and assess the impact of volume-variety characteristics and process reliability on cost.

Learning outcomes

On completion of this unit a learner should:

1 Understand how engineering organisations are structured

2 Be able to plan an engineering activity

3 Be able to analyse the costs associated with an engineering activity.

Unit content

1 Understand how engineering organisations are structured

- Structure of an engineering organisation
  - core functions to include Marketing and Sales, Research and Development, Operations
  - support functions to include IT, HR, Finance, Engineering/Technical
  - role of the operations function, 'to manage the production and delivery of products or services'
  - key performance drivers of the Operations function to include: increase quality, increase speed, increase dependability, increase flexibility, reduce cost.
- Key roles within the Operations function and their responsibilities to include:
  - product design (e.g. preparing drawings, specifications, materials lists, manufacturing instructions)
  - production engineering (e.g. designing/manufacturing tooling, specifying equipment, routings)
  - planning/scheduling (e.g. capacity planning, material requirements planning, production scheduling)
  - purchasing (e.g. sourcing raw material and components)
  - stores (e.g. storage and management of raw materials and components)
  - production (e.g. carrying out manufacturing processes to make components and finished goods)
  - quality assurance (e.g. quality inspection, standardisation, defect analysis and reduction)
  - warehousing (e.g. storage and management of finished goods)
  - logistics (e.g. movement and delivery of finished goods)
  - maintenance (e.g. carrying out planned maintenance schedules, responding to breakdowns)
  - health and safety (e.g. manage statutory requirements such as the Health and Safety at Work Act (HASAWA) and amendments, Control of Substances Hazardous to Health Regulations (COSHH)
  - environmental protection (e.g. manage statutory requirements such as Waste Electrical and Electronic Equipment (WEEE) Directive, Restrictions of Hazardous Substances (ROHS) Directive).
- Communication (e.g. lines of communication, methods of communication, importance of availability of accurate information provided in a timely fashion).
- Process documentation (e.g. engineering drawings, materials lists, purchasing specification, manufacturing instructions, routing, job card, stores requisition, production schedule, quality inspection instructions, test results, standard operating procedures).
- The role of ICT in process management and communications (e.g. specialist software, barcodes/QR codes, handheld scanners, shop floor monitors, real time performance displays).

2 Be able to plan an engineering activity

- Planning an engineering activity (carrying out a maintenance procedure, an installation or the manufacture of a product):
  - interpreting product or service specification documentation (e.g. materials lists, engineering drawings, maintenance procedures)
  - planning sequences of operations to complete an engineering activity (e.g. flow charts, Gantt chart, lists)
  - assigning operations to resources within work/cost centres (e.g. assigning a turning operation to a centre lathe within the machine shop work centre)
  - obtaining components, raw materials or consumables (e.g. stores orders, kanban)
  - selecting and assigning appropriate tools and equipment (e.g. understanding capability of tools and equipment, checking availability/capacity, specifying new tools and equipment)
  - designing production aids (e.g. drawing, instructions, visual aids, sequential photographs, jigs, fixtures)
  - assigning personnel (e.g. availability, skill level, training needs)
  - managing health and safety (e.g. risk assessment)
  - managing environmental protection (e.g. disposal of waste materials or by-products)
  - designing quality inspection procedures (e.g. measuring key dimensions, functional checks, product testing)
  - creating standard operating procedures to ensure engineering activities are performed consistently.
- Producing necessary documentation to coordinate the completion of an engineering activity (e.g. job card, worksheet, works order, risk assessment, inspection record sheet).
- Process review and evaluation techniques (e.g. Critical Path Analysis (CPA), Performance Evaluation and Review Techniques (PERT)), process improvements to reduce time and/or cost without compromising quality (e.g. concurrent processes, grouping similar operations, combining operations, using lower skilled operators).

3 Be able to analyse the costs associated with an engineering activity

- Volume-variety characteristics and typical industrial applications of engineering process types.
  - project processes: characteristics (e.g. usually one-off (very low volume), usually discrete, dedicated resources, high complexity, high variety, long timescales, long intervals between projects), typical applications (e.g. ships, oil rigs and tunneling machines)
  - jobbing processes: characteristics (e.g. often one-off (low volume), high variety, high flexibility, highly skilled workforce, general purpose tools and equipment, low set-up cost), typical applications (e.g. bespoke furniture, custom motorcycles)
  - batch processes: characteristics (e.g. small to large batch (low to medium volume), limited variety, skilled workforce, flexible, some specialist tools and equipment), typical applications (clothing, automotive components)
  - mass processes: characteristics (e.g. mass (medium to high volume), low variety and flexibility, skilled workforce, specialist tools and automated equipment, high set-up costs), typical applications (e.g. consumer electronics, white goods)
  - continuous processes: characteristics (e.g. continuous (high volume), very low variety, low skilled workforce, little or no flexibility, specialised highly automated equipment, high set-up costs), typical applications (e.g. petrochemicals, paper, steel, paper clips).
- Costing engineering activities:
  - direct costs (e.g. materials, labour, tooling, jigs, fixtures, overheads: rent, taxes, rates, energy costs)
  - indirect costs (e.g. support functions: IT, HR, Finance, Research and Development, training, depreciation of equipment).
- Using cost analysis to calculate the direct costs of carrying out an engineering activity:
  - bought in materials (e.g. components, raw materials, consumables), list price, price breaks, standard supply multiples (SSM), delivery costs
  - labour (e.g. high labour rates: skilled operatives, machine setters, qualified operators/technicians; low labour rates: unskilled operators, labourers)
  - set up times (e.g. changing tooling on a press, changing a production line to start the manufacture of a new product)
  - cost of new tooling, jigs, fixtures or equipment
  - effects of volume-variety characteristics on cost.
- Effects of poor process reliability on cost (e.g. labour shortage, material shortage, insufficient capacity, unplanned equipment breakdown, high defect rate).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the structure of a typical engineering organisation	**M1** Analyse the importance of clear and accurate process documentation for the performance of the operations function	**D1** Evaluate the importance of ICT for the performance of the operations function
P2 Explain the key factors driving the performance of the operations function		
P3 Explain the responsibilities of the key roles within the operations function		
P4 Plan to carry out an engineering activity	**M2** Analyse the plan to carry out an engineering activity using a critical path diagram, recommending improvements to the plan	**D2** Evaluate the impact of at least two improvements to a plan to carry out an engineering activity
P5 Produce the documentation required to enable an engineering activity to be carried out effectively		
P6 Describe the volume-variety characteristics of at least three engineering process types	**M3** Compare and contrast the direct costs for an engineering activity carried out using two contrasting process types	**D3** Evaluate the effects of poor process reliability on the cost of an engineering activity
P7 Describe direct and indirect costs for an engineering organisation		
P8 Calculate the direct costs for a given engineering activity		

Essential guidance for tutors

Assessment

Assessment criteria P1, P2, P3, M1 and D1 could be evidenced in an extended written report that examines the structure of a company, how the operations function works in that company, and the impact of ICT on the performance of the operations function.

For P1 learners need to describe the structure of a typical engineering organisation, including how core, support and operations functions relate to each other. Annotated diagrams or flow charts would enable this information to be communicated simply and clearly.

For P2 learners should focus on the operations function and explain at least four key performance drivers. This should include an explanation of the importance of each key driver and examples of how they might influence the organisation and activities carried out within elements of the operations function.

For P3 learners should explain the responsibilities of at least six roles within the operation function.

For M1 learners should examine examples of at least three process documents in order to analyse their importance in controlling different elements of the operations function. This should include the consequences of these documents being inaccurate, misinterpreted or mislaid.

For D1 learners need to provide an evaluation of the advantages and disadvantages of using ICT systems to help manage the operations function, with reference to their impact on key performance drivers.

Assessment criteria P4, P5, M2 and D2 could be covered in a portfolio of evidence.

For P4 learners will develop a plan for an engineering activity, which could be a maintenance activity, an installation or the manufacture of a product. The plan should cover the process from the point where the requirement is received from a customer up to the point where the process is completed or the product delivered.

For P5 learners need to provide sufficient documentation to control and coordinate this process.

For M2 learners should provide a critical path diagram covering some or all of the process and use this to identify at least two possible improvements.

For D1 the potential impact of these improvements to the process should be evaluated. This should include comparing the costs and potential benefits of each improvement and making recommendations as to which is likely to have the greatest impact.

P6, P7, P8, M3 and D3 could also be covered in a portfolio of evidence and could be related to the process planned in the previous assignment.

For P6 learners should provide a written description of the volume-variety characteristics of at least three engineering process types, including examples to illustrate each type in an industrial context.

For P7 and P8 learners should first define direct and indirect costs and describe a range of examples from within an engineering organisation. This can then be expanded upon by calculating the direct costs for an engineering process, which will include things like materials, labour, set up, tooling and equipment.

For M3 learners should change the volume-variety characteristics (and so the process type) of the process costed in P8. The process should then be re-costed to take these changes into account and the resulting costing compared to and contrasted with the original.

Finally, for D3 learners must evaluate the impact of poor process reliability on the cost of carrying out a process. This should involve calculating the additional direct costs incurred in at least two given scenarios and then evaluating which would have the greatest impact. Examples of the effects of poor process reliability might include: a high defect rate that would incur unnecessary scrap material and manufacturing costs; equipment breakdown incurring unplanned maintenance costs; and delays to production leading to the need for overtime in order to complete on time.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Understanding the Operations Function within an Engineering Organisation	You are a new starter in an engineering company working in the production office that coordinates activities carried out on the shop floor. As part of your induction you have been asked to write a report examining the structure of the company, how the Operations function works and the importance of good communication and ICT in ensuring its effectiveness.	Written report or presentation.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, M2, D2	Planning an Engineering Activity	As part of your new role you have been asked to plan the production of a new product through the factory. You will need to plan the sequence of operations required and generate the necessary documentation. Your initial plan should be analysed by drawing a critical path diagram and the impact of any potential improvements evaluated.	Portfolio of evidence including flow charts, appropriate shop floor documentation, critical path diagram, written notes.
P6, P7, P8, M3, D3	Costing an Engineering Activity	As part of your new role you have been asked to look at the process type used to make the new product in anticipation of an increase in volume. You have been asked to calculate the manufacturing cost of the product when manufactured using contrasting high and low volume process types and to evaluate the cost implications of poor process reliability.	Portfolio of evidence, costing calculations, written notes.

Essential resources

For this unit, learners must have access to:

- case study materials specifying a maintenance procedure, an installation or a manufactured product and associated data required to carry out planning and costing activities.
- industry standard pro forma documentation (e.g. job card, worksheet, works order, risk assessment, inspection record sheet).

Indicative reading for learners

Textbooks

Anderson M – *Operations Management for Dummies* (Wiley, 2013) ISBN 9781118551073

Buckenham A – *BTEC Nationals Engineering Student Book* (Pearson Education Limited, 2016) ISBN 9781292141008

Slack N – *Operation Management*, 8th edition (Pearson, 2016) ISBN 9781292098678

Websites

The Chartered Institute of Logistics and Transport sector page for Operations Management	ciltuk.org.uk/About-Us/Professional-Sectors-Forums/Sectors/Operations-Management

Unit 65: Engineering Design

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

An understanding of how the design process operates within an engineering business is important for anyone considering a career in the design and manufacture of products. This unit provides learners with the opportunity to consider design in a holistic way. It combines study of the technical aspects of engineering design with wider issues such as the environment, sustainability and legislation.

The unit introduces and develops the concept of design for manufacture. It is crucial that the design process be effective. Success in the marketplace can be achieved only if products are fit for purpose, marketable and meet customer requirements. The importance of market research, generation of new ideas and the consequences of poor design are investigated.

Learners will also investigate the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture. These issues include the impact of legislation and standards, the need to conform to environmental and sustainability requirements, materials selection and the types of manufacturing process available. On completion of the unit learners will understand the wider implications of engineering design and the reasons why it cannot be carried out in isolation from the rest of the manufacturing/production process.

The unit content is linked together through a practical task which starts with learners interpreting the requirements of a customer and producing a product design specification (PDS). This is followed by an investigation into the legislation, standards and reference sources that are used by designers who work in manufacturing engineering. This knowledge is then used to influence the production of their own design proposals. These proposals are refined and developed into a final design solution which meets the requirements of the customer. Design ideas will have been communicated using a number of techniques including sketching and formal engineering drawing, design calculations and written commentary.

Learning outcomes

On completion of this unit a learner should:

1 Know how the design process operates when dealing with customers

2 Know the impact of legislation, standards and environmental and manufacturing constraints can have on the design function

3 Be able to prepare design proposals that meet the requirements of a product design specification

4 Be able to produce and present a final design solution.

Unit content

1 Know how the design process operates when dealing with customers

The design process: triggers, e.g. market pull, demand, profitability, technology push, innovation, market research; process of design for manufacture; decision making; use of new technologies, e.g. computer aided design (CAD), simulation, rapid prototyping, computer integrated manufacture (CIM); lines of communication

Customer: customer/client relationship; types of customer, e.g. external, internal; requirements of customer, e.g. performance specifications (physical dimensions, mass), compliance to operating standards, reliability and product support, end of life disposal, production quantities (custom built, modification to an existing product, small batch, large volume)

Product design specification (PDS): analysis of customer requirements; production of an agreed PDS; documentation, e.g. physical dimensions, materials, mass, operation and performance

2 Know the impact of legislation, standards and environmental and manufacturing constraints can have on the design function

Legislation and standards: relevant and current legislation, standards and codes of practice, e.g. British Standards (BS), International Standards (ISO), electromagnetic compatibility (EMC) directive, European legislation (European Conformity (CE marking))

Environmental and sustainable constraints: energy efficiency; environmental impact; constraints, e.g. Environmental Protection Act, Waste Electronic and Electrical Equipment Directive; end-of-life disposal, e.g. refurbishment, recycling, disassembly, material recovery, non-recyclable components

Manufacturing constraints: availability of resources, e.g. labour, material, equipment; influence of physical and mechanical properties of a material in relation to manufacturing methods; cost effective manufacture, e.g. set up cost (jigs, tools), production quantities; health and safety in the workplace, e.g. Health and Safety at Work Act, Control of Substances Hazardous to Health (COSHH) Regulations

3 Be able to prepare design proposals that meet the requirements of a product design specification

Requirements of a PDS: interpretation of technical requirements, e.g. operating performance, physical dimensions; interpret economic requirements, e.g. production quantities, product life, market place positioning

Prepare design proposals: ideas generation, e.g. research into existing products, freehand sketching, simulation, flow charts; realistic design proposals, e.g. fitness for purpose, manufacturability, aesthetics, ergonomics

Design reference material: manufacturers' catalogues, e.g. screw fixings, bearings, seals, electrical connectors, drive belts, gear drives; materials databases, e.g. mechanical properties, physical properties; design databases, e.g. structural beam sections, corrosion protection, anthropometric data

4 Be able to produce and present a final design solution

Final design solution: evaluation of proposals and selection of most appropriate for further development, e.g. suitability for available manufacturing processes, cost effectiveness, contribution to profits, visual appearance; development of design proposal into a feasible solution suitable for prototype manufacture, e.g. specify materials, appropriate manufacturing processes, estimation of manufacturing cost, quality; conformity to relevant legislation and design standards

Presentation techniques: 2D engineering drawings, e.g. general arrangement drawing, assembly drawing, detail drawings, circuit diagrams, flow diagrams, schematic diagrams; drawing conventions and relevant British Standards, e.g. BS308, BS8888, BS7307, BS3939, BS2197; documentation, e.g. design diary, logbook, product specification; design calculations, e.g. sizes of materials to meet strength requirements, electric motor power, electronic circuit performance, battery life

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the operation of the design process in an engineering company	**M1** explain the possible impact of a poor design process on customer relationships and requirements	**D1** evaluate the impact of legislation and standards on the design process in relation to the profitability of the business
P2 interpret the requirements of a given customer and produce a product design specification	**M2** explain the importance of using a range of accurate design reference materials when developing design proposals	**D2** evaluate a final design solution against customer requirements and a PDS, and suggest improvements.
P3 describe the appropriate legislation and standards which apply to the design of two different products	**M3** explain the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture.	
P4 describe the environmental, sustainability and manufacturing constraints which influence the design of a given product		
P5 produce design proposals which meet the requirements of a given PDS		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 extract reference information from component manufacturers' catalogues and materials and design databases		
P7 use a range of techniques to present a final design solution which meets the requirements of a given PDS and relevant legislation and design standards.		

Essential guidance for tutors

Assessment

Assessment of this unit could be covered through three assignments. To achieve a pass grade learners are expected to describe how the design process operates in an engineering company and its links to other aspects of the business. It is suggested that during the first assignment the evidence for P1 could be gained by learners visiting the design department of an engineering company, carrying out an interview with an engineering designer and preparing a short report. It is important that learners understand that design cannot be carried out in isolation and that it is an income-generating function with the customer having the final say.

After the visit or similar activity, a written task for P2 should be given that asks learners to produce a PDS from the requirements of a given customer.

A second assignment could involve a research activity. Two different products need to be given to each learner and research carried out to allow them to describe the legislation and standards that apply to each product (P3) and the environmental, sustainability and manufacturing constraints that influenced the design of one of these products (P4).

Learners will need to demonstrate a basic mastery of design and drawing skills and they should be producing sketches and drawings which are broadly in line with British Standards and which use simple drawing conventions. There should be some evidence of design calculations when presenting evidence for P5, P6 and P7.

For assessment of these criteria a third assignment could be set where a PDS should be given and learners asked to produce a range of design proposals (P5). Three proposals would generally be sufficient although, if the solutions are complex, two would be enough. In doing this, it is important that learners use design reference material (P6) and a range of techniques to present the final solution (P7). The techniques used are dependent on the solution (for example if it involves an electronic system then circuit diagrams will be needed as well as perhaps general arrangement drawings).

Learners will demonstrate a basic understanding of the use of information sources such as books, technical reports, data sheets, catalogues, CD ROM and online databases. They should be selecting, interpreting and applying data extracted from a limited range of sources and will have been given guidance on what to look for.

Design work must show good evidence of knowledge gained from the linked units so that learners can be critical about their evolving designs and adapt them, rather than pursue a single idea. Grading criteria P5 and P6 link the extraction of reference information about materials and components to the design proposals being put forward by the learner. This will give more focus when gathering resource material. It is intended that the assessment evidence for criterion P6 is based on development ideas generated in P5.

To achieve a merit grade learners will need to apply evaluative skills and explain the impact of poor design. To achieve M1 the manufacturer/client relationship should be explored in some depth with evidence supported by examples taken from case studies based on real products. These could be discussed during the visit in the first assignment.

M1 builds on knowledge used to achieve P1 and P2 and may be best attempted in the first assignment.

To achieve M2 learners should support their reasons for having accurate reference material by using examples taken from documented sources of products which are mission critical (for example correct specification of dimensions and material for a load bearing structure such as a roof beam). As such, a further written task could be set in assignment three to facilitate M2.

M3 builds on P5 and P7 and a further written could be set task in assignment 3. There should be evidence of thought being given to economic issues and the pressure on a designer to design to a price in order to be competitive. Explanations should be supported by examples relating to real products that learners are familiar with.

To achieve a distinction grade learners should be able to focus on specific legislation and standards when working towards D1. There are strong links here to learning outcome 3 from *Unit 36: Business Operations in Engineering*. Learners should support their evaluation of the impact of legislation and standards on the design process with examples drawn from documented sources (for example businesses that have either lost market share by being caught out by changes in legislation or others that have benefited through anticipating changes and beating competitors in the market). As such, a task targeting D1 could be set as part of assignment 2.

To achieve the criterion D2, evaluation could relate to a design solution provided by the tutor but it may be better to link with P7 so that learners evaluate their own work. A written task in assignment 3 may be appropriate for this.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and M1	Design Report	An activity requiring learners to research and/or visit a design department and investigate the relationship between designer and customer.	A report containing written responses about the design process and its impact on customer relationships. In addition a PDS should be generated from a given customer specification.
P3, P4 and D1	Product Evaluation	An activity requiring learners to research legislation and standards that apply to two different products as well as the manufacturing, environmental and sustainability constraints for one of them.	A report containing written responses outlining legislation and standards that apply to two different products and an evaluation of the manufacturing, environmental and sustainability constraints for one of them in terms of profitability for the business.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M2, M3 and D2	Design Proposals	An activity requiring learners to interpret a given PDS and, by using appropriate research techniques, present a final design solution from a selection of design proposals.	A portfolio of design solutions and a written report explaining how a final design solution has been selected. In addition explanations of the importance of accurate design reference materials and an evaluation of the chosen design solution with reference to the given PDS.

Essential resources

To meet the needs of this unit it is essential that learners have, or have access to, some if not all of the following:

- a range of customer design requirements
- a range of products to investigate design requirement features
- manual drawing equipment
- 2D commercial CAD software
- extracts and illustrations from appropriate drawing standards and conventions
- access to reference material which provides information about the physical and mechanical properties of materials
- access to legislation and design standards
- component and material suppliers' catalogues.

Indicative reading for learners

Textbooks

Dieter G and Schmidt L – *Engineering Design* (McGraw-Hill, 2013, 5th Edition) ISBN 9780073398143

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2012) ISBN 9780080966526

Tooley M and Dingle L – *BTEC National Engineering 3rd Edition* (Newnes, 2010) ISBN 9780123822024

Unit 66: Principles and Applications of Fluid Mechanics

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Hydraulic and pneumatic power is widely used in the operation of engineering systems. The brakes on motor vehicles, railcar doors and hydraulic actuators and presses are typical examples. Fluid power is also widely used on aircraft, particularly for lowering and raising the undercarriage and for operating the flight control surfaces.

The study of this unit will introduce learners to a range of concepts and applications of fluid mechanics that will enable them to solve engineering problems associated with fluid systems.

The unit will provide learners with an understanding of surface tension and the viscous behaviour of Newtonian fluids that will then be used to determine a range of parameters in bearing systems. Learners will be introduced to the characteristics and behaviour of fluids at rest and will apply this knowledge to the inputs and outputs of hydraulic devices and systems, as well as to the determination of thrust forces and pressures that act on immersed rectangular and circular surfaces.

Learners will be introduced to fluid flow in piped systems and to the measurement of flow velocities, pressures and energy, using a variety of measuring instruments. The behaviour of fluid jets will be studied, in particular the jets from nozzles that impinge on stationary vanes, will be considered. This knowledge will be useful as a precursor to the study of turbo-machines, should they choose to go onto more advanced fluid studies. Finally a study of the concepts associated with the wind tunnel testing of models, that find use in the design and testing of motor vehicles and aircraft, when subject to external fluid flows, will be made.

Learning outcomes

On completion of this unit a learner should:

1. Understand the physical properties and characteristic behaviour of fluids and system parameters for oiled bearings
2. Be able to determine the parameters that act in hydrostatic devices and act on immersed surfaces
3. Be able to apply fluid flow theory to determine parameters for pipe measuring systems and nozzle vane systems
4. Understand the use of wind tunnel testing, aerodynamic theory and associated test data to determine the aerodynamic parameters of test models.

Unit content

1 Understand the physical properties and characteristic behaviour of fluids and system parameters for oiled bearings

Physical properties: e.g. surface tension (surface tension coefficient, capillary action), viscosity (dynamic viscosity, coefficient of dynamic viscosity, kinematic viscosity, variation in viscosity with temperature)

Characteristic behaviour: e.g. Newtonian fluids (water, lubricating oils) and non-Newtonian fluids (pseudo plastic, Bingham plastic, Casson plastic, dilatent)

Bearings: e.g. plain journal, plain thrust; system parameters, e.g. bearing dimensions, speed, viscosity of lubricant, viscous resistance, power loss

2 Be able to determine the parameters that act in hydrostatic devices and act on immersed surfaces

Hydrostatic devices: devices, e.g. hydraulic actuator, Bramah press, hydraulic braking system; system parameters, e.g. cylinder dimensions, input and output forces, internal pressure, input and output motions

Immersed surfaces: surfaces, e.g. retaining walls of tanks and reservoirs, lock and sluice gates, immersed rectangular and circular inspection covers and hatches; system parameters, e.g. surface dimensions, depth of immersion, hydrostatic pressure and thrust, position of centre of pressure

3 Be able to apply fluid flow theory to determine parameters for pipe measuring systems and nozzle vane systems

Fluid flow theory: e.g. incompressible flow, equations of continuity of mass and volume, Bernoulli's equation, Reynolds number, turbulent and laminar internal flows, use of D'Arcy's equation

Pipe measuring systems: e.g. standard pipe lengths, tapered pipes, inclined and tapered pipes, measuring instruments (such as Venturi Meter, orifice meter, manometer, Pitot-static tube; parameters, e.g. mass and volume flow rates, entry and exit velocities, pressure energy changes

Nozzle vane systems: e.g. stationary nozzle, normal impinging jet, stationary vane (such as flat plate, hemispherical cup, reaction jet); parameters (thrust forces exerted by a jet, normal impinging forces on vanes, reaction of a jet nozzle)

4 Understand the use of wind tunnel testing, aerodynamic theory and associated test data to determine the aerodynamic parameters of test models

Wind tunnel testing: equipment, e.g. open-section, closed section tunnels, smoke tubes, test data measuring devices (such as digital instruments, speed probes, pitot-static tubes, manometers); test models, e.g. aerofoil sections, fixed wing scale model aircraft, rotary wing scale model aircraft, scale model racing cars and spoilers

Aerodynamic theory: definitions, formulae and evaluation, e.g. external flow around bluff bodies, angle of attack, span, chord, aspect ratio, wing area, airspeed, stall conditions, lift and drag coefficients, dynamic pressure, drag force, lift force, lift/drag ratio, significance of model size, Reynolds number, wind-tunnel pressurisation and speeds and scale effect

Aerodynamic parameters: e.g. pressure distribution, lift and drag coefficients, lift, drag, down force, lift/drag ratio from theory and test data readings

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 determine the surface tension coefficient for a given liquid on glass from its rise in a capillary tube	**M1** calculate the viscous resistance and power loss in a lubricated plain thrust bearing from given data	**D1** explain, compare and contrast, the behaviour of the range of non-Newtonian fluids when they are subjected to shearing forces
P2 explain how the viscosity of Newtonian fluids is affected by changes in temperature and pressure	**M2** determine whether the difference in levels between reservoirs connected by a pipe of given length and diameter is sufficient to supply a given flow rate	**D2** investigate and evaluate the Venturi meter, orifice meter and Pitot-static tube for the measurement of fluid flow.
P3 calculate the viscous resistance and power loss in a lubricated plain journal bearing from given system parameters	**M3** determine, using given test data, the value of Reynolds number at which a particular flow pattern occurs around a model structure and determine the velocity at which the same pattern is likely to occur around the actual structure	
P4 determine the output force and motion of a hydrostatic device from given system parameters	**M4** explain the change in the flow pattern, pressure distribution and the lift and drag coefficient for an aerofoil as its angle of attack is increased up to the stall	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 determine the thrust on and centre of pressure position of, an immersed vertical retaining surface whose top edge is below the free surface of the retained liquid	**M5** explain the significance of down force and how down force may be increased by design features, on high speed racing cars.	
P6 determine the flow velocities at the inlet and exit sections of an inclined tapering pipe, using fluid flow theory and given pressure readings and flow rates		
P7 determine the resultant thrust and the reaction of the jet nozzle, when a jet of fluid impinges normally on a stationary flat plate		
P8 describe the wind-tunnel equipment set-up and experimental measurements needed to produce a pressure distribution plot of an aerofoil section at a fixed angle of attack		
P9 determine the dynamic pressure exerted on a wind tunnel model and its drag coefficient using aerodynamic theory and given test data.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit may be collected from a series of four assignments. The precise nature of the practical aspects of these assignments will be partly or wholly dependent on the available physical resources. However, the assessment guidance detailed below is based on learners having access, on or off site, to the minimum equipment requirements needed to satisfactorily achieve the unit outcomes and grading criteria.

Assuming that the unit is delivered in the same order as the outcomes, learners must first demonstrate an understanding of the physical properties, in particular surface tension and viscosity (P1) and characteristic behaviour (P2) of Newtonian and non-Newtonian fluids, with only Newtonian fluids being subject to quantitative analysis.

Then learners are required to calculate the viscous resistance and power loss in plain journal bearing (P3) and plain thrust bearing (M1). Finally they must compare and explain the behaviour of a range of non-Newtonian fluids when they are subject to shearing forces (D1).

Evidence demonstrating achievement of the above assessment criteria for this outcome could come from the answers to a written/investigative assignment. This assignment could be set in two parts, whereby learners would first be required to answer a set of formal written tasks (P1, P2, P3, M1) and then carry out a literature search investigation for (D1). The tasks for the formal written part of the assessment would require learners to first develop and apply the expression used to determine surface tension coefficient from the rise of liquid in a capillary tube (P1). Next, learners would be required to explain how the viscosity of Newtonian fluids is affected by changes in temperature and pressure (P2), citing examples. Learners would then need to consider a plain journal bearing where they are progressively required, to determine the lubricated area and shearing velocity to meet a series of viscous resistance and power loss requirements (P3). Finally, learners are required to apply the integral calculus to determine the same parameters as above but for a plain thrust bearing.

For the investigative part of the assignment learners would need to carry out a literature search in order to explain, compare and contrast the behaviour (supported by the appropriate rheograms) of the non-Newtonian fluids identified in the unit content.

For learning outcome 2 learners must be able to determine output and input parameters such as force and motion, for hydrostatic devices (P4) and be able to determine the thrust and pressure acting on immersed surfaces (P5). Evidence for these criteria could come from the learner's answer to a second written assignment. Appropriate responses to tasks associated with the determination of output parameters for a hydraulic press, jack or braking system, would provide evidence that P4 had been met. Learners would then need to determine the thrust and centre of pressure position of immersed surfaces to meet P5.

To achieve learning outcome 3 learners must be able to determine the inlet and exit parameters for an inclined tapering pipe, within a piped system, using flow theory and given system data (P6). They will also need to able to determine the resultant thrust and nozzle reaction forces for a jet of fluid impinging normally on a stationary flat plate (P7). These criteria could be covered using a third written assignment which could also include additional tasks to meet M2 and M3.

Suitable tasks to meet criteria M2 could involve the calculation of the likely head loss along a pipe connecting two reservoirs using D'Arcy's formula. The pipe friction coefficient should be given and the estimated friction head loss compared to the potential head difference between the reservoirs. A judgement can then be made as to whether the required flow rate is feasible without the installation of a pump.

The test data required for a task to achieve M3 should include the control dimensions of the test model and actual structure. The model could be of any bluff body such as a cylinder or bridge pier around which a turbulent flow pattern is seen to occur at some particular value of flow velocity. The dynamic viscosity and density of the fluid should also be supplied. If wind-tunnel facilities are available, with appropriate smoke generators or other visualisation equipment, the airflow round the bluff body model could be assessed visually at different velocities.

A final assignment could cover P8, P9, P10, M4, M5 and D2. This assignment should ideally be designed around the use and completion of practical activities, with the minority of the criteria requiring a response to written tasks. The following describes how the appropriate criteria could be met through practical exercises, although it is appreciated that centres may not have all of the relevant equipment. Where this is the case a written task may be used instead.

Tasks to achieve (P8) require learners to describe a wind-tunnel set-up and detail the experimental measurements needed to create a pressure plot for an aerofoil section. Learners can meet this criterion through a written task, although it would assist them to see the equipment first hand.

To achieve P9, learners would benefit from obtaining the experimental measurements practically, rather than being given them. They would need to use a wind-tunnel or wind-tunnel model (such as a building, aircraft or scale model motor vehicle) and take appropriate readings from manometers, velocity meters, Pitot-static probes etc, as well as know the frontal area of the model under test. They could then apply aerodynamic theory to determine the dynamic pressure and drag coefficient.

In order to achieve M4, learners are required to explain the change in flow pattern, pressure distribution and the lift and drag coefficients for an aerofoil, with increasing angle of attack. Their explanation could be enhanced if learners have the opportunity to observe equipment where the changes across the aerofoil section can take place and so take the necessary readings from experiment. Failing this, learners could be given a written task, where they are required to investigate and report on the required changes that take place with the aerofoil, as the angle of attack is gradually increased. An investigative task requiring written answers could be set in order to provide evidence for the achievement of M5, where learners are required to identify and explain the design features that are used on high performance racing cars, to increase down force.

Finally, a task requiring learners to undertake a practical investigation and evaluate the Venturi meter, orifice meter and Pitot-static tube and write a report on their findings, would be the most appropriate way of providing evidence for D2. If this is not possible then a practical assessment of one or more of these instrument plus a theoretical assessment of the others, would be the next best alternative. Irrespective of whether or not a practical or theoretical task is set, reference should be made in their written response to the typical applications, flow impedance, ease of installation, cost and sensitivity of each of these instruments, backing up their argument with technical data.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Nature of Fluids and Bearing Systems	Part written assignment (under controlled conditions) and part investigative.	Written response to set theoretical tasks and written report to investigative work.
P4, P5	Hydrostatic Devices and Immersed Surfaces	Formal written assignment under controlled conditions.	Written answers to set tasks that cover the criteria.
P6, P7, M2, M3	Piped Measuring and Nozzle Vane Systems	Formal written assignment under controlled conditions, with appropriate test data being provided.	Written response to tasks, showing appropriate use of given data and related fluid flow theory.
P8, P9, M4, M5, D2	Determining Aerodynamic Parameters	Investigative assignment, part practical (subject to centre equipment limitations) part literature search.	Written report and observation record on the practical aspects of the assignment (as appropriate) plus written response to set theoretical tasks.

Essential resources

The following equipment is considered the essential minimum for the successful delivery of this unit:

- laboratory equipment for visualisation of adhesion forces and capillary action, such as calibrated test tubes and fluid in glass tube barometers
- Redwood viscometer or similar
- metered hydraulic bench with attachments for investigating differential pressure flow measurement and fully developed laminar flow in pipes.

Recommended resources

Although not essential, the following equipment is highly recommended to enhance learning and promote interest in the subject:

- additional attachments for hydraulic bench, including impact of a jet apparatus, plus the Venturi meter, orifice meter and Pitot-static tube flow measurement instruments
- open or closed section wind-tunnel, with appropriate measuring apparatus and models, such as manometers, digital velocity meters, lift and drag balance, Pitot-static head, aerofoil sections, model buildings/bluff bodies, model aircraft and motor vehicles
- hydraulic or pneumatic brake systems (rigs or on vehicles).

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Option Units* (Elsevier, 2008) ISBN 9780750686570

Douglas J, Gasiorek J, Swaffield J, Jack L – *Fluid Mechanics* (Prentice Hall, 2011) ISBN 9780273717720

Fox R, McDonald A and Pritchard P – *Introduction to Fluid Mechanics* (John Wiley and Sons, 2009) ISBN 9780470234501

Unit 67: Commercial Aspects of Engineering Organisations

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Engineers are employed in a range of organisations where their knowledge and skills are used to solve business needs and contribute to commercial success.

The organisations that employ engineers need to understand the areas in which their engineering expertise is deployed. This knowledge can help them plan their business effectively to secure competitive advantage. Engineering organisations also need to conduct themselves in a professional way and need to have a strong customer focus. Protecting what they do, invent, make or service is equally important for longer-term advantage and survival.

Companies need to operate their commercial activities in a competitive yet legal way. With infrastructure and engineering products and processes becoming increasingly complex, engineers need to integrate consideration of the environmental and social impacts with mainstream and commercial aspects of their work. It is therefore also important that organisations are able to deal with both local and national constraints and can demonstrate their commitment in these areas such as the gaining and use of kitemark systems.

This unit aims to place learners' studies in the context of engineering business planning, competitive commercial activities and the constraints placed upon engineering related organisations. It involves developing an understanding of the areas in which specific businesses operate. The unit will also place the considerations of business planning and corporate expectations into a realistic context.

Any commercial process must generate sufficient income to sustain its operation. The income depends both on customer demand and on whether the products or services provided are able to make a profit or remain within budget. This unit will examine the commercial activities carried out by engineering organisations and the constraints that are placed on them inside a quality framework.

Learning outcomes

On completion of this unit a learner should:

1 Know about the business planning and corporate expectations of an engineering organisation

2 Know about competitive commercial activities

3 Know about local and national constraints

4 Know about the concepts of quality assurance and quality control.

Unit content

1 Know about the business planning and corporate expectations of an engineering organisation

Business planning considerations: methods of securing and managing resources, methods of recruiting and managing staff; financial; managing suppliers (supply chain management) and other interested stakeholders; influence of marketing and sales activities; building relationships with clients; aiming to establish competitiveness

Corporate expectation and customer focus: product or service range; customer considerations, e.g. expectations, corporate image, reputation, effects on success; defined procedures; employer expectations, e.g. rapport, positive attitudes, body language, dress code, clear communications, respect for individual differences and choices; ethical expectations, e.g. accuracy and reliability of information used, honesty and integrity, respect for life, law and public good, responsible leadership, listening and informing

2 Know about competitive commercial activities

Tendering and contracting: terms (expressed, implied); warranties and conditions; implications of non-performance; documents, e.g. estimates, quotations, contracts; promotion of equality and diversity

Intellectual rights: definition and purpose; intellectual property legislation and acts, e.g. UK, International, Patents Act, Copyright, Designs and Patents Act, Patents Rules; processes, e.g. patenting, design registration, trademarking

Innovation: purpose and effects, e.g. innovation and competitive advantage, market competition, fashion; techniques, e.g. systematic thinking, leadership, organisational behaviour, synergy between research and development (R&D) and product development, brainstorming; possible implementation strategies, e.g. technology brokers, outsourcing expertise, partners

3 Know about local and national constraints

Local impact: provision of employment, e.g. employment levels, workforce skill levels, training requirements, local skills councils, impact of outsourcing; effects on the community, e.g. emissions, access and egress of people and materials

Statutory controls: employment protection; equal opportunities; health and safety; environmental controls, e.g. sustainability, environmental impact, use of renewable resources

Public issues: public concerns; public opinion and changes that have occurred; industry attempts to influence opinion; impact upon employment

Kitemark systems: e.g. codes of practice (industrial, professional, organisational), ISO9000, ISO14001, ISO14006, ISO14040, Investors in People (IiP), The Learning Organisation

4 Know about the concepts of quality assurance and quality control

Quality: definitions, e.g. fitness for purpose, compliance with standards, satisfying customer needs and expectations with regard to costs, performance, appeal, reliability, durability, maintenance, safety and customer care

Quality assurance: quality assurance as a company-wide philosophy; total quality management; quality standards and accreditation

Quality control: methods, e.g. inspection, sampling, testing, condition monitoring, planned maintenance; 'right first time' philosophy

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
1 describe what should be considered when carrying out business planning	**M1** explain the importance of successful tendering, contracting and innovation to business planning for an engineering organisation	**D1** evaluate the effects that local and national constraints have on competitive commercial activities.
P2 describe the corporate expectations of an engineering organisation with a customer focus	**M2** explain how the concepts of quality assurance and quality control affect the application of business planning considerations and corporate expectations.	
P3 describe how an engineering organisation carries out tendering and contracting		
P4 describe the intellectual rights an engineering organisation should consider when operating in a competitive environment		
P5 describe how innovation can be used as a competitive commercial activity by an engineering organisation		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe potential local impact, statutory controls and public issues that may affect the operation of a given engineering organisation		
P7 describe the kitemark systems found in a given engineering organisation		
P8 define the term 'quality' as applied to a product or service		
P9 distinguish between quality assurance and quality control.		

Essential guidance for tutors

Assessment

Evidence of achievement can be collected from case studies, assignments and projects which should enable learners to explore business planning, commercial activities, local and national constraints and quality issues.

To achieve a pass, learners must demonstrate knowledge and understanding of business planning and the corporate expectations of an organisation with a customer focus. Learners should describe the intellectual rights an engineering organisation should consider and explain how innovation can gain competitive advantage. They should also have knowledge of local and national constraints that an organisation works within and be able to differentiate between quality assurance and quality control.

The unit could be assessed using four assignments. It may be best to leave the criteria associated with business planning until the end and therefore the first assignment could address the criteria associated with learning outcome 2. Written tasks could be given to ask learners about tendering and contracting (P3), intellectual rights (P4) and innovation (P5). The requirement for P3 should include terms, documentation and promotion of equality and diversity. The task for P4 should ensure that learners have an opportunity to demonstrate what they know about the appropriate legislation, acts and processes associated with innovation, as well as defining and describing the purpose of intellectual rights. A written task targeting P5 could ask learners to explain how innovation can be used by an engineering organisation. In doing this learners will need to show how success is based on the use of techniques and deployment strategies and the effect innovation has on competition.

A second assignment could be a set of written tasks to address criteria P6, P7 and D1. The local impact should be based around the provision of employment and effects on the community, whereas statutory controls cover employment protection, equal opportunities and health and safety as well as environmental controls. A written task is again suitable to address D1.

A third assignment could be a stand-alone assignment involving written tasks for each of P8 and P9.

The final assignment could involve a series of written tasks to cover the remaining criteria, namely P1, P2, M1 and M2. It is only after learners have tackled tasks that relate to learning outcomes 2, 3 and 4 that they will be able to relate business planning considerations and corporate expectations to tendering, contracting, innovation, quality assurance and quality control.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1 and M2	Business Planning and Corporate Expectations	A written activity requiring learners to investigate business planning and the corporate expectations of an engineering organisation.	An assignment containing a series of written tasks in which learners relate business planning and corporate expectations to tendering, contracting, innovation and quality assurance and control.
P3, P4 and P5	Competitive Commercial Activities in Engineering	A written activity requiring learners to investigate tendering and contracting, intellectual rights and innovation in relation to an engineering organisation.	An assignment containing a series of three written tasks in which learners describe how tendering and contracting is carried out, the intellectual rights that relate to an engineering business and the ways that innovation can be used as a competitive tool.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7 and D1	Constraints Affecting Engineering Organisations	A written activity requiring learners to investigate the local and national constraints that can impact upon an engineering organisation.	An assignment containing a series of written tasks in which learners describe local impact and statutory controls and kitemark systems. Learners will also produce a written evaluation of the effects of constraints on commercial activities.
P8 and P9	Concepts of Quality Assurance and Quality Control	A written activity requiring learners to investigate quality in relation to engineering commercial organisations.	An assignment containing two written tasks in which learners define quality and describe the differences between quality assurance and quality control.

Essential resources

Learners will need access to relevant intellectual property legislation. A range of information and data on engineering organisations as identified within the content and criteria is also needed for learning and assessment.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R, Mantovani B, Roberts D, Weatherill B – *BTEC Level 3 National Engineering Student Book* (Heinemann, 2010) ISBN 9781846907241

Gibbs A – *Essentials of Patents* (Wiley and Sons, 2003) ISBN 9780471250500

Grant J, Ashworth C and Charmasson H – *Patents, Registered Designs, Trademarks and Copyright for Dummies* (Wiley-Blackwell, 2010) ISBN 9780470519974

Unit 68: Lean Production System Design

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Industry professionals within engineering companies understand that manufacturing must be seen as a holistic and dynamic system that integrates people, business processes and technology. This unit aims to develop learners' understanding of the issues and dynamics associated with the design and management of modern production systems.

The unit specifically focuses on lean manufacturing – a management philosophy that focuses on the identification and elimination of waste in manufactured products. Lean thinking principles have emerged as a method to improve the flexibility, reliability and profitability of engineering enterprises worldwide. It is being used to reduce inventory, batch size and set-up times. As enterprises have reduced costs and improved quality, the primary competitive measure is the ability to respond to the customer.

This unit first introduces the basic principles of lean (value, value stream, flow, pull, and continuous improvement). The unit will develop these concepts and give learners a full understanding of the skills and competencies required by someone working in a lean manufacturing environment. It then covers lean manufacturing methods and tools designed to put these concepts into practice in a manufacturing environment. Topics explored include flow process analysis, production levelling, kanban systems, set-up reduction, standard operations, total productive maintenance and autonomous maintenance.

Learning outcomes

On completion of this unit a learner should:

1 Know the principles of lean manufacturing

2 Know how to create a flexible production system

3 Be able to apply the single minute exchange of die (SMED) method to a production system

4 Know how to implement a total productive maintenance system.

Unit content

1 Know the principles of lean manufacturing

Minimising waste: definition of waste; areas of waste, e.g. operator motion, waiting time, over production, process time, defects, inventory, transportation, definition of value/non-value added activities; streamline flow, e.g. goal of streamline flow, impact of smoothing production, assumptions of the economic batch quantity, hidden costs of inventory

Group technology techniques: use of classification system; cluster analysis; cell design; exploiting similarities of products within families, e.g. reduced set-ups, smaller batch sizes, improved productivity, reduced inventory, easier handling, standardisation of tasks and equipment, reduced tooling, jigs, fixtures and pallets, simplified production planning and control, improved quality, identification and solving recurring problems, employee job satisfaction

Continuous improvement principles: small incremental improvement steps; benefits over large step-changes, e.g. sustainable reduction/elimination of the 'seven wastes' and the 'six big losses' of production, reduced cost, improved safety, quality, working practices and procedures

Visual management: local visual management systems; visual display techniques; visual control methods; benefits of visual management

Pull production systems principle: demand-driven production; advantages of pull production, e.g. reduced inventory, reduced lead time, improved part synchronisation, elimination of queues, improved defect detection rate

Workplace organisation: correct location for machines, tools, equipment and inventory; point-of-use stock; sort out/clear out; straighten/configure; shine/clean; standardise/conformity; self-discipline/custom and practice; 5S/5Cs audits

2 Know how to create a flexible production system

Flow process analysis: analysis charts, e.g. flow diagrams, multiple-activity charts, man/machine charts, two- handed charts, payback matrix, lead-time analysis, lead time profiles, frequency diagrams; basic mapping procedure, e.g. identify area, map current state, examine, develop future state map, implement and repeat

Production levelling: documentation, e.g. precedence charts, collecting manual, production schedule; line balancing procedure, e.g. walk and machine times, determining customer demand, determining batch size, calculating system cycle time, calculating takt time, calculating number of work stations, assigning tasks; analysis, e.g. line balance ratio, line balance efficiency

Kanban systems: types of Kanban, e.g. production, withdrawal, special, combined, single card system, dual card system; kanban rules, e.g. determining the batch quantity, determining the number of kanban; further kanban systems, e.g. express production kanban, offline kanban, raw material kanban, supplier kanban, footprint kanban, max/min buffers, two bin systems

Standard operating procedure (SOP): rules of the standardised job; documentation (standard combination sheets and standardised work charts); key quality and safety points; work elements; element times, e.g. manual, walking, machine, cycle, takt; equipment and machine layout

3 Be able to apply the single minute exchange of die method to a production system

Single minute exchange of die (SMED): methodology (identify elements, separate internal and external activities, convert internal activities to external, standardisation, reduce internal times, reduce external times, implementation plan); aids (conversion matrix, use of pre-set tooling, special fasteners, manifolds, parallel activities); set-up elements, e.g. preparation, mounting and extraction, establishing control settings, first run capability

4 Know how to implement a total productive maintenance system

Total productive maintenance: major causes of machine breakdowns; the traditional approach to maintenance; elements of a breakdown, e.g. mean time between breakdowns, mean time to repair, availability, activities during machine downtime; principles of total productive maintenance; 5C/5S foundations; prioritisation and elimination of the 'six big losses' to production, e.g. unexpected breakdowns, set-up and adjustments, minor stoppages, actual operating speed, defects, start up yield, role of operator and maintenance engineer during 1st and 2nd line maintenance

Steps to autonomous and planned maintenance: establish autonomous maintenance; establish planned maintenance programme; conduct operator and maintenance engineer training; maintain equipment in optimum condition; set up early equipment management programme

Overall equipment effectiveness (OEE): performance metric and improvement cycle; definition of availability; performance; quality; calculating OEE

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles of minimising waste and the techniques of group technology	**M1** explain the benefits of applying group technology to a production system	**D1** compare and contrast the incremental approach to continuous improvement with that of large step changes
P2 describe the principles of continuous improvement and the use of visual management systems	**M2** explain the advantages of smoothing production	**D2** evaluate the issues encountered when applying lean principles to create a flexible production system from a traditional production system.
P3 describe the principles of a pull production system and the use of workplace organisation	**M3** explain the importance of set-up reduction to the performance of a production system.	
P4 use suitable flow process analysis charts and mapping procedures to determine the current state of a production system		
P5 perform a production levelling exercise to determine a future state map of a production system		
P6 describe a type of kanban system and a further kanban system, including kanban rules		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 compile a SOP for one element of a production system		
P8 apply the SMED to reduce the change over time of one element of a production system		
P9 describe total productive maintenance and the steps required for autonomous and planned maintenance		
P10 gather production data and calculate the overall equipment effectiveness (OEE) of a production system.		

Essential guidance for tutors

Assessment

Evidence of learning outcomes can be collected from the learners' workplace, case studies, assignments and projects. This should enable learners to demonstrate knowledge and understanding of the principles of lean manufacture and the design and analysis of flexible production systems in a manufacturing environment.

For P1 they will need to describe the areas of waste found in a production system when they are describing the principles of minimising waste. This may be achieved in a number of ways, e.g. a short written description of the type of waste or by using suitable annotated photographs. Learners are not expected to write lengthy descriptions to achieve this criterion. Learners must also briefly describe the techniques that can be used to identify part families. Ideally this can be expanded to explain the benefits of exploiting the similarities of products within families and used for evidence towards M1.

P2 requires learners to explain the principles of continuous improvement and explain how visual management systems can be applied to reinforce and sustain improvements. An assignment could be developed on the two approaches and then linked to D1 by asking learners to compare and contrast the incremental approach to continuous improvement with that of large step changes.

P3 requires learners to explain the principles of pull production and its essential prerequisite workplace organisation. This could be achieved via a presentation to the group, or as an annotated poster.

For P4 learners need to use suitable flow process analysis charts to map the current state of a given production system. They must then perform a production levelling exercise and determine a future state map of the production system (P5). Evidence for these criteria could be provided from the learners' involvement in continuous improvement activities in the workplace or through a work placement. If assessed directly by the tutor, suitable evidence from these activities would be standard documentation and observation records. If assessed during a placement, witness statements should be provided by a suitable representative and verified by the tutor. P5 can be expanded to include M2, where learners describe the advantages of smoothing production. Evidence for this could be gathered either in the form of a short report or by a short presentation.

P6 requires learners to describe one kanban and a further kanban systems including their rules. Tutors could allocate different kanban systems to individual learners or groups of learners and ask them to feed back to the class through presentations.

P7 requires learners to compile a standard operating procedure for one element of a production system. Ideally this should be linked to P4 and be done in the workplace, or possibly as part of a work placement. Assessment evidence for this criterion could take a similar format to that for P4.

For P8 learners are asked to apply the SMED approach to reduce the changeover time of an element of a production system. Standard documentation used to aid the analysis may be used as evidence for this criterion. As some learners may not have real access to this form of activity, simulation could be used. Again, learners' evidence could be in the form of a presentation. M3 could be linked to P8 through the use of a short report, with learners explaining the importance of set-up reduction to the performance of a production system.

P9 requires learners to describe total productive maintenance and the steps required to implement autonomous and planned maintenance. This could be achieved by a written description that should include areas identified in the unit content, from major causes of machine breakdowns, to 5C/5S foundations through to prioritisation and elimination of the '6 big losses' to production.

P10 builds on P9 and asks learners to gather production data and calculate the OEE of a production system. Assessment evidence could come from learners' involvement in continuous improvement activities in the workplace or through a work placement. Again, as some learners may not have real access to this form of activity, simulation could be used.

For M1, learners need to explain the benefits of applying group technology. Learners should be able to provide evidence of an understanding of how parts similarities (in terms of geometry, size, tolerances, material and method of production) can be exploited for the benefit of the production system. M2 requires learners to describe the advantages of smoothing production. To achieve M3 learners need to independently explain the importance of set-up reduction to production system performance. Evidence for all the merit criteria is likely to be through written reports.

To achieve D1, learners have to compare the incremental approach to continuous improvement with that of large step changes. Learners should consider both the business and human sides of managing change in terms of improved efficiencies, working practices, procedures, participation and sustainability of the improvement process.

D2 requires learners to evaluate the issues encountered when applying lean principles to develop a flexible production system from a traditional system. It is important that centres do not make this over-complex, otherwise learners will not have the time to achieve this. Learners can explain the issues they encountered during their practical exercises, evaluate their improvement methodology and suggest how this may alter their approach to future improvement activities. Learners should show an appreciation of the culture change required to create a modern production system and the practical, managerial and social challenges this presents.

The assessment of D1 and D2 may be linked and the evidence obtained via a written assessment or a pictorial presentation with notes (possibly using PowerPoint or OHTs) and an annotated poster.

All evidence must be generated in a form suitable for inclusion in learners' portfolios. This could include standard forms (e.g. PDCA forms, data gathering forms, analysis charts, minutes of team meetings etc), images (e.g. photographs, completed charts, diagrams, plans and engineering drawings), presentation slides, written reports, witness statements and solutions to group-set problems.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Principles of Lean Manufacturing	Learners have been asked to produce a report on the benefits of lean manufacturing systems.	A written report or an information poster.
P4, P5, P6, P7, M2, D2	Flexible Production Systems	Learners have been asked to look at ways of improving an existing production system.	A written report supported by a logbook and observation records.
P8, M3	Single Minute Exchange of Die	Learners must apply SMED approach to a production system.	A practical activity evidenced by supporting documentation and observation records. An additional written report explaining the importance of set-up reduction.
P9, P10	Total Productive Maintenance	Learners have been asked to explain total productive maintenance to new apprentices.	A short written report or information poster plus equipment effectiveness calculations based on production data.

Essential resources

To deliver this unit centres will need to have an up-to-date reference library with computer-aided learning resources and appropriate journals.

Indicative reading for learners

Textbooks

Bicheno J and Holweg M – *The Lean Toolbox*, 5th edition (Picsie Press, 2016)
ISBN 9780956830753

Slack N – *Operations Management*, 8th edition (Pearson, 2016)
ISBN 9781292098678

Wilson L – *How to Implement Lean Manufacturing*, 2nd edition (McGraw Hill, 2015)
ISBN 9780071835732

Journal

International Journal of Operations and Production Management

Magazines

Engineering Technology

Manufacturing Engineer

Unit 69: Statistics and Business Improvement Techniques

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit focuses on how the processes of value, risk and quality management can be integrated into continuous improvement activities.

The concept of improving effectiveness and efficiency at work to drive down costs, meet deadlines, improve quality and boost productivity is crucial to surviving in a competitive environment. All processes need to be evaluated to ensure continuous improvement in both quality and productivity.

Businesses need to understand the importance of taking action before rejects or defective products are produced, thus avoiding unnecessary expense and halting production, with all its inherent problems.

Most quality systems also implement value and risk management techniques. Value and risk management are now fundamental components of best practice and are widely recognised as essential activities in the search for improved performance. Whilst risk and value management possess separate origins, they share many characteristics and are increasingly seen as complementary activities.

This unit focuses on how the processes of value, risk and quality management can be integrated into continuous improvement activities. It gives learners the knowledge and skills required to carry out a value engineering activity. This is a function-oriented, systematic team approach used to analyse and improve the value in a product, facility, system or service. This is a powerful tool for solving problems and/or reducing costs while improving performance/quality requirements. By enhancing value, customer satisfaction should also increase.

The unit also covers potential failure modes and effects analysis (FMEA). FMEA is a technique used to identify and eliminate possible causes of failure. The technique requires a sequential, disciplined approach by engineers to assess systems, products or processes in order to establish the modes of failure and the effects of failure on the system, product or process. The unit will enable learners to apply the technique of examining what might fail, looking at the possible results of such a failure and analysing what could cause it. Solutions to the potential failures are then prioritised so that the most significant ones are dealt with first.

Properly applied statistical control can prevent problems and lead to continuous improvement in product quality and productivity. The unit aims to enable learners to acquire and apply basic statistical techniques, statistical process control and process capability studies to a process.

Learning outcomes

On completion of this unit a learner should:

1 Be able to apply the principles and processes of value management

2 Be able to apply the principles and techniques of potential failure modes and effects analysis

3 Understand and apply basic statistical techniques and statistical process control procedures

4 Be able to carry out a process capability study.

Unit content

1 Be able to apply the principles and processes of value management

Principles: definitions of cost, value, value added and non-value added activities; concept of function; reasons for poor value

Total cost model: showing costs related to function; cost of function equation; identification of added and non-value added activities

Supply chain map: showing costs related to function; aligned to Porter's value chain model

Value analysis: tools, e.g. Gage's 12 steps, function analysis system technique (FAST) diagrams, value trees, problem solving tools and techniques; management activity, e.g. identifying customer requirements, setting quantifiable objectives and targets, analysing the function of the product or process, identifying and allocating the costs of the functions, identifying the added and non-value added activities within the process, finding the most appropriate alternatives, detailed proposal (develop alternatives into detailed proposals, present findings from value management activities, prioritise and rank the alternatives, carry out risk assessment of the alternatives, provide costed recommendations and implementation plan for management approval)

2 Be able to apply the principles and techniques of potential failure modes and effects analysis (FMEA)

Principles: definitions of FMEA (failure mode, failure effect, causes of failure); application, e.g. concept, design, product, machine, process, system; teamwork; standard FMEA reports; benefits and limitations of FMEA

Techniques: identify the element of design/process under consideration; identify the FMEA team; collect functional data; define failure modes; causes of failure; effects of failure; probability of failure; using either historical data, Delphi type technique, accident data or expert estimation; determine the severity, effect, frequency/occurrence and detection ratings; calculate the risk priority number (RPN); list current controls; analyse resultant data; determine actions required to reduce severity, detection and occurrence; use RPN to prioritise; assign responsibilities and completion dates for actions; monitor actions; re-evaluate new rankings and calculate new RPN

3 Understand and apply basic statistical techniques and statistical process control procedures

Basic statistics: types of data from product or process, e.g. variable/continuous, concerned with precision measurements, other critical characteristics (such as length, weight, resistance), attribute/discrete, based on characteristics that can be counted (such as accept, reject), characteristics that cannot be measured using any other method; considerations of both types of data; types of inspection equipment, e.g. relative cost, skill levels required, inspection time, sample size; variation, e.g. between components, within components, machine to machine, batch to batch, time to time; causes of variation, e.g. common/un-assignable, special/assignable; characteristics, e.g. population, sample, sample size, frequency, mean, mode, median, range, variance, standard deviation; non-normal distribution curves, e.g. skewed, bimodal, flat topped, anomalies, inspection effect and missing tails; characteristics of a normal distribution (interpreting the change in shape, spread and position of the distribution over time)

Graphical analysis: e.g. bar charts, histograms, stem and leaf diagrams, Pareto diagrams, box plots, run charts, time series charts

Statistical process control procedure: pre-process control procedure (product/process selection, identify critical characteristics, determine type of data, define the measurement system, design check sheet/chart, data collection plan, test procedure, remove special causes of variation, ensure process is capable); design of control procedure, e.g. variable control charts (such as X and R charts), attribute charts (such as np, p, c and u); calculating sample size and frequency; calculating upper and lower control limits; use of control procedure, e.g. plot data, monitor charts, interpreting charts and identification of out of control conditions; outcomes from use, e.g. modify process conditions when necessary, audit process

4 Be able to carry out a process capability study

Process capability study procedure: specification limits and control chart limits; relative precision index, e.g. high, medium, low; consequence of index; equations, e.g. Cp, Cpk, sigma score (Z); precision and accuracy; modified control chart limits; process capability study, e.g. graphical process capability sheet, determine process capability and parts per million outside upper and lower specification limits; analyse information; define improvement activities to improve the process capability; present findings in a process capability report

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles of value management	**M1** develop a detailed proposal for a value management activity	**D1** evaluate the significance of special and common causes of variation
P2 produce a total cost model and supply chain map for a product or process	**M2** analyse the benefits and limitations of potential failure modes and effects	**D2** evaluate the purpose of modified control chart limits.
P3 use value analysis tools to undertake a value management activity on a product or process	**M3** analyse the benefits and limitations of variable/continuous and attribute discrete types of data that can be used in sampling for process control.	
P4 describe the principles of potential failure modes and effects analysis		
P5 use techniques to carry out a potential failure modes and effects analysis for a product or process		
P6 apply basic statistics on a product or process and apply graphical analysis on the data		
P7 carry out a statistical process control procedure		
P8 perform a process capability study procedure for a given process.		

Essential guidance for tutors

Assessment

Assessment evidence can be collected from learners' involvement in continuous improvement activities in their workplace, case studies, assignments and projects. This should enable learners to demonstrate knowledge and understanding of the principles of quality and business improvement in a manufacturing environment.

To achieve a pass grade learners must meet all the pass criteria. For P1, they will need to describe the principles of value management. This could be achieved via a presentation to the group, or as an annotated poster. In these cases it must be remembered that the presentation skills or poster design skills respectively are not being assessed. A written task would also be a method to give learners the opportunity to meet the requirements of P1.

P2 requires learners to produce a total cost model and supply chain map for a product or process. Evidence for this criterion could be provided from the learners' involvement in continuous improvement activities in the workplace or by a work placement. If assessed directly by the tutor, suitable evidence from these activities would be standard documentation and completed observation records. If assessed during a placement, witness statements should be provided by a suitable representative and verified by the tutor. Guidance on the use of observation records and witness statements is provided on the Pearson website. Because some learners may not have real access to this form of activity, simulation could be used to generate evidence for this criterion.

P3 expands on P2 by asking learners to use value analysis tools to undertake a value management activity on a product/process. Ideally, this can be further expanded and linked to M1, where learners can develop a detailed proposal.

P4 requires learners to describe the principles of potential failure modes and effects analysis (FMEA). This could take the form of a short report or a brief presentation and could lead into a practical assignment to cover P5.

For P5, learners could undertake a real or simulated potential failure modes and effects analysis. Ideally this would be planned as a group exercise on a given product or process. Each group could define potential failure modes, causes of failure, effects of failure and probability of failure. The severity, effect, frequency/occurrence and detection ratings can then be selected and the risk priority number (RPN) can be calculated.

P5 could then be linked to M2 by asking learners to discuss the benefits and criticisms of the FMEA technique. This could be achieved by asking learners to contribute in a group discussion held at the end of the analysis task, where they are asked to evaluate and record their experience of the technique. Care should be taken when using group work to ensure all learners have opportunities to meet the criterion.

P6 requires learners to apply basic statistics on a product or process and apply graphical analysis on the data. Learners have to carry out a statistical process control procedure for P7. Learners are then required to perform a process capability study procedure on a given process for P8. Ideally P6, P7 and P8 could be linked with a common problem, product or process. Evidence for these criteria could be provided from the learners' involvement in continuous improvement activities in the workplace or by a work placement. If this is not possible, the activities could be individual or linked simulated exercises.

To achieve a merit grade, learners must achieve all of the pass grade criteria and the three merit criteria. For M1, learners should be able to develop a detailed proposal from a value management activity. M2 requires learners to analyse the benefits and criticisms of FMEA. M3 requires learners to analyse the benefits and limitations of both variable and attribute types of data, in terms of the sample size, type of inspection equipment, techniques and skills required.

The distinction criteria (D1 and D2) could be linked to the tasks or activities carried out for criteria P6, P7, P8 and M3. For D1, learners are required to evaluate the significance of special and common causes of variation. This could be achieved by the identification of special causes of variation found in the task associated with P6 and a brief explanation on the root causes of such variation. The evidence could be obtained via a written assessment or take the form of a pictorial presentation with notes (possibly using PowerPoint or OHPs) and an annotated poster. D2 may be linked to P8 if the process is a high relative precision index. Evidence of this can be obtained via a short written explanation.

All evidence must be generated in a form suitable for inclusion in the learners' portfolios. This could include standard forms (eg FMEA forms, data gathering forms, analysis charts, SPC charts, process capability charts etc), images (eg photographs, scanned images, completed charts, diagrams, plans and engineering drawings), presentation slides, written reports, witness statements and solutions to class-set problems.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Principles of Value Management	Learners have been asked to produce an information poster/ leaflet for new apprentices.	A written task requiring learners to describe value management principles.
P2, P3, M1	Applying Value Management Techniques	Learners have been asked to produce a total cost model and supply chain map and carry out a value management activity for a product or process in the workplace.	A practical assignment evidenced through witness/ observation records and learners' process logbooks.
P4, P5, M2	Failure Modes and Effects Analysis	Learners have been asked to write a short report on potential FMEA and then carry out an FMEA analysis.	A short written task and a practical analysis exercise on a given product or process. A further written evaluation of the benefits and limitations.
P6, P7, P8, M3, D1, D2	Carrying out Statistical Process Control and a Process Capability Study	Learners need to apply basic statistics on a product or process, carry out an SPC procedure and perform a process capability study.	A practical assignment evidenced through witness/ observation records and learners' process logbooks. Further written tasks for D1 and D2.

Essential resources

To deliver this unit centres will need to have an up-to-date reference library with computer aided learning resources and appropriate journals.

Indicative reading for learners

Textbooks

Bicheno J and Holweg M – *The Lean Toolbox*, 5th edition (Picsie Press, 2016) ISBN 9780956830753

Dale B – *Managing Quality*, 6th edition (John Wiley and Sons, 2016) ISBN 9781119130925

Liker J – *The Toyota Way: Fourteen Management Principles from the World's Greatest Manufacturer* (McGraw-Hill Education, 2004) ISBN 9780071392310

Morgan J – *Lean Six Sigma for Dummies*, 3rd edition (John Wiley and Sons, 2015) ISBN 9781119067351

Slack N – *Operations Management*, 8th edition (Pearson, 2016) ISBN 9781292098678

Wilson L – *How to Implement Lean Manufacturing*, 2nd edition (McGraw Hill, 2015) ISBN 9780071835732

Journal

International Journal of Operations and Production Management

Magazines

Engineering Technology

Manufacturing Engineer

Unit 70: Applications of Thermodynamic Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

We are reliant on fossil and nuclear fuels for most of our energy needs and this is likely to be the case for many years to come. It is also likely that resources will become more scarce and that we shall have to use them more efficiently. In addition, it is becoming apparent that the use of fossil fuels is contributing to global warming, giving further cause for increased fuel efficiency.

Fossil and nuclear fuels provide thermal energy which is, in turn, converted into useful mechanical and electrical energy. Thermodynamics is the study of thermal energy production, its transfer and conversion into more useful forms.

The basic laws concerned with the expansion and compression of gases and associated thermal energy transfer and work done will be introduced. These will then be applied to quantify the thermal energy transfer and work done that occurs in closed and open thermodynamic systems.

The combustion of fuels will be examined and methods of determining calorific value explained. Learners will be introduced to the properties of steam as a working substance and to the use of thermodynamic property tables. These will then be used to determine thermal energy transfer and work done in steam-generating plant.

Learning outcomes

On completion of this unit a learner should:

1 Be able to apply thermodynamic principles to the expansion and compression of gases

2 Be able to quantify energy transfer in thermodynamic systems

3 Be able to determine combustion process requirements and the calorific value of fuels

4 Be able to quantify energy transfer in steam plant.

Unit content

1 Be able to apply thermodynamic principles to the expansion and compression of gases

Polytropic processes: process parameters, e.g. absolute pressure, absolute temperature, volume, universal gas constant, molecular weight, characteristic gas constant; general gas equation ($pV/T = Constant$); characteristic gas equation ($pV = nRT$); polytropic process equation ($pV^n = Constant$), value of 'n' for isobaric processes ($n = 0$), isothermal processes ($n = 1$), adiabatic processes ($n = g$)

2 Be able to quantify energy transfer in thermodynamic systems

Closed thermodynamic systems: application of first law of thermodynamics; work done, e.g. general expression for a polytropic process, isothermal work transfer; thermal energy transfer, e.g. specific heat capacities at constant volume and constant pressure, expression for change of internal energy, closed system energy equation, relationship between system constants c_v, c_p, γ and R; systems, e.g. internal combustion engine cylinders, positive displacement compressors

Open thermodynamic systems: application of first law of thermodynamics; work done, e.g. general expression for a polytropic process, isothermal work transfer; thermal energy transfer, e.g. expression for change of enthalpy, open system energy equation; systems, e.g. gas turbines, rotary compressors, coolers

3 Be able to determine combustion process requirements and the calorific value of fuels

Combustion process: stoichiometric equations for complete combustion of fuel elements, e.g. hydrogen ($2H_2 + O_2 = 2H_2O$), carbon ($C + O_2 = CO_2$), sulphur ($S + O_2 = SO_2$), theoretical air requirements, products of combustion

Calorific value: determination of calorific value, e.g. bomb calorimeter to determine gross calorific value of solid fuels and fuel oil, Boys' gas type calorimeter to determine gross and net calorific value of gaseous fuels

4 Be able to quantify energy transfer in steam plant

Steam plant: thermal energy transfer and work done in major steam plant elements, e.g. boiler, superheater, turbine, condenser, thermal efficiency of elements; conditions, e.g. feed water temperature, steam temperatures and pressures, dryness fraction, steam flow rate, fuel consumption rate, power output; use of thermodynamic property tables to determine enthalpy values, e.g. feed water, saturated water, wet steam, dry saturated steam, superheated steam

Throttling process: use of simple throttling calorimeter to determine dryness fraction of wet steam

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 calculate the mass of a gas and its final condition parameters after undergoing a given polytropic process	**M1** determine the polytropic process index '*n*' from the initial and final condition parameters of a gas	**D1** evaluate the work done and thermal energy transfer that occurs when a fixed mass of gas undergoes a given increase in volume according to Boyle's law and according to Charles' law from the same initial conditions
P2 determine the work done and thermal energy transfer during thermodynamic processes in a closed system	**M2** determine the specific heat capacities at constant volume c_v, and constant pressure c_p, for a gas from given values of the adiabatic index γ, the universal gas constant and its molecular weight	**D2** prepare a complete analysis by mass of the products of combustion when unit mass of a given fuel is completely burned with an excess air supply.
P3 determine the rate of work done and thermal energy transfer during thermodynamic processes in an open system	**M3** determine the gross and net calorific values of a gaseous fuel from given test data obtained using a Boys' gas type calorimeter	
P4 use stoichiometric equations to determine the theoretical mass of air required for complete combustion of a given mass of fuel	**M4** determine the efficiency of a boiler from given feed water and output steam conditions and the fuel consumption rate.	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 determine the gross calorific value of a solid or liquid fuel from given test data obtained using a bomb type calorimeter		
P6 determine the rates of thermal energy transfer in a boiler and superheater from given feed water and output steam conditions and steam flow rate		
P7 determine the thermal efficiency of a steam turbine from given input and output steam conditions, steam flow rate and power output		
P8 determine the dryness fraction of a steam sample from test data obtained using a simple throttling calorimeter.		

Essential guidance for tutors

Assessment

Opportunity to achieve criteria P1 and M1 could be provided through a short, timed test or individual assignment. If the latter method is chosen, steps should be taken to ensure that the criteria are achieved autonomously and independently. A task to achieve P1 should require use of the characteristic gas equation, the polytropic process equation and the general gas equation to determine the mass of a given quantity of gas and its final condition parameters after undergoing an expansion or compression process.

A second task to achieve the M1 criterion would require determination of the process index '*n*', from the initial and final condition parameters of a gas and manipulation of the polytropic process equation.

A second timed assessment or assignment could contain tasks to enable P2, P3, M2 and D1 to be achieved. It will be appropriate for the tasks to achieve P2 and P3 to require calculation of final condition parameters prior to the determination of work and heat transfer. The task to achieve M2 will require calculation of the characteristic gas constant prior to manipulation of the relationship formulae to determine the specific heat capacities c_v and c_p. The final task to achieve D1 should lead learners to conclude that the additional heat supplied during isobaric expansion enables the pressure to be maintained and more external work to be done.

The criteria P4, P5, M3 and D2 relate to learning outcome 3. These could be assessed by means of a third timed assignment in which a task to achieve P4 would require calculation of the theoretical amount of air needed for complete combustion of a given mass of fuel. A mass analysis of the fuel will need to be provided and ideally this should contain the range of combustible constituents.

The distinction criterion D2 will require the preparation of a full analysis of the products of combustion when a mass of fuel is completely burned with a given percentage of excess air. In addition to the range of combustible elements, the given mass analysis of the fuel might contain an oxygen content and a quantity of incombustible material. Ideally, the data required to determine calorific value for achievement of P5 and M3 should be obtained from experimental investigations. Where this is not possible, exemplary data will need to be obtained and provided. In the case of the bomb type calorimeter this should include mass of fuel, mass of water heated, water equivalent of the calorimeter and temperature versus time data. In the case of the Boys' gas type calorimeter this should include gas supply pressure and temperature, prevailing atmospheric pressure, volume of gas metered, water inlet and exit temperatures, mass of water collected and mass of condensate collected.

A final timed assignment to achieve criteria P6, P7, P8 and M4 could enable learners to demonstrate an understanding of steam generation, steam plant elements and the use of thermodynamic property tables. Although separate tasks might be set to cover the criteria they might relate to data provided in a single steam plant scenario. Exemplary test data for the throttling calorimeter should include wet steam supply pressure and the temperature and pressure immediately after throttling.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and M1	Using the Characteristic Gas Equation	An assignment in which learners use relevant equations to demonstrate knowledge of the polytropic process.	Timed test or individual case study requiring learners to use characteristic gas equation, polytropic process equation and the general gas equation; and a second task requiring learners determine the process index '*n*'.
P2, P3, M2 and D1	Energy Transfer in Thermodynamic Systems	An assignment in which learners determine energy transfer.	Timed test or individual case study requiring learners to calculate condition parameters and work and heat transfer.
P4, P5 M3 and D2	Combustion Processes and Calorific Value of Fuels	An assignment in which learners demonstrate knowledge of combustion processes and the calorific value of fuels.	Timed test in which learners calculate the theoretical amount of air needed for the combustion of a given amount of fuel.
P6, P7, P8 and M4	Energy Transfer in Steam Plant	An assignment requiring learners to demonstrate their knowledge of steam plant.	Written tasks based on data relating to a given steam plant scenario.

Essential resources

Ideally centres should be equipped with a bomb type calorimeter and a Boys' gas type calorimeter to determine the calorific value of fuels. Failing this, exemplary simulation material and test data will need to be provided. Clement and Desormes' apparatus for determination of the adiabatic index *g* might also be of value in the delivery of learning outcome 1. Learners will need to be provided with, or be encouraged to purchase, a set of thermodynamic property tables.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Option Units* (Newnes, 2003) ISBN 9780750657617

Joel R – *Basic Engineering Thermodynamics* (Prentice Hall, 1996) ISBN 9780582256293

Moran M, Shapiro H – *Fundamentals of Engineering Thermodynamics* (John Wiley and Sons, 2006) ISBN 0470030372

Sonntag R and Bourgnakke C – *Introduction to Engineering Thermodynamics* (John Wiley and Sons, 2006) ISBN 9780471737599

Venkanna B, Swati B – *Basic Thermodynamics* (Prentice Hall, 2011) ISBN 9788120341128

Unit 71: Principles and Applications of Analogue Electronics

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will provide learners with an understanding of analogue electronics and the skills needed to design, test and build analogue circuits.

Although digital circuits have become predominant in electronics, most of the fundamental components in a digital system, particularly the transistor, are based on analogue devices. Advances in technology mean that, as transistors get smaller, it becomes more important when designing digital circuits to account for effects usually present in analogue circuits. This unit will give learners an understanding of the key principles and function of analogue electronics.

Analogue electronics are still widely used in radio and audio equipment and in many applications where signals are derived from analogue sensors and transducers prior to conversion to digital signals for subsequent storage and processing.

This unit will introduce learners to the basic analogue principles used in electronics, such as gain, loss and noise and the principles of a range of classes of amplifier. The unit will also cover the operation of analogue electronic circuit systems and their components, such as integrated circuits (ICs) and the sensors required in analogue (and some digital) circuits.

Learners will be able to apply their understanding of principles and operation in the design and testing of analogue electronic circuits for specified functions using electronic computer-based methods.

Finally, learners will build and test circuits such as a filter, amplifier, oscillator, transmitter/receiver, power control, or circuits/systems with telecommunication applications. This will include the use of circuit assembly and testing methods, such as circuit diagrams, interpreting/recording measurements, analysis of performance and the use of a range of test equipment.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of gain and loss and the function of amplifiers in analogue circuits

2 Understand the operation of analogue electronic circuit systems and their components

3 Be able to use computer-based techniques to design and test analogue electronic circuits for specified functions

4 Be able to build and test an analogue electronic circuit.

Unit content

1 Understand the principles of gain and loss and the function of amplifiers in analogue circuits

Gain and loss: definition and use of the decibel (dB), benefits of using the logarithmic unit for voltage/ power gain; decibel reference to one milliwatt (dBm)

Noise: types of noise, e.g. thermal, cross-talk, shot; effects of noise on typical circuits/components; signal-to-noise ratio

Transistor amplifier: classes of amplifier such as A, B, AB and C; feedback and its effects on gain, bandwidth, input and output impedance, noise and distortion

2 Understand the operation of analogue electronic circuit systems and their components

Analogue integrated circuit (IC): use of and interpretation of manufacturers' data; IC operation, e.g. gain, frequency, power consumption; typical IC systems, e.g. 555 oscillators/timers, amplifiers (operational, power, instrumentation), voltage regulators (linear or switch mode), filters (switched capacitor), phase locked loop (PLL), power control (smart devices, MOSFET bridge driver), sensors (thermal, opto, magnetic), analogue switches

3 Be able to use computer-based techniques to design and test analogue electronic circuits for specified functions

Propose design solutions: use of integrated circuits; use of simulation program with integrated circuit emphasis (SPICE)/electronic computer aided design (ECAD) techniques to analyse and develop circuits

Circuits and systems: e.g. filters (anti-aliasing, mains, notch), amplifiers (specified gain/frequency response, power), oscillators (voltage controlled oscillator (VCO) for frequency shift keying (FSK) or frequency modulation (FM)), PLL for FSK or FM demodulator, opto-transmitter/receiver (fibre link, remote control), power supplies (DC/AC converter, non-interruptible), sensors (environmental), power control (stepper motor driver), circuits and systems with telecommunication applications

Circuit simulation and testing: functional testing using a supplied test specification to determine circuit design inputs and outputs, e.g. test-point voltages, output signals

4 Be able to build and test an analogue electronic circuit

Circuit assembly: use of prototyping methods, e.g. breadboard, stripboard, printed circuit board (PCB); typical circuits, e.g. filter, amplifier, oscillator, transmitter/receiver, power control, circuits/systems with telecommunication applications

Circuit testing: use circuit diagrams; interpret/record measurements, e.g. voltage, frequency, noise, gain; analysis of performance; use of test equipment, e.g. oscilloscope, signal generator, digital multimeters, frequency meter/spectrum analyser, virtual (computer-based) instruments, data capture

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the decibel as a measure of gain and noise	**M1** compare the practical performance of two different classes of amplifier	**D1** analyse the results of a designed electronic circuit with reference to measured signals in terms of both voltage and frequency
P2 describe two different classes of amplifier	**M2** justify the selection of specific analogue integrated circuit devices to meet a given design specification	**D2** evaluate computer-based and practical methods used to analyse the behaviour of analogue circuits with respect to their effectiveness in the design process.
P3 explain four different effects of feedback on the function of an amplifier	**M3** evaluate the performance of an analogue circuit by interpreting measured results.	
P4 explain the operation of three common analogue integrated circuit devices		
P5 describe two system applications for each of three common analogue integrated circuit devices		
P6 use computer-based simulation methods to produce a possible design solution for three different analogue circuit systems		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 use computer-based simulation methods to simulate and test the performance of a given analogue electronic circuit		
P8 build and test an electronic circuit to a given analogue circuit specification.		

Essential guidance for tutors

Assessment

This unit could be assessed through a carefully structured series of activities and assignments that link to each other and culminate in the building and testing of an electronic circuit to a given analogue circuit specification.

P1 could be assessed with a short assignment to determine the voltage gain of a transistor amplifier, expressing this first as a ratio and then converting the voltage gain (or loss) into decibels (dB). Learners could also measure the output noise power (in the absence of a signal) and use this to determine the signal to noise ratio for a given input signal voltage.

The assignment should ensure that it includes tasks to cover all the required aspects of content – definition and use of the decibel (dB), benefits of using the logarithmic unit for voltage/power gain and decibel reference to one milliwatt (dBm). The assignment must also provide an opportunity to consider the required aspects of noise – types of noise, effects of noise on typical circuits/components, signal-to-noise ratio. Setting this within the context of the amplifier investigated by each learner will provide scope for authentic evidence based on individual practical work. Ensuring that each learner is working with a slightly different amplifier could further reinforce this.

Assessment of P2 could build on the learner's work with transistor amplifiers by considering and describing two different classes of amplifier (e.g. class A and class B). The amplifiers described for P2 could then be used for P3, although the choice of amplifiers must ensure that between them, the learner is able to explain at least four different effects of feedback on the function of an amplifier (e.g. its effect on gain/bandwidth/input and output impedance/noise and distortion). This assignment could be designed to also provide learners with an opportunity to work towards M1 by comparing the practical performance of the two different classes of amplifier. An alternative to using two separate amplifiers (one of each class) is that of simply switching the bias of the output stage for operation in either class A or class B mode.

The third assignment, to cover P4 and P5, could require learners to explain the operation of three common analogue integrated circuit (IC) devices. One or more of these could then be used in their final circuit for P8. The explanation will need to address the learner's use and interpretation of manufacturers' data and the operation of each IC for typical IC systems. In addition, learners are required to describe two system applications of each IC. Again, one of these could be the focus of the build and test project for P8. A further task could be added to cover M2, requiring learners to justify the selection of specific IC devices to meet a given design specification. Note the use of 'devices' in the criterion. This implies that the system has more than one IC device operational.

Assessment of P6 and P7 could be through a fourth assignment requiring learners to use SPICE/ECAD to produce circuit designs, with annotated printouts of three different circuits, e.g. filters, amplifiers, oscillators. A more extensive range of examples is given within the unit content section for this criterion. Learners could then simulate and test the performance of one of these in detail (e.g. for DC levels/gain/frequency/bandwidth), which would give an opportunity to achieve P7. In addition, evidence of learners' ability to evaluate the performance of one of these analogue circuits by interpreting measured results, could lead to achievement of M3. If learners are also able to analyse the results of a designed electronic circuit with reference to measured signal in terms of both voltage and frequency then they could achieve D1. Note that another opportunity exists to achieve M3 and D1 during the build and test work for P8. However, M3 or D1 only needs to be achieved once and it is not important whether this is through simulated or real circuit evaluation and analysis.

Finally, P8 should bring together all of the learner's experience within one practical build and test of an actual circuit. This could be built using breadboard, stripboard or printed circuit board (PCB) techniques. The circuit could be one of the simulated circuits used for P6 or P7. Learners could reflect on the techniques carried out for P6, P7 and P8 and work towards achievement of D2. For example, the evaluation of the SPICE/ECAD approach (P6/P7) compared with the practical methods (P8) used to analyse the behaviour of an analogue circuit with respect to their effectiveness in the design process.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Principles of Gain and Loss	A technician has been asked to determine the voltage gain of a transistor amplifier.	A practical investigation evidenced through a written report.
P2, P3, M1	Amplifier Types and Functions	A technician needs to compare different types of amplifier to determine the best for an application in the workplace.	A practical investigation evidenced through a written report.
P4, P5, M2	Analogue Integrated Circuits	A technician needs to explain the operation of circuit devices to a new apprentice.	A written description of circuit devices including justification of choice of amplifiers for specific applications.
P6, P7, M3, D1	Design and Simulation of Analogue Circuits	A technician has been asked to design analogue electronic circuits for three different applications.	A practical activity evidenced through annotated printouts, observation records and a written report interpreting measured results.
P8, D2	Building and Testing Analogue Circuits	A technician needs to build and test an analogue electronic circuit.	A practical design and build activity evidenced through observation records and a written report.

Essential resources

Centres will need to provide access to an electronics workshop including facilities for circuit construction using breadboards/stripboard/PCB methods together with the relevant tools and equipment.

Centres will also need to provide the basic components and appropriate specialised integrated circuits together with relevant catalogues, application notes and data sheets. Access to SPICE/ECAD facilities that permit circuit simulation and testing is essential. Electronic test equipment will also need to be provided to meet the requirements of the unit content and assessment and grading criteria.

Indicative reading for learners

Textbooks

Storey N – *Electronics: A Systems Approach* (Prentice Hall, 2009) ISBN 9780273719182

Tooley M – *Electronics Circuits: Fundamentals and Applications*, 4th edition (Newnes, 2015) ISBN 9781138828926

Unit 72: Construction and Applications of Digital Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of modern digital systems and technology and the skills needed to build and test a range of digital electronic circuits.

Digital electronics play an integral part in modern society. Their wide application, from washing machines and car management systems to street furniture devices (e.g. turning street lighting on and off), means that there is an increased need for safe, low maintenance, energy-efficient systems. These new systems also frequently use alternative energy sources and have their eventual disposal (e-waste) taken into account from their conception.

This unit will give learners an understanding of recent advances in digital electronics and the new technologies that often replace older electrical and electronic systems (legacy systems). Learners will also develop an understanding of how the components of an electronic system are connected together (interfaced) to enable analogue signals to be transmitted digitally. For example, interface circuit devices such as optocouplers can transfer an electrical signal from one circuit to another while electrically isolating the two.

Learners will also have the opportunity to build and test different digital systems, enabling them to understand circuit life cycles, circuit costs and build and test methods.

Learning outcomes

On completion of this unit a learner should:

1 Understand energy efficient use of modern digital electronics technology

2 Understand the transmission of analogue data in a digital system

3 Understand the selection and use of interface devices and logic devices for digital circuits

4 Be able to build and test digital systems.

Unit content

1 Understand energy efficient use of modern digital electronics technology

Small energy sources: source types, e.g. solar (photovoltaic), batteries (lead-acid, nickel-cadmium (NiCad), nickel-iron (NiFe)), alternative sources (small-scale wind/water turbines); maintenance, handling and care, e.g. recharging, testing, replacement techniques, disposal

Extended system life: legacy systems and modern applications, e.g. historical technologies, impact of required energy levels, load evaluation and usage, alternative systems, consideration of e-waste, use of 'fuzzy logic' techniques; applications, e.g. street furniture, charge regulators, thermostats, load diverting controllers, calculators; lifetime costs, efficiencies, reliability, maintenance

2 Understand the transmission of analogue data in a digital system

Data transmission: digital-to-analogue converters (DACs), e.g. digital-ramp, summing amplifier, current switches, R-2R ladder; analogue-to-digital converters (ADCs), e.g. counter, successive approximation, flash; integrated circuits, e.g. slope, dual slope; code converters and function generators (look-up tables); optoelectronic display devices, e.g. 7-segment, 14-segment (starburst), dot-matrix, liquid crystal display (LCD), light-emitting diode (LED), organic light-emitting diode (OLED), plasma, vacuum fluorescent display (VFD)

Tri-state devices: tri-state buffers and line drivers; control of data access to bus or transmission channel; random bus arbitration access; ordered time division multiplexed access

3 Understand the selection and use of interface devices and logic devices for digital circuits

Standard data interface: industry standards, e.g. general applications (International Standards Organisation (ISO), American National Standards Institute (ANSI), British Standards Institute (BSI)), telecommunication applications (Telecommunications Industry Association (TIA), International Telecommunication Union (ITU), European Telecommunications Standards Institute (ETSI), Office of Communications (Ofcom)), electronic applications (Joint Electronic Device Engineering Council (JEDEC)); standard interfaces, e.g. RS232, RS422, RS562, V24, V28, V10, V11; electrical current sourcing and heat sinking requirements; voltage level adjusting; optocouplers/optoisolator; tri-state/bi-directional line driver device in a multiplexed data bus transmission system

Logic devices families: characteristics, e.g. power consumption and interfacing (emitter-coupled logic (ECL), transistor-transistor logic (TTL), low-power Schottky transistor-transistor logic (LSTTL), complementary metal-oxide semiconductor (CMOS), high-speed CMOS (HCMOS)); levels of integration and benefits, e.g. small/medium/large/very large/ultra large scale integration (SSI/MSI/LSI/VLSI/ULSI), system-on-chip (SOC)

4 Be able to build and test digital systems

Circuits and systems: combinational circuit, e.g. logic encoder, decoder, multiplexer, demultiplexer, code converter, function generator; asynchronous/synchronous circuit, e.g. counter, frequency divider, ring counter, clock waveform generator, register, shift register, converters (serial-to-parallel, parallel-to-serial); systems, e.g. security (access control, intruder alarms, fire, nurse call), safety (weight levels, proximity, sensor technologies), monitoring (level indicators, flow rates, temperature), embedded (dedicated computers, RAM/Flash memory)

Circuit testing: aids, e.g. data sheets, test instruments, specialised tools; built-in self-tests, in-circuit emulators; glitches, e.g. electronic pulse of short duration cross-talk, amplitude noise margins; race conditions, e.g. input condition conflicts, floating inputs; hazards (static, timing); test patterns; precautions when testing components, datalines and systems

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how two different types of small energy sources are used to support two different digital electronic systems	**M1** discuss the benefits of combining a small energy source with modern digital technologies	**D1** evaluate a digital system to consider how a modern energy source and/or energy reducing components might improve the system's future life cycle
P2 explain how modern technologies can be used to extend the life of an existing electronic system	**M2** compare the operation of two different types of data transmission device	**D2** evaluate and suggest improvements to the circuit operation of a digital system with respect to the method of data acquisition and human interface employed.
P3 describe how analogue data is transmitted by a digital electronic circuit	**M3** compare the operation of a combinational logic device and a sequential logic device.	
P4 explain the role and operation of a tri-state device in analogue data transmission		
P5 explain the selection and use of two different types of standard data interfaces within working systems		
P6 identify a logic device family, its current levels of integration and the benefits of using it		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 build two different digital electronic circuits to be used in different digital systems		
P8 carry out circuit testing of the two constructed circuits to check system performance against specification.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

To achieve P1, learners need to consider two different given or chosen digital electronic systems, each with a different small energy source. Learners are expected to explain the type of energy source being used and the requirements of that system in terms of the source's maintenance, handling and care. When describing the type of small energy source being used learners should also consider the environment in which it operates and the expected energy levels required by the system to maintain effective operation.

For P2 learners must consider similar aspects to those required for P1 but from the perspective of a legacy system. Once again, the system can be chosen by the learner or be given by the tutor. Learners need to explain how current technologies might be used to enhance the efficiency of operation and maintenance of the existing system. This may draw from some or most of the examples given in the unit content such as historical technologies, impact of required energy levels, load evaluation and usage etc. Typical applications that may be considered are listed in the unit content although others may equally apply. The learner's explanation must cover aspects of lifetime costs, efficiencies, reliability and maintenance.

The work carried out for P1 and P2 will naturally prepare learners for achievement of M1, when they are required to explain the benefits of combining a small energy source together with modern digital technologies.

To achieve P3 and P4, learners need to consider the transmission aspects of data that many systems require in order to effectively process data. P3 requires learners to demonstrate their knowledge and understanding of how analogue and digital signals can be transposed. P4 requires them to show how the data transmitted around the system is controlled. Learners should consider at least one large complete circuit or a series of smaller ones. The written explanations/descriptions should use correct circuit/logic symbols that are based on an appropriate standard. Appropriate standards should be used at all times and learners should provide a key/suitable reference to indicate the standard to which they are working.

The work carried out for P3 and P4 can be extended to M2, when learners compare the operation of two different types of data transmission device.

P5 requires learners to explain the selection and use of two different types of standard data interfaces within working systems. They will need to look at two different and currently operational devices/systems and describe why they are the most appropriate for that situation.

P6 requires learners to identify a logic device family, the available levels of integration and the benefits of that family. This could be achieved by learners taking a digital image of a device/system and making a leaflet to identify the characteristics of the device family and relevant levels of integration that can be achieved.

P7 and P8 should be linked so that learners test the two circuits they have built. P7 requires learners to build two different digital electronic circuits that are to be used within different digital systems. It is expected that one of these would be a combinational circuit, e.g. logic encoder, decoder, multiplexer, de-multiplexer etc. The other digital electronic circuits should be either an asynchronous or synchronous circuit, e.g. counter, frequency divider, ring counter etc. These circuits may be given by the tutor or selected by the learner, with tutor guidance to ensure coverage of unit content. Typically, these circuits will be part of a digital electronic system such as a security system, a safety system, a monitoring system or an embedded system. It is not expected that the constructed circuit be used within the system but learners need to show they understand how it could be integrated within the working system.

The focus of this unit is not on circuit building or testing and it is assumed that learners have gained sufficient knowledge of these elsewhere. Assessment of P7 should therefore concentrate on learners' use of modern digital electronics, their understanding of analogue data transmission and the selection and use of interface devices and logic devices.

P8 requires learners to carry out circuit testing of the two constructed circuits to check system performance against specification. Between the two tests there should be sufficient evidence to meet all the requirements of the unit content. This must include a range of aids to testing, built-in self-tests, in-circuit emulators and identification of circuit glitches, race conditions, hazards, test patterns and precautions.

The need to fully meet the unit content requirements will inevitably influence the choice of suitable circuits for P7 and P8. Where centres wish to allow learner choice/employer involvement, it will be important to maintain sufficient tutor guidance on the circuits chosen to ensure full unit content coverage.

Assessment evidence for P7 and P8 is likely to be in the form of learner notes and records of circuit construction and testing plus tutor observation records of the build and test procedures. Annotated photographic records could also be used.

Achievement of M3 will build on the knowledge and understanding gained from P7 and P8. The two circuits to be compared could be the same as those built and tested for P7 and P8, although this is not essential. Centres may decide that learners would gain a wider understanding by comparing two different circuits provided by the tutor. The comparison should be based on the unit content as a whole, e.g. energy source used, consideration of extended system life, data transmission methods, data interfacing, application of a specific logic family, method of circuit/system construction and how circuits have been/could be tested.

For D1 and D2, learners will need to demonstrate a deeper understanding of working systems and the application of current and future technologies. For D1, learners should focus on small energy sources and energy-reducing aspects of a system. There is a natural link between this criterion and the work undertaken for P1, P2, M1 and M2. Learners should consider and review an existing digital system to establish how the system works and how energy reducing components could potentially improve the future life cycle of the system.

D2 is intended to allow learners to work in a way that may meet their own interests or local needs with either employer or centre guidance. Learners should be directed to consider the various aspects of circuit operation related to input and output for a system, including a good range of circuit level considerations.

Centres that do not wish to leave the delivery and assessment of the distinction criteria to the later part of the unit may wish to guide learners towards a suitable system at an early stage and build upon it as the unit progresses.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1, D2	Efficient Use of Digital Electronics	Learners have been asked to investigate small energy sources and how current technologies might be used to enhance the efficiency of operation and maintenance of an electronic system.	A written report.
P3, P4, M2	Transmission of Analogue Data in a Digital System	Learners need to explain data transmission in electronic systems to a new apprentice.	A written report.
P5	Interface Devices	Learners have been asked to compare the selection and use of different types of data device for specific situations.	A written report.
P6	Logic Devices	Learners have been asked to produce an information leaflet detailing the levels of integration and the benefits of a logic device family.	A written report and/or information leaflet/poster.
P7, P8, M3	Building and Testing Digital Systems	Learners must build and test a variety of digital electronic circuits for a new customer.	A written report/portfolio based on practical activities supported by annotated photos and observation records.

Essential resources

Centres should have sufficient facilities to carry out practical investigations of legacy systems, working devices/ systems and equipment and components for building and testing digital electronic circuits. Relevant software packages should also be available to permit simulation of device and circuit performance.

Indicative reading for learners

Textbooks

Agarwal A and Lang, J – *Foundations of Analogue and Digital Electronic Circuits* (Morgan Kaufmann, 2005) ISBN 9781558607354

Wakerly J – *Digital Design: Principles and Practices* (Prentice Hall, 2006) ISBN 9780131733497

Unit 73: Electronic Fault Finding

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit introduces learners to the principles of electronic fault-finding, including the procedures, techniques and skills required when carrying out fault-finding activities.

An understanding of the operation of electronic circuits is an important issue in the training of technicians and engineers. A complex electronic system is generally a number of individual circuits connected together to perform a specific function. However, to understand the overall circuit it is necessary to break it down into smaller, more easily understood circuits. This is particularly important when testing and fault-finding.

The unit will give learners an understanding of electronic components, circuits and systems and how to solve problems involving simple and complex faults to a professional standard.

Learners will develop their knowledge of the application of electronic components and how electrical signals are employed in a variety of analogue, digital and communications circuits. They will also develop the ability to select fault-finding instruments and apply the techniques used for the diagnosis of faults.

The unit will enable learners to read circuit, schematic and wiring diagrams and carry out fault-finding procedures by obtaining the necessary information, documentation, tools and equipment. They will also learn how to prepare accurate reports of all the steps that have been taken during the fault-finding processes.

The unit will ensure that learners have a firm understanding of safe working practices when carrying out fault-finding activities and that they are able to take the necessary safeguards to protect their own safety and that of others in the workplace.

Learning outcomes

On completion of this unit a learner should:

1 Be able to read and interpret a circuit diagram for an electronic system

2 Be able to plan and implement a fault-finding strategy

3 Be able to diagnose fault conditions using test equipment and record the results.

Unit content

1 Be able to read and interpret a circuit diagram for an electronic system

Circuit diagrams: analogue and digital circuit diagrams drawn to national standards, e.g. British Standards (BS) or American National Standards Institute (ANSI); types of circuit diagrams, e.g. block schematic, circuit, wiring, printed circuit board (PCB) layout diagram that each include a minimum of five components and should show input, output and power supply connections plus any external control connections

Types of analogue circuits: e.g. audio/radio frequency amplifiers, oscillators, multiplexers, demultiplexers, function generators, power supplies

Types of digital circuits: e.g. combinational/sequential logic circuits, flip flops, encoders, decoders, asynchronous/synchronous counters, frequency dividers, ring counters, waveform generators, registers, shift registers, serial-to-parallel and parallel-to-serial code converters

Electronic components: passive components, e.g. resistors, capacitors, inductors, diodes; active devices, e.g. transistor and operational amplifiers – small (SSI), medium (MSI) and large scale integrated (LSI) devices for analogue circuits; logic devices for digital circuits, e.g. logic gates, multivibrators, timers

Input/output signals: circuits working under normal/steady state operating conditions; signal values, e.g. voltage, current, gain, logic levels, alternating sinusoidal and pulse periodic signals at low (LF), medium (MF) and high frequencies (HF), direct current (DC) levels

2 Be able to plan and implement a fault-finding strategy

Fault location strategy: planning, e.g. obtain relevant diagrams (block schematic, circuit wiring diagrams), establish component/circuit tolerances, specifications, restrictions or limitations of operation; predict circuit operation from diagrams, e.g. signal trace through schematic diagrams, produce a test schedule, identify key test nodes/input-output matrix/decision table, function tables; calculate expected signal conditions for analogue and digital circuits, e.g. operational amplifier (determine the expected output voltage level given the input signal voltage and the values of the input and feedback resistors), logic gates (determine the expected logic level of the output given the input level conditions)

Fault location and signal tracing techniques: input-to-output/output-to-input, half-split method, symptom to cause fault hierarchies, unit substitution, visual examination, top-down approach, module and component isolation; use of fault-finding aids, e.g. functional charts, diagrams, trouble-shooting charts, component data sheets, operation and maintenance manuals, software based records and data; fault/repair reporting, e.g. mean time between failure (MTBF) figures; path sensitisation; critical path and fault signal tracing node points

3 Be able to diagnose fault conditions using test equipment and record the results

Test instruments: e.g. ammeter, voltmeter, multimeter, logic probe, cathode ray oscilloscope, signal analyser, frequency counter, digital test set, power meter, software simulation tools

Fault conditions: normal (steady state) equipment operating conditions; component failures, e.g. total, partial; circuit faults, e.g. short circuit and open circuit connections, design and power supply faults; components out of specification; intermittent faults; fault and tolerance testing; digital faults, e.g. input side, output side, logic stuck-at faults

Test data records: e.g. personal logbook, tabulated data, computer based records (tables, spreadsheet, database), referencing of data (indexed, cross-referenced, date), recorded details (description of systems/ circuits, symptoms, operator details, equipment details, test conditions and methods, test results, statistics, comments)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 read a circuit diagram for an electronic system and identify two different types of analogue circuit, the components that make up each circuit and the circuit input and output signals	**M1** compare the circuit diagrams of two different approaches to the same type of circuit	**D1** evaluate a circuit diagram for an electronic system and identify incorrect circuits/ input-output signals
P2 read a circuit diagram for an electronic system and identify two different types of digital circuit, the components that make up each circuit and the circuit input and output signals	**M2** evaluate a fault location strategy and make recommendations for improvement	**D2** examine the fault conditions within an electronic system that presents a fault in more than one circuit.
P3 prepare a written fault location strategy for a given analogue electronic system and identify the fault-finding and signal tracing techniques to be applied	**M3** justify the choice of test instruments selected to identify fault conditions within an electronic system.	
P4 prepare a written fault location strategy for a given digital electronic system and identify the fault-finding and signal tracing techniques to be applied		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 use test instruments to identify fault conditions within an analogue electronic system that has at least one faulty circuit and one component fault		
P6 select and use test instruments to identify fault conditions within a digital electronic system that has at least one faulty circuit and one component fault		
P7 collect and record the test data from an analogue electronic system fault-finding test and prepare a test report		
P8 collect and record the test data from a digital electronic system fault-finding test and prepare a test report.		

Essential guidance for tutors

Assessment

Throughout assessment activities, learners must be made aware of the health and safety hazards applicable to electronic fault-finding operations.

It is likely that a system that has a fault only needs one component to be replaced. However, on some occasions more component failures may be found. Care needs to be taken here not to disadvantage learners if this is the case during their assessment. The criteria can be split into two sets, one for analogue circuits/ systems (P1, P3, P5 and P7) and the other digital (P2, P4, P6 and P8).

P1 and P2 relate to learning outcome 1. To meet P1, learners must be able to read a circuit diagram for an electronic system and identify two different types of analogue circuit within that system, the components that make up each circuit and the circuit input and output signals.

The circuit diagram should have been produced to a national standard, e.g. British Standards (BS) or American National Standards Institute (ANSI). The diagram can be a block schematic, circuit, wiring or printed circuit board (PCB) layout diagram. Each must include a minimum of five components and should show input, output and power supply connections plus any external control connections. The analogue circuits could be audio/radio frequency amplifiers, oscillators, multiplexers, demultiplexers, function generators or power supplies.

P2 requires a similar approach but for two different types of digital circuit, which could be any of those listed in the related section of unit content.

P3 and P4 cover learning outcome 2. Learners are expected to prepare a written fault location strategy for an analogue electronic system (P3) and a digital electronic system (P4) and identify the fault-finding and signal tracing techniques to be applied for each.

The fault location strategy for both P3 and P4 must provide details of the planning that is required for the task (e.g. obtaining relevant diagrams, establishing component/circuit tolerances, etc), predicting the circuit operation from diagrams and calculating expected signal conditions for analogue and digital circuits respectively.

The signal tracing techniques applied will depend on the type of electronic circuit and the fault or faults present. However, learners should identify an appropriate strategy from the list provided in the unit content (e.g. input-to-output/output-to-input, half-split method, symptom to cause fault hierarchies, unit substitution, etc). They are not expected to demonstrate them all for assessment purposes, but should have experienced them all during delivery to enable them to make the most appropriate choice.

Learners should also identify the most appropriate fault-finding aids to be used (eg functional charts, diagrams, trouble-shooting charts, etc). The written strategy should also identify the required level of fault/repair reporting (e.g. MTBF figures and the use of path sensitisation, critical path and fault signal tracing node point techniques).

The remaining pass criteria relate to learning outcome 3 and all require proficiency in the practical techniques relating to fault-finding.

To satisfy P5 and P6, learners need to select and use the most appropriate test instruments for the circuits/ systems under test.

For P7 and P8, learners must collect and record all the relevant test data and prepare relevant test reports. The data must be presented in a clear and legible form, for example use of a personal logbook, tabulated data that includes headings and relevant units (Voltage/mV, Resistance/Ohms, etc, computer based records, etc). It is expected that the report should reach a conclusion on the likely cause of the fault and include the learner's recommendation on how the circuit/system can be restored to full operational order.

When planning and designing assessment activities and assignments tutors should consider how best to incorporate opportunities for the achievement of the merit and distinction criteria. For example, M1 is a natural extension of the tasks carried out to satisfy P1 and P2, which assess learners' ability to read circuit diagrams for analogue/digital electronic systems.

For M1, learners should be able to apply this skill in a deeper way by comparing the circuit diagrams of two different approaches to the same type of circuit. The circuit diagrams could be of an analogue or digital circuit and are likely to be provided by the tutor, although they could come from the learner's workplace if available. The important aspect here is learners' ability to recognise that generally there is always more than one way to produce a given type of circuit.

M2 links with P3 and P4 – preparing written fault location strategies for given analogue/digital electronic systems. Learners should evaluate either a given fault location strategy (analogue or digital) or their own and make recommendations for improvement. This should demonstrate their ability to reflect upon their own work or that of others and apply their understanding to arrive at realistic and relevant improvements.

M3 links with P5 and P6 – the selection and use of test instruments to identify fault conditions in analogue/ digital electronic systems. Learners should justify the choice of test instruments selected to identify fault conditions within an electronic system (analogue or digital). The justification should not only indicate why the test instruments were used but also why others were not. This will show the depth of understanding of a greater range of instruments (eg ammeter, voltmeter, multimeter, logic probe, cathode ray oscilloscope, signal analyser, frequency counter, digital test set, power meter, software simulation tools) than will be possible in the work for P5 and P6.

D1 is an extension of the work undertaken for P1, P2, and M1. Again, the circuit diagram could be either analogue or digital and could be provided by the tutor or from the learner's workplace. It assumes that the circuit provided has errors with respect to either the circuit itself or the signals that have been indicated within the circuit. It is likely that such a circuit diagram will need to be produced by the tutor.

Alternatively, it may be possible for learners to produce work-based evidence of the detection of an error, for example through a quality assurance process in the design phase of an electronic product.

D2 is a natural extension of P5 and P6. It is intended to enable learners to demonstrate their ability to apply the skills gained at pass within a more complex context. This will mean that learners are not only able to appreciate that there is a fault in one of the circuits in a system, but that the symptoms indicate further external influence on the expected performance of the circuit as a whole.

For D2, the satisfactory response from learners will be to independently investigate beyond the original fault and identify the second problem. As this is unlikely to occur naturally, the circuit under investigation will need to be specially prepared for this particular task by the tutor.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Reading and Interpreting Circuit Diagrams	Learners have been asked to look at circuit diagrams for electronic systems used by their employer, identify the components and signals, and suggest alternative circuits.	A written report based on the findings of an analysis of circuit diagrams.
P3, P4, M2	Fault-finding Strategies	Learners have been asked to prepare fault location strategies for analogue and digital electronic systems used by their employer.	A written report/fault-finding strategy identifying details of relevant planning, predicted circuit operation, fault location techniques and appropriate aids.
P5, P6, P7, P8, M3, D2	Diagnosing Electronic Faults	Learners must locate faults in electronic systems from their workplace, collect and record the test data and prepare a test report.	A written report based on the fault diagnostic techniques and instruments used and a test report based on relevant test data.

Essential resources

Centres must provide a range of analogue and digital electronic circuits and systems for practical investigation and suitable hardware and software for computer-based simulation.

Learners will require access to a range of manufacturers' literature for electronic components, devices and circuits/systems and a range of test equipment and their handbooks. The test equipment should be sufficient in number to allow learners to carry out fault-finding exercises on an individual basis.

A range of working and faulty electronic systems, circuits, devices and components should be made available for fault diagnosis purposes, together with the relevant manufacturer's service manuals, parts lists and circuit diagrams. The appropriate tools, safety equipment and a safe working environment must also be provided. In most cases, a typical electronics workshop or laboratory should prove adequate.

Indicative reading for learners

Textbooks

Gates E – *Introduction to Electronics*, 6th edition (Cengage, 2011) ISBN 9781111128531

Loveday G C – *Electronic Testing and Fault Diagnosis* (Longman Scientific and Technical, 1996) ISBN 9780582252424

Sinclair I and Dunton J – *Electronic and Electrical Servicing*, 2nd edition (Routledge, 2007) ISBN 9780750669887

Unit 74: Advanced Composite Materials Manufacturing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the materials typically associated with advanced composites, and the processes and design considerations required to manufacture them. The purpose of the unit is for learners to be able to summarise key aspects of composite materials without investigating any particular aspect in great detail.

A holistic understanding of composite materials is essential for technicians and those seeking employment in industries that utilise or have exposure to these materials. The aerospace, marine, automotive, construction, renewable energies and consumer goods industries exploit the use of composites in a number of forms. Composite materials are becoming more important in widespread engineering and learners need to appreciate their principles and fabrication methods.

This unit covers the various forms of matrix and reinforcements most commonly used across the spectrum. The unit looks at the typical manufacturing methods used in industry, from wet lay-up to infusion, and briefly covers the more niche areas of techniques such as filament winding and automated tape laying. Learners will look at vacuum bagging in detail. The unit covers other key components of the composite production line, including trimming, bonding, finishing and inspection. An overview of design for manufacture is maintained throughout the course.

The unit is a mix of theoretical teaching and practical work. Learners do not need specialist knowledge to take the unit but an understanding of general engineering terms would be an advantage.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Know the different types of matrices and reinforcements commonly used in composite manufacture
2. Understand the differences, advantages and disadvantages of key manufacturing processes
3. Understand the effects of design decisions on component manufacturability
4. Understand bonding processes, finishing processes, inspection and repair techniques.

Unit content

1 Know the different types of matrices and reinforcements commonly used in composite manufacture

Composites: advantages; disadvantages; relevant applications in localised industry and global markets

Reinforcements: nature and purpose; general types of fibre, e.g. glass, carbon, aramid, natural; types of cloth weave available, e.g. chopped strand, plain weave, 5-harness, uni-directional, non-crimp/bi-axial; uses of fibres, e.g. when and where to use 5-harness carbon versus chopped strand glass

The matrix: nature and purpose of the resin; differences and selection of thermosets and thermoplastic resins; general types of resin available, e.g. polyester, epoxy, vinyl-ester, phenolic, bismaleimides, cyanate ester, nylon, polypropylene, polyether ether ketone

Laminate theory: balanced lay-ups; unbalanced lay-ups

Sandwich structures: advantages; disadvantages; types of core materials including timbers, foams, honeycombs and specialist cores; implications of cores on manufacturing complexity

Health and safety: personal protective equipment (PPE); storage considerations; handling of resins, dry fibres and other chemicals; contamination and respiration when carrying out trimming /finishing operations

2 Understand the differences, advantages and disadvantages of key manufacturing processes

Lay-up preparations: workshop considerations; release agents; gel-coats

Wet lay-up: advantages; disadvantages; typical applications; resin metering, mixing and de-gassing; cloth handling; roller applications; brush applications; squeegee resin application; porosity

Vacuum bagging: advantages; disadvantages; typical applications; breather fabrics; release fabrics; consumables, e.g. peel plies, bagging films; quality escapes, e.g. bridging, vacuum integrity

Pre-preg lay-up: advantages; disadvantages; typical applications; processing requirements, e.g. autoclave, out-of-autoclave; clean room and storage conditions

Resin transfer infusion (RTI): advantages; disadvantages; applications including closed moulding and applications to larger structures; tool design; flow media; RTI-specific fabrics; core considerations; advances in RTI

Resin transfer moulding (RTM) and vacuum-assisted resin transfer moulding (VARTM): advantages; disadvantages; typical applications of RTM vs VARTM; tool design; flow media; RTI specific fabrics; core considerations; single part resin systems

Other manufacturing process: compression moulding; pre-forming and hot-drape forming; automated tape laying; filament winding and 3D weaving; process comparisons

3 Understand the effects of design decisions on component manufacturability

Tooling: geometrical effects of component design on part de-moulding; male and female moulds; plug materials and construction including timbers, foams, metals; mould materials and construction including timbers, foams, metals, composites; co-efficients of thermal expansion; glass transition temperature

Costs: raw materials; labour; capital equipment; overheads; effects of design decisions on lifecycle costs, tooling, manufacturing processes; finishing

4 Understand bonding processes, finishing processes, inspection and repair techniques

Bonding: mechanical surface preparations including techniques and advantages; chemical surface preparations including standardised techniques and limitations with various methods; types of adhesives commonly used, e.g. epoxy, acrylic, polyurethanes, silicones; design of interfaces for adhesive joints and bonded joints

Cutting and trimming: trimming of composites post de-moulding including techniques, speeds, cutting tools and waste removal; drilling of composites; drill bit types; delaminations; surface finishing techniques, e.g. wet sanding, polishing and painting

Inspection: types of damage associated with composites including delaminations, porosity, disbond and inclusions; methods of inspecting such as visual inspection, tap test, phased array, mechanical impedance, thermography

Repair: repair methods; surface preparations; layer identification; new material preparation; curing methods; repair specifications.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the use of composite materials, including the types and applications of resins, reinforcements and core materials	**M1** explain why balanced laminates are important in composite design	**D1** numerically evaluate the contribution of fibre and resin to composite strength
P2 describe the main health and safety considerations that need to be taken into account when using composite materials		
P3 describe the process of vacuum bagging, including the uses of various consumable materials in the process	**M2** compare the advantages and disadvantages of different composite manufacturing processes	
P4 describe the key factors affecting release agent selection		
P5 describe the various types of tooling commonly used in composite manufacture	**M3** explain why certain features exist on a tool used for composite production within a local company	**D2** evaluate the process of producing a tool, from CAD drawing to manufacturing the finished tool, including key costs within the process
P6 describe the types of pre-treatments required for the bonding of metallic and carbon fibre parts	**M4** compare and contrast the methods of composite inspection.	**D3** analyse repair processes currently used in industry and any limitations of the process, particularly in structural components.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe typical process parameters and the associated health and safety requirements when drilling solid carbon fibre laminates.		

Essential guidance for tutors

Assessment

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to investigative assignments and controlled assessment (if required).

Four assignments could be set for the assessment of this unit. Assignment 1, encompassing learning outcome 1, could be a series of formal written tasks. Learners will need to distinguish between the function of the fibre and the matrix and core materials in the composite, while noting the difference in thermoset and thermoplastic polymer resins (P1). Health and safety is a key consideration throughout and learners must display knowledge of measures taken to reduce any hazards within the workshop environment (P2). The importance of balancing composite laminates must be explained for Merit grade (M1). Finally, for D1, learners will numerically evaluate the contribution of fibre and resin to composite strength in at least two different scenarios.

The second assignment, covering learning outcome 2, could be a small project. Learners could plan the manufacture of a component (relevant to their places of work, if appropriate) with reference to the method of manufacturing. In this phase, it is recommended that a practical exercise is undertaken but assessed on completion of a short report in a reflective manner. For example, for the aerospace industry, a small representative wing could be manufactured by individual learners or groups. The project should be given to learners with a design concept in mind. The design concept should have key indicators that will influence learners in planning the appropriate method of manufacture to meet key design criteria such as performance, quality, cost, volume etc. This assignment will require the submission of a written report, incorporating selection of release agent materials (P4) and a discussion comparing the advantages/disadvantages of using three different manufacturing processes to manufacture the component (M2). It is recommended that the representative part (simplified so that it can easily be incorporated into the unit) is used to base evidence on and reinforce any arguments made in the written report. The design criteria should be set so that vacuum bagging is incorporated into the overall process (for example wet lay-up and vacuum bagging, RTI, VARTM, pre-preg laminating). The vacuum bagging process should be described for the purposes of fulfilling P3.

The third assignment, covering learning outcome 3, could be a series of formal written tasks. Learners will need to describe the various types of tooling commonly used in composite manufacture, including simple hand tools through to complex mould tooling (P5). Individual learners can achieve a Merit grade if they give written evidence explaining the reasons why certain features exist on a tool used in a local company (M3). For D2, learners must produce a balanced written report that evaluates the process by which a CAD model is taken from design to manufacture of a tool, including a discussion on any associated costs such as machining of the tool and the cost of materials.

For learning outcome 4, a fourth assignment should be set. This assignment could be segregated into three key areas. Practical evidence, such as photographs and anecdotal experience, should be used in all applicable cases to support written submissions. All practical evidence should be supported by a witness statement or observation record. The surface preparations for bonding of adhesives, including mechanical and chemical preparations, should be detailed, with particular reference to bonding of metallic and carbon fibre substrates (P6). Typical characteristics of drilling of composite components and possible quality defects with particular reference to carbon fibre should be noted for P7. Learners will need to compare the advantages and disadvantages of three forms of inspection used within the composite industry (M4). Finally, they will need to investigate and analyse procedures that are used for their repair or the repair of other laminates within the industry (D3).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Types of Matrix and Reinforcements Commonly used in Composite Manufacture	You are working for a local company manufacturing metallic products and have been asked by your manager to investigate the use of composite materials in future products. It is expected that you would explain reasons for using composites in the product line, the function of various aspects of the composite and measures the company should take to ensure HS&E compliance.	Written responses to set written tasks, carried out under controlled conditions.
P3, P4, M2	Manufacturing Processes	Following your initial evaluation of composites in Assignment 1, your manager has now asked that you describe composites manufacturing in more detail.	Evidence gathered by tutor observations and/or learners' written reports and written responses to set tasks.
P5, M3, D2	Component Manufacturability	You are a trainee manufacturing engineer planning the manufacture of a new component that will require new tooling. You are required to compile a written report that details the process of manufacturing tooling and the types of features that they incorporate.	Written responses to set written tasks.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M4, D3	Bonding Processes, Finishing Processes and Quality in Composites	You are a trainee manufacturing engineer planning the assembly of two pre-cured composite components. You must describe the potential bonding methods and surface preparation practices, steps you would take to trim and finish the materials as well as post-assembly inspection.	Written responses to set written tasks.

Essential resources

Learners will require access to a composites engineering workshop environment suitably equipped with:

- appropriate PPE and equipment/hardware to meet health and safety legislation
- various types of resins, cloths, release agents and associated wet lay-up hand tools
- a lay-up table
- vacuum bagging hardware and consumables
- pre-preg materials and associated storage facilities
- autoclave/out-of-autoclave curing capability
- resin transfer infusion hardware and consumables
- hand tools for composite repair
- physical specimens of un-cured and cured composite components for demonstration of each teaching matter where possible
- access to industry representative standard operating procedures
- adhesives, applicators and surface preparation materials
- a minimum of two forms of composite inspection
- hand tools, drills, heatguns, scissors, knives.

Indicative reading for learners

Textbooks

Mazumdar S – *Composites Manufacturing, Materials, Product and Process Engineering* (CRC Press, 2000) ISBN 9780849305856

Ramalingam K – *Handbook of Mechanical Engineering Terms* (New Age International Publishers, 2009) ISBN 9788122426083

Unit 75: Microprocessor Systems and Applications

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will introduce learners to the principles of microprocessors and give them experience of using and programming a microprocessor system for the operation or control of peripheral devices.

Microprocessors can be found in a wide range of commercial, industrial and domestic applications such as electronic thermometers, weighing scales, remote controls, vending machines and cameras.

This unit will provide an introduction to the terminology (e.g. bits, bytes, words) and concepts (e.g. instructions, operation codes and operands, instructions sets, use of mnemonics, coding methods, programs, memories, assemblers, linkers and debuggers, subroutines) related to microprocessor applications.

Learners will be introduced to the ways in which microprocessor-based systems can be applied, including industrial, commercial and domestic applications. Learners will examine a range of input and output devices and consider the implications of connecting devices to a system (interfacing consideration). This will take into account signal types (e.g. analogue, digital) and look at the finer detail of packaging and cooling, environmental considerations, issues relating to electromagnetic compatibility (EMC) and safety.

The unit will also develop learners' understanding of the architecture and operation of microprocessor-based systems and the use of decimal, binary and hexadecimal number systems, instructions and subroutines for programming.

Finally, learners will experience the use of a microprocessor development system to prepare, run and test a typical microprocessor program application.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how microprocessor-based systems can be applied

2 Understand the architecture and operation of a microprocessor system

3 Understand decimal, binary and hexadecimal number systems, instructions and subroutines

4 Be able to use a microprocessor development system to prepare and run a program.

Unit content

1 Know how microprocessor-based systems can be applied

Microprocessor system applications: types of application (industrial, commercial, domestic), e.g. robotic manufacture, vending machine, photocopier, burglar alarm, remote controls, electronic lock, electronic thermometer, keyboard interface, electronic tape measure; input/output devices, e.g. sensors, transducers, seven-segment light emitting diode (LED), liquid crystal display (LCD), matrix and multi-line alphanumeric displays; interfacing consideration; signal types, e.g. analogue, digital; packaging and cooling; environmental considerations; issues relating to electromagnetic compatibility (EMC), safety

2 Understand the architecture and operation of a microprocessor system

Architecture: central processing unit (CPU); registers; arithmetic and logic unit (ALU); instruction decoder; data paths, e.g. internal or external busses; memory (random access (RAM), read only (ROM), erasable programmable ROM (EPROM), electrically erasable/programmable ROM (EEPROM)); input/output (I/O) ports; analogue-to-digital (ADC) and digital-to-analogue (DAC) conversion

Principles of operation: address selection and enabling; chip select/enable; consequence of data bus conflict and avoidance with a tri-state device control; address decoding; commercial chips, e.g. 74LS138, 8205; clock (clk); read/write function; memory map for system; fetch-execute sequence (operation of system and actions between the CPU and memory that involve instruction register and role of program counter)

3 Understand decimal, binary and hexadecimal number systems, instructions and subroutines

Number systems: express numbers in decimal, binary and hexadecimal; conversion between number systems; use of ASCII codes; manipulation, e.g. binary addition/subtraction, signed binary, two's complement; bit-wise AND/OR operations

Instruction groups: e.g. data transfer, arithmetic, logic, branch/jump, test-compare, stack

Subroutines and the stack: subroutines and interrupt routines, e.g. time delay routine, arithmetic operation, I/O operation; call and return instructions; purpose of the stack, e.g. to hold subroutine addresses, data storage

4 Be able to use a microprocessor development system to prepare and run a program

Program operations: data handling, e.g. data I/O, arithmetic operations, time delay routines; programming language, e.g. hexadecimal, assembly language; graphical interpretation, e.g. flowcharts, data flow diagrams; program function, e.g. production of square wave, switch testing, traffic light sequencing

Enter, assemble, download, run and test a program: use of text editor, e.g. create and store program; assemble program to create object file; download, run and test/debug, e.g. tracing, trace table, variable watches, single stepping, breakpoints; typical program applications, e.g. linear program, I/O initialisation, microprocessor system I/O, iteration and single loop time delay, logic operation, arithmetic operation, subroutines, macros, simple interfacing via parallel I/O port

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe three different types of microprocessor system application		
P2 explain the architecture and principles of operation of a microprocessor-based system	**M1** compare the architecture and principles of operation of two different microprocessors	
P3 use decimal, binary and hexadecimal number systems to represent and manipulate data		
P4 identify and explain a programming example for representative instructions taken from five different instruction groups		
P5 explain an example of the use of a subroutine, including the operation of call and return instructions and the function of the stack	**M2** explain the benefits of using an assembler, and describe two examples of assembler directives	
P6 explain the operation of a given section of a program with a specific function		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 use a microprocessor development system to enter, assemble, download, run and test a typical program application.	**M3** identify and correct a linear and a subroutine programming error in given fragments of program.	**D1** explain the use of interrupts and evaluate and contrast the operation of a conventional programmed subroutine with that of an interrupt driven routine
		D2 produce program code to facilitate digital input and output of data using appropriate interfacing and explaining the operation of the interfacing device(s).

Essential guidance for tutors

Assessment

The assessment evidence for P1 could be a brief written description supported by appropriate diagrams of three different microprocessor applications. To meet the requirements of the unit content, these applications should be drawn from the different types of applications listed (industrial, commercial, domestic): for example, an automotive engine management system, a photocopier and a domestic washing machine.

P2 requires learners to explain the architecture and principles of operation of a microprocessor-based system. This work can form the basis of an extended study of one of the systems that learners have examined for P1. Alternatively, a detailed study of a single microprocessor system could be used by the learner as a focus for the other criteria and in particular, the microprocessor that they will develop a program for to satisfy P7.

Evidence to support P2 would typically take the form of a summary of the features of the microprocessor-based system, including the type and principal features of the CPU (e.g. address range, I/O facilities, internal registers, instruction set, power requirements, physical encapsulation, manufacturing technology) and each of its principal support devices (e.g. RAM, ROM, I/O devices, clock generator).

Learners should be able to identify the functions of each of the components and they should produce a diagram showing the architecture of the system identifying principal features (e.g. address bus, data bus, control bus, serial and parallel I/O). They should also be able to show that they understand the need for address decoding and they should be able to explain the function of read/write and chip enable signals.

For P3, learners need to be able to use and convert between all three number systems (decimal, binary and hexadecimal) to represent and manipulate data. This could be achieved through a series of appropriate programming examples, which are then explained (e.g. the result of an AND operation between two hexadecimal numbers where the learner converts the hexadecimal number to binary before applying the AND logic function to each binary digit in turn). The assessment method used should sufficiently guide learners to ensure that all aspects of the criterion and related content are covered and also enable their achievement to be tracked before the criterion is awarded. To ensure the relevance of the work for this criterion, some fragmentation of the criterion might be required but this should be avoided wherever possible or at least kept to a minimum.

P4 requires learners to identify and explain a programming example for representative instructions taken from five different instruction groups. Learners could be given a selection of typical programming instructions taken from at least five major instruction groups as appropriate to the microprocessor family. These might include load and exchange, block transfer and search, arithmetic and logical, rotate and shift, bit manipulation (set, reset, test), jump, call, and return, input/output and CPU control. Learners should be able to identify and then explain what each instruction does and it might be helpful to set this within a typical example of its use.

Assessment of P5 and P6 could be linked. P5 requires learners to explain an example of the use of a subroutine (e.g. a time delay), including the operation of call and return instructions and the function of the stack. Provided that the function and operation of the subroutine is adequately and clearly explained, this could easily be used to cover P6 as well. The explanation of the program operations must include the way that the data is handled, the programming language used, applications of graphical interpretation and the function of the program. The content section for this criterion lists a range of examples for each of these operations.

Appropriate evidence for P7 should include documentation and tutor observation of learners' work relevant to each stage of developing and testing the program (enter, assemble, download, run and test). This will require learners to use a text editor e.g. to create and store the program, assemble program to create object file, download, run and test/debug the program. Typical program applications might be a linear program, I/O initialisation, microprocessor system I/O, iteration and single loop time delay, logic operation, arithmetic operation, subroutines, macros or simple interfacing via parallel I/O port.

For M1, learners should be able to extend the work done for P1 and P2 to encompass a different microprocessor, or base their work on a microcontroller device (e.g. PIC16C84, PIC16F877) rather than a general purpose microprocessor. Microprocessor training kits containing Z80, 6809, 8088, or 6502, or a microcontroller device (e.g. PIC16C84, PIC16F877), or Arduino™ Genuino™ microcontroller hardware, are acceptable providing these are capable of meeting this criterion. In either case, learners need to compare the architecture and principles of operation of two different microprocessor systems.

In order to satisfy M2, learners need to explain the benefits of using an assembler compared with hand assembly involving entry of program instructions in hexadecimal format. They will also need to describe two examples of assembler directives, e.g. those used for conditional assembly or those used to determine program location. Learners should provide a written description of the use of two common assembler directives, explaining how they work and what they do in conjunction with a typical assembly code routine.

For M3, learners should be provided with two code fragments containing different errors. One code fragment should contain linear code error and the other should contain a subroutine error. Typical errors might be the use of an incorrect address mode (linear error), an incorrect offset in a relative jump instruction, or incorrect use of the stack when calling a subroutine. Learners should apply standard debugging procedures, correcting the code fragment before testing it (e.g. by single stepping) in order to confirm its correct operation. Assessment evidence of this work is likely to be in the form of a short report supported by appropriate program trace and register dump, clearly showing the program operation before and after implementing the correction.

Learners should annotate any print-outs to identify both the error and the corrective action taken to resolve the linear and the subroutine programming errors within the given fragments of program.

For D1 learners need to explain the use of interrupts and evaluate and compare the operation of a conventional programmed subroutine with that of an interrupt driven routine. A typical activity might be comparing a polled I/O routine with a comparable interrupt-driven I/O routine.

D2 requires learners to produce program code to facilitate digital input and output of data using appropriate interfacing, and an explanation of the operation of the interfacing device(s). Learners should develop, enter and test program code that will provide a means of inputting and outputting digital data in conjunction with a microprocessor system.

This exercise will require the use of one or more programmable I/O ports. The developed code should include appropriate port initialisation routines (configuring individual I/O lines for use as either input or output) as well as routines that will input and output data. A typical application might involve interfacing a number of LED indicators and switches, the switches to be configured as inputs and the LED indicators to be configured as outputs.

Learners should provide appropriate documentary evidence of the programming process (including evidence of correct program operation), an explanation of the operation of the interfacing circuit (together with relevant circuit details showing, e.g. pull-up resistors, LED drivers) as well as the programmable I/O device (e.g. showing its internal register moder and I/O address map).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Applications and Operation of Microprocessor Systems	Learners produce a report on the types and operation of microprocessor systems.	A written report and supporting diagrams.
P3	Use of and Conversion Between Number Systems	Learners need to convert between decimal, binary and hexadecimal number systems to represent and manipulate data.	A written report.
P4	Instruction Groups	Learners need to explain programming examples for instruction groups.	A written report.
P5, P6, M2	Subroutines and Program Operations	Learners investigate the operation of subroutines and a section of a programme	A written report.
P7, M3, D1, D2	Developing and Testing Programs	Learners need to use a microprocessor development system to enter and test a program.	Written documentation of practical work supported by tutor observation records and printouts.

Essential resources

Centres should provide learners with access to a typical 8-bit development system, including the use of assembler software and facilities for software testing (e.g. single-stepping and/or program tracing). The development system could be based on traditional 8-bit processors or on one or more popular microcontrollers, e.g. 16C84, 16F84, 16F877.

Learners should also be provided with documentation comprising (as a minimum) fully commented instruction sets for each of the microprocessors/microcontrollers used, manufacturers' data sheets, examples of coding sheets and program documentation and instruction manuals relating to microprocessor development systems.

Indicative reading for learners

Textbooks

Anderson K – *Picaxe Project Handbook: A Guide to using Picaxe Microcontrollers Volume 1* (independently published, 2017) ISBN 9781520282572

Bates M – *PIC Microcontrollers: An Introduction to Microelectronics*, 3rd edition (Newnes, 2011) ISBN 9780080969114

Blum J – *Exploring Arduino: Tools and Techniques for Engineering Wizardry*, 2nd edition (John Wiley & Sons, 2019) ISBN 9781119405375

Lincoln D – *Programming and Customizing the Picaxe Microcontroller*, 2nd edition (McGraw-Hill/Tab Electronics, 2010) ISBN 9780071745543

Smith D – *PIC in Practice*, 2nd edition (Newnes, 2006) ISBN 9780750668262

Tooley M – *Electronic Circuits: Fundamentals and Applications*, 4th edition (Routledge, 2015) ISBN 9781138828926

Tooley M – *PC Based Instrumentation and Control*, 3rd edition, (Newnes, 2005) ISBN 9780750647168

Unit 76: Principles and Applications of Microcontrollers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will develop learners' understanding of the features and characteristics of microcontrollers and will give them the skills needed to select, implement and test such devices.

At work and at home we rely on a range of complex electrical and electronic devices and systems to meet our needs. We expect these devices to have numerous features, versatility, reduced costs, increased reliability, energy efficiency and be squeezed into ever-smaller units. This unit will enable learners to understand one of the most versatile building blocks that enable engineers to develop such applications – the microcontroller.

A microcontroller is a 'computer-on-a-chip' and contains all the elements of a computer, such as electronic memory, input/output interfaces and control processes. This provides small size, reduced power consumption and the ability to control (after it has been programmed) processes or events. The microcontroller can be used for applications that measure, store, control, calculate or display information.

This unit will develop learners' understanding of microcontrollers and the main features of microcontroller internal architecture. The unit will cover communication and human interface devices, as their purpose is to be able to receive data and then pass back processed information either to other devices or to the human operator for them to act upon.

Learners will be introduced to real-time operating systems (RTOS) and control instructions. They will also develop their ability to select, implement and test microcontrollers.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the internal architectural features and common characteristics of microcontrollers

2 Understand microcontroller communication interfaces and human interface devices

3 Understand microcontroller hardware control methods

4 Be able to select, implement and test a microcontroller.

Unit content

1 Understand the internal architectural features and common characteristics of microcontrollers

Microcontroller internal architecture: architectural models, e.g. von Neumann, Harvard; modules (central processor unit (CPU), arithmetic logic unit (ALU), control unit and registers, e.g. stack pointer (SP), program counter (PC), instruction register (IR), accumulator, index, file, status); memory options, e.g. volatile (static, dynamic, static random access memory (SRAM), dynamic random access memory (DRAM), battery backup SRAM), non-volatile (read only memory (ROM), mask-ROM, electrically erasable programmable read only memory (EEPROM), Flash memory, non-volatile NV-RAM); endianness, e.g. big endian, little endian; interrupt controller, timer/counter, digital input/output (I/O) ports (parallel and number of pins); registers, e.g. data direction register (DDR), port, port input; analogue I/O (analogue/digital converter, e.g. channel, resolution, differential/bipolar conversion); watchdog timer; debugging unit

Microcontroller characteristics and features: manufacturers, e.g. Intel, Renesas, Microchip, Texas Instruments, Silicon Labs; voltage levels and reasons for such levels; brownout protection; power consumption; power management modes (idle, halt, wakeup); over voltage protection (OVP); charger considerations; low-dropout regulators (LDOs); battery monitoring; power sequencing

2 Understand microcontroller communication interfaces and human interface devices

Interfaces: serial; parallel; synchronous; asynchronous; bus; point-to-point; duplex (full, half), master/slave principle; universal asynchronous receiver transmitter (UART); universal synchronous asynchronous receiver transmitter (USART); configurable parameters, e.g. number of data bits, parity bit, stop bit, baud rate; serial peripheral interface (SPI); synchronous serial port (SSP); serial peripheral port (SPP) master/slave to allow communications between controllers; serial communication interface (SCI); I2C bus – IIC (inter-OC bus); analogue-to-digital converters (A/D); digital-to-analogue convertors (D/A); signal standards, e.g. RS –232, 422, 485, 482; Bluetooth; embedded internet and internet protocol suite; universal serial bus (USB) connection; controller area network (CAN)

Human interface devices: display method, e.g. light emitting diodes (LED), liquid crystal displays (LCD), plasma, thin-film transistor (TFT), vacuum fluorescent display (VFD); on-screen display (OSD) functions, e.g. that support text and graphics display; input/output devices, e.g. keyboards, keypad, touch screens, printers, electronic readers, wireless, USB

3 Understand microcontroller hardware control methods

Real-time operating system (RTOS): event driven; time sharing; kernel (single, multi-stack); implementation (installation procedures, manipulate setting, locks and critical sections, memory management, scheduler); common types, e.g. Windows CE, QNX, RTLinux, LinuxOS, Salvo LE

Control instructions: complex instruction set computer (CISC); reduced instruction set computer (RISC); assembly language categories, e.g. data movement, data processing, execution, processor control; polling; interrupts, e.g. maskable, non-vectored, vectored, arbitration and priority; interrupts, e.g. interrupt enable (IE), interrupt survive routine (ISR), interrupt flag (IF), interrupt mode; reset, e.g. power-on, brown-out, external, watchdog, internal

4 Be able to select, implement and test a microcontroller

Selection and implementation: selection criteria, e.g. based on cost, convenience, availability of development tools, intended use; implementation tools, e.g. assemblers, simulators, resident debuggers, emulators/in-circuit emulators (ICE), Java on embedded system

Testing techniques: operational considerations, e.g. static, dynamic, interoperability, environmental; software tools, e.g. debuggers, emulators; debugging, e.g. breakpoints, scanpoints, profiles; test equipment and instruments, e.g. oscilloscope, probes, analysers, signal-generating devices; internet searches for common faults and solutions; collection of test data, e.g. data sheets, data management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the internal architectural structure of a standard microcontroller		
P2 explain the characteristics and features of a manufacturer's microcontroller family		
P3 explain the function and application of three different microcontroller interfaces		**D1** evaluate two different techniques used for interfacing a microcontroller to an external system
P4 describe the benefits of one particular type of human interface device for a specific microcontroller application	**M1** explain how a microcontroller chip is connected to a human interface device	
P5 explain the role of a real-time operating system		
P6 explain the control instructions of a given microcontroller assembly language program	**M2** compare an RTOS with a CISC/RISC instruction set with respect to how the use of such control methods might influence microcontroller selection	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 select a microcontroller for a given application, stating the selection criteria used, including details of implementation tools available to support the application		**D2** evaluate a microcontroller application to determine what alternative microcontroller chip could be used and the benefits that it would provide.
P8 use one software-based and one instrument-based testing technique to determine the performance of a microcontroller in a given application.	**M3** use a debugging tool to correct a fault in a microcontroller application.	

Essential guidance for tutors

Assessment

Assessment of this unit could consist of a mix of written technical reports, presentations to an audience and hands-on practical work. Evidence for any presentations given will need to include a record of tutor observation plus the learner's notes/slides etc from their preparation and delivery. Annotated photographic evidence could be used to capture any on-site information and support learners' written work.

P1 requires an explanation of the internal architectural structure of a standard microcontroller and could be covered by learners considering either a von Neumann or a Harvard architectural model. Learners need to explain all the aspects ranged in the unit content for the microcontroller selected (e.g. CPU, ALU, registers, memory etc).

To achieve P2, learners must show their understanding of a specific manufacturer's microcontroller family (e.g. Intel, Texas Instruments or any other appropriate manufacturer) by explaining the characteristics and features available as listed in the unit content. For both P1 and P2, evidence could be in the form of a written technical report or presented in some other format, e.g. a formal presentation to the group or production of an information/sales type leaflet. Learners should be advised to keep all their early research materials in a suitable portfolio as this will provide them with a useful reference tool to work with and build on as they progress through the unit.

P3 and P4 are closely related in that there is always a need for an interface between the microcontroller and the device it operates. For P3, learners need to demonstrate that they can differentiate between three different interfaces, their functions and applications. The unit content lists a range of interfaces (e.g. serial, parallel, synchronous, asynchronous, bus, point-to-point, duplex etc) and although it is expected that a centre will cover all of these during the delivery of the unit only three are required for assessment purposes. The choice of interfaces used could be determined by the tutor, employer or the learner.

For P4 learners must consider the physical link between the interface device (P3) and one particular type of input/output device that provides the human interface. It is not essential that the two criteria are linked (although it would be good to know which communication interface is being used) but it would improve the coherence of the assessment activity. Learners need to recognise that there are different types of human interface device but are required to select only one device that is relevant for a specific application for assessment purposes. For example, TFT displays have clear benefits when used with a laptop computer, but would they be appropriate on domestic washing machines?

A link could be established between P4 and M1 and be extended to D1, although it is recommended that pass criteria P5 and P6 are undertaken before allowing learners to fully develop material for this distinction criterion.

P5 requires learners to explain the role of a real-time operating system (RTOS). The explanation does not need to be highly complex and learners need only be able to demonstrate an understanding of the basic principles, which could include a couple of the more advanced features of a selected RTOS.

To achieve P6, learners need to explain the control instructions of a given microcontroller assembly language program. An effective approach would be to get learners to annotate a real assembly language program with the details of each control instruction. It is not necessary for learners to repeatedly demonstrate the same instruction or annotate the complete program. The program selection should, however, contain all appropriate control instructions to cover the requirements of the unit content. If a single program is not available centres can use two different programs but, beyond this, it is likely that the programs would be too simple and not at the expected level of learning.

Having looked at the operating system and explained an assembly language program, learners could compare a RTOS with a CISC/RISC instruction set (M2). It may be helpful to consider the extreme ends of microcontroller applications and what is needed.

A sufficient range of unit content would have been considered for the learner to undertake D1 which requires them to consider the type of data to be transferred and what has to be interfaced with it. Therefore, techniques such as USART could be evaluated in light of their use.

For P7, learners are required to select a microcontroller for a given application and state the selection criteria used, including details of implementation tools available to support the application.

P7 could be effectively linked with P8 which requires learners to use testing techniques to determine the performance of a microcontroller in a given application. The application does not have to be overly complex as it is learners' understanding of the operational considerations of testing and all that it entails that is important. The assessment also needs to confirm that learners can apply the appropriate software and instrument methods to collect relevant data.

There is a possible link from P8 to M3, although M3 does not have to be conducted against the same application. It may be advantageous to do so, however, as it would improve the coherence of the assessment. Note that P8 is looking at performance and M3 is concerned with debugging to correct a fault.

Finally, D2 requires learners to consider an application (which may have already been used in completing other grading criteria), suggest an alternative chip and identify the benefits the alternative would achieve. Clearly, as technology advances, older microcontroller devices/applications could be used as the focus of this criterion. For example, learners could consider multimeters and how their features have been enhanced over recent years.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Characteristics and Features of Microcontrollers	A technician needs to explain the characteristics of microcontrollers to a new apprentice.	A written report or presentation.
P3, P4, M1, D1	Microcontroller Interfaces	A technician has been asked to compare and evaluate interfacing techniques for a microcontroller.	A written report.
P5, P6, M2	Microcontroller Hardware Control	A technician has been asked to explain microcontroller hardware control methods to a new member of staff.	A written report supported by an annotated assembly language program.
P7, P8, M3, D2	Selecting and Testing Microcontrollers	A technician needs to select a microcontroller for an application in the workplace and use testing techniques to determine its performance.	A written report based on results of practical activities, supported by tutor observation and/or annotated photos.

Essential resources

Learners will need access to facilities for carrying out practical investigations into working devices/systems containing microcontrollers and appropriate testing. This should include a range of various microcontrollers, communication interfaces and human display devices.

Learners will also need access to a range of manuals, reference data and manufacturers' products/information.

Indicative reading for learners

Textbooks

Bates M – *PIC Microcontrollers: An Introduction to Microelectronics*, 3rd edition (Newnes, 2011) ISBN 9780080969114

Evans B – *Beginning Arduino Programming: Writing Code for the Most Popular Microcontroller Board in the World* (Apress, 2011) ISBN 9781430237778

Mazidi M, Naimi S, Naimi S – *The AVR Microcontroller and Embedded Systems Using Assembly and C: Using Arduino Uno and Atmel Studio*, 2nd edition (MicroDigitalEd, 2017) ISBN 9780997925968

Unit 77: The Role of the Medical Engineer

Level: 3

Unit type: Pathway mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer. The role focuses on maintenance, testing, fault finding and decommissioning of medical equipment. Decontamination of medical equipment is also involved. The medical engineer provides vital technical support for colleagues and may act as a point of contact for customers, giving advice where needed.

In this unit, learners will explore statutory regulations and organisational safety requirements specific to health and safety in a medical engineering environment, including those relating to working with hazardous substances and appropriate personal protective clothing. They will look at the range of medical equipment that a medical engineer will encounter. Learners will investigate the computerised database systems used by medical engineers to track actions and store information relating to particular pieces of medical equipment. Finally, they will consider the importance of decontaminating medical equipment and how this is done, and will have the opportunity to put their understanding into practice.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Know the range of work undertaken by medical engineers
2. Understand statutory regulations and organisational safety requirements specific to health and safety in a medical engineering environment
3. Know the range of medical equipment used in each clinical area
4. Understand computerised database systems for maintenance of medical equipment
5. Understand the importance of decontamination of medical equipment
6. Be able to decontaminate medical equipment.

Unit content

1 Know the range of work undertaken by medical engineers

Testing of equipment: acceptance testing, scheduled testing and fault-finding of the range of medical equipment; routine activities within clinical engineering stores

Management of equipment: preparing medical equipment for issue from a medical equipment library, or returning from the repair process; performing decontamination of medical equipment in workshop prior to issue or decommissioning; monitoring and recording medical equipment during acceptance testing, scheduled testing, fault finding and decommissioning

Maintenance of database: monitoring and recording the movement of medical equipment between workshops, equipment libraries and clinical areas; recording the issue of equipment following acceptance testing; recording decontaminating and decommissioning of medical equipment

Technical support: assisting in technical support for medical equipment in wards and clinical areas; working on the helpdesk/reception unit taking calls/emails from customers; assisting with technical support when commissioning and replacing medical equipment when required by clinicians; advising regarding safety requirements within a medical engineering environment, providing first line and second line technical support

Use of information: the confidentiality legislation and procedures appropriate to correct use of information, e.g. checking the patient's personal data, appropriate measures to safeguard data including password protection

2 Understand statutory regulations and organisational safety requirements specific to health and safety in a medical engineering environment

Health and safety in a medical engineering environment: activities required by legislation, e.g. identification of hazards and risks, safe use of hazardous materials for the nine main groups of hazardous substances as defined by Classification, Packaging and Labelling of Dangerous Substances Regulations, wearing appropriate personal protective equipment, e.g. protective gloves, safety glasses, chemical splash goggles, face shields, safety shoes, barrier creams, hearing protection, dust masks, respirators, electrostatic discharge bands

Statutory legislation and regulations relevant to the medical engineering workplace: The Health and Safety at Work Act; The Personal Protective Equipment at Work Regulations; The Management of Health and Safety at Work Regulations; Control of Substances Hazardous to Health (COSHH); RIDDOR -– Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, Manual Handling Operations Regulations

Personal protective equipment to be used for specific medical engineering tasks: e.g. disinfection of returned medical equipment from clinical area (gloves, safety glasses), commissioning/decommissioning of medical equipment (safety shoes), cutting or drilling holes in equipment trolleys to make alterations as per specific requirements (hearing protection, dust mask, safety shoes, safety goggles), repair of medical equipment at electronic component level (electrostatic discharge (ESD) bands, ESD table mat)

Organisational safety arrangements: as appropriate to individual workplaces; how to locate relevant health and safety information for tasks, sources of expert assistance when help is needed; procedures to be followed in case of accidents involving injury; first aid facilities in work area and wider organisation; procedures for sounding emergency alarms, evacuation procedures and escape routes to be used

3 Know the range of medical equipment used in each clinical area

Cardiovascular equipment: a selection including non-invasive blood pressure and/or invasive blood pressure monitors, pulse oximeters, electrocardiography (ECG), external temporary pacemaker boxes, defibrillators

Physiological monitoring equipment: a selection including foetal heart monitoring devices, apnoea devices, thermometers, vital sign monitors, electroencephalogram (EEG), pulse oximeters, respiration monitors, audiometers, uroflow meters

Infusion equipment: a selection including feeding pumps, volumetric infusion pumps, syringe drivers, patient controlled analgesia pumps, ambulatory infusion pumps, dialysis machines

Medical therapeutic equipment: a selection including nerve stimulating devices, therapeutic ultrasound devices, therapeutic diathermy devices, traction devices, radiant heater warmers, hydrotherapy equipment, nebulisers, continuous positive airway devices, phototherapy devices, sequential compression devices (SCD)

Operating theatre and surgical equipment: a selection including electro-surgical generators, endoscopes, anaesthesia machines, ventilators, balloon pumps, video equipment, tourniquets, sterilizers, warmers

Patient beds, trolleys, operating tables and assistive technology equipment: a selection including standard ward beds, trolleys, operating tables, wheelchairs, scooters, stair lifts, hoists, walking aids

Medical imaging equipment: a selection including ultrasound scanners, diagnostic x-ray, CT scanners, MRI scanners, linear accelerators, radiation monitoring equipment

Dental equipment: a selection including suction units, drilling units, dental air compressors, dental scalers, dental handpieces, polymerisation units, floor utility service units, dental lighting, amalgamators, amalgam separators

Laboratory equipment: a selection including centrifuges, Coulter counters, particle counters, blood gas analysers, ion selective analysers, flame photometers, chloride meters, pH meters, spectrophotometers, colorimeters, water baths, roller beds, cryostats

4 Understand computerised database systems for maintenance of medical equipment

Database systems: computerised Information Management Systems used to record the work of a medical engineer, such as management of stock of spare parts, equipment and consumables for maintenance, repair or technical use, time-ordered data for routine maintenance of clinical equipment, contact details for the manufacturer/supplier of equipment, all testing records (including acceptance testing and decommissioning), device manuals, buying/acquisition records, software manuals and related documents

5 Understand the importance of decontamination of medical equipment

Decontamination: reasons why medical equipment must be decontaminated on arrival at the workshop and before issue to clinical staff and areas; standard methods of decontamination, e.g. 5% solution of sodium hypochlorite, detergent wipes, alcohol wipes; difference between cleaning, disinfection and sterilisation; use of decontamination certificate

6 Be able to decontaminate medical equipment

Decontaminate: clean and disinfect medical equipment according to Standard Operating Procedures (SOPs), manufacturers' instructions, organisational requirements, relevant legislation and standards, e.g. The Health & Social Care Act: Code of Practice on the prevention and control of infections and related guidance, The Health and Safety at Work Act, The Management of Health and Safety at Work Regulations, The Control of Substances Hazardous to Health (COSHH) Regulations, MHRA's Managing Medical Devices – Guidance for healthcare and social services organisations

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the role of a medical engineer with respect to the testing of equipment		
P2 describe the role of a medical engineer with respect to the management of equipment	**M1** explain what is meant by first line technical support in medical engineering	
P3 describe the roles and responsibilities of self and employer under the Health and Safety at Work Act and other current legislation relating to health and safety		**D1** evaluate organisational safety arrangements in relation to the work of the medical engineer
P4 describe the personal protective equipment to be used for three medical engineering tasks		
P5 give three examples of medical equipment used in each clinical area	**M2** describe the operational function of three different types of medical equipment from three different clinical areas	
P6 describe how to use databases that are required by medical engineers		**D2** justify the importance of maintaining up-to-date databases for medical engineers

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe two reasons for decontaminating medical equipment when it arrives at the workshop		
P8 describe the standard methods of decontamination	**M3** explain the differences between cleaning, disinfection and sterilisation	
P9 clean and disinfect any four pieces of medical equipment in accordance with Standard Operating Procedures, manufacturers' instructions, organisational requirements and relevant legislation and standards		

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show proficiency in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Six assignments could be set for the assessment of this unit.

Assignment 1 will require learners to give details of the main aspects of the role of the medical engineer. For P1, learners need to describe the work of the medical engineer with respect to the testing of equipment (P1), and this must cover acceptance testing, scheduled testing and fault-finding as a minimum, with specific medical engineering examples for all three types of testing. For P2, learners need to describe the role of a medical engineer with respect to the management of equipment, by using one example to cover how a piece of equipment that has been repaired would be correctly reissued back into service. For M1, learners need to explain what is meant by first line technical support in medical engineering, by using a specific example to cover what a medical engineer would and would not be able to do in a first line support scenario.

For Assignment 2, learners are required to consider how safety requirements and arrangements affect them in their role as a medical engineer. For P3, learners should use medical engineering examples to describe their own responsibilities under the Health and Safety at Work Act, as well as the responsibilities of their employer. For P4, learners need to describe the full range of personal protective equipment to be used for three medical engineering tasks, such as disinfection of returned medical equipment from clinical area, commissioning/decommissioning of medical equipment, repair of medical equipment where electronic components are exposed, cutting or drilling holes in equipment trolleys to make alterations as per specific requirements, carrying out electrical safety tests on a device, repair of jammed wheels of a medical device or patient trolley. For D1, learners need to evaluate organisational safety arrangements in relation to the work of the medical engineer, and this requires a specific response that makes judgements about the provision of guidance and the appropriateness of first aid facilities, alarms, evacuation procedures and escape routes in areas of the organisation where the medical engineer will work on a regular basis.

For Assignment 3, learners are required to reflect on types of medical equipment. For P5, learners must give three examples of medical equipment used in each clinical area. They must correctly allocate three different pieces of medical equipment to each of the nine clinical areas set out in the unit content for learning outcome 3 – a total of 27 different examples. For M2, learners need to describe the operational function of three different types of medical equipment from any three of the different clinical areas – a total of 9 different examples. The operational function for each will include full reference to set-up/start-up, normal working and close down/storage.

For Assignment 4, learners will consider databases. For P6, learners need to describe how to use databases that are required by medical engineers, by covering those that are used to register, track, monitor and reorder medical equipment and spare parts as a minimum. For D2, learners will need to justify the importance of maintaining up-to-date databases for medical engineers, with specific examples of what could go wrong in a medical environment if they are not constantly updated in real time.

For Assignment 5, learners are required to give details about medical engineering decontamination. For P7, learners must describe two reasons for decontaminating medical equipment when it arrives at the workshop by using specific medical engineering examples to clarify why decontamination is so important. For P8, learners need to describe the standard methods of decontamination. This must include the physical processes needed for the different stages of decontamination, as well as the chemicals involved and their safe handling and disposal. For M3, learners will need to explain the differences between cleaning, disinfection and sterilisation by giving specific medical engineering examples of where each process would be used on a piece of equipment and why that process is more suitable than the other two.

For Assignment 6, learners need to clean and disinfect any four pieces of medical equipment in accordance with Standard Operating Procedures (SOPs), manufacturers' instructions, organisational requirements and relevant legislation and standards. P9 is assessed through practical work, with learners demonstrating their proficiency in cleaning and disinfecting four different pieces of medical equipment so they are ready to be worked on/maintained. Learners should keep a logbook with annotated photographs and a space for the qualified witness/tutor comments.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	The Role of the Medical Engineer	You are an apprentice medical engineering technician and your supervisor has asked you to produce a guide for new apprentices on the main aspects of the role of a medical engineer. You will need to cover testing/management of medical equipment and providing first line technical support.	Written report, leaflet or PowerPoint slides
P3, P4, D1	Safety as a Medical Engineer	You are an apprentice medical engineering technician and your supervisor has now asked you to explain to one of the new apprentices how the Health and Safety at Work Act and other relevant legislation will affect them and the personal protective equipment that they will need to use for different tasks. You also need to provide some details about organisational safety arrangements.	Written report

Criteria covered	Assignment title	Scenario	Assessment method
P5, M2	Medical Equipment	You are an apprentice medical engineering technician and your supervisor has now asked you to produce a guide for the new apprentices on the different types of medical equipment they will encounter in different clinical areas and how they are used.	Written report, poster or PowerPoint slides
P6, D2	Databases for Medical Engineers	You are an apprentice medical engineering technician and one of the new apprentices has asked you about the databases used in your workplace. You need to give them the details and also explain why it is important, as a medical engineer, to keep databases up to date.	Written report
P7, P8, M3	Decontaminating Medical Equipment	You are an apprentice medical engineering technician and your supervisor has now asked you to produce notes for the new apprentices about cleaning, disinfection, sterilisation and decontamination of medical equipment, including the differences between the processes and how they are carried out.	A written report with labelled diagrams or labelled diagram with notes for verbal explanation

Criteria covered	Assignment title	Scenario	Assessment method
P9	Practical Activities Relating to Cleaning and Disinfecting Medical Equipment	As part of your role as an apprentice medical engineering technician, you need to clean and disinfect a range of medical equipment.	Logbook with annotated photographs to detail proficiency in all aspects of cleaning and disinfecting the relevant medical equipment

Essential resources

Learners will need access to a medical engineering workshop with a range of medical equipment.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://worksmart.org.uk/work-rights/health-and-safety/rights-and-responsibilities/employee-what-legal-duties-are-placed-me	Legal duties of employees under the Health and Safety at Work Act
https://www.bcpft.nhs.uk/documents/policies/i/881-infection-prevention-and-control-assurance-sop-7-decontamination/file	Example of Standard Operating Procedures for medical equipment decontamination in an NHS trust
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance
https://www.ebme.co.uk/articles/management/acceptance-testing-of-medical-equipment	Acceptance testing, including record keeping, acceptance checks and safety, availability and suitability of equipment
https://www.healthcareers.nhs.uk/explore-roles/healthcare-science/roles-healthcare-science/physical-sciences-and-biomedical-engineering/medical-engineering	The role of the medical engineer
https://www.qcs.co.uk/what-is-the-difference-between-cleaning-disinfection-and-sterilisation/	Cleaning information
https://www.srft.nhs.uk/EasysiteWeb/getresource.axd?AssetID=32711&type=full&servicetype=Inline	Example of a cleaning, disinfection and sterilisation policy in an NHS trust
https://www.ukstandards.org.uk/PublishedNos-old/MAN123%2001%20New%20version.pdf	National Occupational Standards for complying with statutory regulations and organisational safety requirements

Unit 78: Acceptance Testing, Maintaining, Fault Finding and Decommissioning of Medical Equipment

Level:	**3**
Unit type:	**Pathway mandatory**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in acceptance testing, maintaining, fault finding and decommissioning medical equipment.

Electrical medical equipment plays a key role in healthcare, being vital for diagnosis, therapy, monitoring and rehabilitation. Effective acceptance testing, maintenance, fault finding and disposal of this equipment is essential in providing high quality patient care, ensuring smooth and safe running of the system, reducing waste of resources and time, and minimising incidents that cause harm to patients. The equipment must be managed proactively, with scheduled maintenance and replacement of parts, to prevent repetition of adverse incidents.

Medical engineers need to know the systems in place for planning, carrying out and recording acceptance testing, scheduled maintenance and fault finding activities for electrical medical equipment, along with reporting issues arising from these activities. Knowledge of the consequences of inadequate maintenance, testing and calibration is also required. Procedures associated with decommissioning and disposal should also be understood.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of electrical medical equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the importance of the acceptance process for new medical equipment

2 Be able to perform acceptance testing on a range of new medical equipment

3 Know electrical risks and statutory regulations designed to minimise these risks within a medical engineering environment

4 Understand the importance of and techniques for scheduled maintenance of medical equipment

5 Know how to find faults in medical equipment in accordance with Standard Operating Procedures, manufacturers' instructions and legislation

6 Understand the procedures involved in the safe decommissioning and disposal of electrical medical equipment.

Unit content

1 Understand the importance of the acceptance process for new medical equipment

Importance of the acceptance process: health and safety of users, e.g. patients, medical engineers, clinicians; ensuring equipment is fit for purpose, e.g. ensuring equipment can run at full capacity, making sure any existing peripheral equipment fits correctly and still operates effectively; training for use; preventing waste of time and resources by identifying problems at the earliest opportunity

Steps in the acceptance process: inspection, mechanical safety testing, calibration or set-up tests, functional tests; purpose of each step; how each step protects users

2 Be able to perform acceptance testing on a range of new medical equipment

Classes and types of medical equipment based on method and degree of protection against electric shock: classes: I, II, III; types: B, BF, CF; symbol and definition for each type; reasons for class and type categorisation

Acceptance testing: Standard Operating Procedures; inspection, e.g. any damage to enclosure or peripheral parts, dislocation, excessive pressure or damage to display (LCD), integrity of power cables and connecting tubes; mechanical safety testing, e.g. fittings and fixtures, trolleys, stands and wheels, joints connected with other devices or fixed points on walls or ceiling; calibration or set-up tests, e.g. infusion and syringe pump, defibrillator; functional tests, e.g. use of simulating test equipment to do functional test of ECG, SpO_2, NIBP, Doppler monitor etc; completion of acceptance test report form; inclusion of device on equipment register

3 Know electrical risks and statutory regulations designed to minimise these risks within a medical engineering environment

Risks of electric shocks and effects of electric shock on body: e.g. cardiac arrest, burns to tissues and organs, muscle spasms, impact on the nervous system

Specific electrical safety tests for medical equipment: sequence of operations, tools and equipment required, health and safety control measures, observed and required outcomes; normal condition and single fault conditions; protective earth continuity; insulation tests; leakage current measuring device; earth leakage current; enclosure leakage current or touch current; patient leakage current; patient auxiliary current; mains on applied parts (patient leakage)

Statutory regulations: relevant regulations and location of information: e.g. scope, object, principles and use of relevant parts of statutory wiring, installation and site regulations: Health and Safety at Work Act, Electricity at Work Regulations, Electricity Safety, Quality and Continuity Regulations, Electrical Equipment (Safety) Regulations, Electromagnetic Compatibility Regulations, International Electrotechnical Commission (IEC) standards

Organisational requirements: how statutory regulations are implemented within the specific workplace; the role of specific individuals

4 Understand the importance of and techniques for scheduled maintenance of medical equipment

Importance of maintenance: increasing operational efficiency; reducing down-time; ensuring safety of patients; ensuring safety of staff; prevention/reduction of normal-running damage to equipment; reducing risk of catastrophic damage to equipment

Schedule: differing schedules: continuous, daily, weekly, annually, e.g. what should be done on a daily/weekly basis, by whom, how long it will take and the tools/equipment and documentation required; use of a chart/roster showing responsibilities of individuals/groups and relevant dates, including substitutes for those sick or on holiday

Record keeping: schedule specification from the manufacturer for most equipment detailing routines: frequency of maintenance, expected lifetimes; manuals and reference documentation may contain functional charts, diagrams, flow charts, troubleshooting charts, component data sheets, operation and maintenance manuals, notes of specialised equipment needed; software-based schedules may be linked to record keeping files to include accurate details of observations, test results, faults, replacement parts; constant vigilance, e.g. staying observant, spotting irregularities; knowing the procedure for reporting the unexpected

Scheduled maintenance: regular cleaning of equipment using appropriate safety precautions; daily/weekly visual checks, e.g. casings, connector cables, plugs and sockets, particularly for devices regularly connected/disconnected; continual checks for 'low battery' warnings; inspection of battery chargers; decontamination where appropriate; checking expected recharge dates; recharging devices for the specified time and voltage setting; stock rotation where appropriate

Accessing maintainable equipment: ensuring disconnection from mains supply; ensuring decontamination; removing covers for batteries or fuses; checking their details; sourcing replacements; installing; re-covering; testing safety and functionality

5 Know how to find faults in medical equipment in accordance with Standard Operating Procedures, manufacturers' instructions and legislation

Preparation for fault finding: referring to manufacturer's maintenance documentation; following Standard Operating Procedures and protocols; complying with relevant legislation; collecting personal protective equipment; ensuring the safe isolation of equipment (mechanical, electrical, gas, air, fluids); following decontamination procedures; applying electrostatic discharge (ESD) protection procedures when handling sensitive components

Fault finding: collecting evidence from, e.g., the person who reported the fault, visual inspection, other sensory input (sound, smell, touch), servicing records, fault reports; using a range of test equipment: multimeter, oscilloscope, signal generator, electrical safety analyser, temperature measuring devices, flow measuring devices, pressure measuring devices; using fault-diagnostic techniques: input/output technique, half-split technique, unit substitution, function testing; using a range of diagnostic aids: manuals, flow charts, troubleshooting guides, maintenance records

6 Understand the procedures involved in the safe decommissioning and disposal of electrical medical equipment

Decommissioning: purpose, e.g. to render devices safe and unusable while minimising environmental damage; seeking and following manufacturer's (or MHRA's) advice; ensuring power disconnection; ensuring cooling system disconnection; erasing stored patient data by overwriting

Disposal: duties imposed on manufacturers by The Waste Electrical and Electronic Equipment Regulations; requirement to consult regulations regarding disposal; need for specialised disposal of devices containing certain metals such as mercury, some batteries; correct disposal of devices containing batteries: pacemakers, neuro-stimulators, defibrillators, drug pumps

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe why new medical equipment needs to be acceptance tested before use		**D1** justify the importance of each step of acceptance testing in terms of the health and safety of the users of the medical equipment
P2 describe the different classes and types of medical equipment	**M1** explain why medical equipment is categorised into a class and type	
P3 carry out acceptance testing of two pieces of new medical equipment according to local Standard Operating Procedures		
P4 describe how electric shock affects the physiology of the body		
P5 describe the procedures to carry out two electrical safety tests on one piece of medical equipment	**M2** explain how two statutory electrical regulations are applied when carrying out two electrical safety tests on one piece of medical equipment	
P6 plan a preventative maintenance schedule for one piece of medical equipment	**M3** explain the importance of scheduled maintenance of medical equipment	
P7 describe how to diagnose a fault for one piece of medical equipment using approved procedures		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 describe how to decommission and dispose of one piece of electrical medical equipment		**D2** justify the importance of correct decommissioning and disposal of obsolete electrical medical equipment

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show proficiency in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Five assignments could be set for the assessment of this unit.

Assignment 1 will require learners to focus on acceptance testing as a medical engineer and the classes and types of medical equipment. For P1, learners must describe why new medical equipment needs to be acceptance tested before use, by providing at least three valid reasons, only one of which can be directly related to health and safety. For D1, learners need to justify the importance of each step of acceptance testing in terms of the health and safety of the users of the medical equipment. The steps should cover inspection, mechanical safety testing, calibration or set-up tests and functional tests and the users should include patients, medical engineers and clinicians. For P2, learners need to describe the different classes and types of medical equipment, including I, II and III, and B, BF and CF and the symbols used for each type. For M1, learners need to explain why medical equipment is categorised into a class and type with three different and specific examples, such as vital signs monitor, ECG device, infusion pump, CPAP machine, battery operated blood pressure monitor.

For P3, learners need to follow the Standard Operating Procedures of their organisation to carry out acceptance testing of two new pieces of medical equipment. The two pieces of medical equipment should be of a different class and type, and the acceptance testing process for each must include inspection, mechanical safety testing, calibration or set-up tests and functional tests. Learners should keep a logbook with annotated photographs and a space for the qualified witness/tutor comments.

Assignment 2 will require learners to focus on electrical safety testing as a medical engineer. For P4 learners need to describe how electric shock affects the physiology of the body. All of the effects stated in the unit content for learning outcome 3 should be covered by the learner. For P5, learners must describe the procedures to carry out two electrical safety tests on one piece of medical equipment. This will include the correct sequence of operations, all tools and equipment required, health and safety control measures as well as the required outcomes. For M2, learners will explain how two statutory electrical regulations are applied when carrying out two electrical safety tests on one piece of medical equipment. This will relate to the procedures described for P5, and requires learners to refer to the relevant aspects of the two electrical regulations and how they are applied during the two electrical safety tests on the medical equipment.

Assignment 3 requires learners to consider scheduled maintenance for medical equipment. For P6, learners will need to produce a preventative maintenance schedule for one piece of medical equipment, including what should be done on a daily/weekly basis, by whom, how long it will take and the tools/equipment and documentation required. Learners should generate their own template documentation for this. For M3, learners also need to explain why scheduled maintenance of medical equipment is important, by providing at least three reasons and relating them to specific medical engineering examples.

Assignment 4 requires learners to describe how to diagnose a fault for one piece of medical equipment using approved procedures. For P7, learners need to cover collecting evidence, visual and other types of sensory inspection, servicing records, fault reports, using a range of test equipment and diagnostic techniques and aids. Consequently, the fault should not be obvious.

Assignment 5 requires learners to consider the decommissioning and disposal of medical equipment. For P8, learners need to describe how to decommission and dispose of one piece of electrical medical equipment and must itemise and detail all of the steps to be taken to ensure safe end-of life decommissioning and disposal that also ensures data destruction and minimises environmental impact. For D2, learners must justify the importance of correct decommissioning and disposal of obsolete medical equipment with specific examples of what could happen if either is carried out incorrectly or some steps are not taken.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Acceptance Testing of New Medical Equipment	You are an apprentice medical engineering technician and your supervisor has asked you to show a group of new apprentices how to carry out acceptance testing for two new pieces of medical equipment. You have also been asked to prepare notes for them giving reasons for acceptance testing and why each step of the process is important in terms of the health and safety of users, and providing information about the different classes and types of medical equipment.	Written notes (approximately two sides of A4) and a logbook supported by observation records
P4, P5, M2	Electrical Safety Testing of Medical Equipment	You are an apprentice medical engineering technician and your supervisor has asked you provide a report on how electric shock affects the physiology of the body, and the procedures used and regulations applied to carry out electrical safety tests on medical equipment, so they can justify an increase in resources for these activities.	Written report

Criteria covered	Assignment title	Scenario	Assessment method
P6, M3	Preparation for Scheduled Maintenance of Medical Equipment	You are an apprentice medical engineering technician and your supervisor has asked you to prepare a preventative maintenance schedule for a piece of equipment and to explain to new apprentices why scheduled maintenance is so important.	A suitable maintenance schedule and a written report detailing reasons why scheduled maintenance of medical equipment is needed
P7	Fault Finding for Medical Equipment	You are an apprentice medical engineering technician and your supervisor has asked you to produce PowerPoint slides setting out fault-finding procedures for a piece of medical equipment.	PowerPoint slides
P8, D2	Decommissioning and Disposing of Electrical Medical Equipment	You are an apprentice medical engineering technician and your supervisor has asked you to produce an information booklet for new apprentices describing the processes involved in decommissioning and disposing of a piece of medical equipment. Your booklet also needs to give reasons why it is so important that each step is carried out correctly.	Information booklet including diagrams

Essential resources

Learners will need access to a range of medical equipment of different classes and types, suitable for acceptance testing, maintenance, fault finding and decommissioning. They will also need access to appropriate testing devices, manufacturers' information and fault reports.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

apps.who.int/bookorders/anglais/detart1.jsp?codlan=1&codcol=93&codcch=264&content=1	Medical equipment maintenance programme overview – WHO Medical Device Technical Series
assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/421028/Managing_medical_devices_-_Apr_2015.pdf	Managing medical devices: Chapter 5: Receiving a new device Chapter 8: Maintenance and repair Chapter 9: Decontamination Chapter 10: Decommissioning and disposal of devices
www.bcpft.nhs.uk/documents/policies/m/918-medical-devices-sop-3-acceptance-of-medical-devices/file	Example of Standard Operating Procedure for acceptance of medical devices in an NHS trust
www.ebme.co.uk/articles/electrical-safety/test-and-inspection-protocols	Example inspection and test protocol
www.ebme.co.uk/articles/electrical-safety/classes-and-types-of-medical-electrical-equipment	Definitions of classes and types of devices and symbols used

www.ebme.co.uk/articles/electrical-safety/electrical-safety-tests	Description of various electrical safety tests, e.g. protective earth continuity, insulation and leakage currents
www.ebme.co.uk/articles/maintenance/fault-finding-on-medical-electronic-devices	Step-by-step guidance on fault finding
www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance, advocating proactive rather than reactive management

Unit 79: Anatomy, Physiology and Measurement

Level: 3

Unit type: Pathway mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The human body is made up of many different systems that work together and allow us to take part in a huge variety of activities. Having an understanding of body systems is important in understanding the relevance of measurements used within medical engineering. When our systems fail to function, the baseline measures provide guidance for determining the relevance of changes in those measures linked to ill health.

In order to appreciate how each of the body systems function, you will consider the levels of organisation within the human body and explore the structure and functions of the body systems, as well as factors that affect normal functioning of our physiology. You will further explore the significance of the interrelationships between these body systems and their collaborative functioning.

You will be required to use physiological measurements to determine the health status of an individual and to consider the contribution of regular monitoring in supporting health and making diagnostic assessments.

Learning outcomes

On completion of this unit a learner should:

1 Understand the levels of organisation within the human body

2 Understand the structure and functions of the body systems

3 Be able to carry out and interpret physiological measurements of the cardiovascular and respiratory systems

4 Understand how physiological measurement is used in the treatment of health conditions.

Unit content

1 Understand the levels of organisation within the human body

Anatomy and physiology: definitions; difference between the two

Organisation: cells; tissues; organs; organ systems

Cells: characteristics of eukaryotic cells; cell membrane, nucleus, cytoplasm; organelles – mitochondria, endoplasmic reticulum (smooth and rough), Golgi apparatus, lysosome

Tissues: epithelial tissue: simple (cuboidal, columnar, squamous, ciliated), compound (simple, keratinised); connective tissue: includes blood, cartilage, bone, areolar, adipose; muscle tissue: striated, non-striated, cardiac; nervous tissue: neurones, neuroglia; examples of where each tissue type might be found

Body organs: location and function of heart, lungs, brain, stomach, liver, pancreas, duodenum, ileum, colon, kidneys, bladder, ovaries/testes, uterus; structure and function of the skin

2 Understand the structure and functions of the body systems

Main structures and functions of body systems:

Cardiovascular system: heart – structure, cardiac cycle, blood vessels; pulmonary and systemic circulation; structure and function of the blood

Respiratory system: role of air passages in the nose; structure and functions of trachea, bronchi, alveoli; intercostal muscles; diaphragm; ventilation, gaseous exchange, diffusion

Digestive system: alimentary canal – role of digestive system in breakdown and absorption of food materials; role of enzymes in digestion

Renal system: functions of the kidneys; maintaining overall fluid balance; regulating and filtering minerals from blood; filtering waste materials; hormone production to support production of red blood cells, promote bone health, regulate blood pressure

Nervous system: central nervous system (CNS); peripheral nervous system – motor neurones, sensory neurones, nerve cells; parasympathetic nervous system and sympathetic nervous system; conduction of nerve impulses to and from the CNS

Endocrine system: hypothalamus; pituitary gland; thyroid gland; pancreas; adrenal glands – the 'fight or flight' response via the hormone adrenaline

Reproductive systems: female: reproductive functions of ovaries, fallopian tubes, uterus, cervix, vagina, vulva; male: reproductive functions of penis, urethra, scrotum, testes, vas deferens, seminal vesicles

Muscular system: how muscles are attached to the body; function of the muscular system: movement; antagonistic pairs; location and action of major muscles

Skeletal system: axial skeleton; appendicular skeleton; types of bone; location of major bones; joints; function of skeletal system: support; protection; attachment for skeletal muscle; source of blood cell production; store of minerals

Lymphatic system/immune system: lymphatic vessels; lymph organs, functions of the lymphatic system; outline of defensive role

Abnormal functioning of body systems due to health conditions: diabetes; cardiovascular disease; kidney disease; asthma; obesity; obstructive airway disease; respiratory disease; infections

Homeostasis: definition; concept of negative feedback as a regulatory mechanism

Homeostatic mechanisms for regulation of heart/respiratory rate: roles of internal receptors, autonomic nervous system – sympathetic and parasympathetic nerve supply, cardiac centre, sinoatrial node; effects of increased body temperature and adrenaline on heart rate and breathing rate

Homeostatic mechanisms for regulation of body temperature: production of heat by the body through metabolic processes; loss of heat by the body; roles of hypothalamus, autonomic nervous system – sympathetic and parasympathetic, skin – role of arterioles and sweat glands; effects of shivering; implications of surface area to volume ratios; fever; blood glucose levels: roles of pancreas, liver, insulin, glucagon

3 Be able to carry out and interpret physiological measurements of the cardiovascular and respiratory systems

Physiological measurements: definition; concept of baseline measurements

Types of measurement:

Measurement of temperature: normal temperature; fluctuations; high temperature as a sign of infection; equipment and techniques for measuring temperature

Measurement of blood pressure: normal parameters; systolic and diastolic blood pressure, equipment and techniques for measuring blood pressure

Measurement of pulse rates: normal pulse rate limits; factors affecting the raising or lowering of pulse rates, e.g. illness, gender, age, body temperature, pain, exercise, blood pressure; pulse sites on the body, e.g. carotid, brachial, ulnar femoral; techniques for taking pulse rate

Measurement of pulse oximetry: normal levels; possible conditions affecting blood oxygen level; risks of low levels; analysis and implications of pulse oximetry findings, O2 saturation level, possible causes of incorrect readings; equipment and techniques for measuring blood oxygen levels

Measurement of respiratory rate: normal rates; implications of a change in respiratory rate; techniques for measuring respiratory rate

Measurement of heart electrical activity: use of electrocardiograph (ECG) to measure the rate, rhythm and electrical activity of the heart; circumstances in which ECG is used; techniques for use of ECG

Measurement of peak flow: normal scores; use in managing asthma; equipment and techniques for measuring peak flow

Importance of accuracy in physiological measurements: effects of poor quality measurements, e.g. impairment of reliable diagnosis and prognosis, stress to service users, waste of resources, requirement for repeat tests, delay to effective treatment

4 Understand how physiological measurement is used in the treatment of health conditions

Common health conditions that require recording/monitoring of physiological measurements: hypertension; hypotension; diabetes; cardiovascular disease; kidney disease; asthma; obesity; obstructive airway disease; respiratory disease; infections

The importance of undertaking physiological measurements in healthcare settings: to ensure the patient's health status pre- and post-surgery; baseline measurements when commencing new treatment programmes; in intensive care; medications that require physical measurement taken; monitoring for signs of abnormality; to draw conclusions about the patient's health status and any treatment they may require

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 define the difference between anatomy and physiology	**M1** explain the relationship between cells, tissues, organs and organ systems in the organisation of the human body	
P2 describe how the eukaryotic cell is organised in terms of the functions of the organelles		
P3 describe four different tissue types and the function of each in the human body	**M2** explain the tissues that make up three major organs in the human body and the function of each of the three organs	
P4 describe the structure and function of five body systems	**M3** explain the ways that two body systems interact to support the normal functioning of the human body	
P5 describe the abnormal functioning of body systems as a result of two different health conditions	**M4** explain the process of homeostasis with two examples	**D1** assess the contributions of organs and organ systems to the maintenance of homeostasis in the human body
P6 describe the ways that baseline measurements of the cardiovascular and respiratory systems are carried out	**M5** explain the causes of deviations in measurements in relation to the functioning of the cardiovascular and respiratory systems	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 accurately carry out and record measurements of the normal functioning of the cardiovascular and respiratory systems	**M6** compare and contrast the measurements obtained with the normal parameters of those measures	**D2** analyse the importance of accuracy and the effective recording of physiological measurements
P8 describe four common health conditions that require regular recording of physiological measurements		
P9 explain the importance of undertaking physiological measurements in healthcare settings		**D3** evaluate the use of physiological measurements in the diagnosis and treatment of two common health conditions

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria could be collected from reports, case studies and practical work.

For this unit, learners will need access to equipment in order to carry out non-invasive physiological measurements, perhaps on peers. Permission should be sought before any measurements are taken.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three assignments could be set for the assessment of this unit. Many of written responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams and images are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 will require learners to consider cells, tissues, organs and systems and homeostasis as a medical engineer. For P1, learners will need to describe the difference between anatomy and physiology and should include at least two examples of the specific differences. For P2, learners are required to describe how a eukaryotic cell is organised in terms of the function of the organelles. This should cover each type of organelle and the activities that they carry out. This could take the form of an annotated model or poster with a detailed key to cover each organelle. For P3, learners must describe the four different tissue types (epithelial, connective, muscle, nervous) and the function of each in the human body, again with specific examples. For M1, learners must explain the relationship between cells, tissues, organs and organ systems in the organisation of the human body, again with two examples, such as the digestive system and the nervous system. For M2, learners need to explain the tissues that make up three major organs in the human body (such as the stomach, kidney and heart), referring both to the tissue types and to the specialist cells that make up the types of tissues in these organs. They need to show understanding that each of these organs is made up of complex layers of these tissues with specialist functions. Learners also need to explain the function of the three organs in the human body. This could be achieved through the creation of a booklet or presentation. For P4, learners need to describe the structure and normal functioning of five body systems, and can cover any five from those listed in the unit content for learning outcome 2. For M3, learners need to explain the ways that two body systems interact to support the normal functioning of the human body, for example by covering the way that the cardiovascular system supports the functioning of the respiratory system to provide a person with energy. For P5, learners must describe the abnormal functioning of body systems as a result of two different health conditions from those listed in the unit content for learning outcome 2, such as diabetes and infection. For M4, learners must provide an explanation of the process of homeostasis with two examples from those listed in the unit content for learning outcome 2, such as the effects of increased body temperature and adrenaline on heart rate and breathing rate and changing blood glucose levels. For D1, learners must assess the contributions of organs and organ systems to the maintenance of homeostasis in the human body. This requires a detailed response that covers at least two organs and organ systems and also details the consequence of homeostatic dysfunction.

Assignment 2 requires learners to consider and carry out physiological measurements related to the cardiovascular and respiratory systems as a medical engineer. For P6, learners need to describe the ways that baseline measurements of the cardiovascular and respiratory systems are carried out, and this should cover blood pressure, pulse rates, pulse oximetry, respiratory rate, heart electrical activity and peak flow. For M5, learners must explain the causes of deviations in measurements in relation to the functioning of the cardiovascular and respiratory systems. This could be based on the use of case studies, with learners considering the meaning of at least four deviations in readings (for example, blood pressure, pulse rates, respiratory rate, heart electrical activity) from the normal parameters and then relating their findings to the functioning of the systems. For P7, learners are required to accurately carry out and record measurements of the normal functioning of the cardiovascular and respiratory systems. All six (blood pressure, pulse rates, pulse oximetry, respiratory rate, heart electrical activity and peak flow) must be measured and recorded and the learner could provide annotated photographs/a data table for this as well as the tutor providing an observation record. For M6, learners need to compare and contrast the measurements obtained (for P7) with the normal parameters of those measures. If all of the measurements physically taken are within normal parameters the tutor should provide six theoretical measurements (one each for blood pressure, pulse rates, pulse oximetry, respiratory rate, heart electrical activity and peak flow) that are outside of normal parameters so that learners can detail the measurement differences both numerically and graphically. For D2, learners must analyse the importance of accuracy and the effective recording of physiological measurements. This should focus on the care of individuals with health conditions and must provide several specific examples of where accuracy in the recording of physiological measurements will make a difference to how clinicians respond to the information provided.

Finally, Assignment 3 requires learners to consider as a medical engineer the use physiological measurements in relation to common health conditions. For P8, learners need to describe four common health conditions that require regular recording of physiological measurements and can cover any four from those listed in the unit content for learning outcome 4. For P9, learners need to explain the importance of undertaking physiological measurements in healthcare settings, and this should cover at least three examples taken from those listed in the unit content for learning outcome 4, such as pre/post surgery, in intensive care and when considering new treatments. For D3, learners will need to evaluate the use of physiological measurements in the diagnosis and treatment of two common health conditions, such as hypertension and diabetes, and must cover both healthcare and home settings as well as the advantages and disadvantages of both settings when considering frequency, accuracy and efficacy.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, M1, M2, M3, M4, D1	Cells, Tissues, Organs and Systems and Homeostasis as a Medical Engineer	You are an apprentice medical engineering technician working in a hospital. Your supervisor has asked you to produce training materials to support new apprentices in understanding cells, tissues, organs and systems and homeostasis as a medical engineer.	Written report, annotated model, poster, presentation, booklet etc with diagrams/images
P6, P7, M5, M6, D2	Physiological Measurements of the Cardiovascular and Respiratory Systems as a Medical Engineer	You are an apprentice medical engineering technician and your supervisor has asked you to explain and demonstrate to the new apprentices how to carry out physiological measurements and record and interpret the results.	Written report, annotated photographs, tutor observation record, data tables, graphs
P8, P9, D3	The Use of Physiological Measurements in Relation to Common Health Conditions as a Medical Engineer	You are an apprentice medical engineering technician and your supervisor has asked you to produce an evaluative essay on the use of physiological measurements in the diagnosis and treatment of common health conditions.	Essay

Essential resources

Learners will require access to a range of equipment, including thermometers, peak flow meters, sphygmomanometers, heart rate monitors and pulse oximeters.

Indicative reading for learners

Textbooks

Boyle M, Senior K – *Human Biology*, 3rd edition (Collins Educational, 2008) ISBN 9780007267514

Fullick A – *Body Systems and Health (Life Science In Depth)* (Heinemann, 2006) ISBN 9781403475190

Johnson M – *Human Biology: Concepts and Current Issues*, 8th edition (Pearson, 2016) ISBN 9780134042435

Nisha G, Prince J, Sundaram S – *Bio-Medical Instrumentation: Medical Applications* (Lambert Academic Publishing, 2020) ISBN 9786200549532

Waugh A, Grant A – *Ross & Wilson Anatomy and Physiology in Health and Illness*, 13th edition (Elsevier, 2018) ISBN 9780702072765

Webster J – *The Physiological Measurement Handbook* (CRC Press, 2014) ISBN 9781439808474

Websites

www.bbc.co.uk/health	BBC Health
www.biologyguide.net	A-level revision site for biology
www.nhs.uk/conditions	A-Z information on health conditions
www.physoc.org	The Physiological Society

Unit 80: ICT for Medical Engineers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the importance of secure IT systems in a clinical setting. Modern medical record keeping generates a vast amount of data about patients, much of which is sensitive or personal. The quantity of data rules out physical filing systems, and the Data Protection Act, which implements the General Data Protection Regulation (GDPR), requires us to treat data with respect and utmost confidentiality and security.

A medical engineer needs to know the fundamentals of IT systems, from the hardware devices to the firmware and software that are run on them, and how they are used in healthcare contexts. The interconnectivity of a system provides useful ease of access but also security problems. Knowledge of IP addresses and network topology enables the engineer to understand how to undertake basic fault finding. Physical connectivity and the use of command line controls such as PING and TRACERT will be considered in this unit, as will port forwarding.

Multi-level security measures (the access control level, the hardware level and the network level) will be considered as a means of both encrypting and securing confidential data in transit and at rest.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the importance of maintaining a safe and secure network to ensure compliance with the principles of data protection and the ethics of modern medicine.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how to apply protective standards and regulations for data protection

2 Understand the fundamentals of hardware and software as applied to medical systems, networking, communications and healthcare information systems

3 Know how to apply the fundamentals of network topology

4 Know how to troubleshoot computerised medical devices and networks using appropriate diagnostic tools

5 Understand the principles of system and network security and actions necessary to ensure regulatory compliance.

Unit content

1 Know how to apply protective standards and regulations for data protection

The Data Protection Act and General Data Protection Regulation (GDPR): data subject; data controller; Information Commissioner; data register; Principles: fair, lawful and transparent processing; purpose limitation; data minimisation; accuracy; data retention periods; data security; accountability

Data stored on medical devices: personal data; sensitive data; rights of data subject (patient, employee); benefits of and problems (issues/risks) with Electronic Medical Records (EMR)

Protective measures: password rotation; multi-factor authentication; firewalls; encryption at rest; back-ups

2 Understand the fundamentals of hardware and software as applied to medical systems, networking, communications and healthcare information systems

Hardware devices and what they do: desktop or laptop PC (known as 'clients'); other devices common to all networks: modem, router, hub, ethernet cables (including Cat5e, 6, 6a, 7 and 8), switch, server, proxy server, wireless access point

Communication between devices: IP addresses (internet protocol addresses) IP4, IP6; DHCP server

Types of software: firmware installed on devices; databases; office software; firewall; utility programs, e.g. antivirus, anti-malware, backup, disc tools

3 Know how to apply the fundamentals of network topology

Wired network topology: star; ring; bus; mesh

Wireless network topology: ad hoc; wireless mesh

Network types: LAN; WAN; PAN; WLAN; CAN; MAN; SAN; VLAN

4 Know how to troubleshoot computerised medical devices and networks using appropriate diagnostic tools

Computerised medical devices: such as telemetry ECG systems, centralised patient monitoring systems, patient connected ambulatory devices, IP connected Point of Care Testing (PoCT) devices

Internet address: use of DNS (Domain Name System) network addresses, IP

Troubleshooting basics: systematic approach to check physical connectivity (switched on, cables etc.); command line utilities, e.g. PING (checking hardware and connectivity to the internet), TRACERT (checking which part of a network has failed); port forwarding, i.e. allowing a remote desktop PC to check another desktop PC; troubleshooting problems with localised monitoring devices, e.g. connection failure between a patient monitor and central hub by the nurse station in an ICU, interference resolution or signal coverage for an ambulatory ECG device connected to a patient, inability to perform quality control (QC) procedure remotely on a point-of-care device (e.g. blood gas analyser) and system-wide problems, e.g. cyber security of Windows-based medical devices,

data security and connectivity issues with cloud-connected medical devices at patients' homes and mobile phone apps classed as medical devices

5 Understand the principles of system and network security and actions necessary to ensure regulatory compliance

Importance of maintaining network security in a medical context: need to protect confidential patient records; interconnected nature of record keeping in healthcare; risk of cyber attack that could have multiple negative impacts; damage to organisation

Basic concepts: access control, e.g. usernames and passwords, personalised (chip) cards; antivirus/anti-malware software; cloud control; back-up

Other techniques: use of proxy server/VPN; use of FTP and SFTP; encryption at rest; VLAN

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the main principles of the Data Protection Act	**M1** explain the difference between personal data and sensitive data	**D1** evaluate the use of Electronic Medical Records
P2 describe three examples of protective measures in a medical setting to ensure compliance with GDPR		
P3 describe the main hardware devices that make up a medical IT network system	**M2** explain how devices in an IT system communicate with each other	
P4 describe three examples of the different types of software installed on hardware devices		
P5 describe the types of network topology	**M3** compare the relative merits of LAN, WLAN and VLAN when used in a medical environment	
P6 describe how to check for physical connectivity in a LAN network		
P7 outline the use of PING and TRACERT to identify problems in a network	**M4** explain the advantages of port forwarding when identifying problems on a desktop PC	**D2** compare and contrast two troubleshooting methods to use for a problem with a localised monitoring device on a network and a system-wide problem

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8 describe why it is important to maintain network security in a medical context		
P9 describe the use of access controls to maintain network security	**M5** explain why medical records should be protected by SFTP, encryption and VPN	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from, for example, written responses, presentations with notes, detailed posters and diagrams.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Six written assignments could be set for the assessment of this unit. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams and are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to consider the Data Protection Act, the General Data Protection Regulations and Electronic Medical records as a medical engineer. For P1, learners need to describe the main principles of the Data Protection Act 2018. All of the principles stated in the unit content for learning outcome 1 must be covered, with specific reference to the context of medical records for each principle. For M1, learners need to explain the difference between personal data and sensitive data. The response for this criterion must be based on the statements in the General Data Protection Regulations and must again be generated with medical records as the context. For D1, learners need to evaluate the use of Electronic Medical Records. The response for this criterion should be detailed and should show a good understanding of both the benefits of and problems with (including issues and risks) Electronic Medical Records. For P2, learners need to describe protective measures in a medical setting to ensure compliance with GDPR. Learners must cover at least three examples of protective measures used in a medical setting, including multi-factor authentication, firewalls and back-ups.

Assignment 2 requires learners to show an understanding of a medical IT network system as a medical engineer. For P3, learners must describe the main hardware devices that make up a medical IT network system. All of the devices stated in the unit content for learning outcome 2 must be covered and the response must refer to both the physical and information connectivity of the devices. For M2, learners must explain how devices in an IT system communicate with each other, which will involve showing an understanding of the IP addresses used to aid communication between devices and how a DHCP server operates.

Assignment 3 for P4 requires learners to describe three examples of different types of software installed on hardware devices, such as firmware, an office suite and a utility program (for example, medical devices management/database software, antivirus/anti-malware software). This can include specialist firmware installed in medical settings. Learners should not describe three examples of the same type of software, such as word processing, spreadsheet and publishing programs in an office suite.

Assignment 4 requires learners to consider the fundamentals of network topology as a medical engineer. For P5, learners need to describe the types of network topology, and this must include both wired and wireless. For M3, learners must compare the relative merits of LAN, WLAN and VLAN when used in a medical environment and must give contextualised examples of the advantages and disadvantages of all three when used across a large medical environment such as a hospital.

Assignment 5 requires learners to consider troubleshooting computerised medical devices and networks as a medical engineer. For P6, learners will need to describe how to check for physical connectivity in a LAN network. Learners must provide the details of a systematic and methodical approach covering, for example, access points, physical obstacles etc. For P7, learners must outline the use of PING and TRACERT to identify problems in a network. For this criterion, learners should refer to specific network problems and the suitable use of each command line utility to identify them. For M4, learners need to explain the advantages of port forwarding when identifying problems on a desktop PC. Learners need to explain the advantages from the perspective of both the troubleshooter and the person with the problem PC. For D2, learners need to compare and contrast at least two troubleshooting methods to use for a problem with a localised monitoring device on a network and a system-wide problem. The issue with the localised monitoring device could be connection failure between a patient monitor and central hub in a clinical ward, an ambulatory ECG device connected to a patient and its central monitor, a point-of-care device (e.g. blood gas analyser) and its central monitor. The system-wide problem could be cyber security of Windows-based medical devices, data security and/or connectivity issues with cloud-connected medical devices at patients' homes and mobile phone apps classed as medical devices. Learners need to compare and contrast by considering the advantages and disadvantages of both methods for each problem.

Finally, Assignment 6 requires learners to consider network security and the protection of medical records as a medical engineer. For P8, learners need to describe why it is important to maintain network security in a medical context. The reasons must relate to those stated in the unit content for learning outcome 5 and contextualised examples must be provided for each. For P9, learners need to describe the use of access controls to maintain network security, with a focus on at least two different techniques used to secure networks and file transfer between devices, including usernames/passwords and personalised (chip) cards. For M5, learners need to explain why medical records should be protected by SFTP, encryption and VPN. For this criterion learners must give specific details of the protection provided by each of them and why this protection is vital for medical records in particular.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	The Data Protection Act, the General Data Protection Regulations (GDPR) and Electronic Medical Records as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to give a presentation to a group of new apprentices about the Data Protection Act and the General Data Protection Regulations and how they impact on medical records. They also want you to cover Electronic Medical Records.	Presentation with detailed presentation notes
P3, M2	A Medical IT Network System as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a poster or leaflet to show new apprentices what the main hardware devices are in a medical IT network, how they connect and how they communicate with each other.	Detailed poster or illustrated leaflet
P4	Software Installed on Hardware Devices	You are an apprentice medical engineering technician, and your supervisor has asked you to summarise for a new colleague the software installed on hardware devices that are used in a medical IT network system in your workplace.	Written report

Criteria covered	Assignment title	Scenario	Assessment method
P5, M3	The Fundamentals of Network Topology as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to explain to a group of colleagues about the main network topologies and their relative advantages/disadvantages in a medical environment.	PowerPoint slides with detailed notes and referenced diagrams
P6, P7, M4, D2	Troubleshooting Computerised Devices and Networks as a Medical Engineer	You are a final year medical engineering apprentice and have been asked by your supervisor to produce a guide for a new trainee showing how to troubleshoot computerised devices and networks. You will need to include checking for physical connectivity in a LAN, using PING and TRACERT, the advantages of port forwarding, and at least two different troubleshooting methods for a problem with a localised monitoring device on a network and a system-wide problem.	Written report
P8, P9, M5	Network Security and the Protection of Medical Records as a Medical Engineer	You are a final year medical engineering apprentice and have been asked by your supervisor to prepare an easy to understand guide for new apprentices about the importance of maintaining network security (including access controls) and why medical records should be protected by SFTP, encryption and VPN.	Written report

Essential resources

Learners will need access to a range of ICT systems, hardware and software appropriate to a medical engineering setting.

Indicative reading for learners

Textbooks

Arnold S – *Guide to the Wireless Medical Practice* (HIMSS, 2007) ISBN 9780977790388

Benson T – *Principles of Health Interoperability: SNOMED CT, HL7 and FHIR*, 3rd edition (Springer, 2016) ISBN 9783319303680

Bonaventure O – *Computer Networking: Principles, Protocols and Practice* (2016) ISBN 9781365185830

Chan A – *Biomedical Device Technology: Principles and Design*, 2nd edition (Charles C Thomas Publisher, 2016) ISBN 9780398090838

ECRI Institute – *Medical Technology for the IT Professional* (ECRI, 2009) ISBN 9780981924113

Zouridakis G, Moore J – *Biomedical Technology and Devices*, 2nd edition (CRC, 2013) ISBN 9781439859599

Journals

Grimes, Stephen – Using 80001 to Manage Medical Devices on the IT Network, *Biomedical Instrumentation & Technology*, Managing Medical Devices on the IT Network, Sep 2011, Vol. 45, No. s2, pp. 23-26.

Holden, William – Bridging the Culture Gap Between Healthcare IT and Medical Device Development, *Biomedical Instrumentation & Technology*, Connecting the Dots, Sep 2014, Vol. 48, No. s2, pp. 22-28

Swim, Richard – Understanding the Wireless Spectrum in a Healthcare Facility, *Biomedical Instrumentation & Technology*, May 2013, Vol. 47, No. 3, pp. 212-214

Websites

https://www.bbc.co.uk/bitesize/guides/z6kj6sg/revision/2	Data protection information for KS4
https://www.bbc.co.uk/bitesize/guides/z9nk87h/revision/4	Data protection and computer-related law for KS3
https://www.cisco.com/c/en_uk/products/security/what-is-network-security.html	Network security information
https://www.ciscopress.com/articles/article.asp?p=2273070&seqNum=2	Troubleshooting methods for Cisco IP Networks

https://commotionwireless.net/docs/cck/networking/learn-networking-basics/	Networking basics
https://www.computerhope.com/jargon/c/commandi.htm	Command line details
https://digitalguardian.com/blog/data-protection-data-in-transit-vs-data-at-rest	Data in transit versus data at rest
https://www.ebme.co.uk/articles/maintenance/fault-finding-on-medical-electronic-devices	Fault finding on medical electronic devices
https://www.fzacpa.com/tech-101/	Basic network security concepts
https://www.gov.uk/data-protection	Data Protection Act 2018
https://www.itpro.co.uk/network-access-control/30329/what-is-a-dhcp-server	DHCP server and network access control
https://labtestsonline.org.uk/articles/point-care-testing	Information about point of care testing (PoCT)
https://www.linkedin.com/pulse/clinical-engineering-role-information-technology-salah-alkhallagi	Clinical engineering and IT
https://www.ncsc.gov.uk/collection/10-steps-to-cyber-security/the-10-steps	10 steps to cyber security (National Cyber Security Centre)
https://www.pluralsight.com/blog/it-ops/network-troubleshooting-tools	Tools for troubleshooting
https://www.softwaretestinghelp.com/computer-networking-basics/	Tutorial 16 for troubleshooting
https://www.softwaretestinghelp.com/network-security/	Network security types and management
https://www.softwaretestinghelp.com/network-troubleshooting-steps-tools/	Basic network troubleshooting tools

http://www.steves-internet-guide.com/networking/	Basic networking concepts
https://study.com/academy/lesson/types-of-network-security.html	Types of network security (requires registration/log in for 30 days free)
https://www.verywellhealth.com/ambulatory-ecg-monitoring-4171275	Information about ambulatory ECG, including continuous monitoring via 'cloud'
https://vinciworks.com/blog/8-principles-data-protection-act-gdpr-guide/	8 principles of data protection
https://www.windows-commandline.com/find-ip-address/	Finding IP address
https://www.youtube.com/watch?v=5cPIukqXe5w	Proxy server information
https://www.youtube.com/watch?v=zbqrNg4C98U	Network topologies
https://www.youtube.com/watch?v=4_zSIXb7tLQ	Network types
https://www.youtube.com/watch?v=jC6MJTh9fRE	VLAN explained
https://www.youtube.com/watch?v=tOj8MSEIbfA	FTP (File Transfer Protocol), SFTP, TFTP explained
https://www.youtube.com/watch?v=NmFWJDQWnKc	Encryption of data in transit and data at rest
https://www.youtube.com/watch?v=Mad4kQ5835Y	Difference between modem and router
https://www.youtube.com/watch?v=OxiY4yf6GGg	Difference between wireless access point and wifi router
https://www.youtube.com/watch?v=1z0ULvq_pW8	Hub, switch and router explained

https://www.youtube.com/watch?v=_NX99ad2FUA	Ethernet cables
https://www.youtube.com/watch?v=5cPIukqXe5w	Proxy server explained
https://www.youtube.com/watch?v=mdzRQRD61Uc	Data at rest
https://www.youtube.com/watch?v=KLDOrVx4cIs	De-identification of protected health information

Unit 81: Principles of Servicing Cardiovascular Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in the maintenance and testing of cardiovascular equipment. Effective maintenance, testing and disposal of this equipment is essential in ensuring the constant availability of equipment and the safety of operators and patients.

The unit gives learners an overview of the structure of the human heart and how it works, so that they can relate this to the waveforms produced by an electrocardiograph (ECG). They will also have the opportunity to explore the function and operation of a range of other cardiovascular equipment, such as non-invasive and/or invasive blood pressure monitoring equipment, pulse oximeters, external temporary pacemaker boxes and defibrillators.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for cardiovascular equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness in of the general principles associated with the safe use of cardiovascular equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and structure of the human heart in relation to electricity

2 Understand how cardiovascular equipment operates

3 Understand the importance of servicing cardiovascular equipment

4 Understand the processes used to test cardiovascular equipment for safety

5 Be able to inspect, test and service cardiovascular equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the function and structure of the human heart in relation to electricity

Relationship between the chambers of the heart and its electrical pathways: atria; ventricles; sinoatrial (SA) node; atrioventricular (AV) node; interatrial pathway; internodal pathway; right and left bundles

Types of arrhythmia: atrial fibrillation; ventricular fibrillation; ventricular tachycardia; premature ventricular beats (PVCs); bradycardia

Benefits and electrical risks of cardiovascular equipment: function and use of cardiovascular equipment and associated electrical risks in case of malfunction, e.g. ECG monitor, non-invasive blood pressure (NIBP) monitor, pulse oximeter, defibrillator (external and implantable), pacemaker, implantable cardiac loop recorder, ambulatory ECG equipment

Observing heart rhythm: heartbeat pattern (PQRST); detection by electrocardiogram (ECG) device; variation in traces for different heart arrhythmias

2 Understand how cardiovascular equipment operates

Basic types of cardiovascular equipment: non-invasive blood pressure monitor, pulse oximeter, monitoring only electrocardiograph (ECG) equipment; normal function of each

Complex types of cardiovascular equipment: invasive blood pressure monitor, diagnostic ECG equipment, ambulatory ECG equipment, external temporary pacemaker box, defibrillator (internal and external); normal function of each

Operating principles of each type of cardiovascular equipment: patient preparation, attachment, switch on sequence, equipment warm-up, adjusting/setting initial conditions and safety/functional testing of equipment as appropriate, observing or measuring and recording findings, closing down procedures

Underlying technology of the cardiovascular devices specified above: function and application of components used in equipment: switches, sensors, control devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs); use of overload protection devices

3 Understand the importance of servicing cardiovascular equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for correct readings; adjusting to the correct calibration, e.g. minimising measurement uncertainty, adjusting the precision and accuracy of measurement equipment, quantifying and controlling measurement errors, frequency; replacing 'lifed' items

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors; electric shocks; incomplete treatment or over-treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

4 Understand the processes used to test cardiovascular equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing process: planning and communicating the testing activities so as to minimise disruption to normal working; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; obtaining and using the correct issue of manufacturer's drawings and testing documentation or local SOP; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment, other relevant safety regulations and procedures; ensuring that the correct equipment decontamination procedure has been adhered to before and after the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids); providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online record of testing

Safe preparation for testing: care in dismantling or reassembling cardiovascular equipment: switching off, unplugging, de-soldering, removal of screwed, clamped and crimped connections, removal of pipes, hoses and mechanical components; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

5 Be able to inspect, test and service cardiovascular equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multimeters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating the equipment, applying electrostatic discharge (ESD) precautions, dismantling equipment to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical units/components, removing and replacing mechanical units/components, soldering and de-soldering, checking components for serviceability, replacing damaged/defective components, replacing all 'lifed' items, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment, carrying out electrical safety tests, functionally testing the serviced equipment

Typical components that may need to be replaced or repaired: batteries, cables and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, locking and retaining devices, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, pumps, motors, hoses/pipework, structural components, e.g. hinges, covers and wheels

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; complete record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the relationship between the chambers of the heart and its electrical paths		**D1** evaluate the benefits and electrical risks of cardiovascular equipment
P2 describe three different types of heart arrhythmia		
P3 identify ECG traces for three different heart arrhythmias	**M1** explain how the ECG complex waveform pattern (PQRST) corresponds to heart function	
P4 describe the normal function of two basic types of cardiovascular equipment	**M2** describe the normal function and the operating principles of two basic types and two complex types of cardiovascular equipment	
P5 describe the reasons why cardiovascular equipment must be serviced and calibrated regularly	**M3** explain the effects of incorrect servicing and calibration of cardiovascular equipment	
P6 produce a risk assessment for the safe testing of one complex type of cardiovascular equipment	**M4** explain the safe preparation for testing of one complex type of cardiovascular equipment	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe how to use an electrical safety analyser when testing one complex type of cardiovascular equipment in accordance with regulations		
P8 inspect and test safely, with practical assistance, one basic type and one complex type of cardiovascular equipment appropriately	**M5** inspect and test safely, with some guidance, two basic types and two complex types of cardiovascular equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of cardiovascular equipment appropriately
P9 service safely, with practical assistance, one basic type and one complex type of cardiovascular equipment appropriately	**M6** service safely, with some guidance, two basic and two complex types of cardiovascular equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports and practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, information leaflets and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Four written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to consider the operation of the heart itself and how electricity is central to, for example, its function and the diagnosis of problems. For P1, learners need to describe the relationship between the chambers of the heart and its electrical paths by focusing on and referring to the sinoatrial node, atria, atrioventricular node and ventricles and the related impulses and signals as a minimum. For P2, learners must describe three different types of heart arrhythmia. Any three can be chosen from the unit content for learning outcome 1. For D1, learners must evaluate the benefits and electrical risks from cardiovascular equipment. This requires a detailed response for at least three types of equipment mentioned in the unit content, where learners show a good understanding of the advantages of using cardiovascular equipment for the patient and also the potential risks of its use when a fault occurs, especially where electricity is involved. For P3, learners need to identify ECG traces for three different heart arrhythmias. Consequently, they will need to be provided with the actual ECG traces for three different heart arrhythmias so they can identify each arrhythmia and provide reasons why it is that arrhythmia. For M1, learners need to explain how the ECG complex waveform pattern (PQRST) corresponds to heart function. For this criterion, learners should source a diagram showing a cardiac cycle and its consistent patterns and annotate it to explain what the heart is doing at each stage.

Assignment 2 requires learners to cover the function and operation of cardiovascular equipment as a medical engineer. For P4, learners need to describe the normal function of two basic types of cardiovascular equipment. Any two can be chosen from those defined in the unit content for learning outcome 2, and the description must also cover the primary and any secondary functions of each (where applicable). For M2, learners must describe the normal function and the operating principles of two basic types and two complex types of cardiovascular equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 2. Again, the description must also cover the primary and any secondary functions of each, and either a sequential list or a flowchart could be used when learners describe the normal operation of each piece of equipment, and this must go from start-up through to shut-down (or equivalent).

Assignment 3 requires learners to consider the importance of servicing and calibration of cardiovascular equipment as a medical engineer. For P5, learners need to describe the reasons why cardiovascular equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to cardiovascular equipment. For M3, learners must explain the effects of incorrect servicing and calibration of cardiovascular equipment. The response for this criterion will build upon that provided for P5 and will cover the possible implications of incorrect servicing and calibration of cardiovascular equipment in particular, and must include potential technical, medical and financial issues.

Assignment 4 requires learners to consider the safe testing of cardiovascular equipment as a medical engineer. For P6, learners must produce a risk assessment for the safe testing of one complex type of cardiovascular equipment. Any complex type of cardiovascular equipment can be chosen from those defined in the unit content for learning outcome 2. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the cardiovascular equipment or disconnection of peripheral parts. For P7, learners must describe how to use an electrical safety analyser when testing one complex type of cardiovascular equipment in accordance with regulations. Any complex type of cardiovascular equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 2, and the description must cover at least one test, such as a ground continuity test, insulation test, high voltage test or a line leakage test. For M4, learners must explain the safe preparation for testing of one complex type of cardiovascular equipment. Any complex type of cardiovascular equipment can be chosen from those defined in the unit content for learning outcome 2. The response for this criterion must cover in detail how the complex type of cardiovascular equipment will be dismantled or disassembled and made ready for a mechanical or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P8, P9, M5, M6 and D2 are assessed through practical work, involving cardiovascular equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor’s comments. Some assistance is permissible for P8 and P9, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M5 and M6, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 5. In the context of P8, P9, M5, M6 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use as required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	The Operation of the Heart and How electricity is Central to its Function and the Diagnosis of Problems	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a document for new apprentices covering how the heart normally functions, what arrhythmias are, how to read ECG traces and the potential benefits and electrical risks of using cardiovascular equipment.	Written report with diagrams
P4, M2	The Function and Operation of Cardiovascular Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to describe the function and operation of four pieces of cardiovascular equipment as a guide for visitors to the hospital.	Written response with diagrams and flowcharts

Criteria covered	Assignment title	Scenario	Assessment method
P5, M3	Why Cardiovascular Equipment Needs Servicing and Calibration as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating cardiovascular equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes
P6, P7, M4	The Safe Testing of Cardiovascular Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of cardiovascular equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use an electrical safety analyser and explains safe preparation for the testing of cardiovascular equipment.	Risk assessment Detailed information leaflet

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M5, M6, D2	Practical Activities Relating to the Inspection, Testing and Servicing of Cardiovascular Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of cardiovascular equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspecting, testing and servicing the relevant cardiovascular equipment

Essential resources

Learners will need access to a range of cardiovascular equipment, including non-invasive and invasive blood pressure monitors, pulse oximeters, electrocardiography (ECG) equipment (monitoring/diagnostic/ambulatory), external temporary pacemaker boxes and defibrillators.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight* (synthesis lectures on biomedical engineering) (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance
https://www.ebme.co.uk/articles/clinical-engineering/cardiac-monitoring	Basic principles of using ECG monitoring
https://www.flukebiomedical.com/blog/electrical-safety-why-its-important	Electrical safety for medical devices
https://www.medicaldesignbriefs.com/component/content/article/mdb/features/articles/17281	Circuit protection for medical devices

Unit 82: Principles of Servicing Physiological Monitoring Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in the maintenance and testing of physiological monitoring equipment.

Continuous measurements of patient parameters, such as heart rate, respiration rate, blood pressure, temperature and blood-oxygen saturation, have become a common feature of patient monitoring, especially at the bedside, in critical care and before, during and after surgery. In addition, during a surgical procedure or critical care, it is often necessary to measure or monitor other features such as brain activity, heart rhythms and depth of anaesthesia. While carrying out these measurements, it is essential to maintain the highest standards of hygiene and infection control precautions.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for physiological monitoring equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration. Safety issues should be understood and safe working practised.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of physiological measuring equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of patient monitoring and diagnostics

2 Understand the techniques used to operate physiological monitoring equipment

3 Understand the importance of servicing physiological monitoring equipment

4 Understand the processes used to test physiological monitoring equipment for safety

5 Be able to inspect, test and service physiological monitoring equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the principles of patient monitoring and diagnostics

Principles of monitoring: observation of disease or an individual parameter over a period of time; individual meters, e.g. thermometer; combinations of devices to monitor more than one aspect of a given condition, e.g. respiratory monitoring equipment, which includes respiratory rate (breaths per minute) and devices to measure oxygen and carbon dioxide concentrations

Diagnostics: tests to determine cause of observed symptoms, e.g. measuring blood pressure after a patient faints

Importance of undertaking physiological measurements: assessment, e.g. body functions and health status, variations in physiology with time; providing information on, e.g. extent of disease or disability, provision and/or response to therapeutic interventions

Purpose of specific monitoring equipment: the human physiology directly associated with monitoring equipment; devices, e.g. foetal heart monitoring device, apnoea device, thermometer, vital sign monitor, electroencephalograph (EEG), pulse oximeter, respiration monitor, audiometer, uroflow meter

2 Understand the techniques used to operate physiological monitoring equipment

Basic types of physiological monitoring equipment: thermometer, foetal heart monitoring device, pulse oximeter, weighing scale; normal function of each

Complex types of physiological monitoring equipment: apnoea device, vital sign monitor, EEG, respiration monitor, audiometer, uroflow meter; normal function of each

Operating principles of each type of physiological monitoring equipment: switch on sequence, warm-up, adjusting/setting initial conditions and safety/functional testing of equipment as appropriate; observing or measuring and recording findings; closing down procedures

Underlying technology of the physiological monitoring devices specified above: function and application of components used in equipment, switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

3 Understand the importance of servicing physiological monitoring equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for correct readings; adjusting to the correct calibration, e.g. minimising measurement uncertainty, adjusting the precision and accuracy of measurement equipment, quantifying and controlling measurement errors, frequency; replacing 'lifed' items

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors, electric shocks; incomplete treatment or over-treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

4 Understand the processes used to test physiological monitoring equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing processes: planning and communicating the servicing activities so as to minimise disruption to normal working; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures to realise a safe system of work; ensuring that the correct equipment decontamination procedure has been adhered to before the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids), providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online record of servicing

Safe preparation for testing: care in dismantling or reassembling physiological monitoring equipment: switching off, unplugging, de-soldering, removal of screwed, clamped and crimped connections, removal of pipes, hoses and mechanical components; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

5 Be able to inspect, test and service physiological monitoring equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multimeters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating and locking off, applying electrostatic discharge (ESD) precautions, dismantling to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical components, removing and replacing mechanical components, soldering and de-soldering, checking components for serviceability, replacing damaged/defective components, replacing all 'lifed' items, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment for normal function, carrying out electrical safety tests, functionally testing the serviced equipment

Typical components that may need to be replaced or repaired: batteries, cables and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, locking and retaining devices, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, pumps, motors, hoses/pipework, structural components, e.g. hinges, covers and wheels

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; complete record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles of patient monitoring and how they are used in diagnosis		**D1** evaluate the importance of undertaking physiological measurements
P2 describe the normal function of two basic types of physiological monitoring equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of physiological monitoring equipment	
P3 describe the reasons why physiological monitoring equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of physiological monitoring equipment	
P4 produce a risk assessment for the safe testing of one complex type of physiological monitoring equipment	**M3** explain the safe preparation for testing of one complex type of physiological monitoring equipment	
P5 describe how to use an electrical safety analyser when testing one complex type of physiological monitoring equipment in accordance with regulations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 inspect and test safely, with practical assistance, one basic type and one complex type of physiological monitoring equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and two complex types of physiological monitoring equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of physiological monitoring equipment appropriately
P7 service safely, with practical assistance, one basic type and one complex type of physiological monitoring equipment appropriately	**M5** service safely, with some guidance, two basic and two complex types of physiological monitoring equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports and practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, information leaflets and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require evidence that demonstrates additional depth and/or breadth of response.

Four written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to consider the principles of physiological patient monitoring, how this affects diagnosis and the importance of undertaking measurements. For P1, learners must describe the principles of patient monitoring and how they are used in diagnosis. The learner must cover observation, the use of individual meters and the use of multiple devices by using examples to describe how each can be used to diagnose the causes of symptoms. For D1, learners need to evaluate the importance of undertaking physiological measurements. Learners could use a case study for this criterion and must cover in detail the advantages of taking physiological measurements, in terms of the provision of information, assessment and treatment, as well as the disadvantages, side-effects or inconvenience when considering the impact on the patient's lifestyle.

Assignment 2 requires learners to cover the function and operation of physiological monitoring equipment as a medical engineer. For P2, learners need to describe the normal function of two basic types of physiological monitoring equipment. Any two can be chosen from those defined in the unit content for learning outcome 2, and the description must also cover the primary and any secondary purposes of each. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of physiological monitoring equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 2. Again, the description must also cover the primary and any secondary purposes of each, and either a sequential list or a flowchart could be used when learners describe the normal operation of each piece of equipment, and this must go from start-up through to shut-down (or equivalent).

Assignment 3 requires learners to consider the importance of servicing and calibration of physiological monitoring equipment as a medical engineer. For P3, learners need to describe the reasons why physiological monitoring equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to physiological monitoring equipment. For M2, learners must explain the effects of incorrect servicing and calibration of physiological monitoring equipment. The response for this criterion will build on that provided for P4 and will cover the possible implications of incorrect servicing and calibration of physiological monitoring equipment in particular, and must include potential technical, medical and financial issues.

Assignment 4 requires learners to consider the safe testing of physiological monitoring equipment as a medical engineer. For P4, learners must produce a risk assessment for the safe testing of one complex type of physiological monitoring equipment. Any complex type of physiological monitoring equipment can be chosen from those defined in the unit content for learning outcome 2. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the physiological monitoring equipment or disconnection of peripheral component(s). For P5, learners must describe how to use an electrical safety analyser when testing one complex type of physiological monitoring equipment in accordance with regulations. Any complex type of physiological monitoring equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 2, and the description must cover at least one test, such as a ground continuity test, insulation test, high voltage test or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of physiological monitoring equipment. Any complex type of physiological monitoring equipment can be chosen from those defined in the unit content for learning outcome 2. The response for this criterion must cover in detail how the complex type of physiological monitoring equipment will be dismantled or disassembled and made ready for a mechanical or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P6, P7, M4, M5 and D2 are assessed through practical work, involving physiological monitoring equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P6 and P7, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 5. In the context of P6, P7, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, D1	The Principles of Physiological Patient Monitoring, How this Affects Diagnosis and the Importance of Undertaking Measurements	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a document for new apprentices covering the principles of physiological patient monitoring, how this affects diagnosis and the importance of undertaking measurements.	Written report with diagrams
P2, M1	The Function and Operation of Physiological Monitoring Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to describe the function and operation of four pieces of physiological monitoring equipment as a guide for visitors to the hospital.	Written response with diagrams and flowcharts

Criteria covered	Assignment title	Scenario	Assessment method
P3, M2	Why Physiological Monitoring Equipment Needs Servicing and Calibration as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating physiological monitoring equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes
P4, P5, M3	The Safe Testing of Physiological Monitoring Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of physiological monitoring equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use an electrical safety analyser and explains safe preparation for the testing of physiological monitoring equipment.	Risk assessment Detailed information leaflet

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M4, M5, D2	Practical Activities Relating to the Inspection, Testing and Servicing of Physiological Monitoring Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of physiological monitoring equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspecting, testing and servicing the relevant physiological monitoring equipment

Essential resources

Learners will need access to a range of physiological measuring equipment, including foetal heart monitoring devices, apnoea devices, thermometers, vital sign monitors, EEG, pulse oximeters, respiration monitors, audiometers and uroflow meters.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight* (synthesis lectures on biomedical engineering) (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance

Unit 83: Principles of Servicing Infusion Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in servicing clinical infusion equipment, in accordance with approved procedures. The process of infusion introduces a solution other than blood into the circulatory system. Often, the solution is directed into a vein but the infusion could be into an artery (as in some types of chemotherapy), enter subcutaneously (like insulin) or be inserted into the epidural space in the spine (for anaesthetising the lower body).

Learners will be required to service a range of infusion equipment, including infusion and feeding pumps, syringe drivers and patient-controlled analgesia. This will involve dismantling, removing and replacing faulty items, at component or unit level, on infusion equipment appropriate to the equipment being serviced and the type of components being removed/replaced. It will include electrical, electronic and mechanical units and components.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of infusion equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the function of and the techniques used to operate infusion equipment

2 Understand the importance of servicing infusion equipment

3 Understand the processes used to test infusion equipment for safety

4 Be able to inspect, test and service infusion equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Know the function of and the techniques used to operate infusion equipment

Classes of pump: large-volume pumps for fluid replacement such as saline solution, medication, and nutrient infusion to a patient; small-volume pumps to infuse hormones and medicines in small and precise quantities, such as insulin

Types of pump: general-purpose/volumetric pump, syringe driver, patient-controlled analgesia (PCA) pump, ambulatory (portable)

Basic types of infusion equipment: feeding pump, syringe driver, volumetric infusion pump; normal function of each

Complex types of infusion equipment: patient-controlled analgesia (PCA) pump, ambulatory infusion pump, dialysis machine; normal function of each

Operating principles of each type of infusion equipment: switch on sequence, warm-up, adjusting/setting initial conditions and safety/functional testing of equipment as appropriate; observing or measuring and recording findings; closing down procedures

Underlying technology of the infusion equipment specified above: function and application of components used in equipment, switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

2 Understand the importance of servicing infusion equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for controlled flow; testing for adjustment to the correct calibration of infusion rate, e.g. minimising uncertainty, adjusting the precision and accuracy, quantifying and controlling errors, frequency; replacing 'lifed' items; checking supports for infusion equipment

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose; appropriately fused, earthed and/or double insulated

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors, risks to the human body from external energy sources; electric shocks; incomplete treatment or over-treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the processes used to test infusion equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing process: planning and communicating the servicing activities so as to minimise disruption to patient care; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures to realise a safe system of work; ensuring that the correct equipment decontamination procedure has been adhered to before the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids); providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online record of servicing

Safe preparation for testing: care in dismantling or reassembling infusion equipment: switching off, unplugging, de-soldering, removal of screwed, clamped and crimped connections, removal of pipes, hoses and mechanical components; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

4 Be able to inspect, test and service infusion equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multimeters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating and locking off, applying electrostatic discharge (ESD) precautions, dismantling to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical components, removing and replacing mechanical components, soldering and de-soldering, checking components for serviceability, replacing damaged/defective components, replacing all 'lifed' items, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment for normal function, carrying out electrical safety tests, functionally testing the serviced equipment

Typical components that may need to be replaced or repaired: batteries, cables and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, phototherapy lighting tubes, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, locking and retaining devices, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, pumps, motors, hoses/pipework, structural components

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; complete record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how different classes of pump operate		**D1** evaluate the use of one class of pump used in one complex type of infusion equipment
P2 describe the normal function of two basic types of infusion equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of infusion equipment	
P3 describe the reasons why infusion equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of infusion equipment	
P4 produce a risk assessment for the safe testing of two different types of infusion equipment	**M3** explain the safe preparation for testing of one complex type of infusion equipment	
P5 describe how to safely use pressure and flow meters when testing one type of infusion equipment in accordance with regulations		
P6 describe how to use an electrical safety analyser when testing one type of infusion equipment in accordance with regulations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 inspect and test safely, with practical assistance, one basic type and one complex type of infusion equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and two complex types of infusion equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of infusion equipment appropriately
P8 service safely, with practical assistance, one basic type and one complex type of infusion equipment appropriately	**M5** service safely, with some guidance, two basic and two complex types of infusion equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports and practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, information leaflets and from tutor observation of practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to show their understanding of pumps and the function and operation of infusion equipment as a medical engineer. For P1, learners must explain how two different classes of pump operate. Any two examples of infusion pumps can be chosen from those mentioned in the unit content for learning outcome 1, and learners should give details of the operational differences, including diagrams. For D1, learners must evaluate the use of one class of pump used in one complex type of infusion equipment. Any complex type of infusion equipment can be chosen from those defined in the unit content for learning outcome 1. For P2, learners need to describe the normal function of two basic types of infusion equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of infusion equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1. A sequential list or a flowchart could be used when learners describe the normal operation of each piece of equipment, and this must go from start-up through to shut-down (or equivalent).

Assignment 2 requires learners to consider the importance of servicing and calibration of infusion equipment as a medical engineer. For P3, learners need to describe the reasons why infusion equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to infusion equipment. For M2, learners must explain the effects of incorrect servicing and calibration of infusion equipment. The response for this criterion will build upon that provided for P3 and will cover the possible implications of incorrect servicing and calibration of infusion equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of infusion equipment as a medical engineer. For P4, learners must produce a risk assessment for the safe testing of one complex type of infusion equipment. Any complex type of infusion equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the infusion equipment or disconnection of peripheral part(s). For P5, learners must describe how to use pressure and flow meters when testing one type of infusion equipment in accordance with regulations. Any type of infusion equipment can be chosen from those defined in the unit content for learning outcome 1, and the description must cover attachment of the meters to the infusion equipment and carrying out measurements to determine, for example, leakage. For P6, learners must describe how to use an electrical safety analyser when testing one type of infusion equipment in accordance with regulations. Any type of infusion equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of infusion equipment. Any complex type of infusion equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of infusion equipment will be dismantled or disassembled and made ready for a mechanical, pneumatic or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P7, P8, M4, M5 and D2 are assessed through practical work, involving infusion equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P7 and P8, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 4. In the context of P7, P8, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Showing Understanding of Pumps and the Function and Operation of Infusion Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce relevant information covering types of pumps and the function and operation of four pieces of infusion equipment as a guide for visitors to the hospital.	Written report with diagrams and flowcharts
P3, M2	Why Infusion Equipment Needs Servicing and Calibration as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating infusion equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3	The Safe Testing of Infusion Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of infusion equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use pressure and flow meters and an electrical safety analyser and explains safe preparation for the testing of infusion equipment.	Risk assessment Detailed information leaflet
P7, P8, M4, M5, D2	Practical Activities Relating to the Inspection, Testing and Servicing of Infusion Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of infusion equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant infusion equipment

Essential resources

Learners will need access to a range of infusion equipment, including feeding pumps, volumetric infusion pumps, syringe drivers, patient-controlled analgesia pumps, ambulatory infusion pumps and dialysis machines.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/clinical-engineering/infusion-devices-training-tutorial	Infusion devices training tutorial
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance

Unit 84: Principles of Servicing Medical Therapeutic Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in servicing medical therapeutic equipment. Effective maintenance, testing and disposal of this equipment is essential in ensuring the constant availability of equipment and the safety of operators and patients. Learners will have the opportunity to explore the function and operation of a range of medical therapeutic equipment, including devices to help patients to breathe, patient warming devices, exercise equipment, devices to prevent deep vein thrombosis and devices designed to treat various conditions affecting the skin, muscles and joints.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for medical therapeutic equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration. Safety issues should be understood and safe working practised.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of medical therapeutic equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of medical therapeutic equipment

2 Understand the importance of servicing medical therapeutic equipment

3 Understand the processes used to test medical therapeutic equipment for electrical safety

4 Be able to inspect, test and service medical therapeutic equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the function and operation of medical therapeutic equipment

Principles and purpose of medical therapeutic equipment: exchanging or administering energy; supporting, modifying, replacing or restoring biological functions or structures with a view to treatment or alleviation of an illness or injury

Basic types of medical therapeutic equipment: nerve stimulating device, traction device, radiant heater warmer, hydrotherapy equipment, exercise equipment, hypo/hyperthermia therapy; normal function of each

Complex types of medical therapeutic equipment: sequential compression device (SCD), therapeutic ultrasound device, therapeutic diathermy device, nebuliser, interferential therapy device, continuous positive airway pressure device, phototherapy device; normal function of each

Operating principles of each type of medical therapeutic equipment: switch on sequence, warm-up, adjusting/setting initial conditions and safety/functional testing of equipment as appropriate; observing or measuring and recording findings; closing down procedures

Underlying technology of the medical therapeutic equipment specified above: function and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

2 Understand the importance of servicing medical therapeutic equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for correct readings/flow; adjusting to the correct calibration, e.g. minimising uncertainty, adjusting the precision and accuracy, quantifying and controlling errors, frequency; replacing 'lifed' items

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose; appropriately fused, earthed and/or double insulated

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors, electric shocks; incomplete treatment or over-treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the processes used to test medical therapeutic equipment for electrical safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing processes: planning and communicating the servicing activities so as to minimise disruption to patient care; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures to realise a safe system of work; ensuring that the correct equipment decontamination procedure has been adhered to before the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids), providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online record of servicing

Safe preparation for testing: care in dismantling or reassembling medical therapeutic equipment: switching off, unplugging, de-soldering, removal of screwed, clamped and crimped connections, removal of pipes, hoses and mechanical components; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

4 Be able to inspect, test and service medical therapeutic equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multi-meters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating and locking off, applying electrostatic discharge (ESD) precautions, dismantling to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical components, removing and replacing mechanical components, soldering and de-soldering, checking components for serviceability, replacing damaged/defective components, replacing all 'lifed' items, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment for normal function, carrying out electrical safety tests, functionally testing the serviced equipment

Typical components that may need to be replaced or repaired: batteries, cables and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, phototherapy lighting tubes, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, locking and retaining devices, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, pumps, motors, hoses/pipework, structural components

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; completing record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles and purpose of medical therapeutic equipment		**D1** evaluate the use of two types of medical therapeutic equipment
P2 describe the normal function of two basic types of medical therapeutic equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of medical therapeutic equipment	
P3 describe the reasons why medical therapeutic equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of medical therapeutic equipment	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 produce a risk assessment for the safe testing of one type of medical therapeutic equipment	**M3** explain safe preparation for testing of one complex type of medical therapeutic equipment	
P5 describe how to safely use pressure and flow meters when testing one type of medical therapeutic equipment in accordance with regulations		
P6 describe how to use an electrical safety analyser when testing one type of medical therapeutic equipment in accordance with regulations		
P7 inspect and test safely, with practical assistance, one basic type and one complex type of medical therapeutic equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and one complex type of medical therapeutic equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of medical therapeutic equipment appropriately
P8 service safely, with practical assistance, one basic type and one complex type of medical therapeutic equipment appropriately	**M5** service safely, with some guidance, two basic types and one complex type of medical therapeutic equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports and practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, information leaflets and from tutor observation of practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to show their understanding of medical therapeutic treatments, how electrical shock affects the physiology of the body and the function and operation of medical therapeutic equipment as a medical engineer. For P1, learners must describe the principles and purpose of medical therapeutic equipment. The response for this criterion will cover the principles in a general sense, for example what medical therapeutic equipment tries to achieve, how, and what it tries to avoid, but the response must also be contextualised by including two descriptions of different types of medical therapeutic equipment. For D1, learners must evaluate the use of two types of medical therapeutic treatment. Learners could use case studies for this criterion and must cover in detail the specific benefits of the two chosen types of medical therapeutic equipment, in terms of, for example, disease prevention and/or the elimination of symptoms/pain, as well as the specific risks of use of the two chosen types of medical therapeutic equipment when considering, for example, short-term and long-term side effects. For P2, learners need to describe the normal function of two basic types of medical therapeutic equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of medical therapeutic equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1, and either a sequential list or a flowchart could be used when learners describe the normal operation of each piece of equipment, and this must go from start-up through to shut-down (or equivalent).

Assignment 2 requires learners to consider the importance of servicing and calibration of medical therapeutic equipment as a medical engineer. For P3, learners need to describe the reasons why medical therapeutic equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to medical therapeutic equipment. For M2, learners must explain the effects of incorrect servicing and calibration of medical therapeutic equipment.

The response for this criterion will build upon that provided for P3 and will cover the possible implications of incorrect servicing and calibration of medical therapeutic equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of medical therapeutic equipment as a medical engineer. For P4, learners must produce a risk assessment for the safe testing of one type of medical therapeutic equipment. Any type of medical therapeutic equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the medical therapeutic equipment. For P5, learners must describe how to use pressure and flow meters when testing one type of medical therapeutic equipment in accordance with regulations. Any type of medical therapeutic equipment that is pneumatic in nature can be chosen from those defined in the unit content for learning outcome 1, and the description must cover attachment of the meters to the medical therapeutic equipment and carrying out measurements to determine, for example, leakage. For P6, learners must describe how to use an electrical safety analyser when testing one type of medical therapeutic equipment in accordance with regulations. Any type of medical therapeutic equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test, or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of medical therapeutic equipment. Any complex type of medical therapeutic equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of medical therapeutic equipment will be dismantled or disassembled and made ready for a mechanical, pneumatic or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P7, P8, M4, M5 and D2 are assessed through practical work, involving medical therapeutic equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P7 and P8, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 4. In the context of P7, P8, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Showing Understanding of Medical Therapeutic Treatments and the Function and Operation of Medical Therapeutic Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce relevant information covering medical therapeutic treatments and the function and operation of four pieces of medical therapeutic equipment as a guide for visitors to the hospital.	Written report with diagrams and flowcharts
P3, M2	Why medical Therapeutic Equipment Needs Servicing and Calibration as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating medical therapeutic equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3	The Safe Testing of Medical Therapeutic Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of medical therapeutic equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use pressure and flow meters and an electrical safety analyser and explains safe preparation for the testing of medical therapeutic equipment.	Risk assessment Detailed information leaflet
P7, P8, M4, M5, D2	Practical Activities Relating to the Inspection, Testing and Servicing of Medical Therapeutic Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of medical therapeutic equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant medical therapeutic equipment

Essential resources

Learners will need access to a range of medical therapeutic equipment, including nerve stimulating devices, therapeutic ultrasound devices, therapeutic diathermy devices, traction devices, radiant heater warmers, hydrotherapy equipment, nebulisers, continuous positive airway devices, phototherapy devices, exercise equipment, hypo/hyperthermia therapy and sequential compression devices (SCD).

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight* (synthesis lectures on biomedical engineering) (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance

Unit 85: Principles of Servicing Operating Theatre and Surgical Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in maintaining and testing operating theatre and surgical equipment, which plays a key role in healthcare. Operating theatre and surgical equipment is vital for routine and emergency activities to explore, monitor, extract, replace, implant or correct by surgery.

A wide variety of instruments and other equipment of electrical, mechanical or pneumatic form will often be involved. Effective maintenance, testing and disposal of this equipment is essential in ensuring the constant availability of equipment and the safety of operators and patients. The equipment must be managed with scheduled maintenance and replacement of parts to prevent system and equipment failures.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for operating theatre and surgical equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration. Safety issues associated with disposal should be understood and practised.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of operating theatre and surgical equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the purposes and functioning of operating theatre and surgical equipment

2 Understand the importance of servicing operating theatre and surgical equipment

3 Understand the processes used to test operating theatre and surgical equipment for safety

4 Be able to inspect, test and service operating theatre and surgical equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the purposes and functioning of operating theatre and surgical equipment

Basic types of operating theatre and surgical equipment: pneumatic tourniquet, steriliser, blood warmer/patient warmer, gas monitoring device/flow and pressure gauge, surgical lighting equipment/examination lamp, pneumatic drilling/sawing device, surgical instruments; normal function of each

Complex types of operating theatre and surgical equipment: electrosurgical generator/surgical diathermy device, endoscope, defibrillator, anaesthetic machine, ventilator, balloon pump, external temporary pacemaker box, video equipment; normal function of each

Operating principles of each type of operating theatre and surgical equipment: patient preparation, attachment, switch on sequence, equipment warm-up, adjusting/setting initial conditions and safety/functional testing of equipment as appropriate, observing or measuring and recording findings, closing down procedures

Underlying technology of the operating theatre and surgical devices specified above: function and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs), electrodes, optic fibres, lenses

2 Understand the importance of servicing operating theatre and surgical equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for correct readings/flow; adjusting to the correct calibration, e.g. minimising uncertainty, adjusting the precision and accuracy, quantifying and controlling errors, frequency; replacing 'lifed' items

Minimising danger: preventing danger to patients or to staff from improperly working or inadequately maintained equipment

Electrical safety checks to ensure that equipment, cables and connections are: cables free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose

Regular maintenance: minimising wear; avoiding unplanned breakdowns; diminishing need for costly repairs or equipment replacement

Operational efficiency: maximising use; performing servicing activities at times when theatre is inactive; using substitute equipment on rotation

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the processes used to test operating theatre and surgical equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing processes: planning and communicating the schedule to minimise disruption to normal working of the operating theatre; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; obtaining and using the correct issue of manufacturer's drawings and testing documentation or local SOP; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and workplace procedures; ensuring that the correct equipment decontamination procedure will be adhered to before the testing activities; ensuring that safe isolation of equipment (such as electrical, mechanical, gas, air, fluids) is possible; arranging for provision and maintenance of safe access and working arrangements for the testing area; reading documents including service and calibration history, risk assessment, relevant testing schedules to carry out the required work

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; previous repair and maintenance records; assembling necessary tools and instruments; checking instruments for calibration and zero errors; obtaining necessary spare parts for 'lifed' equipment; arranging to allow equipment removal and testing to a separate, sterile work area if necessary

Safe preparation for testing: taking standard precautions for infection prevention and control including cleaning of equipment, hand hygiene, wearing protective clothing, laying out special bags/containers for waste disposal; isolating equipment; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices; dismantling equipment, e.g. switching off, unplugging, de-soldering, removing screwed, clamped and crimped connections; removing pipes, hoses and mechanical components; attaching identification markers to removed items; noting site of any leakages; identifying any fault conditions indicated and preparing to apply appropriate corrective action for operating room equipment; checking replacement components meet required specification: power rating, voltage range, operating temperature, working range, pressure tolerance; ensuring all potential defects are identified and reported for future action

4 Be able to inspect, test and service operating theatre and surgical equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: signs of leakage, damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multimeters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating and locking off equipment and apply electrostatic discharge (ESD) precautions; dismantling equipment to the appropriate level; disconnecting and reconnecting wires and cables; attaching suitable cable identification markers; removing and replacing electrical units/components; de-soldering and re-soldering; checking components for serviceability; replacing damaged/defective components; replacing all 'lifed' items; tightening fastenings to the required torque; setting, recalibrating and adjusting replaced components; making visual checks before powering up; carrying out electrical safety tests; checking equipment operating parameters; functionally testing the serviced equipment

Oil and grease: moving parts of equipment such as wheels/castors, gears, bearings, pumps, hinges, locking and retaining devices

Typical components that may need to be replaced or repaired: cables and connectors, diathermic electrodes, printed circuit boards, overload protection devices, switches, locking and retaining devices, power supplies, analogue or digital integrated circuits, potentiometers, diaphragms, rectifiers, filters, sensors, thermistors, transformers, transducers, regulators, timers, seals, batteries, gears, bearings, indicators (lamps, LEDs), lighting bulbs, display units, pressure gauges, valves, pumps, motors, hoses/pipework, structural components, e.g. hinges, covers, wheels/castors

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; completing record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the normal function of two basic types of operating theatre and surgical equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of operating theatre and surgical equipment	**D1** assess risks to users and patients in relation to operating two complex types of operating theatre and surgical equipment
P2 describe the reasons why operating theatre and surgical equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of operating theatre and surgical equipment	
P3 produce a risk assessment for the safe testing of one complex type of operating theatre and surgical equipment	**M3** explain safe preparation for testing of one complex type of electrical operating theatre and surgical equipment	
P4 describe how to safely use pressure and flow meters when testing one type of operating theatre and surgical equipment in accordance with regulations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 describe how to use an electrical safety analyser when testing one type of operating theatre and surgical equipment in accordance with regulations		
P6 inspect and test safely, with practical assistance, one basic type and one complex type of operating theatre and surgical equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and two complex types of operating theatre and surgical equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of operating theatre and surgical equipment appropriately
P7 service safely, with practical assistance, one basic type and one complex type of operating theatre and surgical equipment appropriately	**M5** service safely, with some guidance, two basic and two complex types of operating theatre and surgical equipment appropriately	

Essential guidance for tutors

Assessment

Evidence for achievement of the criteria can be collected from written reports and practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, information leaflets and from tutor observation of practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require evidence that demonstrates additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to cover the function and operation of operating theatre and surgical equipment as a medical engineer. For P1, learners need to describe the normal function of two basic types of operating theatre and surgical equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of operating theatre and surgical equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1. Either a sequential list or a flowchart could be used when learners describe the normal operation of each piece of equipment, and this must go from start-up through to shut-down (or equivalent). For D1, learners need to assess risks to users in relation to operating two complex types of operating theatre and surgical equipment. Any two complex types of operating theatre and surgical equipment can be chosen from those defined in the unit content for learning outcome 1. This criterion requires a detailed response, where learners show a good understanding of the specific dangers of operating both types of equipment as well as how they could be unintentionally misused.

Assignment 2 requires learners to consider the importance of servicing and calibration of operating theatre and surgical equipment as a medical engineer. For P2, learners need to describe the reasons why operating theatre and surgical equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration (where required/applicable) and include at least three explicit reasons with examples that are specific to operating theatre and surgical equipment. For M2, learners must explain the effects of incorrect servicing and calibration of operating theatre and surgical equipment. The response for this criterion will build upon that provided for P2 and will cover the possible implications of incorrect servicing and calibration of operating theatre and surgical equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of operating theatre and surgical equipment as a medical engineer. For P3, learners must produce a risk assessment for the safe testing of one complex type of operating theatre and surgical equipment. Any complex type of operating theatre and surgical equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly or dismantling of peripheral parts of the operating theatre and surgical equipment. For P4, learners must describe how to use pressure and flow meters when testing one type of operating theatre and surgical equipment in accordance with regulations. Any type of operating theatre and surgical equipment that is pneumatic in nature can be chosen from those defined in the unit content for learning outcome 1, and the description must cover attachment of the meters to the operating theatre and surgical equipment and carrying out measurements to determine, for example, leakage. For P5, learners must describe how to use an electrical safety analyser when testing one type of operating theatre and surgical equipment in accordance with regulations. Any type of operating theatre and surgical equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of operating theatre and surgical equipment. Any complex type of operating theatre and surgical equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of operating theatre and surgical equipment will be dismantled or disassembled and made ready for a mechanical, pneumatic or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P6, P7, M4, M5 and D2 are assessed through practical work, involving operating theatre and surgical equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P6 and P7, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 4. In the context of P6, P7, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	The Function and Operation of Operating Theatre and Surgical Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to describe the function and operation of four different pieces of operating theatre and surgical equipment, as well as the risks to users when operating them, as a guide for visitors to the hospital.	Written response with diagrams and flowcharts
P2, M2	Why Medical Operating theatre and Surgical Equipment Needs Servicing and Calibration as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating operating theatre and surgical equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P5, M3	The Safe Testing of Operating Theatre and Surgical Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of operating theatre and surgical equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use pressure and flow meters and an electrical safety analyser and explains safe preparation for the testing of operating theatre and surgical equipment.	Risk assessment Detailed information leaflet
P6, P7, M4, M5, D2	Practical Activities Relating to Inspecting, Testing and Servicing of Operating Theatre and Surgical Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of operating theatre and surgical equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant pieces of equipment

Essential resources

Learners will require access to a range of operating theatre and surgical equipment, including electrosurgical generators/surgical diathermy devices, endoscopes, defibrillators, anaesthetic machines, ventilators, gas monitoring devices/flow and pressure gauges, surgical lighting equipment/examination lamps, pneumatic drilling/sawing devices, balloon pumps, external temporary pacemaker boxes, video equipment, pneumatic tourniquets, sterilisers and warmers.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance

Unit 86: Principles of Servicing Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in the maintenance and testing of mechanical/electromechanical equipment such as patient beds, trolleys, operating tables and assistive technology equipment such as wheelchairs, hoists, walking aids, orthotics, prosthetics and hearing aids.

Equipment for transporting patients plays a key role in healthcare and is vital both for movement within and between sites and for assisting patient positioning. Effective maintenance and testing of this equipment are essential in providing high quality patient care. The equipment must be managed proactively to reduce the risk of harm to patients. Orthotics, prosthetics and hearing aids are precisely tailored to the requirements of individual patients, whose wellbeing and ability to carry out daily activities depend on the correct functioning of these devices.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance, for testing the correct functioning of the equipment and for reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use and servicing of mechanical/electromechanical equipment and assistive technology equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the function and operation of patient beds, trolleys, operating tables and assistive technology equipment

2 Understand the importance of servicing patient beds, trolleys, operating tables and assistive technology equipment

3 Understand the principles of visual and performance verification checks on patient beds, trolleys, operating tables and assistive technology equipment

4 Understand the processes used to test patient beds, trolleys, operating tables and assistive technology equipment for safety

5 Be able to inspect, test and service patient beds, trolleys, operating tables and assistive technology equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Know the function and operation of patient beds, trolleys, operating tables and assistive technology equipment

Basic types of patient beds, trolleys and assistive technology equipment/devices: mechanical patient bed, trolley (such as patient transfer, drug, dressings), walking aids, patient self-transfer aids, mechanical wheelchair, commode, orthotic devices, upper and lower limb prostheses; normal function of each

Complex types of patient beds, operating tables and assistive technology equipment/devices: electrical patient bed, operating table, electric wheelchair, scooter, stair lift, hoist, seating system, bathing equipment, pressure redistribution and relief device, hearing aid; normal function of each, including how they are patient-operated if applicable

Underlying technology of the devices specified above: function and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

Risks to patients and users from using the equipment/devices: risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; general and specific risks where applicable, e.g. electric shock, brakes failure, mechanical malfunction, electronic failure

2 Understand the importance of servicing patient beds, trolleys, operating tables and assistive technology equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for free movement; replacing 'lifed' items

Minimising danger: from moving or closing parts; from flammable materials or electricity; from external energy sources; from equipment that is not working and/or maintained properly

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose

Regular maintenance: minimising wear; avoiding unplanned breakdowns; reducing need for costly repairs or equipment replacement

Operational efficiency: maximising use; maintaining, testing and replacing activities at times when demand is low; using substitute equipment in rotation

Other implications of poor servicing: delayed or missed servicing may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the principles of visual and performance verification checks on patient beds, trolleys, operating tables and assistive technology equipment

Performance verification checking: ensuring correct operation of locks; load testing; remaining compliant with predefined process requirements; ensuring continuous operation within specifications; remaining compliant with quality standards necessary for correct performance of operation of device

Observing stationary parts/sensory checks: using sensory inputs including sight (e.g. signs of leakage, cracked pipes/glassware/clips/grips, split pipes, missing parts, wear/fraying/ discoloration/ageing, signs of corrosion, distortion), sound (e.g. squeaking, clicking), smell (e.g. gas, burning), touch (e.g. unexpected roughness, flexibility, tightness of nuts and bolts, sharp edges)

Testing moving and stopping parts: free movement of hinges; full angular movement at adjustable hinged joints according to specification; free running (but not excessive lateral movement ('play') of wheels/castors/bearings; free movement of sliding parts such as retractable handles and height adjustable supports; wheel/castor braking system pedals (may be dual-sided); operating all advertised features such as directional locking of each individual wheel/castor, locking all wheels/castors, all free-running; wear on frictional surfaces such as tyres/rubberised castors, brakes, control buttons and keypads

4 Understand the processes used to test patient beds, trolleys, operating tables and assistive technology equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional using mechanical test meters, e.g. electrical safety testing of operating table, hoist, pneumatic test of hoist, height adjustable patient trolley, mechanical safety test of walking aids, wheelchair etc

Safe testing processes: planning and communicating the schedule to ensure adequate availability of mobile equipment; obtaining and using the correct issue of manufacturer's drawings and servicing documentation or local SOP; adhering to procedures or systems in place for risk assessment (such as COSHH, personal protective equipment and other relevant safety regulations and workplace procedures); ensuring that the correct equipment decontamination procedure will be adhered to before the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids); reading documents including service history, risk assessment, previous repair and maintenance records; assembling necessary tools and instruments; checking instruments for calibration and zero errors; obtaining necessary spare parts for 'lifed' equipment; arranging to allow equipment removal to a separate, sterile work area if necessary; providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online testing record

Safe preparation for testing: isolating equipment; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD); dismantling equipment: switching off, unplugging, removing screwed, clamped and crimped connections; removing pipes, hoses and mechanical components; harnessing and securing cables and components; attaching identification markers to removed items; noting site of any leakages; identifying any fault conditions indicated and preparing to apply appropriate corrective action for operating room equipment; checking replacement components meet required specification: power rating, voltage range, weight limit, working range, pressure tolerance; ensuring all potential defects are identified and reported for future action

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations

Testing activities: isolating the equipment and applying electrostatic discharge precautions; dismantling equipment to the appropriate level; disconnecting and reconnecting wires and cables as needed; attaching suitable identification markers to disconnected wires; removing and replacing electrical, pneumatic or mechanical units as required particularly if visibly damaged, worn or disposable, e.g. cables, brake pads, pipes, hoses; check removed items for serviceability; checking torque settings on fastenings, e.g. hose clips; set and adjust replaced components; testing joints, washers and seals for leaks; carrying out electrical safety tests such as earth continuity using an electrical safety analyser; returning the equipment to service on completion of the activities; attaching a 'Tested on....' label as appropriate together with a date for next test as appropriate

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

5 Be able to inspect, test and service patient beds, trolleys, operating tables and assistive technology equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multi-meters, indicators, torque measuring devices; identification of component(s) that need repair or replacement

Servicing activities: isolating equipment, applying electrostatic discharge (ESD) precautions, dismantling equipment to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical units/components, removing and replacing pneumatic units/components, removing and replacing mechanical units/components, de-soldering and re-soldering, checking components for serviceability, replacing damaged/defective components, oiling and greasing, replacing all 'lifed' items, checking operation of locking and retaining devices, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment, carrying out electrical safety tests, functionally testing the serviced equipment

Typical components that may need to be replaced or repaired: batteries, cables and connectors, hoses and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, heating elements, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, washers, pumps, motors, hoses/pipework, structural components, e.g. hinges, covers and wheels/castors

Completion and return to use: final testing for electrical safety and for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; completing record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the normal function of two basic devices from patient beds, trolleys and assistive technology equipment	**M1** describe the normal function of two basic devices and two complex devices from patient beds, trolleys, operating tables and assistive technology equipment	
P2 produce a risk assessment for a patient using a mechanical wheelchair		**D1** assess risks to patients in relation to two complex devices from patient beds, trolleys, operating tables and assistive technology equipment
P3 describe the reasons why patient beds, trolleys, operating tables and assistive technology equipment must be serviced regularly	**M2** explain the effects of ineffective servicing for patient beds, trolleys, operating tables and assistive technology equipment	
P4 describe how to complete a sensory check on two basic devices from patient beds, trolleys and assistive technology equipment		
P5 describe how to carry out a performance verification check on a patient transport trolley	**M3** explain how to carry out a performance verification check on an operating table	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe how to safely use appropriate pneumatic or mechanical test meters in accordance with regulations when testing a patient transport trolley		
P7 describe how to use an electrical safety analyser when testing one piece of patient-operated assistive technology equipment in accordance with regulations		
P8 inspect and test safely, with practical assistance, one basic device and one complex device from patient beds, trolleys and assistive technology equipment appropriately	**M4** inspect and test safely, with some guidance, two basic devices and two complex devices from patient beds, trolleys, operating tables and assistive technology equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic devices and two complex devices from patient beds, trolleys, operating tables and assistive technology equipment appropriately
P9 service safely, with practical assistance, one basic device and one complex device from patient beds, trolleys and assistive technology equipment appropriately	**M5** service safely, with some guidance, two basic devices and two complex devices from patient beds, trolleys, operating tables and assistive technology equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records and tutor comments.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, guides, information leaflets and from tutor observation of practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Four written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to show their understanding as a medical engineer of the function and operation of patient beds, trolleys, operating tables and assistive technology equipment, as well as the risks to patients from using the equipment. For P1, learners need to describe the normal function of two basic devices from patient beds, trolleys and assistive technology equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function of two basic devices and two complex devices from patient beds, trolleys, operating tables and assistive technology equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1. Either a sequential list or a flowchart could be used when learners describe the normal operation of each device, and this must go from start-up through to shut-down (or equivalent). For P2, learners must produce a risk assessment for a patient using a mechanical wheelchair. The risk assessment must be on a suitable template, cover all five steps and be based on the normal functioning of a mechanical wheelchair. For D1, learners need to assess risks to patients in relation to two complex devices from patient beds, trolleys, operating tables and assistive technology equipment. Any two complex devices can be chosen from those defined in the unit content for learning outcome 1. This criterion requires a detailed response, where learners show a good understanding of the specific dangers of using the devices as well as how the devices could be unintentionally misused.

Assignment 2 requires learners to consider the importance of servicing patient beds, trolleys, operating tables and assistive technology equipment as a medical engineer. For P3, learners must describe the reasons why patient beds, trolleys, operating tables and assistive technology equipment must be regularly serviced. The learner response for this criterion must include at least three explicit reasons with examples that are specific to patient beds, trolleys, operating tables and assistive technology equipment. For M2, learners need to explain the effects of ineffective servicing for patient beds, trolleys, operating tables and assistive technology equipment The response for this criterion will build upon that provided for P3 and will cover the possible implications of ineffective servicing of patient beds, trolleys, operating tables and assistive technology equipment, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider sensory and performance verification checks as a medical engineer. For P4, learners must describe how to complete a sensory check on two basic devices from patient beds, trolleys and assistive technology equipment. Any two devices can be chosen from those defined in the unit content for learning outcome 1. The sensory checks (carried out without the use of special equipment) for both devices must refer to sight, sound, smell and touch checks and give specific examples of each for each device. For P5, learners need to describe how to carry out a performance verification check on a patient transport trolley. The description must cover a full performance verification check that would be required before a patient transport trolley is put back into service after, for example, a repair is carried out off-site. For M3, learners must explain how to carry out a performance verification check on an operating table. The explanation must cover a full performance verification check that would be required before an operating table is put back into service after, for example, a repair is carried out off-site. The reasons for each check must also be explained for this criterion.

Assignment 4 requires learners to consider the safe testing of a trolley and patient-operated assistive technology equipment as a medical engineer. For P6, learners must describe how to safely use appropriate pneumatic or mechanical test meters in accordance with regulations when testing a patient transport trolley. The description must cover attachment of the meters to the patient transport trolley and carrying out tests to determine, for example, the load that can be carried. For P7, learners must describe how to use an electrical safety analyser when testing one piece of patient-operated assistive technology equipment in accordance with regulations. Any type of patient-operated assistive technology equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test or a line leakage test.

Criteria P8, P9, M4, M5 and D2 are assessed through practical work, involving patient beds, trolleys, operating tables and assistive technology equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor’s comments. Some assistance is permissible for P8 and P9, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 5. In the context of P8, P9, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' information. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Function and Operation of Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment, and the Risks to Patients from using the Equipment	You are an apprentice medical engineering technician, and your supervisor has asked you to describe the function and operation of four different pieces of patient beds, trolleys, operating tables and assistive technology equipment, as well as the risks to patients from using them, as a guide for visitors to the hospital.	Written response with diagrams and flowcharts Risk assessment
P3, M2	The Importance of Servicing Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing patient beds, trolleys, operating tables and assistive technology equipment, including the effects of poor servicing.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, M3	Sensory and Performance Verification Checks on Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to provide a guide for other medical engineers that informs them how complete sensory and performance verification checks on patient beds, trolleys and assistive technology equipment.	Written guide
P6, P7	The Safe Testing of a Trolley and Patient-operated Assistive Technology Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to provide an information leaflet for new apprentices that describes how to use mechanical test meters and an electrical safety analyser when testing a trolley and patient-operated assistive technology equipment.	Written report

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M4, M5, D2	Practical Activities Relating to Inspecting, Testing and Servicing of Patient Beds, Trolleys, Operating Tables and Assistive Technology Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of patient beds, trolleys, operating tables and assistive technology equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant pieces of equipment

Essential resources

Learners will require access to a range of patient beds, trolleys, operating tables and assistive technology equipment, including a selection from wheelchairs, scooters, stair lifts, hoists, seating systems, walking aids, patient self-transfer aids, commodes, bathing equipment, pressure redistribution and relief devices, orthotic devices, upper and lower limb prostheses and hearing aids.

Indicative reading for learners

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance
www.hee.nhs.uk/our-work/prosthetics-orthotics	NHS information about prosthetics and orthotics

Unit 87: Principles of Medical Imaging

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in inspecting and testing medical imaging equipment, in accordance with approved procedures.

Medical imaging involves a variety of scientific processes such as reflection, transmission, absorption and the production of various types of radiation. Ultrasound scans and x-ray photographs are the most familiar methods of medical imaging. The former uses reflection of high frequency sound, while the latter uses the fact that x-radiation is transmitted through soft tissue but absorbed by hard matter such as bones. CT scans, while based on x-rays, produce an overall 3D image formed from combining many cross-sectional layers. In contrast, MRI scans detect radio frequency waves, which are emitted due to interactions of magnetic fields, to produce 3D images by computerised layering of images. Other forms of radiation are emitted by radioactive nuclei, inserted into the body, which are detected externally to produce images.

Learners will be required to inspect and test a range of medical imaging equipment, including equipment using ultrasound, magnetic resonance and ionising radiations such as radio, x-rays and gamma rays. It will include electrical, electronic and mechanical units and components. The equipment may present hazards associated with different types of ionising radiation.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of medical imaging equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of medical imaging equipment

2 Understand the importance of servicing medical imaging equipment

3 Understand the processes used to test medical imaging equipment for safety

4 Be able to inspect and test medical imaging equipment in accordance with the relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the principles of medical imaging equipment

Principles: reflection – ultrasound scanning; transmission/absorption – diagnostic x-ray, CT scanner; emission/radionuclide tracing – MRI scanner, PET scanner, linear accelerator; detection/radiation monitoring – radiation monitoring equipment; different uses in medical imaging

Basic types of medical imaging equipment: ultrasound probe, ultrasound scanner, radiation monitoring equipment; normal function of each

Complex types of medical imaging equipment: diagnostic x-ray equipment, CT scanner, MRI scanner, PET scanner, linear accelerator; normal function of each

Underlying technology of the medical imaging equipment specified above: function and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

Risks to patients or users from the use of the equipment: general risks – electric shock, crushing between an accidentally broken part of a heavy piece of equipment such as a CT or X-ray scanner, malfunction of CT or MRI scanner's patient table; specific risks – allergy to ultrasound lubricant jelly or latex probe covering, excessive x-rays from x-ray equipment or CT scanner, ferrous material attraction to MRI machine's magnet

2 Understand the importance of servicing medical imaging equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for intensity of image controls; testing for adjustment to the depth and spread controls; adjusting to the correct calibration, e.g. minimising uncertainty, adjusting the precision and accuracy of equipment, quantifying and controlling errors, frequency; replacing 'lifed' items

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose; appropriately fused, earthed and/or double insulated

Radiological safety checks: background count, for leaks, shielding, security of containment facilities, availability of dosimeters (e.g. film or TLD badges), availability of protective clothing

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors, risks to the human body from external energy sources; electric shocks; incomplete treatment or over-treatment; cell damage/mutations; burns; radiation sickness

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the processes used to test medical imaging equipment for safety

Electrical, radiological and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; radiation monitoring devices: Geiger-Mueller ratemeter, personal dosimeters; mechanical tests: flexibility, strength, frictional; particular importance of planning when working with radioactive materials or with x-rays as exposure time must be minimised

Safe testing processes: planning and communicating the testing activities so as to minimise disruption to patient care; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures to realise a safe system of work; ensuring that the correct equipment decontamination procedure has been adhered to before the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids), providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on...' label as appropriate; completing hard copy or online record of testing

Safe preparation for testing: care in dismantling or reassembling medical imaging equipment: observing procedures and precautions to be adopted to eliminate/protect against exposure to radiation and monitor exposure; switching off, unplugging; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant testing schedules to carry out the required work; complying with The Ionising Radiation (Medical Exposure) Regulations and The Ionising Radiation (Medical Exposure) (Amendment) Regulations, organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

4 Be able to inspect and test medical imaging equipment in accordance with the relevant legislation, standards and manufacturers' instructions

Inspection and testing: sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: radiation monitoring devices, multi-meters, indicators, torque measuring devices

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'Tested on…' label on device to include date for next scheduled test; handover and confirmation of completion

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles of ultrasound scanning		
P2 describe the principles of x-rays in medical imaging	**M1** explain the different uses of ultrasound scanning and x-rays in medical imaging	
P3 describe the normal function of two basic types of medical imaging equipment	**M2** describe the normal function and the operating principles of two basic types and two complex types of medical imaging equipment	**D1** assess risks to patients or users related to the use of two complex types of medical imaging equipment
P4 describe the reasons why medical imaging equipment must be serviced and calibrated regularly	**M3** explain the effects of incorrect servicing and calibration of medical imaging equipment	
P5 explain the main features of the ionising radiation regulations		
P6 produce a risk assessment for the safe testing of one complex type of medical imaging equipment	**M4** explain safe preparation for testing of one complex type of medical imaging equipment	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe how to use an electrical safety analyser when testing one type of medical imaging equipment in accordance with regulations		
P8 describe how to safely use a radiation monitor when testing one type of medical imaging equipment in accordance with regulations		
P9 inspect and test safely, with practical assistance, one basic type and one complex type of medical imaging equipment appropriately	**M5** inspect and test safely, with some guidance, two basic types and two complex types of medical imaging equipment appropriately	**D2** inspect and test safely, with limited guidance, two basic types and two complex types of medical imaging equipment appropriately

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, guides, information leaflets and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to consider the principles and uses of ultrasound scanning and x-rays, as well as the function and operation of medical imaging equipment and the risks to patients from the use of the equipment. For P1, learners must describe the principles of ultrasound scanning. The learner response must, as a minimum, refer to radiation, reflection, human tissue and the use of sound pulses and waves. Similarly, for P2, learners must describe the principles of x-rays in medical imaging. The learner response must, as a minimum, refer to radiation, transmission/absorption, electrons, low/high energy rays and the generation of 'negative' images. For M1, learners need to explain the different uses of ultrasound scanning and x-rays in medical imaging. The learner response for this criterion should build on those provided for P1 and P2. Two examples of uses must be provided for each, such as the use of ultrasound scanning for examining a baby in a womb and for diagnosing the causes of swelling, and the use of x-rays (or CT scans, if applicable) for examining broken bones. The explanations must cover how the medical image is generated in a contextual manner, for each example. For P3, learners must describe the normal function of two basic types of medical imaging equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M2, learners must describe the normal function and the operating principles of two basic types and two complex types of medical imaging equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1, and either a sequential list or a flowchart could be used when learners describe the normal operation of each of piece of equipment, and this must go from start-up through to shut-down (or equivalent). For D1, learners need to assess risks to patients related to the use of two complex types of medical imaging equipment. Any two complex types of medical imaging equipment can be chosen from those defined in the unit content for learning outcome 1, but the learner must not choose diagnostic x-ray equipment and a CT scanner. This criterion requires a detailed response, where learners show a good understanding of the specific dangers when using the chosen equipment as well as how the chosen equipment could be unintentionally misused.

Assignment 2 requires learners to consider the importance of servicing and calibration of medical imaging equipment. For P4, learners need to describe the reasons why medical imaging equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to medical imaging equipment. For M3, learners must explain the effects of incorrect servicing and calibration of medical imaging equipment. The response for this criterion will build upon that provided for P4 and will cover the possible implications of incorrect servicing and calibration of medical imaging equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of medical imaging equipment as a medical engineer. For P5, learners must explain the main features of the applicable ionising radiation regulations. As a minimum, learners must show their understanding of the responsibilities of duty holders with regards to exposure/doses and provide specific medical imaging examples of how the responsibilities are adhered to. For P6, learners must produce a risk assessment for the safe testing of one complex type of medical imaging equipment. Any complex type of medical imaging equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly (albeit minor) of the medical imaging equipment. For P7, learners must describe how to use an electrical safety analyser when testing one type of medical imaging equipment in accordance with regulations. Any type of medical imaging equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test or a line leakage test. For P8, learners must describe how to safely use a radiation monitor when testing one type of medical imaging equipment in accordance with regulations. Any type of medical imaging equipment where there is some exposure to radiation can be chosen from those defined in the unit content for learning outcome 1, and the description must cover the carrying out of measurements in the most appropriate area at a specific point in time or over a specific time period. For M4, learners must explain the safe preparation for testing of one complex type of medical imaging equipment. Any complex type of medical imaging equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of medical imaging equipment or its peripheral components will be dismantled or disassembled and made ready for a mechanical, electrical or radiological test. The response may be provided in the form of a sequential list or flow chart.

Criteria P9, M5 and D2 are assessed through practical work involving medical imaging equipment inspection and testing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P9, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting and testing the equipment correctly. In the context of P9, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected and tested equipment must be left in a functioning condition (where possible) and ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Principles and Uses of Ultrasound Scanning and X-rays, the Function and Operation of Medical Imaging Equipment and the Risks to Patients from the Use of the Equipment	You are an apprentice medical engineering technician, and your supervisor has asked you to explain the principles and uses of ultrasound scanning and x-rays and to describe the function and operation of four different pieces of medical imaging equipment, as well as the risks to patients when using them, as a guide for visitors to the hospital.	Written response with diagrams and flowcharts
P4, M3	The Importance of Servicing and Calibration of Medical Imaging Equipment	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating medical imaging equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, P8, M4	The Safe Testing of Medical Imaging Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of medical imaging equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that explains the ionising radiation regulations, how to use an electrical safety analyser and radiation monitor and safe preparation for the testing of medical imaging equipment.	Risk assessment Detailed information leaflet
P9, M5, D2	Practical Activities Relating to Inspecting and Testing of Medical Imaging Equipment	In your role as an apprentice medical engineering technician you are required to inspect and test a range of medical imaging equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspecting and testing the relevant pieces of medical imaging equipment

Essential resources

Learners will need access to a range of medical imaging equipment, including ultrasound scanners, diagnostic x-ray, MRI scanners, PET scanners, CT scanners, linear accelerators, radiation monitoring equipment and radionuclide tracing equipment.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/clinical-engineering/extremity-computerised-tomography-ct-imaging	Extremity Computerised Tomography (CT) imaging
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance

http://www.legislation.gov.uk/uksi/2017/1322/contents/made	The Ionising Radiation (Medical Exposure) Regulations 2017
http://www.legislation.gov.uk/uksi/2018/121/contents/made	The Ionising Radiation (Medical Exposure) (Amendment) Regulations 2018

Unit 88: Principles of Servicing Dental Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in the maintenance and testing of dental equipment.

Dental equipment plays a key role in healthcare, being vital for monitoring, diagnosis and therapy. Effective maintenance, testing and disposal of this equipment is essential in reassuring patients and providing high quality patient care and in ensuring the constant availability of equipment and the safety of operators and patients. The equipment must be inspected, tested and serviced proactively to prevent repetition of adverse incidents.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for dental equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of dental equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of dental equipment

2 Understand the importance of servicing dental equipment

3 Understand the processes used to test dental equipment for safety

4 Be able to inspect, test and service dental equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the function and operation of dental equipment

Basic types of dental equipment: suction unit, drilling unit, dental handpiece, dental lighting; normal function of each

Complex types of dental equipment: dental air compressor, dental scaler, polymerisation unit, floor utility service unit, dental chair, amalgamator, amalgam separator; normal function of each

Operating principles of each type of dental equipment: preparing materials, switch on sequence, equipment warm-up; adjusting/setting initial conditions and safety/functional testing of equipment as appropriate, observing or measuring and recording findings, closing down procedures

Underlying technology of the dental equipment specified above: functioning and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, heating equipment, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

Risks to users and patients from operating the equipment: electric shock, damage to moving parts of equipment resulting in pieces scattering in the environment, leakage of pressurised tubing, electrical failure during operation, operating light failure, suction unit malfunction resulting in no fluid suction capability

2 Understand the importance of servicing dental equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for correct readings; adjusting to the correct calibration, e.g. minimising uncertainty, adjusting the precision and accuracy of equipment, quantifying and controlling errors, frequency; replacing 'lifed' items

Regular maintenance: minimising wear; avoiding unplanned breakdowns; reducing need for costly repairs or equipment replacement

Operational efficiency: maximising use; maintaining, testing and replacing activities at times when demand is low; using substitute equipment in rotation

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose

Implications of medical abnormalities caused by poor servicing or lack of servicing/calibration: misdiagnosis may lead to inappropriate treatment, dosage errors, risks to the human body from external energy sources; electric shocks; incomplete treatment or over-treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services

3 Understand the processes used to test dental equipment for safety

Electrical, radiological, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; visual tests for mechanical integrity

Safe testing processes: planning and communicating the testing activities so as to minimise disruption to normal working; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; obtaining and using the correct issue of manufacturer's drawings and testing documentation or local SOP; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures; ensuring that the correct equipment decontamination procedure has been adhered to before and after the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air, fluids); providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate, completing hard copy or online record of testing

Safe preparation for testing: care in dismantling dental equipment: switching off, unplugging, de-soldering, removing screwed, clamped and crimped connections, removing pipes, hoses and mechanical components; attaching of identification markers to removed items; observing procedures and precautions to be adopted to protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant testing schedules to carry out the required work; complying with organisational guidelines, Standard Operating Procedures (SOPs) and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

Standard precautions for infection prevention and control: legal requirements, cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal

4 Be able to inspect, test and service dental equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: identifying any fault conditions in and apply corrective action as appropriate to dental equipment listed in the unit content for learning outcome 1; sensory input: sight, sound, smell, touch; visual checks: damage, missing parts, wear/deterioration; alignment checks; movement checks: excessive movement or clearance, loose fittings and connections; information from monitoring equipment or gauges; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multi-meters, indicators, torque measuring devices; carrying out electrical safety tests using an electric safety analyser: earth continuity, leakage currents; carrying out mechanical tests: flexibility, strength, frictional; carrying out pneumatic tests: pressure, flow rate, leakage; identification of component(s) that need repair or replacement

Servicing activities: isolating and locking off equipment and applying electrostatic discharge (ESD) precautions; dismantling equipment to the appropriate level; disconnecting and reconnecting wires and cables; attaching suitable cable identification markers; removing and replacing electrical units/components; de-soldering and re-soldering; checking components for serviceability; replacing damaged/defective components; replacing all 'lifed' items; tightening fastenings to the required torque; setting, recalibrating and adjusting replaced components; making visual checks before powering up; carrying out electrical safety tests; checking equipment operating parameters; functionally testing the serviced equipment

Oil and grease: moving parts of equipment such as wheels/castors, gears, bearings, pumps, hinges, locking and retaining devices

Typical components that may need to be replaced or repaired: cables and connectors, printed circuit boards, overload protection devices, switches, locking and retaining devices, power supplies, analogue or digital integrated circuits, potentiometers, diaphragms, rectifiers, filters, sensors, thermistors, transformers, transducers, regulators, timers, seals, batteries, gears, bearings, indicators (lamps, LEDs), lighting bulbs, display units, pressure gauges, valves, pumps, motors, hoses/pipework, structural components, e.g. hinges, covers and wheels/castors

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the normal function of two basic types of dental equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of dental equipment	**D1** assess risks to users and patients in relation to operating two complex types of dental equipment
P2 describe the reasons why dental equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of dental equipment	
P3 produce a risk assessment for the safe testing of one complex type of dental equipment	**M3** explain safe preparation for testing of more one complex type of dental equipment	
P4 describe how to safely use pneumatic test meters when testing one complex type of dental equipment in accordance with regulations		
P5 describe how to use an electrical safety analyser when testing one complex type of dental equipment in accordance with regulations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 inspect and test safely, with practical assistance, one basic type and one complex type of dental equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and two complex types of dental equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of dental equipment appropriately
P7 service safely, with practical assistance, one basic type and one complex type of dental equipment appropriately	**M5** service safely, with some guidance, two basic and two complex types of dental equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records and tutor comments. Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, guides, information leaflets and from tutor observation of practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to show their understanding as a medical engineer of the function and operation of dental equipment, as well as the risks to users from operating the equipment. For P1, learners must describe the normal function of two basic types of dental equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of dental equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1, and either a sequential list or a flowchart could be used when learners describe the normal operation of each of piece of equipment, and this must go from start-up through to shut-down (or equivalent). For D1, learners need to assess risks to users in relation to operating two complex types of dental equipment. Any two complex types of dental equipment can be chosen from those defined in the unit content for learning outcome 1. This criterion requires a detailed response, where learners show a good understanding of the specific dangers of operating both types of equipment as well as how they could be unintentionally misused.

Assignment 2 requires learners to consider the importance of servicing and calibration of dental equipment as a medical engineer. For P2, learners need to describe the reasons why dental equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to dental equipment. For M2, learners must explain the effects of incorrect servicing and calibration of dental equipment. The response for this criterion will build upon that provided for P2 and will cover the possible implications of incorrect servicing and calibration of dental equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of dental equipment as a medical engineer. For P3, learners must produce a risk assessment for the safe testing of one complex type of dental equipment. Any complex type of dental equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the dental equipment. For P4, learners must describe how to safely use pneumatic test meters when testing one complex type of dental equipment in accordance with regulations. Any complex type of dental equipment that has a pneumatic element can be chosen from those defined in the unit content for learning outcome 1, and the description must cover attachment of the meters to the dental equipment and carrying out measurements to determine, for example, leakage and the load that can be carried. For P5, learners must describe how to use an electrical safety analyser when testing one complex type of dental equipment in accordance with regulations. Any complex type of dental equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test, or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of dental equipment. Any complex type of dental equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of dental equipment will be dismantled or disassembled and made ready for a mechanical, pneumatic or electrical test. The response may be provided in the form of a sequential list or flow chart.

Criteria P6, P7, M4, M5 and D2 are assessed through practical work, involving dental equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P6 and P7, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly.

In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 4. In the context of P6, P7, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Function and Operation of Dental Equipment and Risks to Users from Operating the Equipment	You are an apprentice medical engineering technician, and your supervisor has asked you to describe the function and operation of four different pieces of dental equipment, as well as the risks to users when operating them, as a guide for visitors to the hospital.	Written response with diagrams and flowcharts
P2, M2	The Importance of Servicing and Calibration of Dental Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating dental equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P5, M3	The Safe Testing of Dental Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of dental equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to use pneumatic test meters and an electrical safety analyser and explains safe preparation for the testing of dental equipment.	Risk assessment Detailed information leaflet
P6, P7, M4, M5, D2	Practical Activities Relating to Inspecting, Testing and Servicing of Dental Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of dental equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant pieces of dental equipment

Essential resources

Learners will need access to a range of dental equipment, including suction units, drilling units, dental air compressors, scalers, dental handpieces, polymerisation units, floor utility service units, dental chairs, dental lighting, amalgamators and amalgam separators.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians* (Kendall Hunt, 1995) ISBN 9780787200657

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
https://www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
https://www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance
http://www.legislation.gov.uk/uksi/2017/1322/contents/made	The Ionising Radiation (Medical Exposure) Regulations 2017
http://www.legislation.gov.uk/uksi/2018/121/contents/made	The Ionising Radiation (Medical Exposure) (Amendment) Regulations 2018

Unit 89: Principles of Servicing Medical Laboratory Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the role of the medical engineer in the maintenance and testing of medical laboratory equipment. The modern medical laboratory features a wide range of equipment, such as centrifuges, Coulter counters, blood and gas analysers, flame photometers, chloride meters, roller beds, colorimeters, spectrophotometers, particle counters, ion selective analysers, pH meters and blood co-oximetry equipment. All of these provide data necessary for monitoring the health of patients and assist in the diagnosis of various illnesses and prevention of disease. Data such as the FBC (full blood count), ESR (erythrocyte sedimentation rate), CRP (C-reactive protein), BMP (basic metabolic panel) and PT (prothrombin time) are generated by medical laboratory machines and provide vital indicators of a patient's wellbeing.

Medical engineers need to know the systems in place for planning, carrying out and recording maintenance and testing activities for laboratory equipment, along with reporting issues arising from these activities. They also need to know potential consequences of inadequate maintenance, testing and calibration. Safety issues should be understood and safe working practised. While carrying out these procedures, it is essential to maintain the highest standards of hygiene and infection control precautions.

The unit encompasses both theoretical teaching and practical work. It aims to raise learner awareness of the general principles associated with the safe use of testing devices and medical laboratory equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the normal function and underlying technology of laboratory equipment found in a general medical laboratory

2 Understand the importance of servicing laboratory equipment

3 Understand the processes used to test laboratory equipment for safety

4 Be able to inspect, test and service laboratory equipment in accordance with relevant legislation, standards and manufacturers' instructions.

Unit content

1 Understand the normal function and underlying technology of laboratory equipment found in a general medical laboratory

Main areas in a general medical laboratory: reception, sample collection area, laboratory/testing area, reporting section, store room; main risk areas in a general medical laboratory, including chemical (reactive, toxic, flammable, corrosive), biological (microbes, animals, plants, genetically modified agents), and physical (slipping, heating devices, noise, projectiles, moving machinery)

Basic types of medical laboratory equipment: water bath, pH meter, chloride meter, roller bed, colorimeter, flame photometer, microscopes; normal function of each

Complex types of medical laboratory equipment: centrifuge, Coulter counter, particle counter, blood gas analyser, ion selective analyser, spectrophotometer, cryostat; specialist instruments for haematology: machines that investigate blood, including analysers, flow cytometers, coagulation analysers, slide stainers; specialist instruments for histology and pathology, including microtomes, flow cytometers; normal function of each

Operating principles of each type of medical laboratory equipment: preparing samples, switch on sequence, equipment warm-up; adjusting/setting initial conditions and safety/functional testing of equipment as appropriate, observing or measuring and recording findings, closing down procedures

Underlying technology of the devices specified above: functioning and application of components used in equipment: switches, sensors, control devices, overload protection devices, transformers, thermistors, heating equipment, valves and pumps, hoses, display units/meters, indicators (lamps, LEDs)

Risks to users from operating the equipment: electrical (electric shock), physical (noise, projectiles, moving machinery, hot equipment), biological (inhaling, touching, spills of microbes, animals, plants, genetically modified agents), chemical (contact with reactive, toxic, flammable or corrosive material)

2 Understand the importance of servicing laboratory equipment

Reasons for servicing: to ensure the safety of the user and the patient, to ensure the equipment operates correctly, to prevent avoidable malfunctions, to generate a maintenance record, to ensure confidence

Ensuring normal function: testing for controlled flow; adjusting to the correct calibration of infusion rate, e.g. minimising uncertainty, adjusting the precision and accuracy of equipment, quantifying and controlling errors, frequency; replacing 'lifed' items

Regular maintenance: minimising wear; avoiding unplanned breakdowns; reducing need for costly repairs or equipment replacement

Operational efficiency: maximising use; maintaining, testing and replacing activities at times when demand is low; using substitute equipment in rotation

Electrical safety checks to ensure that equipment, cables and connections are: free from damage or wear; in a safe and usable condition; organised correctly for the intended purpose; appropriately fused, earthed and/or double insulated

Implications of incorrect data caused by poor servicing or lack of servicing/calibration: risks to the patient from misdiagnosis; excessive time for treatment; over-treatment; incorrect medication level; incomplete treatment

Other implications of poor servicing/calibration: delayed or missed servicing/calibration may lead to more serious damage or failure of equipment; a repeat service may be required following an initial poor service; financial waste, e.g. cost of replacement equipment, underuse of ancillary services, poor return on significant investment

3 Understand the processes used to test laboratory equipment for safety

Electrical, pneumatic and mechanical safety where applicable: electrical safety tests using an electric safety analyser: earth continuity, leakage currents; pneumatic tests using pressure and flow meters: pressure, flow rate, leakage; mechanical tests: flexibility, strength, frictional

Safe testing processes: planning and communicating the servicing activities so as to minimise disruption to normal working; risk assessment (five steps), e.g. identify hazards, decide who might be harmed and how, evaluate the risks and decide on precautions, record findings, review and update as necessary; obtaining and using the correct issue of manufacturer's drawings and testing documentation or local SOP; adhering to procedures or systems in place, e.g. COSHH, personal protective equipment and other relevant safety regulations and procedures; ensuring that the correct equipment decontamination procedure has been adhered to before and after the testing activities; ensuring the safe isolation of equipment (such as electrical, mechanical, gas, air or fluids); providing and maintaining safe access and working arrangements for the testing area; carrying out the testing activities using appropriate techniques and procedures; returning the equipment to service on completion of the activities; disposing of waste items in a safe and environmentally acceptable manner; leaving the work area in a safe condition; attaching a 'Tested on....' label as appropriate; completing hard copy or online record of testing

Safe preparation for testing: care in dismantling or reassembling laboratory equipment: switching off, unplugging, de-soldering, removing screwed, clamped and crimped connections, removing pipes, hoses and mechanical components; observing procedures and precautions to be adopted to eliminate/protect against electric shock and electrostatic discharge (ESD) when working on sensitive equipment or devices; taking standard precautions within Standard Operating Procedures for infection prevention and control including cleaning of equipment, hand hygiene, wearing protective clothing, using special bags/containers for waste disposal; taking statutory precautions (COSSH) when in contact with laboratory reagents and chemicals

Compliance with statutory regulations, organisational guidelines and protocols: following the relevant servicing schedules to carry out the required work; complying with organisational guidelines and codes of practice, workplace documents, manufacturer's operation range, relevant and current HTM documentation, equipment and associated BSEN standards, CE marking, International Electrotechnical Commission (IEC) standards and, where appropriate, BS 7671/IEE Wiring Regulations; ensuring the equipment functions to specification; ensuring the equipment remains compliant with all standards and regulations; ensuring all potential defects are identified and reported for future action

Processes for removal and replacement of components: attachment of identification markers to removed items; checking replacement components meet required specification before retesting: power rating, voltage range, operating temperature, working range, tolerance

4 Be able to inspect, test and service laboratory equipment in accordance with relevant legislation, standards and manufacturers' instructions

Inspection and testing: identifying any fault conditions in and apply corrective action as appropriate; sensory input: sight, sound, smell, touch; visual checks: leakage, damage, missing parts, wear/deterioration, alignment; movement checks: excessive movement or clearance, loose fittings and connections; checking loads/pressure such as spring pressure, belt or chain tension; checking overheating: in bearings, between friction surfaces; information from monitoring equipment or gauge; operating tests: manual operation, timing and sequencing; test instrumentation measurement: pressure, flow, timing, sequence, movement; measuring instruments: multi-meters, indicators, torque measuring devices, feeler gauges; identification of component(s) that need repair or replacement

Servicing activities: e.g. isolating and locking off, applying electrostatic discharge (ESD) precautions, dismantling to the appropriate level, disconnecting and reconnecting wires and cables, attaching suitable cable identification markers, removing and replacing electrical components, removing and replacing mechanical components, soldering and de-soldering, checking components for serviceability, replacing damaged/defective components, replacing all 'lifed' items, tightening fastenings to the required torque, setting and adjusting replaced components, making visual checks before powering up, checking equipment operating parameters, recalibrating and/or adjusting equipment for normal function, carrying out electrical safety tests, functionally testing the serviced equipment

Oil and grease: moving parts of equipment, e.g. wheels/castors, gears, bearings, pumps, hinges, locking and retaining devices

Typical components that may need to be replaced or repaired: batteries, cables and connectors, heater elements, printed circuit boards, overload protection devices, switches, power supplies, analogue or digital integrated circuits, potentiometers, rectifiers, sensors, thermistors, transformers, transducers, timers, seals, regulators, locking and retaining devices, oxygen cells, display units/meters, indicators (lamps, LEDs), valves, pumps, motors, hoses/pipework, structural components (e.g. hinges, covers and wheels)

Completion and return to use: final testing for electrical safety and, where applicable, for performance; checking all accessories are present; ensuring controls are set to zero or to the settings noted during inspection; 'SERVICED' label on device to include date for next scheduled service; handover and confirmation of completion; complete record of servicing for management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the main risk areas in a general medical laboratory		
P2 describe the normal function of two basic types of medical laboratory equipment	**M1** describe the normal function and the operating principles of two basic types and two complex types of medical laboratory equipment	**D1** assess risks to users when operating two complex types of medical laboratory equipment
P3 describe the reasons why medical laboratory equipment must be serviced and calibrated regularly	**M2** explain the effects of incorrect servicing and calibration of medical laboratory equipment	
P4 produce a risk assessment for the safe testing of one complex type of medical laboratory equipment	**M3** explain safe preparation for testing of one complex type of medical laboratory equipment	
P5 describe how to safely use pressure and flow meters when testing one complex type of medical laboratory equipment in accordance with regulations		
P6 describe how to use an electrical safety analyser when testing one complex type of medical laboratory equipment in accordance with regulations		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 inspect and test safely, with practical assistance, one basic type and one complex type of medical laboratory equipment appropriately	**M4** inspect and test safely, with some guidance, two basic types and two complex types of medical laboratory equipment appropriately	**D2** inspect, test and service safely, with limited guidance, two basic types and two complex types of medical laboratory equipment appropriately
P8 service safely, with practical assistance, one basic type and one complex type of medical laboratory equipment appropriately	**M5** service safely, with some guidance, two basic and two complex types of medical laboratory equipment appropriately	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports or practical assignments, supported by a logbook/report of activities carried out, plus observation records.

Throughout the course, learners will have opportunities to show capability in many aspects of the work and these should be recorded in a logbook/portfolio.

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to assignments, presentations, guides, information leaflets and from tutor observation of the practical work completed.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or distinction grade will require answers that demonstrate additional depth and/or breadth of response.

Three written assignments could be set for the assessment of this unit, to supplement continuous assessment and observation of practical tasks. Some of the responses to the tasks in the assignments will need to be suitably sourced and it is very important they are properly referenced in the assessment evidence provided. Diagrams are also likely to be used in the assessment evidence provided, and again they should be suitably sourced and properly referenced.

Assignment 1 requires learners to show their understanding as a medical engineer of the risk areas in a medical laboratory and the function and operation of medical laboratory equipment, as well as the risks to users from operating the equipment. For P1, learners must describe the main risk areas in a general medical laboratory. The response for this criterion must cover chemical, biological and physical risks and give specific examples. For P2, learners must describe the normal function of two basic types of medical laboratory equipment. Any two can be chosen from those defined in the unit content for learning outcome 1. For M1, learners must describe the normal function and the operating principles of two basic types and two complex types of medical laboratory equipment. Any two can be chosen for each type from those defined in the unit content for learning outcome 1, and either a sequential list or a flowchart could be used when learners describe the normal operation of each of piece of equipment, and this must go from start-up through to shut-down (or equivalent). For D1, learners need to assess risks to users in relation to operating two complex types of medical laboratory equipment. Any two complex types of medical laboratory equipment can be chosen from those defined in the unit content for learning outcome 1. This criterion requires a detailed response, where learners show a good understanding of the specific dangers of operating both types of equipment as well as how they could be unintentionally misused.

Assignment 2 requires learners to consider the importance of servicing and calibration of medical laboratory equipment as a medical engineer. For P3, learners need to describe the reasons why medical laboratory equipment must be serviced and calibrated regularly. The learner response for this criterion must cover both servicing and calibration and include at least three explicit reasons with examples that are specific to medical laboratory equipment. For M2, learners must explain the effects of incorrect servicing and calibration of medical laboratory equipment. The response for this criterion will build upon that provided for P3 and will cover the possible implications of incorrect servicing and calibration of medical laboratory equipment in particular, and must include potential technical, medical and financial issues.

Assignment 3 requires learners to consider the safe testing of medical laboratory equipment as a medical engineer. For P4, learners must produce a risk assessment for the safe testing of one complex type of medical laboratory equipment. Any complex type of medical laboratory equipment can be chosen from those defined in the unit content for learning outcome 1. The risk assessment must be on a suitable template, cover all five steps and be for a test that includes some form of disassembly of the medical laboratory equipment. For P5, learners must describe how to safely use pressure and flow meters when testing one complex type of medical laboratory equipment in accordance with regulations. Any complex type of medical laboratory equipment that has a pneumatic element can be chosen from those defined in the unit content for learning outcome 1, and the description must cover attachment of the meters to the medical laboratory equipment and carrying out measurements to determine, for example, leakage. For P6, learners must describe how to use an electrical safety analyser when testing one complex type of medical laboratory equipment in accordance with regulations. Any complex type of medical laboratory equipment that is mains operated can be chosen from those defined in the unit content for learning outcome 1, and the description must cover at least one test, such as a ground continuity test, insulation test, or a line leakage test. For M3, learners must explain the safe preparation for testing of one complex type of medical laboratory equipment. Any complex type of medical laboratory equipment can be chosen from those defined in the unit content for learning outcome 1. The response for this criterion must cover in detail how the complex type of medical laboratory equipment will be dismantled or disassembled and made ready for a mechanical, pneumatic or electrical test. The response may be provided in the form of a sequential list or flow chart.

P7, P8, M4, M5 and D2 are assessed through practical work, involving medical laboratory equipment inspection, testing for functionality and servicing, and should be assessed continuously and on-site. Learners will have several opportunities to show capability during the course and should keep a logbook of their activities with space for the tutor's comments. Some assistance is permissible for P7 and P8, meaning that the tutor/supervisor may intervene at certain points so the learner can get back on track. Some guidance is permissible for M4 and M5, meaning that the learner may ask questions and seek clarification while undertaking the work. In order to achieve D2, guidance must be limited to confirmation that the learner is inspecting, testing and servicing the equipment correctly. In the context of this unit, to 'service' means to repair/replace components or consumables for the relevant piece of equipment safely so that it operates correctly. 'Components' can include consumables such as solder and lubrication. The range and type of components and consumables that would typically need to be replaced/repaired is defined in the unit content for learning outcome 4. In the context of P6, P7, M4, M5 and D2, 'appropriately' means by applying the relevant legislation, standards, requirements and procedures from the manufacturers' instructions. 'Appropriately' also means that all inspected, tested and serviced equipment must be left in a functioning condition ready to be returned to use if required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Risk Areas in a Medical Laboratory, the Function and Operation of Medical Laboratory Equipment and Risks to Users from Operating the Equipment	You are an apprentice medical engineering technician employed in a medical laboratory, and your supervisor has asked you to describe the function and operation of four different pieces of medical laboratory equipment, and the risks to users when operating them, as well as the main risk areas in a general medical laboratory as a guide for visitors.	Written response with diagrams and flowcharts
P3, M2	The Importance of Servicing and Calibration of Medical laboratory Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to prepare PowerPoint slides to guide new apprentices about the importance of servicing and calibrating medical laboratory equipment, including the effects of poor servicing and calibration.	PowerPoint slides with detailed notes

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3	The Safe Testing of Medical Laboratory Equipment as a Medical Engineer	You are an apprentice medical engineering technician, and your supervisor has asked you to produce a risk assessment for the safe testing of medical laboratory equipment so it can be referred to by other medical engineers. They also want you to provide an information leaflet for new apprentices that describes how to safely use pressure and flow meters and an electrical safety analyser and explains safe preparation for the testing of medical laboratory equipment.	Risk assessment Detailed information leaflet
P7, P8, M4, M5, D2	Practical Activities Relating to Inspecting, Testing and Servicing Medical Laboratory Equipment	In your role as an apprentice medical engineering technician you are required to inspect, test and service a range of medical laboratory equipment in accordance with relevant legislation, standards and procedures from the manufacturers' instructions.	Logbook (including annotated photographs) to detail capability in all aspects of inspection, testing and servicing the relevant pieces of medical laboratory equipment

Essential resources

Learners will need access to a range of laboratory equipment, including centrifuges, Coulter counters, particle counters, blood gas analysers, ion selective analysers, flame photometers, chloride meters, pH meters, spectrophotometers, colorimeters, water baths and cryostats.

Indicative reading for learners

Textbooks

Atles L, Segalewitz S – *Affinity Reference Guide for Biomedical Technicians (Kendall Hunt, 1995) ISBN 9780787200657*

Carr J, Brown J – *Introduction to Biomedical Equipment Technology*, 4th edition (Pearson, 2001) ISBN 9780130104922

Iadanza E – *Clinical Engineering Handbook*, 2nd edition (Academic Press, 2019) ISBN 9780128134672

Taktak A, Ganney P, Long D, White P (eds) – *Clinical Engineering: A handbook for clinical and biomedical engineers*, 2nd edition (Academic Press, 2019) ISBN 9780081026946

Wang B – *Medical Equipment Maintenance: Management and oversight (synthesis lectures on biomedical engineering)* (Morgan & Claypool, 2012) ISBN 9781627050562

Willson K, Ison K, Tabakov S – *Medical Equipment Management* (CRC, 2014) ISBN 9781420099584

Websites

https://apps.who.int/iris/bitstream/handle/10665/255261/9789241565479-eng.pdf;jsessionid=2CCEC22D27B30580ECB3D19B5E538932?sequence=1	WHO Human Resources for Medical Devices, Chapter 9: Role of biomedical engineers in the management of medical devices
www.bbc.co.uk/bitesize/guides/z9nr6yc/revision/5	Simple introduction to flame tests
www.ebme.co.uk/articles/electrical-safety/hazards-of-medical-electrical-equipment	Hazards of electrical medical equipment
www.ebme.co.uk/articles/management/planning-maintenance	Planned preventative maintenance
www.explainthatstuff.com/how-ph-meters-work.html	pH meters explained
www.healthline.com/health/blood-tests#important-blood-tests	Blood test information

www.hse.gov.uk/pubns/clinical-laboratories.pdf	Government guidance on health and safety in laboratories
https://labtestsonline.org.uk/	Clinical laboratory tests
www.mynewlab.com/blog/working-in-a-laboratory-the-hazards-and-risks/	Laboratory hazards and risks
https://en.wikipedia.org/wiki/Medical_laboratory	General information about medical laboratories
https://www.youtube.com/watch?reload=9&v=2tJqZStFwjU	Flame photometry/Flame Emission Spectroscopy (FES)/Atomic absorption spectroscopy (AES)
https://www.youtube.com/watch?v=EQXPJ7eeesQ	Flow cytometry explained
https://www.youtube.com/watch?v=bYfZk9PU3XI	Coulter counter explained

Unit 90: Basic Polymer Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit enables learners to gain a knowledge of the classification of polymers, the modification of their properties using additives and the processing methods used to produce them. The unit also enables learners to gain skills in testing the physical properties of polymers.

This unit introduces learners to the terminology, materials and processes associated with the polymer industry. It is intended for learners who may be commencing a career in polymers or have little prior knowledge of the industry. Topics covered are relevant to both the plastics and rubber sectors of the industry. The unit covers the fundamental concepts which formulate the way in which polymers and their starting materials sources are classified. Learners will gain a knowledge of how to modify the properties of polymers by the use of additives to enable them to be suitable for a range of applications in everyday use. They will be introduced to processing methods of how to produce products such as plastic bottles and damp proof membranes. It is important that learners develop skills to enable them to investigate the properties of polymers such as their impact and tensile strength. Learners will also gain a knowledge of the sources of starting materials, their sustainability, a knowledge of polymers that can be recycled and the environmental effects of polymers.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how to classify polymers and their sources using correct terminology

2 Know how additives modify polymer properties

3 Be able to investigate processing methods by which polymers can be processed into products

4 Be able to investigate the testing of materials to determine the physical properties of polymers.

Unit content

1 Know how to classify polymers and their sources using correct terminology

Terminology and definitions: natural, synthetic, monomer; polymer; co-polymer; composites; polymerisation; elasticity; plasticity

Classification of polymers: thermoplastic; thermoset; elastomer; bioplastic; standard abbreviation in each classification; molecular structures

Physical properties: tensile strength; hardness; impact strength; density; decomposition (biodegradability); environmental effects

Sources of starting materials: petroleum oil; sugars; cornstarch; cellulose; hydroxycarboxylic acids; recycling; sustainability

2 Know how additives modify polymer properties

Basic properties of polymers: basic molecular chain and 3-dimensional structures

Modification of polymers: modification, e.g. strength, stiffness, service life, costs

Function of additives: fillers; plasticisers; cross-linking agents; impact modifiers; antioxidants; stabilisers; blowing agents

Calculations: mix densities; material costs; energy costs

3 Be able to investigate processing methods by which polymers can be processed into products

Construction and operation of processing equipment: two roll mill; internal mixers; extruders; calenders; presses; injection moulding machines; thermoforming; blow moulding

4 Be able to investigate the testing of materials to determine the physical properties of polymers

National and international standards for materials testing: BS; ISO; ASTM; DIN

Standard testing procedures: tensile strength; hardness; impact strength; density; melt flow; state of cure

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe and classify polymers and their sources using correct terminology	**M1** explain the classification of polymers with reference to general molecular structures	**D1** evaluate the classification of polymers using examples of actual polymeric materials
P2 describe the modification of polymer properties by the addition of various additives	**M2** explain the effect of various additives on polymer properties	**D2** evaluate the effect of a range of additives on polymer properties with reference to their effect on molecular structure
P3 carry out processing methods by which polymers can be processed into products, using safe working practices	**M3** explain the operation of polymer processing equipment	**D3** justify the process selected for the production of polymer products
P4 describe the test procedures used to determine the physical properties of polymers	**M4** explain the reasons for standardisation of testing procedures.	**D4** compare and contrast the results obtained from standard laboratory tests with the characteristics of a product in service.
P5 carry out the testing of materials to determine the physical properties of polymers, using safe working practices.		

Essential guidance for tutors

Assessment

Evidence is best produced as a series of reports of learners' investigatory work, and related interpretative exercises. Presentations are also an appropriate method through which learners can generate evidence to meet the assessment and grading criteria. If presentations are selected as an assessment method they must be supported by assessor witness testimony to confirm criteria achieved.

To meet the assessment criteria for a pass grade, learners must be familiar with polymer-related terminology and be able to classify polymers and their starting material sources. They need to include the emphasis on sustainability, recycling and the effects of polymers on the environment. They must provide evidence which describes how polymers are modified by various additives, the processing methods used and the testing of materials to determine the physical properties of polymers. They must also carry out two processing methods that can be used to manufacture polymer-based products and carry out two testing processes that can be used to determine the physical properties of two polymers.

For the merit criteria, learners need to explain the classification of polymers to general molecular structures; the effect of additives on polymer properties; the operation of the processing equipment and reasons for standardisation of testing procedures. Learners should start by introducing the topics and then give the 'how' or 'why' to fully support their explanations.

For the distinction criteria, learners need to evaluate techniques and processes used in the polymer industry and investigate standard laboratory test results with products in service.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Classification of Polymers, their Sources and Properties	Training officer has been asked to produce materials for a polymer conference.	Posters, leaflet
P2, M2, D2	Modification of Polymer Properties	Laboratory technician to produce materials on the effects of additives on polymers.	Table, report
P3, M3, D3	Processing Methods	Laboratory technician/operative uses processes (or reports on) to produce polymer products.	Laboratory report
P4, P5, M4, D4	Testing of Materials	Laboratory technician has been asked to carry out and report on the properties of a number of polymers.	Laboratory report

Essential resources

Learners need access to appropriate laboratory facilities and specialist resources to cover the contextualisation of the underlying concepts to their polymer specialism, e.g. plastics, rubber or related areas. Site visits to relevant industrial facilities to see practical techniques in operation would be invaluable. Input from industry experts as guest speakers would enhance unit delivery.

Indicative reading for learners

Journals

British Rubber and Plastics

Materials Foresite

Materials World

Plastics, Rubber and Composites

Websites

www.bpf.co.uk	British Plastics Federation
www.cia.org.uk	Chemical Industries Association
www.cogent-ssc.com	COGENT – Sector Skills Council
www.en.wikipedia.org/wiki/polymers	Polymers
www.expainthatstuff.com/bioplastics.html	Bioplastics
www.iom3.org	The Institute of Materials, Minerals and Mining
www.iom3.org/content/polymersociety	The Polymer Society
www.practicalchemistry.org	Practical experiments on polymers
www.rsc.org.uk	The Royal Society of Chemistry
www.stemnet.org.uk	Network for Science, Technology, Engineering and Maths – Network Ambassadors Scheme

Unit 91: Plastics Materials

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit enables learners to gain a knowledge of commodity and high performance plastics and an understanding of the importance of polymer morphology in predicting polymer properties. Learners will also develop practical skills and techniques through the laboratory investigation of flow and thermal behaviour of plastics materials.

This unit builds on the concepts of plastics technology and provides an opportunity for learners to develop a knowledge of the properties and uses of commodity and high performance plastics. Learners also need to develop an understanding of the importance of the predictability of polymer properties and their effects on the environment and sustainability. Learners will gain an understanding of glass transition temperature, the factors that determine level of crystallinity, the concept of co-polymerisation, including the structures of different co-polymers and addition co-polymerisation. The unit provides opportunities for learners to explore practically the flow and thermal behaviour of plastics materials and develop their knowledge, skills and understanding through practical laboratory investigation using safe working practices.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the properties and applications of commodity plastics and unsaturated polyester resins

2 Know the classification properties and applications of high performance plastics, epoxy and polyester composites

3 Understand the importance of polymer morphology in predicting polymer properties

4 Be able to investigate the flow and thermal behaviour of plastics materials.

Unit content

1 Know the properties and applications of commodity plastics and unsaturated polyester resins

Polyethene: structure; types; grading; processing properties; mechanical properties; cost; applications; decomposition

Polystyrene: structure; grading; processing properties; mechanical properties; cost; applications; decomposition

Polypropylene: structure; types; grading; processing properties; mechanical properties; cost; applications; decomposition

Polyvinylchloride: structure; types; additives; mixing techniques; processing properties; mechanical properties; cost; applications; decomposition

Acrylonitrile butadiene styrene: structure; types; grading systems; processing properties; mechanical properties; cost; applications; decomposition

Polyester resins (unsaturated): structure; types of resin; reinforcement materials; methods of processing, e.g. hand lay-up, automated techniques; mechanical properties; cost; applications

Phenol formaldehyde resin: structure; resol and novolak; additives; laminating resins; moulding resins; processing properties; mechanical properties; cost; applications

Biodegradable plastics: Polyactide (PLA); polyhydroxyalkanoates (PHA); structure; costs; applications; decomposition

2 Know the classification properties and applications of high performance plastics, epoxy and polyester composites

Polymethylmethacrylate: structure; types; grading; processing properties; mechanical properties; cost; applications

Polyamide: structure; types; grading; additives; processing properties; mechanical properties; cost; applications

Polyacetal: structure; types; grading; processing properties; mechanical properties; cost; applications

Polycarbonate: structure; types; grading; processing properties; mechanical properties; cost; applications

Epoxy and polyester composites: structure; types; additives; reinforcing agents; mixing; processing; mechanical properties; cost; applications

3 Understand the importance of polymer morphology in predicting polymer properties

Glass transition temperature: factors that determine Tg; relate Tg to polymer performance; the Tg for commodity plastics; the Tg for high performance plastics; Tg values for different polymers

Crystallinity: factors that determine the level of crystallinity; relate crystallinity to polymer performance; rate the commodity plastics in terms of crystallinity; rate the high performance plastics in terms of crystallinity

Co-polymerisation: the concept of co-polymerisation; random, alternating, block and graft co-polymers; addition co-polymerisation; effect of co-polymerisation on polymer performance

4 Be able to investigate the flow and thermal behaviour of plastics materials

Flow behaviour: Newtonian; non-Newtonian; Bingham; pseudo-plastic and dilatent flows; shear rate; shear stress; apparent viscosity; orientation effects

Thermal behaviour: specific heat; viscosity temperature graphs; rate of cooling; shrinkage; residual stress; thermal stability of plastics during processing

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the properties of commodity plastics and unsaturated polyester resins	**M1** compare the suitability of different commodity plastics for given applications	**D1** analyse the cost of producing products using different commodity plastics
P2 describe the applications of commodity plastics and unsaturated polyester resins		
P3 describe the classification properties of high-performance plastics, epoxy and polyester composites	**M2** compare the suitability of different high-performance plastics for given applications	**D2** relate the structure of high-performance plastics materials to their physical properties
P4 describe the applications of high-performance plastics, epoxy and polyester composites		
P5 describe the importance of polymer morphology in predicting polymer properties	**M3** explain the factors that affect the glass transition temperature and crystallinity	**D3** evaluate the effects of processing conditions on the mechanical properties of plastics materials
	M4 explain the effect of co-polymerisation on the performance of a plastic material	**D4** analyse the effect of temperature changes, during processing and in-service, on plastics materials.
P6 carry out investigations into the flow and thermal behaviour of plastic materials, using safe working practices.	**M5** distinguish between the types of flow apparent in plastic materials.	

Essential guidance for tutors

Assessment

The focus of assessment should be on learners carrying out the required tasks and producing evidence towards meeting the unit assessment and grading criteria. Tutors should observe learners undertaking practical activities and clearly record assessment decisions using an appropriate assessor's observation record, retained for audit purposes.

Safety requirements must be applied to all activities. Learners must work safely and accurately within supplied methods; this must be applied rigorously to all activities.

For the pass criteria, learners will firstly need to describe the mechanical and processing properties of four commodity plastics and the mechanical properties of two unsaturated polyester resins. For the same commodity plastics and unsaturated polyester resins, learners then need to give details of their typical uses. The evidence provided could be in the form of a table with suitable headings. The table could be expanded to include the evidence for M1 and D1, thus giving a comprehensive, holistic approach to assessment. For high-performance plastics, learner evidence could follow a similar approach to that for commodity plastics, and again the table could be expanded to include the requirements of M2 and D2. Learners must also describe the importance of polymer morphology in predicting the properties of polymers. Finally, learners will conduct practical investigations into the flow and thermal behaviour of given plastic materials. The practical investigations must enable learners to investigate three plastic materials that have different flow and thermal behaviours. An observation record of the practical investigations must form part of the assessment evidence.

For the merit criteria, learners will need to compare the suitability of four commodity plastics and four high-performance plastics for two given applications. The evidence for this could be in the form of a table. Learners will also need to explain the factors that affect crystallinity and the glass transition temperature and how co-polymerisation affects the performance of polymer materials. Finally, learners will need to analyse the results of their practical investigations to distinguish between the different types of flow demonstrated by the given plastic materials.

The distinction criteria require learners firstly to research and analyse the costs associated with using four commodity plastics for two given products. Learners need to give details of how the structure of different three high-performance plastics determines their processing and mechanical properties. Learners will also need to evaluate the effects of processing conditions on the mechanical properties of plastic materials. Finally, learners will analyse how changes in temperature affects two different plastic materials during processing and throughout the life of products made from these plastics.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Commodity Plastics and Unsaturated Polyester Resins	The marketing department request a chart of commodity plastics and unsaturated polyester resins from the polymer chemist.	Chart Table
P3, P4, M2, D2	High Performance Plastics	The marketing department request a chart of high-performance plastics from the polymer chemist.	Chart Table
P5, M3, M4, D3, D4	Predicting Polymer Properties	The British Plastics Federation has asked your company for a report on predicting polymer properties.	Report
P6, M5	Flow and Thermal Behaviour of Plastic Materials	The polymer chemist has asked you to report on the quality control of the latest batch of plastic materials.	Laboratory report containing annotated photographs and an observation record.

Essential resources

Learners need access to appropriate laboratory facilities and specialist resources to cover the contextualisation of the underlying concepts to their polymer specialism, e.g. plastics, rubber or related areas. Site visits to relevant industrial facilities to see practical techniques in operation would be invaluable. Input from industry experts as guest speakers would enhance unit delivery.

Indicative reading for learners

Journals

British Rubber and Plastics

Materials Foresite

Materials World

Plastics, Rubber and Composites

Websites

www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/polymers.html	Article on polymers including Tg, copolymers and crystallinity
www.bpf.co.uk	British Plastics Federation
www.cia.org.uk	Chemical Industries Association
www.cogent-ssc.com	COGENT – Sector Skills Council
www.en.wikipedia.org/wiki/polymers	Polymers
www.expainthatstuff.com/bioplastics.html	Bioplastics
www.iom3.org	The Institute of Materials, Minerals and Mining
www.iom3.org/content/polymersociety	The Polymer Society
www.practicalchemistry.org	Practical experiments on polymers
www.rsc.org.uk	The Royal Society of Chemistry
www.stemnet.org.uk	Network for Science, Technology, Engineering and Maths – Network Ambassadors Scheme

Unit 92: Plastics Processing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit enables learners to gain a knowledge of moulding techniques and the techniques used to manufacture products from laminates. Learners will also gain a knowledge of plastics extruder design and extrusion processes and develop an understanding of how film and sheet materials are manufactured and converted into products.

This unit builds on the concepts of plastics technology and provides an opportunity to develop knowledge of plastics processing methods. This unit also builds on the polymer processing covered in the Basic Polymer Technology unit. Learners will develop an understanding of plastics processing techniques for thermoplastic and thermoset materials. The unit provides opportunities for learners to develop their understanding through practical investigation.

The unit addresses the process engineering principles used in the polymer industry. Learners will gain knowledge of the systems used in typical polymer processing plants such as injection moulding machines, extruders, presses and mills. It is important that operatives and technical staff have an understanding of the concepts and principles in plastics processing enabling them to suggest ways to improve efficiency. For example, finding ways of reducing the use of resources such as water and heating, and the effect of waste on the environment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the moulding techniques used for manufacture of plastic products

2 Understand the features of plastics extruder design and extrusion processes

3 Understand the manufacture of film and sheet materials and conversion to products

4 Know the techniques used in the manufacture of products from phenolic, epoxy and polyester laminates.

Unit content

1 Know the moulding techniques used for manufacture of plastic products

Compression moulding: press design; upstroke and downstroke; positive and semi-positive mould design; preparation of moulding materials and performs; advantages and disadvantages of compression moulding

Transfer moulding: pot transfer moulds; transfer presses; advantages and disadvantages of transfer moulding

Injection moulding: machine design (screw and barrel design, nozzles, clamping systems); mould design (runners, gates, ejection systems, cooling systems, single and multi-daylight, hot runner systems, injection moulding variables); advantages and disadvantages of injection moulding

Moulding defects: e.g. blistering, shrinkage, colour streaks, surface marks, voids, burn marks

Remedies: e.g. check material dryness, moisture content, shrinkage calculations, temperature profile, mould rigidity

2 Understand the features of plastics extruder design and extrusion processes

Extruder design: screw nomenclature; barrel and feed hopper; breaker plate; die and die swell

Extrusion processes: pipe, wire and film; ancillary equipment; polymers used

3 Understand the manufacture of film and sheet materials and conversion to products

Manufacture of film and sheet material: tubular blown film; cast film; extruded; calendered sheet

Conversion of sheet material to products: thermoforming, e.g. male and female forming, drape, plug assisted, air-slip; fabrication, e.g. welding, bag-making, machining, mechanical fasteners

4 Know the techniques used in the manufacture of products from phenolic, epoxy and polyester laminates

Polymers and fibres: phenolics, epoxies and polyesters; paper; cotton fibre; glass fibre; carbon fibre

Lamination techniques: hand lay-up; spray lay-up; DMC; SMC; pultrusion; filament winding

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the moulding techniques used for the manufacture of plastic products	**M1** compare the advantages and disadvantages of different moulding processes	**D1** evaluate moulding processes, including hot runner systems
P2 describe moulding defects and remedies		
P3 describe the features of plastics extruders	**M2** explain two given extrusion processes	
P4 describe the manufacturing processes used to produce film and sheet materials	**M3** compare the advantages and limitations of different sheet and film manufacturing processes	**D2** evaluate the most appropriate process for the production of different types of sheet material and products
P5 describe the processes of converting film and sheet polymer materials into products		
P6 describe the techniques used in the manufacture of products from phenolic, epoxy and polyester laminates	**M4** compare the advantages and limitations of processes for manufacturing laminated products	**D3** justify the most appropriate laminate processes for different products

Essential guidance for tutors

Assessment

The focus of assessment should be on learners carrying out practical tasks, as well as producing reports as evidence towards meeting the assessment and grading criteria. Throughout this unit, learners need to be aware of issues such as sustainability and the effects of waste products on the environment. Learner presentations, supported by tutor witness testimony, would also form a suitable assessment method. Tutors should observe learners undertaking practical activities and clearly record assessment decisions using an appropriate assessor's observation record, retained for audit purposes.

Safety requirements must be applied to all activities. Learners must work safely and accurately within supplied methods; this must be applied rigorously to all activities.

For the pass criteria, learners need firstly to write a report that describes the three different moulding techniques that can be used in the manufacture of plastic products, before describing three different moulding defects and their associated remedies. P3 requires learners to describe three of the features of plastic extruders detailed in the unit content. For P4, learners need to describe one manufacturing process used to manufacture sheet material and one manufacturing process used to manufacture film materials. For P5 learners must describe two different manufacturing processes that are used to convert materials into products. Finally, for P6, learners will need to describe three different lamination techniques that can be used to manufacture products from phenolic, epoxy and polyester resins.

For the merit criteria, learners need to write a report that compares the advantages and disadvantages of three moulding processes that can be used in the manufacture of plastic products. Learners will also need to compare the advantages and limitations of two different film material manufacturing processes and two different sheet material manufacturing processes. M4 requires learners to compare the advantages and disadvantages of four lamination techniques that can be used to manufacture products from phenolic, epoxy and polyester resins. Finally, for M2 learners will need to explain the operation of two given extrusion processes.

For the distinction criteria, learners need to compile a written report that evaluates the hot runner moulding process and another two given moulding processes. They will then determine the most appropriate production process for two given sheet materials and two given plastic products. Finally, learners will justify why a certain lamination process is the most appropriate for three given laminated products.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Moulding Techniques	The processing engineer has been asked to produce a report on the moulding techniques being used on the processing plant.	Illustrated written report
P3, M2	Extruder Design and Extrusion Process	The process engineer has asked for a report on the make of the extruder and the extrusion process.	Illustrated written report
P4, P5, M3, D2	Film and Sheet Products	The research polymer scientist has been asked to provide information about how different types of film and sheet materials are manufactured and how they are converted to products.	Illustrated written report
P6, M4, D3	Manufacture of Laminates	As the technical editor of the main polymer magazine, you are writing an article on the techniques to manufacture laminates.	Illustrated written report

Essential resources

Learners need access to appropriate laboratory facilities and specialist resources to cover the contextualisation of the underlying concepts to their polymer specialism, e.g. plastics, rubber or related areas. Site visits to relevant industrial facilities to see practical techniques in operation would be invaluable. Input from industry experts as guest speakers would enhance unit delivery.

Indicative reading for learners

Journals

British Rubber and Plastics

Materials Foresite

Materials World

Plastics, Rubber and Composites

Websites

www.bpf.co.uk	British Plastics Federation
www.cia.org.uk	Chemical Industries Association
www.cogent-ssc.com	COGENT – Sector Skills Council
www.en.wikipedia.org/wiki/polymers	Polymers
www.expainthatstuff.com/bioplastics.html	Bioplastics
www.iom3.org	The Institute of Materials, Minerals and Mining
www.iom3.org/content/polymersociety	The Polymer Society
www.rsc.org.uk	The Royal Society of Chemistry
www.stemnet.org.uk	Network for Science, Technology, Engineering and Maths – Network Ambassadors Scheme

Unit 93: Polymer Process Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The unit provides learners with an understanding of mechanical drive systems including belt, gear and chain drives. Learners will develop knowledge, skills and techniques through investigation of hydraulic systems and the methods used to heat and control polymer processing equipment. Learners will also explore the types and applications of industrial robots.

The unit addresses the process engineering principles used in the polymer industry. This unit builds on the polymer processing covered in the Basic Polymer Technology unit. Learners will gain knowledge of the systems used in typical polymer processing plants such as injection moulding machines, extruders, presses and mills. It is important that operatives and technical staff have an understanding of the concepts and principles in polymer process engineering to suggest ways to improve efficiency and find ways of reducing the use of resources such as water and heating, and the effect of waste on the environment.

Learners will also explore the principles of drive systems, hydraulics, temperature measurement and control, and the use of robots in processing plants.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of mechanical drive systems

2 Understand the construction and operation of hydraulic systems

3 Understand the heating systems, temperature measurement and control used on polymer processing equipment

4 Understand the different types and applications of industrial robots.

Unit content

1 Understand the principles of mechanical drive systems

Belt drive systems: construction; operation; flat belt; V-belts; toothed belts; benefits of each type; limitations of each type; typical applications within the polymer industry

Belt calculations: speed ratios; belt speeds

Gear systems: construction and reasons for use of spur; helical; herringbone; benefits of each type; limitations of each type; typical applications within the polymer industry

Gear calculations: speed ratios for simple, compound gear trains

Roller chain systems: construction; operation; benefits; limitations

2 Understand the construction and operation of hydraulic systems

Principles of hydraulics: typical fluids and their properties; how hydraulic systems transmit a force

Circuit diagrams: terminology; standard symbols; hydraulic circuit diagrams

Standard hydraulic components: construction; operation; pumps (gear, vane and piston types); fixed and variable displacement; valves (pressure relief, pressure regulator and directional control valves); cylinders (single acting, double acting, differential, and cushioned types); accumulators (gas-filled diaphragm and bladder designs); intensifiers; motors (gear, vane and piston types); fixed and variable displacement

Simple circuits for polymer processing equipment: 'upstroke' and 'downstroke' presses; injection moulding machines; hydrostatic variable speed drives

Pressure measurement: principles; bourdon tube gauges; pressure transducers

3 Understand the heating systems, temperature measurement and control used on polymer processing equipment

Electrical methods of heating: polymer processing equipment; resistance, induction, dielectric systems infrared high frequency and microwave

Fluid heating methods: polymer processing equipment; steam, oil, pressurised water

Temperature measuring device: principles; operation; thermocouples; expansion thermometers; resistance thermometers; pyrometers

Temperature control: 'on-off'; proportional band; PID controllers

4 Understand the different types and applications of industrial robots

Applications of robots: applications, e.g. 'pick and place', machining, inspection, coating, packaging

Common robot configuration: cartesian; cylindrical; revolute; pendulum; degrees of freedom; axis of movement; operating envelope

End effectors and types of grippers: mechanical; vacuum

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the operation of belt, chain and gear drives	**M1** calculate drive ratios for belt drive systems and simple and compound gear trains	**D1** compare and contrast the benefits and limitations of belt drive, gear drive and roller-chain drive systems
P2 describe the construction and reason for use of spur, helical and herringbone gears		
P3 describe the construction of roller-chain systems		
P4 describe the principles of operation of hydraulic systems and the construction and operation of typical hydraulic components	**M2** explain the operation of a simple hydraulic circuit used in polymer processing equipment	**D2** evaluate applications of hydraulic components and pressure measuring systems used in polymer processing equipment
P5 describe the types of heating systems, temperature control and temperature measurement devices used in polymer processing equipment	**M3** explain the principles of operation of different heating methods and temperature measuring devices.	**D3** evaluate different heating systems and measuring devices for their applications in polymer processing equipment.
P6 describe typical applications of industrial robots used in polymer process engineering		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe common industrial robot configurations and the types of robot end effectors/gripping systems that can be used in polymer process engineering.		

Essential guidance for tutors

Assessment

The focus of assessment should be on learners carrying out the required tasks, as well as producing reports as evidence to meet the assessment and grading criteria. Learner presentations, supported by assessor witness testimony, would also form a suitable assessment method. Tutors should observe learners undertaking practical activities and clearly record assessment decisions using an appropriate assessor's observation record, retained for audit purposes. Throughout this unit learners need to be aware of issues such as sustainability and the effects of waste products on the environment.

Safety requirements must be applied to all activities. Learners must work safely and accurately within supplied methods; this must be applied rigorously to all activities.

For the pass criteria, learners need to describe the operation of both a belt drive system and a gear drive system. They must also describe the operation and construction of a roller-chain drive system. For P2, learners must describe the construction of spur, helical and herringbone gears and the reasons for their use. For P4, learners must describe the principles of hydraulic fluid power, including the types of hydraulic fluid that can be used within hydraulic systems. Learners will then describe the construction and operation of at least four hydraulic components from the list of components in the unit content. For P5, learners must describe at least three types of heating system and two types of temperature control devices and two types of temperature measurement devices that are typically used within polymer processing equipment. For P6 and P7, learners must describe a minimum of two applications for industrial robots within polymer process engineering and describe two types of configuration from the list given in the unit content. For example, they could describe the meaning of the terms 'degrees of freedom' and 'axis of movement'. Finally, learners will need to describe at least two types of robot end effectors or gripping systems that are typically used by industrial robots in polymer process engineering applications.

For the merit criteria, learners must calculate the drive ratio for at least two given belt drive systems and the drive ratio for one given simple gear train and one complex gear train. Minor mathematical calculation errors are acceptable, as the assessment emphasis should be on the mathematical process rather than obtaining the correct answer. For M2, learners must explain the operation of a simple hydraulic circuit, from a given schematic diagram of a typical hydraulic system used within polymer processing equipment. As part of the explanation, learners must explain the operation of any circuit protection devices such as pressure relief valves contained within the circuit. For M3, learners must explain the principles of operation of one electrical and one fluid heating method used on polymer processing equipment. They will also need to explain the principles of operation of two temperature measuring devices.

For the distinction criteria, learners need to compare and contrast the advantages and limitations of belt drive, gear trains and roller-chain drive systems. This could be completed as a table with suitable headings. The information contained within the table must be comprehensive to ensure that the learners demonstrate the appropriate depth of knowledge and understanding of the subject matter. For D2 and D3, learners will need to adopt a more evaluative approach to engineering systems. It may be appropriate to analyse one activity in detail as a group exercise.

Thereafter, activities may be left to independent study, with appropriate guidance from tutors. If group work is undertaken, tutors must ensure that each learner individually produces sufficient evidence to meet the assessment and grading criteria and that assessment decisions are clearly recorded using an appropriate observation sheet.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Mechanical Drive Systems	The processing engineer has been asked to report on the mechanical drive systems being used on the processing plant.	A written report, including relevant diagrams
P4, M2, D2	Hydraulic Systems	The quality control engineer has asked for an investigation into construction and operation of the plant hydraulic systems.	A written report, including relevant diagrams
P5, M3, D3	Heating Systems	The plant manager has asked for an investigation to be carried out on heating systems to find out if any reductions can be made in heat losses.	A written report
P6, P7	Industrial Robots	The process engineer has been asked to investigate different types and applications of robots to upgrade the process plant.	A written report

Essential resources

Learners need access to appropriate laboratory facilities and specialist resources to cover the contextualisation of the underlying concepts to their polymer specialism, e.g. plastics, rubber or related areas. Site visits to relevant industrial facilities to see practical techniques in operation would be invaluable. Input from industry experts, as guest speakers, would enhance unit delivery.

Indicative reading for learners

Journals

British Rubber and Plastics

Materials Foresite

Materials World

Plastics, Rubber and Composites

Websites

www.bpf.co.uk	British Plastics Federation
www.cia.org.uk	Chemical Industries Association
www.cogent-ssc.com	COGENT – Sector Skills Council
www.en.wikipedia.org/wiki/polymers	Polymers
www.expainthatstuff.com/bioplastics.html	Bioplastics
www.iom3.org	The Institute of Materials, Minerals and Mining
www.iom3.org/content/polymersociety	The Polymer Society
www.rsc.org.uk	The Royal Society of Chemistry
www.stemnet.org.uk	Network for Science, Technology, Engineering and Maths – Network Ambassadors Scheme

Unit 94: Composite Materials and Processing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The aim and purpose of this unit is to give learners the opportunity to gain knowledge of structures, properties and uses of composite materials. They will also gain knowledge of processing methods, including bonding, fastening and testing of composite materials.

In-depth knowledge of the structure and behaviour of composite materials is vital for anyone expected to select or specify them for applications within the engineering industry. This unit gives learners knowledge of the structure and mechanical and physical properties of composite materials used in engineering. It will enable them to select composite materials for different applications.

This unit is appropriate for learners engaged in manufacturing, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials, some of which learners may not be familiar with initially.

For composite products and components to be manufactured to a required standard, the processes used to produce them need to be operated in an efficient and safe manner. This unit aims to provide learners with a detailed knowledge of composite processing techniques.

This unit will make learners aware of the effects of processing on the behaviour of composite materials and the variables that need to be controlled in order to produce a high-quality product. The unit also looks at bonding and fastening of composite components and the considerations that need to be taken into account when deciding on how to join them.

Finally, learners will study various methods of destructive and non-destructive testing used on composite components to determine physical properties and the onset of failure. Learners will gain an appreciation of how these tests work and how to analyse results.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the structures, resins, reinforcements and properties of composite materials

2 Know the various processing methods used to produce composite components and the relevant safety considerations required

3 Know the effects of processing on composite materials, including the variables that need to be controlled

4 Know about bonding, fastening and sealing of composite components

5 Be able to test composite materials to determine their structural integrity and properties.

Unit content

1 Know the structures, resins, reinforcements and properties of composite materials

Structures: fibre reinforced, e.g. fibreglass/glass reinforced plastic, carbon fibre; polymer foams, e.g. PVC, polystyrene; balsa wood; honeycombs, e.g. metal foams and expanded metals

Resins: thermosetting resins, e.g. epoxy resin, polyester, phenolic, vinyl ester, polyurethane; thermoplastic resins, e.g. polyamide, polybutylene terephthalate, polyethylene terephthalate, polycarbonate, polyethylene, polypropylene, polyvinyl chloride; gel coats and release agents; catalysts

Reinforcement: types of reinforcement, e.g. glass, carbon, aramid, quartz; characteristics, e.g. filament, tow, chopped strand, random mat, unidirectional mat, woven mat, woven performs, pre-preg

Properties: mechanical properties, e.g. strength, hardness, toughness, ductility, malleability, elasticity, brittleness; physical properties, e.g. density, melting temperature; thermal properties, e.g. expansivity, conductivity; electrical and magnetic properties, e.g. conductivity, resistivity, permeability, permittivity

2 Know the various processing methods used to produce composite components and the relevant safety considerations required

Processes: pultrusion; filament winding and preform weaving; lay-up, e.g. wet lay-up, spray lay-up, automated tape lay-up and fibre placement; moulding, e.g. resin transfer moulding, vacuum assisted resin transfer moulding; pre-preg laminating; finishing, e.g. trimming of composites, measuring, marking and cutting/drilling of composite materials

Tooling: open moulding; closed moulding; auto-clave; vacuum bag; jigs and fixtures; mould materials and uses; mould design considerations, e.g. venting, gating and flow analysis

Safety: main safety aspects in relation to processing of composite components, e.g. contact with resin, contact with fibres, dust/fume extraction

3 Know the effects of processing on composite materials, including the variables that need to be controlled

Effects of processing: fibres, e.g. fibre alignment, de-lamination, matrix/reinforcement ratio; voids; flow interfaces

Processing variables and their effects: processing parameters, e.g. resin viscosity, wet out, flow analysis, curing time, curing temperature; design parameters, e.g. tooling design, matrix reinforcement combination

4 Know about bonding, fastening and sealing of composite components

Bonding and fastening of composite components: types of fastener, e.g. Hi-Lok fasteners, pan head bolts, countersunk bolts, RXL radial expanding lock bolts, RXB radial expanding bolts, slave bolts, dowels, self-centring nuts and bolts, torque-controlled slave pins; applications for fasteners on composite components; effects of drilling holes in composite component structure

Sealants: types of sealant, e.g. Interfay, aerodynamic filler/sealants, fillet sealants and gap sealants, adhesion promoters and adhesives

5 Be able to test composite materials to determine their structural integrity and properties

Testing: methods, e.g. ultrasonic testing, tensile testing, compressive testing, shear testing, flexural analysis, fatigue analysis, creep analysis, moisture absorption, resin viscosity testing; analysis, e.g. data handling, graphical representation, comparison with theoretical values

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the structure associated with composite materials, including the types and applications of resins and reinforcements	**M1** explain how the structure and properties of composite materials give advantages over non-composite materials for a given product	**D1** justify the selection of an engineering composite for a given application, describing the reasons the selection meets the required criteria
P2 describe the mechanical, physical, thermal and electrical and magnetic properties of composite materials and state one practical application of each property in an engineering context		
P3 describe composite processing methods and tooling and the main health and safety considerations that need to be taken into account when producing composite materials	**M2** explain the advantages of different composite processing methods for a given composite component	**D2** justify the selection of a composite processing method for a given component, describing the reasons the selection meets the required criteria
P4 describe the effects of processing and processing variables on the properties of composite materials		
P5 describe bonding, fastening and sealing of composite components		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 perform and record the results of different tests on a composite material to determine the structural integrity and properties of the material	**M3** explain the significance and usefulness of different tests on a composite material through the analysis of the results obtained	

Essential guidance for tutors

Assessment

To achieve a pass grade, all the pass criteria must be met. Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1 and P2 could be gained by means of a written assignment, following a combination of tutor-led practical and theory sessions and individual research. P1 and P2 require the range of materials given to include composite materials created from different reinforcement and matrix combinations. The use of at least three different types of reinforcement and characteristics of reinforcement are anticipated. M1 and D1 could be covered in the same assessment. To achieve M1, learners are required to explain how the structure of composite materials gives advantages over non-composite materials (such as polymers or metals) for a given product, for example aircraft wings, bicycle frames, prosthetic limbs. To achieve D1, learners must select a composite material for a given application and justify their selection in relation to material properties. Learners should compare advantages and disadvantages in order to develop a reasoned argument for the selection of their chosen composite material.

The evidence to satisfy the pass criteria P3, P4 and P5 could be gathered by means of a second written assignment, following a combination of tutor-led practical and theory sessions and individual research. To allow learners to meet P3 and P5, the tutor could perform a series of practical demonstrations to show the various composite processing and joining techniques. To meet P3 fully, learners should also describe the various health and safety considerations that need to be taken into account when processing composite materials. This could be done through the use of a case study or it could be linked to practical demonstrations. Learners could research and provide a written response or give a presentation on the processes they observed and how they were performed. To meet P5 learners could research and provide a written response or give a presentation on case studies of composite materials that have failed as a result of processing defects. To meet M2, learners are required to explain the advantages of different composite processing methods for a given composite component. The component should be quite straightforward and the correct processing method should be clearly identifiable. To meet D2, learners are required to justify a composite processing method for a given component. The component given should be capable of being processed using a number of processing techniques, allowing for advantages and disadvantages to be considered.

The evidence to satisfy the pass criterion P6 could be gathered by means of a third assignment, following a combination of tutor-led practical and theory sessions and individual research. To meet P6 and M3, learners should perform at least two material tests using given material(s). To meet P6, learners need to provide evidence of carrying out the tests and recording results, this can be gathered through observations, witness testimonies or written records. To meet M3, learners need to be able to analyse the results obtained and draw appropriate conclusions.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Structure and Properties of Composite Materials	Structure and properties of composites considered in an industrial scenario	Written report/presentation
P3, P4, P5, M2, D2	Processing and Joining of Composite Components and Safety Considerations	Processing and joining of composites considered in an industrial scenario	Written report/presentation
P6, M3	Testing of Composite Materials	Typical testing/sampling regime for a composite manufacturer	Observation record/witness testimony with written analysis/ evaluation of recorded results

Essential resources

Centres will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Centres need access to equipment to conduct at least two destructive or non-destructive tests and related composite materials.

Indicative reading for learners

Books

Alfred C Loos and Raju S Dave – *Processing of Composites* (Carl Hanser Verlag GmbH and Co, 1999) ISBN 9781569902264

Balasubramanian M – *Composite Materials and Processing* (CRC Press, 2013) ISBN 9781439879351

Barbero E – *Introduction to Composite Materials Design*, Second Edition (CRC Press, 2010) ISBN 9781420079159

Gibson R – *Principles of Composite Material Mechanics*, Fourth Edition (CRC Press, 2016) ISBN 9781498720694

Matthews F L and Rawlings, R D – *Composite Materials: Engineering and Science* (Woodhead, 2003) ISBN 9781855734739

Potter K – *Resin Transfer Moulding* (Springer, 2011) ISBN 9789401064972

Wanberg J – *Composite Materials Fabrication Handbook #3* (Wolfgang Publications, 2013) ISBN 9781935828662

Unit 95: Aircraft Gas Turbine Engines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Gas turbine engines have become the major source of propulsive power for modern-day commercial and military aircraft, due to their superior power output and efficiency savings in relation to their reciprocating piston engine counterparts. Gas turbine engines also encompass all specialist engineering areas and have revolutionised global travel and power production, making them one of the most significant technological advances of the age.

In this unit, learners will examine the scientific principles that underpin the operation of gas turbine engines, including changes to the working fluid as it passes through the main components of the engine. They will compare the function, operation and construction of the different types of gas turbine engine. Next, they will explore the function and operation of the principal components and systems that make up the modern gas turbine engine. Finally, learners will examine the factors that affect the performance and environmental impact of aircraft gas turbine propulsion.

Studying this form of aircraft propulsion is essential if learners want to work in the aeronautical sector. This unit will help to prepare them for an aircraft engineering apprenticeship, as well as helping them to gain employment in an aircraft technician role. Alternatively, learners could choose to continue to study this area in higher education.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust

2 Examine the function and operation of gas turbine engine components and systems that produce thrust

3 Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion.

Unit content

1 Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust

Scientific principles relating to gas turbine engines

- The gas laws and the expansion and compression of perfect gases; including Charles', Boyle's; and the combined gas law and their parameters.
- Boyle's law and isothermal expansion and compression, adiabatic (constant heat) expansion and compression.
- The theoretical Brayton gas turbine cycle (including assumptions made), cycle states (adiabatic compression, constant pressure heat addition, adiabatic expansion, constant pressure heat rejection).
- Use of pressure/volume and temperature/volume diagrams.
- The practical working Brayton cycle, including compression, combustion, expansion and induction, losses incurred in comparison with theoretical cycle.
- Newton's laws and their relationship to aircraft thrust.
- Flight thrust, including:
  - basic net thrust FN = $\dot{m}$ (vj – va) where $\dot{m}$ = mass flow rate of the air moving rearwards, vj = is the velocity of the gas stream at exit/exhaust from engine and va = the velocity at the engine inlet
  - total net flight thrust (TNFT) (subsonic) = FN = $\dot{m}$ (vj – va) + $\dot{m}_f v_i$ where $\dot{m}_f$ = mass flow rate of the fuel
- Supersonic flow at propelling nozzle, chocked nozzles:
  - TNFT (supersonic) = $\dot{m}$ (vj – va) + $\dot{m}_f v_i$ + A(pc – pamb) where A = cross-sectional area of propelling nozzle, pc = chocked pressure of gas at propelling nozzle, pamb = ambient air pressure.

Types and operation of aircraft gas turbine engines

- Turbojet engines:
  - operation of the common core gas generator, including the function of the compressor, combustor, turbine and exhaust, the temperature, pressure and velocity changes made to the working fluid as it passes through the gas generator components
  - operation of the turbojet engine, including the production of thrust from the working fluid entering the intake, passing through the gas generator and exhausting via the propelling nozzle to the ambient atmosphere, the limitations of the pure turbojet engine
  - construction, arrangement and location of the intake, compressor, combustor, turbine, exhaust, propelling nozzle and associated gearing and connections of a single shaft turbojet engine
  - limitations including use of high velocity exhaust gases for thrust production, noise pollution, reduced propulsion efficiency.

- Turbofan engines:
  - operation, including function of the addition of a high bypass ratio fan and low pressure turbine, the production of thrust and the passage and function of the working fluid through the fan and low pressure turbine
  - construction, arrangement and component location, including the differences between a multi-shaft high bypass turbofan engine and its single shaft turbojet counterpart
  - relative advantages of turbofan engines over turbojets, including fuel efficiency, propulsive efficiency, cooling and noise reduction.
- Turboprop engines:
  - operation of turboprop engines, including the function of the low pressure turbine, gearbox and propeller in the conversion of torque from the drive shaft into thrust from the propeller
  - construction, arrangement and component location, including the addition of a low pressure turbine, main gearbox and propeller, over the core gas generator components
  - relative advantages and disadvantages over turbofan engines, including better power to weight ratio, unsuitability for high speed applications.
- Turboshaft engines:
  - operation of turboshaft engines, including the function of the low pressure turbine and drive shaft to produce torque, the production of thrust for helicopter operation and the passage of the reverse gas flow through the engine
  - construction, arrangement and component location, including the need for a larger diameter drive shaft and more robust compressors and turbines with fewer stages
  - relative advantages, including a range of different industrial applications, e.g. turbomachinery, marine.

2 Examine the function and operation of gas turbine engine components and systems that produce thrust

Function and operation of turbine engine components

- Compressors and fans:
  - function and operation of axial flow compressors, including stage rotors and stators, stage velocities and pressure rises and governing factors, multi-stage compressor pressure and temperature rises, function of variable inlet guide vanes (VIGV) and variable stator vanes (VSV)
  - function and operation of centrifugal compressors, including function of inlet duct and vanes, the impeller, rotating guide vanes and radial diffuser vanes, airflow and pressure rise through the compressor and centrifugal action of the air
  - function and operation of fans, including compression of the bypass air, feeding supercharged air into core, high bypass ratio single stage compression, need for multi-stage fans for military aircraft, form of fan blade, fan disc, attachments and casing.

- Combustors:
  - combustor types, including multiple combustion chamber, tubo-annular and annular
  - combustor requirements, including high combustion efficiency, reliable ignition, restart at altitude, low pressure losses, low emissions and high durability
  - function and operation, including velocity control of the combustible gases, factors affecting combustion efficiency, fuel injectors, vaporisers, fuel spray nozzles, igniters and combustion chamber cooling.
- Turbines:
  - turbine function and operation, including types – single and multi-stage, impulse and reaction turbines, dependence of energy transfer from gas on – gas mass flow rate, blade speed and swirl velocity change
  - turbine components function and operation, including turbine casing, discs, shafts, nozzle guide vanes (NGV) and blades.
- Intakes and exhausts:
  - intakes function and operation, including civil aircraft turbofan short, circular intake design, minimisation of drag at cruise speeds, integration with engine cowlings, necessity for heating and anti-icing features, military-side mounted and under-fuselage and supersonic intakes
  - engine exhausts function and operation exhaust gas propelling nozzles, reverse thrusters, thrust vectoring nozzles for vertical/short take-off and landing V/STOL aircraft.

Function and operation of engine starter and fluid systems

- Starter systems:
  - starter systems, including starting phase operation from ignition, through dry cranking, acceleration to thermal soak at ground idles, design considerations for hot and cold weather starting, starting methods, e.g. air turbine, electric, gas turbine and cartridge
  - engine starting precautions for personnel, including knowledge and avoidance of engine intake and exhaust danger zones, positioning and handling of fire appliances, radio or other contact with pilot.
- Fluid systems:
  - engine air system cooling, including the need and methods used for air cooling turbine blades, NGVs, discs, shafts and casings
  - air system sealing, e.g. labyrinth, brush and leaf, carbon and ring seals and sealing methods
  - airframe fuel system function and operation, including fuel storage, shut-off valves, fuel distribution, booster pumps, manifolds, pipes, bypass and cross-feed valves, fuel system contents, temperature and pressure indications
  - engine fuel system interaction, including fuel system operation from start-up to cruise and descent, fuel filtration, metering and demand control
  - engine oil system function and operation, including full flow and pressure relief systems, spline lubrication methods
  - engine oil sub-systems and component functions, including pressure feed and distribution, scavenge and vent sub-systems, oil tank, filters, feed pump and oil cooling heat exchangers.

3 Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion

Aircraft gas turbine engine performance

- Measures of performance, including:
  - specific thrust = output thrust/engine inlet mass flow
  - specific power = output power/engine inlet mass flow
  - specific fuel consumption (SFC) = fuel flow rate/output thrust or power, where SFC is measured in kilogrammes of fuel burnt per hour per Newton of thrust or kg/hr/N.
- Effect and implications of gas turbine cycle parameters on performance, including effect of compressor pressure ratio and turbine entry temperature (TET) on SFC and specific thrust or power.
- Effect and implications of thermal efficiency $\eta_{\text{thermal}} = \dfrac{\left[\dfrac{\dot{m}}{2\left(v_j^{\,2} - v_a^{\,2}\right)}\right]}{\left[\dot{m}_f LCV\right]}$ and propulsive efficiency $\eta_{\text{prop}} = \dfrac{2}{1 + \dfrac{v_j}{v_a}}$ on aircraft specific fuel consumption and thrust $F_{\text{N}} = \dot{m}\,(v_{\text{j}} - v_{\text{a}})$ performance of turbojet and high bypass turbofan aircraft,

  where $\dot{m}_f$ = mass flow rate of the fuel in kilogrammes per second (kg/s) and

  LCV = lower calorific value of the fuel in joules per kg (J/kg).
- Thrust enhancement, including use of variable area nozzles, reheat, water and water/methanol.

Environmental impact of gas turbine engines

- Noise, including:
  - noise measurement and limits, including decibel (dB) rating, noise limit regulation
  - sources of aircraft noise and its reduction, including fan, exhaust jet, low pressure turbine and combustor noise, turbine engine noise testing
  - gas turbine operating emissions and effects on the environment, including health risks from global warming and acid rain.
- Emissions, including:
  - nature and effects of gas turbine emissions, including carbon dioxide (CO2), water vapour (H2O), contrails and the production of (H2O) and sulphuric acid (H2SO4), carbon monoxide (CO), oxides of nitrogen (Nox) and sulphur (Sox) and smoke particulates
  - airport pollution, including emissions monitoring and the effect of the introduction of the standard landing and take-off cycle (LTO)
  - modern gas turbine emission reduction methods, including the control of unburnt hydrocarbons and carbon monoxide (CO), improvements in combustor design, use of high bypass turbofan engines, relationship of top turbine temperature (TTT), engine performance and the production and control of oxides of nitrogen (Nox).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the application of scientific principles to aircraft gas turbine engine cycles and thrust production **P2** explain the operation of two types of aircraft gas turbine engines	**M1** analyse the application of scientific principles to aircraft gas turbine engine cycles and thrust production **M2** analyse the operation of two types of aircraft gas turbine engines, making comparisons between types	**D1** evaluate, using vocational language, the application of scientific principles to the cycles, operation and thrust production of two types of aircraft turbine engines, making comparisons between types
P3 explain the function and operation of gas turbine engine components **P4** explain the function and operation of gas turbine starter and fluid systems	**M3** analyse the function and operation of gas turbine engine components and engine starter and fluid systems, making comparison between component types	**D2** evaluate the function and operation of gas turbine engine components and engine starting and fluid systems, making comparisons between component and system types

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain, using research, how gas turbine engine performance is measured and improvements in thrust production and fuel efficiency are achieved in turbofan engines **P6** explain, using research, the nature of environmental pollutants produced from gas turbine engines and the methods used to mitigate their effects.	**M4** analyse, using research, how gas turbine engine performance is measured and improved using turbofan engines and the methods used to mitigate the effects of aircraft environmental pollutants.	**D3** justify, using research, how gas turbine engine performance is measured and improved using turbofan engines and the methods used to mitigate the effects of aircraft environmental pollutants suggesting possible future improvements.

Essential guidance for tutors

Assessment

For P1, learners will explain the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine parameters. They will show how Boyle's law is related to isothermal and adiabatic expansions and compressions in the theoretical Brayton cycle, and use appropriate graphical examples to explain the differences between the theoretical and real cycles.

An explanation of Newton's laws and their application to basic thrust and total net flight thrust under subsonic and supersonic flight conditions will be included.

For P2, learners will explain the operation of two types of gas turbine engine, clearly indicating how the construction, components and passage of the gases through the engine affect the function and operation of each to produce thrust.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example omitting or incorrectly identifying some constructional detail of a particular engine. Also, when using the gas laws to mathematically determine parameters, minor arithmetic and scaling errors are acceptable, as are 'carry through' errors provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For P3, learners will explain the function and operation (which includes the principles, features, construction and layout) of intake, compressor, combustor, turbine and exhaust engine components, using qualitative examples to explain the application of scientific principles. For example, to explain the compression ratio of air as it passes through an axial compressor, learners will relate its magnitude qualitatively to the convergent nature of the compressor casing, the number of stages and the mass flow rate of the air.

Learners will explain for P4, the function and operation of engine starting, air, fuel and oil systems as well as the function of the starter and fluid system components.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies, for example by omitting a minor component in an engine fuel system, or being slightly confused over its function within the system.

For P5, learners will explain, using research, how gas turbine engine performance is measured using specific fuel consumption and specific thrust, and improved by using turbofan engines.

Learners will explain for P6, the nature of the environmental pollutants gas turbine engine operation produces and the methods used to mitigate their effects.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies. For example, in providing an explanation of the performance improvements achieved using turbofan engines, explanations may be patchy in parts through omitting some minor detail or, where quantitative examples have been given, the process followed may contain some minor arithmetic and scaling errors and 'carry through' errors. These errors are acceptable, provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For M1, learners will analyse the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine parameters. They will show how Boyle's law is related to isothermal and adiabatic expansions and compressions in the theoretical Brayton cycle, and use appropriate graphical examples to assess the differences between the theoretical and real cycles.

A quantitative analysis of Newton's laws and their application to basic thrust and total net flight thrust under subsonic and supersonic flight conditions will be included.

For M2, learners will compare the operation of two types of gas turbine engine, assessing how changes in the constructional features, components and passage of the gas flow affect the function and operation of each. For example, comparing a turboprop engine with the addition of a gearbox and propeller producing thrust, with a pure turbojet designed to produce thrust using high temperature and high velocity exhaust gases.

Overall, the evidence should be logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. For example, the numerical work will be to an appropriate degree of accuracy, given the context of the engine being investigated. For example, appropriate significant figures and decimal places.

For M3, learners will analyse the function and operation of intake, compressor, combustor, turbine and exhaust engine components, making comparisons between different types, using quantitative examples where appropriate, to explain their operating principles. For example, when considering the operation of engine exhausts, comparisons could be made between reheat and variable area nozzles as a means of increasing thrust, using quantitative examples involving the gas laws and the supersonic thrust formula to explain their operation.

Learners will analyse the function and operation of engine starting, air, fuel and oil systems, as well as the layout and function of the starter and fluid systems components.

Overall, the evidence should be logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. For example, the numerical work will be to an appropriate degree of accuracy, given the context of the engine being investigated. For example, appropriate significant figures and decimal places.

For M4, learners will analyse, using research, how gas turbine engine performance is measured using specific fuel consumption, specific thrust and other efficiency measures, and improved by using turbofan engines. Learners will also analyse the nature of the environmental pollutants gas turbine engine operation produces and the methods used to mitigate their effects. For example, learners could analyse how improvements to combustor ignition, fuel injection and control have reduced the amount of unburnt hydrocarbons and carbon monoxide (CO) pollutants.

Overall, the evidence will be well researched, logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. The numerical results used, for example to illustrate the performance improvements achieved from the use of turbofan engines, will be quoted to an appropriate number of significant figures and decimal places.

For D1, learners will evaluate the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine the parameters. They will show analytically how Boyle's law is related to isothermal and adiabatic expansions and compressions in the theoretical Brayton cycle, clearly differentiating between the theoretical and real cycles, using appropriate graphical examples.

A quantitative analysis of Newton's laws and their application to basic thrust and total net flight thrust under subsonic and supersonic flight conditions will be included.

Learners will compare the two types of gas turbine engine, covering the way in which each type changes the passage of the working fluid as it passes through it and also, collectively, how these changes and differences in their constructional features and components affect function and operation of these engines. Quantitative examples should be used, where appropriate, to show differences in the gas flow parameters through each engine. For example, how the addition of a large fan and low pressure turbine in a high bypass turbofan engine quantitatively changes the mass flow and velocity of gas on its passage through the engine and how in turn this produces high thrust and, comparing this engine with the function and operation of a turboshaft engine designed to produce high torque.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct engineering terms. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be presented correctly in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to an appropriate degree of accuracy, given the type of engine being investigated, through the use of appropriate significant figures.

For D2, learners will evaluate the function and operation of intake, compressor, combustor, turbine and exhaust engine components, comparing the differences in design between component types and the effect these differences have on component and overall engine operational performance. For example, learners could compare the differences in the operational efficiency of a single axial compressor with its separate twin or triple compressor counterpart.

The evaluation should also include an assessment of the function and operation of different engine starter, air, fuel and oil systems, including making comparisons between different types of a particular system and considering the layout and function of system components. For example, by comparing the relative operational advantages/disadvantages between air turbine and electric starting systems.

Overall, the evidence presented will be easy to read, logically structured and well presented. It will also provide a comprehensive, in-depth assessment of the operational differences between component types, using quantitative examples for comparisons, as appropriate. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be presented correctly in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to an appropriate degree of accuracy, given the particular component parameters being investigated, through the use of appropriate significant figures.

For D3, learners will justify, using research, how gas turbine engine performance is measured and improved by the use of turbofan engines. The justification will include an analysis of how high bypass turbofan engines and components help to improve specific fuel consumption, specific thrust and other efficiency measures. Learners will back their analysis up with quantitative examples demonstrating these improvements with the turbofan engine, and by comparing them with their pure turbojet counterpart.

Learners will justify the methods used to mitigate the effects of aircraft pollutants from aircraft turbine engine operation and suggest possible future improvements. For example, quantitatively assessing the relationship between gas turbine entry temperatures, their efficient operation and the release of nitrous oxides into the atmosphere. Learners will assess the nature and feasibility of future improvements, such as operating gas turbine engine aircraft at higher altitudes.

Overall, the evidence will provide a wide-ranging, well-researched justification, which includes the methods used to measure and improve gas turbine performance, and the nature of pollutants and the methods used to mitigate their effects. Evidence will include possible future technical and operational improvements that could be made to further safeguard the environment. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions used to illustrate, for example, the improvements in specific thrust and other efficiency measures achieved by using turbofan engines. Small and large numerical values will be presented correctly in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to an appropriate degree of accuracy through the use of appropriate significant figures.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Scientific Principles, Types and Operation of Relating Aircraft Gas Turbine Engines	An activity requiring learners to research scientific principles, function and operation of aircraft gas turbine engines.	A report covering the scientific principles, function and operation of two engine types selected from turbojet, turbofan, turboshaft and turboprop gas turbine engines.
P3, P4, M3, D2	Function and Operation of Turbine Engine Components and Starter and Fluid Systems	An activity requiring learners to research the function and operation of turbine engine components and starter and fluid systems.	A report covering the function and operation of aircraft gas turbine engine components, and starting and fluid systems.
P5, P6, M4, D3	Performance and Environmental Impact of Aircraft Gas Turbine Engines	An activity requiring learners to research the performance of aircraft gas turbine engines, their environmental impact and measures being taken to reduce negative impacts.	A report covering the factors that affect the performance of aircraft gas turbine engines and the nature and measures being taken to help reduce the adverse effects of gas turbine engine pollutants.

Essential resources

Please note that the required physical resources may not necessarily be directly available at the centre delivering the unit but can be made available on the premises of a partner organisation.

For this unit, learners must have access to:

- gas turbine engine(s) with an axial flow compressor, preferably sectioned, capable of allowing access to, or at least sight of, internal components
- gas turbine engine components on or off engine, including centrifugal compressor, can-annular or annular combustors, single and/or multi-stage turbines, exhaust systems with or without reheat
- sight of turboshaft, turboprop and high bypass turbofan engines
- installed engines on a training aircraft, showing intake, engine installation method, engine cowlings and fairings and exhaust
- sight of engine internal fluid systems and components, e.g. air cooling and sealing, oil lubrication, fuel control
- external ancillary equipment and systems, e.g. engine ignition and starter, airframe fuel supply system, auxiliary gearbox.

Unit 96: Human Factors and Performance in Aviation

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 90

Unit introduction

To enable engineers working in aviation to work effectively and efficiently as individuals and as team members, they need an understanding of human factors and behaviours in the workplace. They also need an understanding of factors that affect human performance in the workplace.

In this unit, you will learn about how vital it is in the aviation industry to pay attention to detail of the factors and behaviours that affect human performance in the workplace. This is to ensure that errors, incidents and accidents are kept to an absolute minimum. You will gain an understanding of the importance of human factors, features and limitations of human performance, and aspects of social psychology in an aeronautical engineering environment. You will also gain an understanding of how personal factors, physical aspects of the working environment and categories of work tasks can affect human performance. You will study aspects of communication in the workplace, error models and risk assessments in aeronautical engineering.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand why human factors are important in aviation

2 Understand features and limitations of human performance

3 Understand aspects of social psychology

4 Understand personal factors that affect human performance

5 Understand how physical aspects of the working environment affect human performance

6 Understand how categories of tasks can affect human performance

7 Understand communication in the workplace

8 Understand error models within aeronautical engineering

9 Understand risk assessments in aeronautical engineering environments.

Learning outcomes and unit content

What needs to be learnt
Learning outcome 1: Understand why human factors are important in aviation
• The term 'human factors': meaning and how it is used in aviation (SHEL Model, Murphy's Law, anthropometry, Dirty Dozen, ergonomics) **Importance** • Safety of employees, passengers, people on the ground etc. • Safety of assets, e.g. aircraft, equipment • Long-term health of employees • Efficiency of the organisation **Categories of human factors** • Working environment • Work patterns • Social habits • Workload • Communication • Employee health
Learning outcome 2: Understand features and limitations of human performance
Seeing images and their interpretation • Main parts of the eye • How each part of the eye reacts to light • Rods and cones • Seeing in high and low light • Peripheral vision • Interpretation by the brain **Hearing sounds and their interpretation** • Main parts of the ear • Vulnerable parts of the ear • Effect of noise – percussive, prolonged high intensity, varying pitch • Noise Induced Hearing Loss (NIHL) **Human memory limitations** • Time from exposure to information • Form that information is in (audio, visual, words, pictures etc.) • Fatigue • Age • Complexity of information • Artificial stimulants/depressants • Types (iconic, echoic, episodic, semantic)

- Stress
- Low motivation
- Poor health

Factors affecting attention span

- Overconfidence
- Boredom
- Fatigue
- Complexity of information
- Artificial stimulants/depressants

Degraded eyesight and hearing effects

- Individually and in combination (such as in older people)
- Sight, e.g. long- and short sight, optical illusion, including the strobe effect, persistence, moving from light area to work in the dark, optimum lighting for typical tasks, use of spectacles and magnifiers
- Hearing, e.g. high and low tone deafness, tinnitus, hearing damage, poor communication
- Social isolation (at work and at home)

Challenging environments and risks

- At height and in confined spaces, e.g. claustrophobia, fear of heights, limited access/egress to a large space
- Uncomfortable climate
- Specific tasks, e.g. inspections on fuselage crown or in equipment bays
- Low concentration
- Rushing the task
- Cutting corners
- Poor vision

Learning outcome 3: Understand aspects of social psychology

Individual and group responsibility

- Outline of a typical organisation (must include aviation maintenance)
- Typical roles and responsibilities
- Individuals and groups or teams
- Individual responsibility when working alone and within a team
- Group or team responsibilities
- Overview of group and inter-group dynamics, e.g. rivalry, polarisation, 'social loafing'
- Importance of balancing individual, group and team responsibilities

Motivation and demotivation

- Fulfilling individual needs
- Maslow's Hierarchy of Needs
- Herzberg Satisfaction Theory
- Individual motivation
- Motivation by management
- Characteristics of motivation and demotivation

- Effect of internal and external factors, e.g. management decisions, staffing and resources, workload (very high or very low), organisational culture, personal situation

Peer pressure, e.g.

- Conformity and non-conformity
- Pressure from co-workers, not management
- Advice and pressure from more experienced colleagues to adopt particular work practices
- How it can affect performance of maintenance tasks

Company culture

- Overview of different types of culture, e.g. safety, organisational, shift, team, social, individual
- Time constraints ('can do' culture, 'press-on-itis')

Team working

- What is a team?
- Advantages and disadvantages of team working
- Belbin Team Theory
- Team identity
- Working with other teams
- Ownership of tasks
- Communication
- Cooperation
- Mutual support

Engineering manager and supervisor – primary responsibilities

- Difference between management and supervisor roles
- What should an employee expect from a supervisor, e.g. motivation, support, guidance?
- Engineering organisations, e.g. Part-145, military maintenance organisation

Leadership basic concepts

- What is a leader?
- Different leadership styles (autocratic/democratic)
- The basic characteristics of a leader
- How and when any individual might provide leadership, e.g. passing on knowledge and experience to colleagues
- Organising and directing group tasks
- Inspection and reporting on the work of others

Learning outcome 4: Understand personal factors that affect human performance
Personal health and fitness effects • Legal requirement for individual physical and mental fitness while at work • Types of medical condition that might affect work, e.g. minor illness (cold, 'flu, sickness etc.) • Major physical illness, e.g. heart attack, stroke, cancer • Mental illness, e.g. depression • Minor physical injury, e.g. sprained wrist, pulled muscle, cramp • Major physical injury, e.g. broken bones, lacerations • Effects of toxins and other substances, e.g. carbon monoxide, alcohol, drugs • Gradual deterioration in physical condition **Effects of stress** • Define 'stress' (eustress, distress, acute stress, chronic stress, hypo stress, hyper stress) • Sources: home, e.g. family illness, divorce, work (organisational, task related) • Types: acute and chronic stress • Signs of stress (physical, health, behaviour, cognitive, other) • Explanation of how stress can affect individual performance at work **Effects of setting time deadlines** • Actual, perceived and self-imposed deadlines • Effects of time pressure and deadlines • Managing time pressure and deadlines **Work overload and underload** • Definition of work overload and underload • Results of work overload and underload • Factors determining workload • Workload management **Effects of shift work on sleep and fatigue** • What is sleep? • Five stages of sleep • Circadian rhythms • Fatigue (causes, symptoms) • Working at night • Types of shift pattern **Effects of alcohol, medication and substance abuse** • Removal of alcohol from the blood • Effects while fatigued, hungry or combined with medication • Types, effects, short- and long-term consequences of abuse of: alcohol, prescription medication, over-the-counter medication, illegal drugs • Effects on individual work performance

Personal legal obligations, e.g.

- Alcohol limits and legal requirements for aircraft engineers
- CAP 562/AN47
- Transport legislation/AN45
- Health and safety legislation
- Legal requirements for hearing protection
- Correct protection for frequency range

Maintaining individual professional currency, e.g.

- Refresher training
- Reading briefing material
- Notices and amendments to maintenance procedures
- Reading professional journals
- Undertaking up-skilling and further licence training

Learning outcome 5: Understand how physical aspects of the working environment affect human performance

Effects of noise on, e.g.

- Concentration
- Communication

Effects of fumes on, e.g.

- Concentration
- Communication
- Longer term effects
- Safe oxygen levels

Varying illumination effects, e.g.

- Ability to see detail
- Moving between areas of different illumination, including well-lit hangar and night flight line
- Strobe effect and propellers

Climate variation effects, e.g.

- Cold/wet, warm/dry, hot/humid environments

Exposure to constant motion and vibration, e.g.

- Working at height on scissor platforms and cherry picker
- Unsteady platforms
- Use of rotating or percussive tools

Working environment layout, e.g.

- The three components of a working environment: layout, cleanliness, ease of movement between work areas
- Lighting, noise, atmosphere, temperature etc.
- Social environment
- Tasks, tools and information

Learning outcome 6: Understand how categories of tasks can affect human performance
Planning task execution, e.g. • Defining the task • Defining the resources • Personal skills and proficiency • Information **Effects of physically demanding work relating to, e.g.** • Health and physical condition, effects of age • Work environment • Physical effort **Effects of repetitive tasks relating to, e.g.** • Ignoring manuals, job cards etc. • Complacency • Making assumptions **Visual inspection requirements, e.g.** • Importance of good eyesight • Knowledge of the inspection area • Illumination • Concentration • Systematic search **Complex systems aspects, e.g.** • Simple system: transparent to the engineer • Complex system: opaque to the engineer • Clear understanding of the purpose of the system • System-specific training • Pooling of knowledge and skills • Clear and comprehensive information and guidance
Learning outcome 7: Understand communication in the workplace
Good communication • Within and between groups, e.g. prevention of accidents • Maintaining good working relations • Organisational efficiency • Common communication protocols used in the aviation industry **Accurate work logging, e.g.** • Formal work logging • Shift logging • Shift handover • Task staging • Duplicate • Inspection • Stage sheets/check

Modes of communication, e.g. • Verbal • Written • Body language • Workplace social culture • Communication between all levels of an organisation
Learning outcome 8: Understand error models within aeronautical engineering
Error models, e.g. • Induced • Variable • Reversible/irreversible • Slips, lapses and mistakes • The 'Swiss Cheese Model' **Types of error, e.g.** • Complacency • Environmental capture • Rule-based errors • Violations • Individual practices and habits • Errors associated with visual inspection • Latent/active errors **Error-incident-accident chain, e.g.** • Self-discipline • Safety management system • Anonymous and blame-free reporting • Training • Logging and analysis • Error prevention methods
Learning outcome 9: Understand risk assessments in aeronautical engineering environments
Risk assessment terms • Hazard • Risk • Severity • Likelihood (probability) **Five steps** 1 – Identify hazards 2 – Decide who might be harmed and how 3 – Evaluate risks and decide on precautions 4 – Record findings and implement them 5 – Review and update

Associated risks for workplace hazards

- Step 1 – Identify hazards

Conclusions from risk assessments

- Step 2 – Decide who might be harmed and how
- Recommend ways of eliminating or reducing, to an acceptable level, a range of identified risks

Manage workplace emergencies

- Step 3 – Evaluate risks and decide on precautions
- Step 4 – Record findings and implement them; reduce the likelihood of them happening
- Step 5 – Review and update; policies, procedures, regular training, management of workplace emergency situations such as fire, spillage, personal injury etc.

Assessment and grading criteria		
Pass To achieve a pass grade the evidence must show that the learner is able to:	**Merit** To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	**Distinction** To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
Learning outcome 1: Understand why human factors are important in aviation		
P1 define the term 'human factors' in aviation		
P2 state the categories of human factors and reasons why human factors are important in aeronautical engineering	**M1** explain the importance of human factors for an individual working within the aviation industry and the consequences of ignoring the psychology of human factors	**D1** evaluate the importance of human factors for the aviation industry
Learning outcome 2: Understand features and limitations of human performance		
P3 describe the effects on human performance and behaviour of degraded eyesight and hearing		
P4 describe how human memory can become limited and how working in challenging environments presents risk to personal safety and airworthiness	**M2** analyse the potential consequences of human errors caused by working in challenging environments	

Learning outcome 3: Understand aspects of social psychology		
P5 describe areas of individual and group responsibility in aerospace engineering environments	**M3** explain how the concepts of team working help with group responsibility	**D2** evaluate the importance of balancing group, individual and team responsibilities within an aeronautical engineering environment
P6 describe what is meant by the terms 'motivation', 'demotivation' and 'peer pressure'	**M4** explain the importance of achieving an optimum level of motivation amongst staff	
P7 describe the basic concepts of leadership		
Learning outcome 4: Understand personal factors that affect human performance		
P8 describe the effects that personal health and fitness have on work performance	**M5** explain the effects on individuals of shift work, alcohol, medication and substance abuse	
P9 describe the sources and types of stress and the effects within a working environment		
P10 describe the effects of setting time deadlines on individual work performance	**M6** compare the effects on team performance of individuals working to their own perceptions of deadlines and individuals working to agreed group deadlines	**D3** evaluate the benefits of clearly defined and agreed work deadlines within an aerospace engineering organisation
P11 outline the personal legal obligations of individuals working in the aerospace industry		

Learning outcome 5: Understand how physical aspects of the working environment affect human performance		
P12 explain how concentration and communication can be affected by the working environment		
P13 explain the effects of exposure to constant motion and vibration while working		
P14 explain the effects of layout of a working environment on individual performance		
Learning outcome 6: Understand how categories of tasks can affect human performance		
P15 explain the importance of planning the execution of a task		
P16 explain the effects of physically demanding work and the effects of repetitive tasks on individual performance		
P17 explain aspects of working on complex systems		
Learning outcome 7: Understand communication in the workplace		
P18 explain the modes of communication between individuals and teams and the importance of good communication in the workplace	**M7** explain the common communication protocols used in the aviation industry to enhance flight safety	
P19 explain the importance of accurate work logging		

Learning outcome 8: Understand error models within aeronautical engineering		
P20 explain the types of error, the error-incident-accident chain and the error models and theories used in aeronautical engineering	**M8** evaluate the methods used to prevent incidents and accidents within the aerospace industry	
Learning outcome 9: Understand risk assessments in aeronautical engineering environments		
P21 define the terms associated with risk assessment and describe the five steps to risk assessment	**M9** compare associated risks and conclusions from two aviation risk assessments	
P22 explain how to manage workplace emergencies		

Essential guidance for tutors

Assessment

This unit is assessed internally by the centre and externally verified by Pearson.

Please read this guidance in conjunction with *Section 8 Assessment*.

Learning outcome 1: Understand why human factors are important in aviation

Learning outcome 2: Understand features and limitations of human performance

Assignment title: Human factors and human performance

For distinction, learners will review the knowledge and understanding they have gained from completing the pass and merit criteria to draw conclusions about the importance of human factors for the aviation industry.

For merit, learners will apply their knowledge from the pass criteria to provide relevant information, highlighting the importance of the psychology of human factors and consequences of ignoring it, for example providing a good safe working environment and an acceptable workload. This could be presented as a table using important features and consequences. Learners will be required to examine the causes of human error and provide details of their interpretation of the potential consequences. This could be carried out using case studies.

For pass, learners will need to give the meaning and definition of the term 'human factors' and detail how it is used in aviation and its related concepts such as the SHEL model. Learners should give a minimum of two reasons why human factors are important in the workplace and document the importance to aeronautical engineering staff of at least three different categories. Learners will need to include clear details of and valid reasons for the limitations of human memory, and give a minimum of three factors that affect attention span, for example fatigue owing to working long hours in challenging environments. They will then need to give clear details of reasons why this can be a risk to personal safety and airworthiness.

Learning outcome 3: Understand aspects of social psychology

Learning outcome 4: Understand personal factors that affect human performance

Assignment title: Social psychology and personal factors

For distinction, learners will use their knowledge and understanding from the pass and merit criteria to balance the strengths and weaknesses of working as an individual or as a member within a group or team to achieve overall targets within an aeronautical engineering environment.

For merit, learners will apply their knowledge form the pass criteria to provide clear details of how the concepts of team working help with group responsibility. Learners will need to give valid reasons for achieving an optimum level of motivation, such as achieving goals and lowering levels of staff absence. Learners will need to make an appropriate comparison of the effects on team performance from individuals own perceptions of deadlines and individuals working to agreed group deadlines and draw conclusions from the advantages and disadvantages. Learners will need to specify details of the effects on individuals of personal factors including shift work, alcohol, medication and substance abuse. This may include the effects on work performance, sleep and fatigue levels.

For pass, learners will outline a typical aerospace organisation focusing on the roles and responsibilities of individuals and groups within aviation maintenance. The use of relevant labelled diagrams could support their evidence where appropriate. Learners need to specify characteristics of, and valid reasons for, motivation and demotivation, and how peer pressure can affect the staff performance in an aviation maintenance environment. This could include reference to behavioural theories, for example Maslow's Hierarchy of Needs. They will also need to give relevant information on what is meant by leadership in an aviation engineering environment. They will also need to specify details of the effects within a working environment of a minimum of four sources and four types of stress. This can be expanded to include clear details of how these personal factors affect human performance in an aviation engineering environment, and appropriate reasons why. This could be presented in an appropriate table or chart. Learners will need to give clear details and reasons for the importance of personal responsibilities including legal obligations such as following the requirements for hearing protection and maintaining their professional currency, for example keeping up to date through continuing professional development.

Learning outcome 5: Understand how physical aspects of the working environment affect human performance

Learning outcome 6: Understand how categories of tasks can affect human performance

Assignment title: Physical aspects of the working environment and categories of tasks

For pass, learners will need to provide valid reasons for how concentration and communication can be affected by the working environment. These will include the effects on the individual and the group or team. This should include the effects of noise, fumes, varying illumination and climate, exposure to constant motion and vibration, and the layout of the working environment. The evidence could be presented in a table or mind map using examples. This could be expanded to include how categories of tasks affect human performance, including the importance of planning, the effects of physically demanding work, repetitive tasks and working on complex systems.

Learning outcome 7: Understand communication in the workplace

Assignment title: Communication

For merit, learners will need to provide details and functions of communication protocols such as communication between ground personnel and aircraft personnel to enhance flight safety.

For pass, learners will need to provide clear details of, and give valid reasons for, the importance of good communication and the need for accurate work logging, for example for shift handover. They will also need to provide clear details of the different modes of communication in the aviation workplace. The use of examples/templates of modes could support their evidence.

Learning outcome 8: Understand error models within aeronautical engineering

Learning outcome 9: Understand risk assessments in aeronautical engineering environments

Assignment title: Error models and risk assessment

For merit, learners will apply their knowledge from the pass criteria to provide clear details of methods used to prevent incidents and accidents, such as developing and following accurate procedures and practices. Learners will compare the associated risks and conclusions from risk assessments of two aviation tasks and explain how they differ. The evidence could be presented in an appropriate table.

For pass, learners will need to provide clear details and functions of error models such as the 'Swiss Cheese Model'. The use of relevant labelled diagrams will support their evidence where appropriate. They will then need to provide clear details of the types of error and why they occur when working on aircraft. Learners will describe the concept of the error-incident-accident chain, including how it is used in aviation. This can be expanded to include methods of how to manage and avoid errors. Learners will need to describe the meaning of risk assessment in an aeronautical engineering environment to include a minimum of two terms such as hazard and severity. They will need to include information about the five steps to risk assessment. The evidence could be presented in an appropriate table or risk assessment template form.

This can be expanded to specify valid features of associated risks in the workplace and recommendations of how to reduce risks. For example, using the functions and objectives of organisational procedures and practices to manage workplace emergencies.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. Alternatively, you can integrate learning outcomes 1 to 7 into one assignment and learning outcomes 8 and 9 into one assignment. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Learning outcomes and assessment criteria	Assignment title	Scenario	Assessment method
Learning outcome 1 – Understand why human factors are important in aviation **Learning outcome 2** – Understand features and limitations of human performance	Human Factors and Human Performance	You have been asked to produce some introductory exemplar training materials on the role of human factors, their features and limitations.	A written report with labelled diagrams, use of case studies and tables where appropriate.
Learning outcome 3 – Understand aspects of social psychology **Learning outcome 4** – Understand personal factors that affect human performance	Social Psychology and Personal Factors	You have been asked to produce introductory materials on social psychology and personal factors that affect human performance.	A written report with use of case studies, labelled diagrams and tables.
Learning outcome 5 – Understand how physical aspects of the working environment affect human performance **Learning outcome 6** – Understand how categories of tasks can affect human performance	Physical Aspects of the Working Environment and Categories of Tasks	You have been asked to give a presentation to a number of new learners on how the working environment and tasks carried out can affect human performance.	A written report with use of case studies, labelled diagrams and tables.

Learning outcomes and assessment criteria	Assignment title	Scenario	Assessment method
Learning outcome 7 – Understand communication in the workplace	Communication	You are leading a group of fellow learners on how to communicate within the aviation workplace environment.	A written report with examples/ templates where appropriate.
Learning outcome 8 – Understand error models within aeronautical engineering **Learning outcome 9** – Understand risk assessments in aeronautical engineering environments	Error Models and Risk Assessment	You have been asked to contribute to a session on error models and ways of reducing incidents and accidents in the aviation maintenance environment.	A technical written report, including labelled diagrams and tables where appropriate.

Alternative model of assignments

Learning outcomes and assessment criteria	Assignment title	Scenario	Assessment method
Learning outcomes 1 to 7	Staff Performance in an Aeronautical Engineering Environment	You have been asked to carry out a study of staff performance in an aeronautical engineering environment. Divide your report into three sections using the titles below. 1 – Aspects of social psychology and the importance of human factors 2 – Human performance in the workplace – categories of tasks, physical aspects of the working environment and communication 3 – Features and limitations of human performance	A written report, including case studies, labelled diagrams and tables where appropriate.
Learning outcome 8 – Understand error models within aeronautical engineering **Learning outcome 9** – Understand risk assessments in aeronautical engineering environments	Error Models and Risk Assessment	You have been asked to contribute to a session on error models and ways of reducing incidents and accidents in the aviation maintenance environment.	A technical written report, including labelled diagrams and tables where appropriate.

Essential resources

The resources needed for this unit are:

- the internet
- a library or learning resource centre.

Indicative reading for learners

Books

HSE – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Patankar M S, Taylor J C – *Applied Human Factors in Aviation Maintenance: A Practical Guide to Improving Safety* (Ashgate, 2004) ISBN 9780754619406

Swanson R – *Analysis for Improving Performance: Tools for Diagnosing Organizations & Documenting Workplace Expertise* (Berrett Koehler, 2007) ISBN 9781576753415

Websites

Aviation Safety Network	www.aviation-safety.net
Business Education Resource (Learning Zone)	www.bized.co.uk
Civil Aviation Authority (CAA):	www.caa.co.uk
CAP 715 – *Introduction to Aircraft Maintenance Engineering Human Factors*	
CAP 716 – *Aviation Maintenance Human Factors*	
CAP 718 – *Human Factors in aircraft maintenance and inspection*	
CAP 719 – *Fundamental Human Factors Concepts*	
Health and Safety Executive	www.hsegov.uk/humanfactors/index.html
Human factors in aviation	www.boeing.com/commercial/aeromagazine/aero_08/human_textonly.html
The Times 100 case studies	www.thetimes100.co.uk
YouTube – Managing Human Error	www.youtube.com/watch?v=5jk0uAVdBC4
YouTube – Swiss cheese model	www.youtube.com/watch?v=QdLZFiUonPk
YouTube –5 Aviation Accidents Caused by Human Factors | IHF	www.ihf.co.uk/blog/2014/07/5-aviation-accidents-caused-by-human-factors/

Unit 97: Aircraft Radio and Radar Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will develop learners' understanding of the principles of aircraft communications and navigation systems.

Modern aircraft make extensive use of complex avionic systems for communication and navigation. These systems rely primarily on radio and radar for their operation.

This unit provides an introduction to the principles of aircraft communications and navigation systems. Learners will gain an understanding of radio waves and how radio transmitters and receivers operate. They will also look at the operation and use of aircraft radio and radar antennas. Learners will gain an understanding of the principles, characteristics and applications of the different systems used for aircraft navigation and the operation of radar systems.

The unit covers the essential underpinning knowledge needed by those involved in the design, manufacture and maintenance of military and commercial aircraft radio and radar systems. The unit also provides some of the knowledge and understanding for learners wishing to progress on to category B of the UK Part 66 licensing requirements, Module 13 and European Aviation Safety Agency (EASA) Part 66 licensing requirements, Module 13.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles and operation of aircraft radio transmitters and receivers

2 Understand the principles and operation of aircraft radio and radar antennas and feeders

3 Understand the principles and operation of aircraft navigation systems

4 Understand the principles and operation of aircraft radar systems.

Unit content

1 Understand the principles and operation of aircraft radio transmitters and receivers

Radio principles: radio waves (ground, sky, space); radio wave propagation at different frequencies, e.g. very low (VLF), low (LF), medium (MF), high (HF), very high (VHF), ultra high (UHF), super high (SHF); principles, characteristics and applications of different modulation methods, e.g. amplitude modulation (AM) (including DSB and SSB), single-sideband (SSB), frequency modulation (FM), digital modulation (Frequency-shift keying (FSK), Phase-shift keying (PSK), differential phase-shift keying (DPSK))

Transmitters: principles, operation, characteristics and applications of transmitters, e.g. AM, FM and SSB and for use at different frequencies such as HF, VHF (datalinks VDL and HFDL), and UHF, aircraft communication addressing and reporting system (ACARS); block schematic diagrams of transmitters showing internal functional blocks, e.g. oscillators, frequency multipliers, mixers, frequency synthesisers, phase-locked loops (PLL), modulators, filters, compressors, automatic level control (ALC), antenna matching units; typical transmitter specifications, e.g. output power, frequency range, frequency accuracy, frequency stability, number of channels, modulation depth

Receivers: principles, operation, characteristics and applications of receivers, e.g. tuned radio frequency (TRF), single superhets, double superhets; block schematic diagrams of receivers showing internal functional blocks, e.g. radio frequency (RF) amplifiers, mixers, oscillators, frequency synthesisers, phase-locked loops (PLL), intermediate frequency (IF) amplifiers, filters, automatic gain control (AGC), automatic frequency control (AFC), demodulators; typical receiver specifications, e.g. image channel rejection, adjacent channel rejection, sensitivity, frequency range, frequency accuracy, frequency stability, number of channels

2 Understand the principles and operation of aircraft radio and radar antennas and feeders

Antennas: principles, operation, characteristics and applications of radio and radar antennas, e.g. isotropic radiator, half-wave dipole, quarter wave unipole, beam, ground-plane, discone, loaded monopole, helical, parabolic reflector, phased array, rod, slot, loop, plate, horn and dielectric types; uses (HF, VHF)

Feeders: principles, operation, characteristics and applications of coaxial (flexible and rigid) and waveguide (rigid and flexible) feeders; feeder specifications, e.g. characteristic impedance, loss, frequency response and power handling

3 Understand the principles and operation of aircraft navigation systems

Navigation systems: principles, operation, characteristics and applications of systems used for aircraft navigation, e.g. VHF omnidirectional range (VOR) tactical air navigation (TACAN), distance measuring equipment (DME), automatic direction finding (ADF), instrument landing system (ILS), microwave landing system (MLS), hyperbolic navigation system, Doppler navigation, global positioning system (GPS), global navigation satellite systems (GNSS), in-flight meteorological information (VOLMET), VLF/Omega; typical performance specifications for aircraft navigation systems, e.g. operating frequency/ frequency band, accuracy, maximum range, availability, reliability

4 Understand the principles and operation of aircraft radar systems

Radar: principles, operation, characteristics and applications of primary and secondary pulsed and continuous wave (CW) radar transmitters, e.g. radar altimeter, secondary surveillance radar (SSR), weather radar (WXR), traffic alert and collision avoidance system (TCAS); block schematic diagrams of radar showing internal functional blocks, e.g. mixer, oscillator, intermediate frequency (IF) amplifier, demodulator, clutter reduction, sensitivity time control (STC), automatic frequency control (AFC), magnetron, klystron, travelling wave tube (TWT), Gunn effect diode, high power oscillator (HPO) and master oscillator power amplifier (MOPA); factors affecting the performance of radar systems, e.g. slant range, bearing, elevation angle, clutter, transmitter power, receiver sensitivity, frequency of operation, beam shape and scanning method, pulse repetition frequency (PRF), pulse duration (PD); typical radar specifications, e.g. operating frequency/frequency band, accuracy, maximum range, resolution/target discrimination, peak and mean operating power, pulse repetition frequency

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the principles of radio wave propagation (ground waves, sky waves and space waves) at different frequencies (LF, MF, HF, UHF and above)	**M1** describe a typical application for an aircraft voice communication system and give a typical specification for the equipment used	**D1** evaluate the performance of two different aircraft navigation systems with reference to their application, performance specification and the antennas used
P2 explain the different methods of modulation	**M2** describe a typical application for an aircraft navigation system and give a typical specification for the equipment used	**D2** evaluate the performance of two different aircraft radar systems with reference to their application, performance specification and the antennas used.
P3 explain the principles, characteristics, application and specifications of a typical aircraft radio transmitter with reference to a labelled block schematic diagram	**M3** describe a typical application for an aircraft radar system and give a typical specification for the equipment used.	
P4 explain the principles, characteristics, application and specifications of a typical aircraft radio receiver with reference to a labelled block schematic diagram		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain the principles, operation, characteristics and specifications of two different types of aircraft radio antenna (one for use at HF and one for use at VHF)		
P6 explain the principles, operation, characteristics and specifications of coaxial and waveguide feeders		
P7 explain the principles, operation, characteristics, applications and performance specifications of three different aircraft navigation systems		
P8 explain the principles, operation, characteristics, applications and specifications of typical primary and secondary, pulsed and continuous wave radar transmitters with reference to labelled block schematic diagrams		
P9 describe the factors affecting radar system performance for a given radar specification.		

Essential guidance for tutors

Assessment

It is likely that at least four assessment instruments will be required for this unit. If practical investigations and tests are also used then the total number of pieces of assessed work could be even more. This should be carefully considered so that it does not place an unduly heavy assessment burden on learners or the tutor.

The method of assessment preferred by national legislative bodies involves the use of multiple choice questions. For example, many centres may have existing banks of multiple choice questions designed to prepare and test learners for Module 13 of EASA Part-66. Where learners are aiming to achieve recognised licensed status, this method of assessment could be adopted as a means of supporting and checking learning. Multiple-choice questions should not, however, be used as assessment instruments for the purposes of this unit.

The first assignment could cover learning outcome 1 (P1, P2, P3, P4, M1) and is likely to consist of a series of written tasks. P1 requires learners to provide an explanation of radio wave propagation at different frequencies. An acceptable explanation should include mention of ground waves, sky waves and space waves and should include the range of frequencies normally associated with each type of propagation. Learners should also explain how and why radio wave propagation informs the use and application of radio in aircraft. For example, learners should associate long-distance HF radio communication with single and multi-hop sky wave propagation, space wave propagation at UHF/SHF with orbiting satellites for GNSS and GPS etc.

P2 could be assessed through an investigative task into modulation techniques. Learners should be able to describe in words and using appropriate diagrams where this helps, the principles of amplitude modulation (including DSB and SSB), frequency modulation (FM), and digital modulation. Learners should also explain how and why modulation techniques inform the use of voice and data communication in aircraft. For example, learners should associate the narrow bandwidth available with HF radio systems with relatively low data rates used for High Frequency Data Link (HFDL); the wider bandwidth of VHF radio systems with faster data rates used with Very High Frequency Data Link (VDL) and the Aircraft Communication Addressing and Reporting System (ACARS).

Learners can achieve P3 by drawing a labelled block diagram of an aircraft radio transmitter (this can be either an HF or VHF unit). The diagram should include appropriate annotation and should clearly show the links between blocks. Each block should be clearly labelled with its function, for example ‘Frequency Multiplier’, ‘Modulator’, ‘Antenna Filter’. Learners should provide a brief written explanation of the function of each stage as well as the overall function of the unit together with typical operational specifications and a suggested application for the unit.

For P4, learners could draw a labelled block diagram of an aircraft radio receiver (this can either be an HF or VHF unit). The diagram should include appropriate annotation and should clearly show the links between blocks. Each block should be clearly labelled with its function, for example ‘RF amplifier’, ‘Mixer’, ‘IF filter’. Learners should provide a brief written explanation of the function of each stage as well as the overall function of the unit together with typical operational specifications and a suggested application for the unit.

M1 could be achieved through a detailed investigation of an aircraft voice communication system. This can be either an HF or a VHF unit. Learners should provide an adequately detailed description of how the system works and what it is used for. The description should relate specifically to the primary application of the chosen aircraft voice communication system and should include, for example, the need for ALC and AGC, channel selection using frequency synthesis and cockpit mounted control units etc. Learners should also provide a description of the application and type of traffic handled by the system, for example ATC instructions, VOLMET, as well as an outline specification including, for example, frequency range, receiver sensitivity, transmitter output power, input/output impedance, modulation types (AM, SSB, DPSK), number of channels, etc.

The second assignment could require learners to describe (using labelled sketches and a supporting written explanation) the principles of at least two antennas, for example a VHF blade antenna and HF slot antenna (P5). Feed-points should be clearly identified and the directional characteristics of each antenna should be described. For P6, an investigation of coaxial (flexible and rigid) and waveguide (flexible and rigid) feeders could be used. Learners should describe (again using labelled sketches where this may help and a supporting written explanation) the principles and operation of each types of feeder. They should also summarise the characteristics, typical operational specifications and a suggested application for each type.

A third assignment could cover P7, M2 and D1. This will need to involve an investigation of three different aircraft navigation systems (P7), such as VOR, DME, GPS/GNSS, ILS, MLS or Loran-C. Learners should describe and explain the principles on which their chosen systems operate as well as providing a summary of the characteristics and applications as well as typical specifications relevant to the systems that they have chosen.

M2 could be achieved through a detailed investigation of an aircraft navigation system. This will usually be a VHF system, such as ILS or VOR but could also be based on GPS or GNSS. Learners should provide an adequately detailed description of how the system works and what it is used for. The description should relate specifically to the primary application of the chosen aircraft navigation system and should include, for example, the need for ground-based equipment (such as beacons and antennas). Learners should also provide a description of the application as well as an outline specification including, for example, frequency range, receiver sensitivity, transmitter output power, input/output impedance, modulation types (AM, SSB, DPSK), number of channels, etc.

D1 could be achieved through an extension of the work carried out for M2. D1 requires them to evaluate the performance of two different navigation systems (for example, evaluating hyperbolic and satellite-based systems and then providing a detailed comparison of the two systems). Learners should quote comparative specifications and should summarise advantages and disadvantages of each system investigated. Learners should be expected to relate the overall performance of a system to the properties and characteristics of the individual components (receivers, transmitters, antennas, feeders, ground-based equipment, etc) as well as the vagaries of propagation (effect of anomalous propagation, variations in MUF) noise, errors and other disturbances.

The final assignment would cover learning outcome 4 and would require learners to draw a labelled block diagram of typical primary and secondary radar systems, such as weather radar and surveillance radar systems (P8). The diagram should include appropriate annotation and should clearly show the links between blocks. Each block should be clearly labelled with its function, for example 'Magnetron', 'Directional coupler', 'IF amplifier', 'Antenna'. Learners should provide a brief written explanation of the function of each stage as well as the overall function of the unit together with typical operational specifications and a suggested application.

For P9 learners should provide a written description of the factors that affect radar performance for a given specification (such as primary or secondary surveillance radar system, and weather radar system). Their description should include references to factors such as range, target discrimination, freedom from clutter in relation to performance parameters such as peak radiated power, pulse width, antenna beam width, as relevant to the chosen system.

For M3, learners could carry out a detailed investigation of an aircraft radar system. This will usually be a weather radar system. Learners should provide an adequately detailed description of how the system works and what it is used for. The description should relate specifically to the primary application of the chosen aircraft radar system and should, for example, include the need for scanning, antenna tilt, anti-clutter, etc. Learners should also provide a description of the application as well as an outline specification including, for example, operating frequency, antenna beam width, receiver sensitivity, peak and mean output power, pulse repetition frequency, input/output impedance, etc.

Learners could achieve D2 through an extension of work carried out for M3. D2 requires them to evaluate the performance of two different aircraft radar systems (for example, evaluating a secondary radar system used for distance measurement (DME) or tactical navigation (TACAN) and a primary radar system used for weather (WXR) and then providing a detailed comparison of the two systems in terms of frequency, power, range, etc). Learners should quote comparative specifications and should summarise advantages and disadvantages of each system investigated. Learners should be expected to relate the overall performance of a system to the properties and characteristics of the individual components (receivers, transmitters, antennas, feeders, ground-based equipment, etc) as well as the vagaries of propagation (effect of anomalous propagation, ducting, rain and moisture), noise, errors, false reflections and other disturbances.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Transmitters and Receivers	The learner has been asked to produce a report on the operation of aircraft radio transmitters and receivers.	A written report
P5, P6	Antennas and Feeders	The learner has been asked to produce a report on the operation of aircraft antennas and feeders.	A written report, including relevant diagrams
P7, M2, D1	Aircraft Navigation Systems	The learner has been asked to produce a report on the operation of aircraft navigation systems.	A written report
P8, P9, M3, D2	Radar Systems	The learner has been asked to produce a report on the operation of aircraft navigation systems.	A written report

Essential resources

It is accepted that apart from Civil Aviation approved training organisations and specialist training providers, access to modern communications/radar systems and equipment will be severely limited. However, sight of such systems and equipment will greatly enhance delivery. Centres with limited equipment are strongly advised to incorporate a structured industrial visit into their teaching, so that learners have, at the very least, sight of aircraft radio, radar, radio navigation and opto-electronic systems and equipment.

Access to system hardware, such as transmission lines, aerials and wave-guides would also be beneficial. Computer packages, illustrating aircraft communications and radar systems and equipment would also be of tremendous benefit.

Indicative reading for learners

Textbooks

Eismin T – *Aircraft Electricity and Electronics*, 7th edition (McGraw-Hill, 2019) ISBN 9781260108217

Tooley M and Wyatt D – *Aircraft Communications and Navigation Systems* (Butterworth-Heinemann, 2007) ISBN 9780750681377

Unit 98: Helicopter Aerodynamics and Flight Principles

Level:	**3**
Unit type:	**Optional; pathway mandatory in Aerospace Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The usefulness of a helicopter lies in its ability to take off and land vertically on almost any terrain, to hover stationary relative to the ground, and to fly forward, backward or sideways. These unique flying characteristics, however, come at a price, including complex aerodynamic problems and relatively large power requirements compared to fixed wing aircraft of the same weight.

In this unit, learners will gain an understanding of the atmosphere in which aircraft of all types fly and the mechanical and fluid principles associated with their flight. They will explore, through practical experimentation, the effects of airflow over aerodynamic surfaces, as well as how lift and drag are generated and how they interact during flight. Finally, learners will gain an understanding of the principles of helicopter flight and how helicopter control is obtained.

If learners want to work in the rotary wing aircraft industry then understanding how lift is achieved and how helicopters are controlled is essential. Studying this unit will help them progress to aircraft engineering technician roles in rotary wing aircraft manufacture, maintenance, component overhaul and repair. It will also help learners progress to higher education to study aerodynamics or flight mechanics or, alternatively, assist with gaining entry to other aeronautical engineering degrees.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Examine the atmospheric, mechanical and fluid principles affecting flight

2 Explore safely the lift and drag force generation and interaction that create aircraft flight

3 Explore helicopter flight principles and how control of a helicopter is obtained.

Unit content

1 Examine the atmospheric, mechanical and fluid principles affecting flight

The atmosphere, the International Standard Atmosphere (ISA) and its effect on flight

- The atmosphere:
  - composition of the air in the Earth's atmosphere
  - layers of the Earth's atmosphere to include the troposphere, stratosphere, mesosphere, thermosphere and exosphere
  - changes to the atmospheric air pressure, density and temperature
  - danger to flight due to severe atmospheric events, including:
    - lightning strike and the methods used to mitigate the effects
    - severe air turbulence and the possible effects on the aircraft
    - bird strike, hail strike
    - frost and ice accretion and their effects on aerodynamic performance.
- The International Standard Atmosphere (ISA):
  - the need for and functions of the ISA
  - define pressure (barometric, atmospheric, absolute), temperature (Kelvin, Centigrade, Fahrenheit, absolute), density, density ratio, dynamic viscosity, kinematic viscosity and sonic velocity
  - significance of and numerical values for the tropopause, temperature lapse rate, the temperature in the stratosphere
  - standard ISA values for the properties of air at ground level and their changes with altitude, to include pressure (P), density (ρ), temperature (T) dynamic (absolute) viscosity (μ), kinematic viscosity (v) sonic velocity (a)
  - define the characteristic gas constant (R), the specific heat capacity of a gas at constant volume (Cv) and constant pressure (CP), the ratio of specific heats $\gamma = \frac{C_P}{C_V}$
  - numerical values of R, CV, CP and γ, for air, under standard conditions
  - the use of the ideal gas laws and characteristic gas equation in mass form pv = mRT to solve numerical problems on the density, pressure, mass and temperature of air, under differing conditions
  - the use of ISA tables to find changes in pressure, density, absolute viscosity, kinematic viscosity and sonic velocity, for varying altitudes
  - the density ratio (σ), and its relationship to the equivalent airspeed (EAS) and true airspeed (TAS) at varying altitudes
  - the use of the temperature lapse rate equation (T = T0 – Lh), the sonic velocity approximation a = $\sqrt{\gamma RT} = 20.05\sqrt{T}$ and the density ratio, to determine properties of air at varying altitudes.

Fluid flow and mechanical principles

- Newton's laws, including:
  - second law and its relationship to forces generated by aircraft acceleration
  - third law and its relationship to flight forces and to the generation of aircraft lift.
- Continuity equation for laminar constant incompressible steady flow, volume flow rate given by $Q = A_1v_1 + A_2v_2$ and for unsteady variable density flow, the mass flow rate is given by $Mdot = \rho 1A1v1 = \rho 2A2v2$
- The Venturi principle and the nature of flow through a Venturi tube.
- The Bernoulli equation for incompressible steady flow:
  $\rho gh_1 + \frac{1}{2}\rho v^2{}_1 + p_1 = \rho gh_2 + \frac{1}{2}\rho v^2{}_2 + p_2$ also for total energy in a steady stream $p + \frac{1}{2}\rho v^2 = c$
- Centripetal and centrifugal accelerations where $a = \frac{v^2}{r}$ and resulting forces where $F = \frac{mv^2}{r}$
- Couples and turning moments where torque $T = F \times r$
- Principle of moments and balancing forces.
- Pressure measurement (mercury and aneroid barometer, manometer).

Application of mechanical principles to aircraft flight

- Flight forces:
  - position and equality of lift, weight, thrust and drag forces for straight and level flight
  - flight force couples (lift/weight and thrust/drag), action about centre of gravity (CG) and centre of pressure (CP)
  - balancing aerodynamic force from tailplane
  - using the principle of moments, determine balancing forces needed to maintain aircraft in static equilibrium.
- Flight forces in steady manoeuvres:
  - diagrammatic arrangement for system of forces and their components during gliding flight, diving flight, climbing flight and turning flight where $L\sin\theta = \frac{mv^2}{r}$ and $\tan\theta = \frac{v^2}{gr}$
  - the definition and significance of load factors
  - analytical solution of flight force parameters, during flight manoeuvres
  - the effects of excessive manoeuvre loads on airframe structure, including pulled rivets, skin buckling, fuel and oil leakage, visual structural cracking, asymmetry of structure
  - methods used to prevent the loss of aircraft structural integrity in the event of overstressing damage, including: failsafe, safe life and on-condition structure, redundancy, radiation shields, planned maintenance, maintenance frequency

- post-flight checks after flight through severe atmospheric events, including: examination of aircraft structure for damage, symmetry, examination for lightning and high intensity radiation field (HIRF) damage, instrument damage and degaussing, controls freedom of movement.

2 Explore safely the lift and drag force generation and interaction that create aircraft flight

The nature and effects of subsonic airflow over aerofoil sections

- The nature of subsonic airflow, including streamline, laminar and turbulent flow, compressibility effects at higher subsonic speeds.
- Aerofoil terminology, including aerofoil profile, camber, upper, lower and mean camber lines, chord line, leading and trailing edge, thickness/chord ratio or fineness ratio, angle of attack (AOA), angle of incidence (AOI).
- Viscosity effects and the boundary layer, including resistance to motion, velocity gradient, shear rate, boundary layer separation (transition point, separation point).
- Flow over aerofoil sections, including free stream, laminar and turbulent flow, relative airflow, up and down wash, stagnation point, separation.
- Pressure and flow changes at low, medium and high angles of attack and aerofoil stall effects.
- Airflow and aerodynamic shape, including aerofoils (flow over thin, medium, thick and symmetrical aerofoil sections), wings (aspect ratio, generation of tip vortices).

Aircraft lift, drag and their interaction

- Lift:
  - factors affecting lift, including aerofoil shape, lift coefficient, angle of attack, air density, airspeed and stall
  - centre of pressure and lift force
  - parameters and use of the lift equation, $L = CL \frac{1}{2} \rho v2S$
  - wing plan form designs for aircraft subject to low subsonic, high subsonic and transonic speed airflows
  - effects that wing plan forms have on the generation of lift
  - use and types of wind tunnel apparatus, e.g. air blowers, lift and drag balances, open and closed section tunnels, flow visualisation equipment, airflow pressure and speed-measuring devices, aerofoil sections and whole aircraft models
  - measurement of lift forces using wind-tunnel apparatus
  - significance and interpretation of pressure plots for varying angles of attack and airspeed.
- Drag:
  - types of drag, including total, induced (trailing vortex), profile skin friction, profile form, interference
  - factors affecting drag, including aerofoil shape, angle of attack, drag coefficient, airspeed, streamlining, damage to lift producing surfaces, ice and frost accretion
  - drag reduction methods, including polished surfaces, fairings

- parameters and use of the drag equation $D = C_D \frac{1}{2} \rho v^2 S$
- significance and interpretation of profile, induced and total drag plots versus airspeed
- measurement of drag forces using wind tunnel apparatus
- theoretical determination of drag forces.

- Lift and drag interaction:
  - significance and interpretation of lift and drag plots
  - polar plots of lift coefficient against drag coefficient and their interpretation
  - plots of profile drag and induced drag (total drag) against airspeed
  - minimum drag, the lift/drag ratio and aerofoil efficiency
  - optimum angle of incidence (AOI).
- Interpretation of aircraft model wind tunnel test results for lift, drag and pitching moment.

3 Explore helicopter flight principles and how control of a helicopter is obtained

Helicopter flight principles

- modes of flight (vertical, lateral, fore and aft, hover, spot turns)
- coning angle, Coriolis effect, translational lift, dissymmetry of lift, gyroscopic precession
- autorotation, vortex ring state

Helicopter control

- main rotor disc
- collective and cyclic controls
- tail rotor
- yaw control
- main rotor head control:
  - swash plate, spider arm
  - effect of control movement.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 calculate the atmospheric changes due to varying altitudes and conditions, explaining the effects of these changes on aircraft flight **P2** explain the mechanical and fluid principles that enable flight **P3** explain the nature of the loads and loading parameters imposed on the airframe during flight manoeuvres	**M1** analyse the dangers to flight caused by altitude and severe atmospheric events, identifying the nature of possible damage and appropriate mitigation methods **M2** analyse the forces that result from aircraft flight, identifying the nature of structural damage that may occur from the aircraft being subject to excessive loading	**D1** evaluate how the structural design of an aircraft mitigates the impact of excessive flight forces and how post flight checks identify defects
P4 conduct experiments safely to determine the lift and drag forces produced from steady state air at two different speeds flowing over two different aerofoil sections set at three angles of attack	**M3** conduct experiments accurately to determine the lift and drag forces produced from variable state and variable speed air flowing over different aerofoil sections set at three angles of attack	**D2** evaluate the lift and drag forces and lift/drag ratios produced from variable state, variable speed air flowing over aerofoil sections under three angles of attack, comparing the results from safely conducted experiments and theoretical calculations

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain, using theoretical calculations and experimental results, the lift and drag forces produced from steady state air at two different speeds flowing over two different aerofoil sections set at three angles of attack	**M4** analyse, using theoretical calculations and experimental results, the lift and drag forces and lift/drag ratios produced from variable state, variable speed air flowing over different aerofoil sections set at three angles of attack	
P6 describe the modes of flight that are possible in a helicopter **P7** explain the purpose of the three helicopter flight controls and how they affect their respective rotor blades.	**M5** explain how main rotors are arranged on different types of helicopter to compensate for gyroscopic precession.	**D3** evaluate how translating tendency, Coriolis effect and dissymmetry of lift are controlled in different types of helicopter.

Essential guidance for tutors

Assessment

For P1, learners will include in their evidence a series of calculations to determine the properties of atmospheric air at differing altitudes. For P2 and P3, explanations may be limited to the more obvious changes that occur with altitude, such as the drop in temperature, pressure and density of the air in the troposphere and their effect on lift forces. Learners' explanations should connect these changes with one or two of the more obvious atmospheric events. For example, how a drop in temperature and precipitation conditions increases the risk of frost/ice accretion and the effects this may have on aerodynamic performance and controls handling.

Evidence should demonstrate the relationship between the Venturi principle, Bernoulli's theorem, Newton's second law and the generation of aircraft lift forces. Aerodynamic forces that occur during aircraft manoeuvres, including gliding, climbing, pulling out from a dive and turning flight, should be explained using vector diagrams.

Overall, the explanations should be logically structured, although basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology, such as confusing dynamic viscosity with kinematic viscosity or using the term 'transition point', when they are really talking about the separation point. Also, the calculations may contain some minor arithmetic errors.

For P4 and P5, learners will safely and correctly set up and carry out a series of experiments and obtain results. A minimum of two experiments, each with a different aerofoil section, will be used to determine the effects on lift and drag across them at low, medium and high angles of attack. There may be some minor inaccuracies in the recording of the results, estimating lift and drag forces, and relating to the engineering terminology used.

Overall, learners' explanations will be logically structured and clearly identify the changes to airflow over the aerofoil sections at different angles of attack up to the stall, explicitly commenting on their effect on lift and drag. The explanation of each experiment will include scale diagrams that are annotated with relevant figures, for example lift and drag forces. Theoretical calculations will also be included, but there may be minor numerical and diagrammatic errors.

For P6 and P7, learners will be able to describe all modes of helicopter flight and the flight controls the pilot must operate to achieve each mode of flight. Learners will also be able to explain the purpose of each of the three helicopter flight controls and the effect each flight control has on their respective rotor blades.

Overall, the explanations should be logically structured, although basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

For M1 and M2, learners will provide evidence for each severe atmospheric condition of one area of damage that has been identified and the corresponding mitigation methods considered.

The quantitative analysis of forces that occur during all phases of flight should include taxiing, climbing, cruising, turning and diving manoeuvres. There should be clear evidence presented that identifies the nature, and considers the likely cause of, the structural damage that may occur from excessive loading during all phases of flight.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For M3 and M4, learners will conduct accurate experimental work, to include setting up the measuring equipment and recording results methodically. The practical work will also involve running the experiments under different airflow conditions, for example to conduct the experiments under steady streamlined and unsteady/turbulent airflows.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Theoretical calculations of lift and drag forces and lift/drag ratios must be accurate and conform to accepted conventions.

For M5, learners will explain how the rotors are arranged on different types of helicopter. For example, learners will explain the rotor arrangement on helicopters with two blades, four blades and five blades. The evidence produced will detail how lift and drag vary as a helicopter blade varies its angle of attack through its circular flight path and how gyroscopic precession is used to control flight due to these changes in lift and drag.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For D1, learners will produce evidence that includes a balanced evaluation of the structural design features and post-flight procedures used to ensure continuing airworthiness, including those problems presented by structural degradation. The evidence will include an accurate analysis of the aerodynamic forces acting on the aircraft during all phases of flight, as well as the dangers and atmospheric effects on flight through extreme weather events and their combined adverse effect on the aircraft during flight. In addition, there will be an evaluation of the structural design methods used to mitigate adverse effects and the post-flight procedures used to identify the defects resulting from adverse conditions.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer.

For D2, learners will produce a balanced evaluation of at least two experiments undertaken with two different aerofoil sections and under different conditions, for example angles of attack. There should also be theoretical calculation of lift and drag forces and lift/drag ratios based on the airflow over at least two aerofoil sections.

The evaluation should include a comparison of the results obtained through safe experimentation and theoretical calculations, and explain why the variations occur, for example from experimental error and also from the limitations of the theoretical equations and the aerodynamic effects of wind tunnel testing when compared with real aircraft flight. Also, for example, there are the limitations with Bernoulli's theorem, when used experimentally with both steady streamlined and unsteady/turbulent airflows.

Overall, the experimental evidence, for example a report, should be logically structured.

For D3, learners will evaluate how the aerodynamic problems associated with helicopter flight are controlled by design in different types of helicopter.

Overall, the evidence produced will be easy to read and understand by a third party who may or may not be an engineer.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Atmospheric Events and Mechanical and Fluid Principles Affecting Flight	An activity requiring learners to research the atmospheric events and mechanical and fluid principles that affect flight.	A report covering the atmosphere, the analysis of atmospheric parameters, mechanical and fluid principles and their effect on flight and continuing airworthiness.
P4, P5, M3, M4, D2	Lift and Drag Force Generation and Interaction	A series of experiments into lift and drag forces, with supporting documentation.	A portfolio of results gathered by experimentation when investigating airflow over aerofoil surfaces, and lift and drag generation and interaction. Supported by images, observation records, graphs and mathematical analysis.
P6, P7, M5, D3	Helicopter Flight and Control	An activity requiring learners to research helicopter flight control methods and the aerodynamic effects relating to rotary wing flight.	A technical report covering the modes of helicopter flight, gyroscopic precession, translating tendency, Coriolis effect, dissymmetry of lift and how rotor blades are arranged to allow flight to be controlled.

Essential resources

For this unit, learners must have access to:

- mechanical laboratory equipment, such as centripetal acceleration/force apparatus, Venturi and Bernoulli apparatus, Newton's cradle/Newtonian demonstrator, or similar apparatus to verify these principles
- flow visualisation apparatus, such as a smoke tunnel or a wind tunnel and prepared aerofoil sections with streamers
- an open- or closed-section wind tunnel, with lift and drag measurement equipment, speed and pressure measurement equipment. Please note that wind tunnels with manometers would be more suitable for experimental work than those with digital read-out equipment
- standard aerofoil sections, such as NACA 12 and others with known geometric parameters and pressure measurement plumbing
- workshop barometer and thermometer or other pressure and temperature measurement equipment
- actual helicopter airframes, control systems, main rotor heads and tail rotors.

Unit 99: Aircraft Workshop Methods and Practice

Level:	**3**
Unit type:	**Optional in Aerospace Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

Familiarity with the aircraft workshop, components, tools and information sources and standards, together with developing a knowledge of mechanical and electrical inspection and fitting processes, provide an essential foundation for all prospective aircraft engineering technicians and engineers, irrespective of their chosen specialism.

In this unit, learners will be introduced to the aircraft workshop environment and be made aware of safety and operational processes, as well as the function and safe use of aircraft hardware and consumable components, and tools. They will develop practical skills by carrying out a series of mechanical and electrical workshop inspection and fitting activities. Finally, learners will be asked to reflect on how their general engineering skills, workshop inspection and fitting skills and behaviours were applied during the unit.

This unit will help to prepare learners for an aircraft engineering apprenticeship as well as, more specifically, assisting them in gaining employment in an aircraft technician role. Alternatively, they could choose to continue their studies in higher education.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Explore safe working practices and suitable component selection in an aircraft workshop environment

2 Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness

3 Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness

4 Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance.

Unit content

1 Explore safe working practices and suitable component selection in an aircraft workshop environment

Workshop safety procedures and housekeeping

Safety procedures, or other relevant international equivalents, and action to be followed, including:

- awareness of local workshop electrical safety hazards and actions, including:
  - electrical hazards when handling electrical power tools and circuit boards
  - electrostatic hazards with sensitive electrical instruments and tools
  - electric shock prevention methods
  - first-aid treatment and actions for electric shock
  - safety and pre-use checks when using portable and static electrical driven tools and machinery
- care and handling of low/high pressure gases, including compressed air lines, gas bottles, special precautions when handling oxygen and cryogenic substances
- control of hazardous substances, including handling and storage of hydraulic fluids, lubricants, fuels, paints, cleaning fluids and corrosive substances
- safety equipment to be used and procedures to followed when working at height
- compliance with workshop health and safety provision and procedures, including:
  - the care, application and use of firefighting equipment, positioning of fire points and fire drills
  - first-aid facilities and equipment, local procedures, accident/incident recording
- compliance with manual handling operations and personal protection regulations, including:
  - use of protective clothing
  - hand, eye and ear protection when handling sheet metal, cutting tools and corrosive substances, and using workshop machinery and tools
  - personal hygiene, and use of barrier creams.

Workshop information sources and standards

- Awareness of and compliance with civil and military information sources or other relevant international equivalents, e.g.:
  - civil publications of aviation transport association British Aviation Transport Association (BATA) 100 series, presented in written, microfilm and computer form, Civil Aviation Authority (CAA) publications, European Aviation Safety Agency (EASA) publications
  - military aviation aircraft publications AP101 series for maintenance and repair, military specifications (MIL SPEC), defence standards (DEF STAN)
  - other information sources, such as printed maintenance and repair manuals, microfilm and microfiche readers, computer databases, posters, wall charts, tables.

- Awareness of and compliance with standards or other relevant international equivalents, including:
  - fluids BS 2917, International Standards Organization ISO1219
  - electrical BS 3939, European Standard EN 60617-2-11
  - drawing BS 8888-2013
  - limits, fits, tolerances EN 20286.

Tool management

Tool control, care and use, including:

- tool control methods, including shadow boards, portable servicing kits, toolboxes, tool tags, electronic coded labelling, booking in/out systems
- missing tool and loss article actions
- user precautions, pre-use and safety checks for workshop tools, including:
  - marking out and work-holding tools, e.g. rule, callipers, scribe, centre punch, fitter's square, combination set, surface plate, clamps, vices, griper pins
  - precision measuring instruments, e.g. micrometers, vernier callipers, vernier height and depth gauges, bevel protractors and their calibration and control
  - cutting and metal removal tools, e.g. guillotines, hacksaws, files, electrical and pneumatic drills, nibblers, reamers, grinding machines, countersinks
  - riveting tools, e.g. bend bars, bending machines, hand and powered riveting pliers, guns, lazy tongs, reaction blocks, countersinks
  - assembly/dismantling tools, e.g. steel and hide faced hammers, pliers, spanners, wrenches, torque wrenches, screwdrivers
  - electrical cable crimping and sheathing tools and equipment.

Hardware and consumable components

- Recognition, care and use of hardware components, including:
  - fluid plumbing, e.g. flexible hoses, rigid pipes, unions, fittings, connectors
  - transmissions, e.g. springs, belts, chains, pulleys, sprockets, gears, bearings, screwjacks, lever devices, push-pull rods
  - control cables, e.g. control cable runs, Bowden cable, teleflex, screwed and pinned end fittings, turnbuckles, turn barrels, cable tensioners
  - electrical, e.g. wire types, polyvinylchloride (PVC), nylon, Kapton®, Teflon™, Tezel, connectors, terminations, plugs, sockets, cleats, sheathing.
- Identification and use of consumable components, including:
  - threaded fasteners, including screws, bolts, studs, nuts, washers, friction-locking devices, lock wire, split pins
  - fasteners, including quick release, toggle
  - rivets, including solid universal/pan head, solid countersunk, blind and hi-shear rivets, e.g. Tucker POP®, Avdel®, Chobert®, Jo-Bolts.
- Consequences of non-compliance with information sources and standards, tool management and hardware and consumable components when carrying out mechanical and electrical inspection and fitting processes.

2 Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness

Preparation for mechanical hardware inspection and fitting processes

- Consult information sources to determine aircraft mechanical hardware inspection and fitting processes, including standards.
- Identify and select all required consumables and hardware components for designated mechanical inspection and fitting activity, from information sources.
- Comply with laid-down processes, including tests and inspection checks, for designated mechanical fitting activity.

Mechanical hardware inspection and fitting processes

- Mechanical hardware component inspection and fitting processes, e.g.:
  - sheet metal structure and panels
  - scab patch or insert repairs
  - panel fasteners
  - fluid plumbing
  - transmissions
  - control cable runs.
- Quality control checks, including:
  - fitting activities in compliance with information source procedures, standards and limits
  - visual and physical inspection checks, e.g. wear, serviceability, correct fitting and assembly, security of attachment, locking, freedom, sense and range of movement, tolerances, limits and fits
  - mechanical inspection and fitting checks, including dimensional accuracy, tolerance, critical dimensions, joint quality, surface finish.

3 Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness

Preparation for electrical hardware inspection and fitting processes

- Consulting information sources to determine aircraft electrical hardware inspection and fitting processes, including standards.
- Identifying and selecting all required consumables and hardware components for designated electrical inspection and fitting processes, from information sources.
- Complying with laid-down processes, including tests and inspection checks, for designated electrical fitting processes.

Electrical hardware inspection and fitting processes

- Electrical hardware inspection and fitting processes, e.g.:
  - electrical cable crimping
  - electrical cable replacement
  - electrical terminations, plugs and sockets
  - sheathing, assembling and looming cable runs.

- Quality control checks, including:
  - fitting processes in compliance with information source procedures, standards and limits
  - electrical checks for continuity, bonding and insulation
  - visual and physical inspection checks, e.g. wear, damage, serviceability, correct fitting and/or assembly, security of attachment.

4 Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance

Lessons learned from workshop inspection and fitting processes

The scope of the lessons learned should cover:

- health and safety skills, to include familiarity and compliance with laid down health and safety procedures and hazard prevention actions when carrying out mechanical and electrical inspection and fitting processes
- aircraft workshop mechanical and electrical inspection and fitting skills, e.g. to include interpreting information sources, tool care, control and use, selection of hardware and consumables components, good husbandry of the work area, sustainability, e.g. efficient use of hardware, energy usage and waste products
- general engineering skills, e.g. mathematics and interpreting drawings.

Personal performance when carrying out workshop inspection and fitting processes

Understanding relevant behaviours for working in an aircraft workshop, including:

- taking initiative and responsibility for own actions when applying knowledge and practical skills to mechanical and electrical inspection and fitting processes. This is so that they are safe, efficient and independent, e.g. selecting and using appropriate tools and hardware components
- communication and literacy skills to interpret and comply with workshop health and safety processes, and to follow and implement instructions appropriately and to explain own intentions to others
- problem solving issues as they occur, e.g. when correct tensioning of a control cable after installation results in the turn barrel being out of safe alignment.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how information sources and standards are effectively applied to ensure aircraft airworthiness **P2** explain how effective tool management and the correct selection of hardware and consumable components ensure aircraft airworthiness	**M1** assess the possible effects on aircraft airworthiness of inspecting and fitting mechanical and electrical components that comply and do not comply with safe working practice	**D1** justify the possible effects on aircraft airworthiness of inspecting and fitting mechanical and electrical components that comply and do not comply with safe working practice and suggest actions to mitigate these effects
P3 inspect and fit two appropriate mechanical hardware components safely	**M2** inspect and fit accurately and efficiently two appropriate mechanical hardware components	**D2** refine, during the process, the inspection and fitting of mechanical and electrical hardware components to ensure system serviceability and integrity while complying with safe working practice
P4 inspect and fit two appropriate electrical hardware components safely	**M3** inspect and fit accurately and efficiently, two electrical hardware components	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain how health and safety, mechanical and electrical inspection and fitting processes, and general engineering skills were applied effectively in an aircraft workshop **P6** explain how relevant behaviours were applied effectively to mechanical and electrical inspection and fitting processes.	**M4** recommend improvements to the mechanical and electrical hardware component inspection and fitting activities and to the relevant behaviours applied.	**D3** demonstrate consistently good technical understanding and analysis of the mechanical and electrical hardware component workshop inspection and fitting activities, including the application of relevant behaviours and engineering skills to a professional standard.

Essential guidance for tutors

Assessment

For P1, learners will know workshop safety procedures and practices that apply to mechanical and electrical inspection and fitting activities. Specifically, they will explain how information sources and laid-down standards are applied to ensure safe working practice. Finally, for P2, they will demonstrate an understanding of workshop tool care and control (management) methods, as well as the identification methods and codes used for aircraft consumable parts and hardware components.

Overall, the explanations will be logically structured, although basic in parts. They may have one or two omissions in their selection of information sources and standards that are applied across all areas of workshop practice. They may also fail to correctly identify all hardware and consumable components from their packaging, although still being aware of their purpose.

For P3 and P4, learners will safely complete two mechanical and two electrical inspection and fitting activities. Evidence that the particular workshop activity has been completed safely and in accordance with laid-down procedures may be obtained from observation, witness statements and learners' written accounts.

There may be minor errors in accuracy and in the approach taken towards the completion of the allotted workshop activity and on completion; the hardware component will be fit for purpose. For example, a control system turnbuckle may be fit for purpose, as the turnbuckle end fittings are safety fitted and the wire locking is seen to be laid in the correct direction. However, the cut ends of the wire may not have been turned over correctly, causing a possible injury hazard. Another example is fitting a sheet metal insert where it would be acceptable if there are one or two minor errors, such as with the non-critical dimensions being out of tolerance and minor surface finish marks, providing they do not degrade the integrity of the repair.

For P5 and P6, learners will show in their evidence (for example, a technical report of between circa 500 and 1000 words) the lessons learned during each of the two mechanical and two electrical inspection and fitting activities. The evidence will explain the:

- actions taken to ensure their own personal safety and the safety of others in the workplace, such as the use of personal protective clothing, pre-use checks and care and control procedures for tools and equipment, and how any unforeseen safety issues were dealt with
- mechanical and electrical inspection and fitting skills, such as using pneumatically and electrically powered riveting, crimping and cutting tools, and the skills needed to correctly dismantle, assemble and check hardware components
- general engineering skills, such as the interpretation of engineering drawings and other relevant information in maintenance and repair manuals, and the reading and interpretation of measurements taken using precision instruments
- relevant behaviours that were applied when working in an aircraft workshop, such as time management to ensure completion of work to deadlines, good husbandry to ensure cleanliness and safety in and around the work area.

Overall, the evidence will be well organised and laid out clearly, so that a third party would be able to understand how learners' skills have been applied. Efforts will be made to use some technical language where appropriate, although there may be some inaccuracies with spelling and grammar. Some parts of the evidence may be considered in greater depth than others.

For M1, learners will consider in the assessment the consequences of both compliance with and the failure to comply with or the misinterpretation of laid-down safety and operational standards and procedures for aircraft workshop practices. For example, the consequences of mishandling pneumatically/electrically powered tools, the misinterpretation of labelling for hardware consumables or the failure to carry out all necessary quality control checks.

Overall, the assessment will be logically structured, technically accurate and easy to understand.

For M2 and M3, learners will accurately and efficiently inspect and fit three mechanical and two electrical hardware components. Evidence of the efficiency of the method being undertaken may be gauged by those witnessing or testifying to the logical approach adopted by learners. This will be in respect of information gathering, the handling and interpretation of documentation, order of fitting operations, and sequence and nature of stage inspection checks.

Accuracy will be measured against the laid-down standards given in the appropriate information sources, and evidenced from the results of checks and/or measurements carried out during each particular activity. For example, when fitting a sheet metal insert, the measurements for rivet pitch, land and allowance meet or are within the tolerances laid down on the drawing/s or those given in aircraft maintenance or repair manuals.

For M4, learners will make recommendations as to where improvements could be made. For example:

- the logic in the order of the steps and stage inspection checks made in the method, such as, ensuring security of attachment and correct assembly of the hardware component prior to carrying out functional test and checks
- the management of health and safety to decrease the risk of harm to self and others, for example posting warning notices before post-fit functional tests and/or inspection checks are carried out, where moving parts are to be involved
- applications of relevant behaviours to ensure time goals are met, and inspection and fitting practice is completed in a more efficient manner.

Overall, the improvements suggested will be reasonable and practical, and explanations will be professional and engineering terminology will be used accurately. Some parts of the evidence may have more emphasis than others making it more difficult for a third party to understand.

For D1, learners will justify the need for laid-down workshop procedures, standards, safety precautions and control measures. This justification must include an analysis of the consequences associated with the misinterpretation of operational procedures and sub-standard workmanship in the workshop itself, but also consideration of the wider implications for aircraft airworthiness resulting from both compliance with and lapses in workshop safe working practice. Learners will suggest actions to mitigate the effects of non-compliance, for example the amendment of a specific procedure where it is seen that the addition of essential stage checks is required or, the amendment of the text to ensure that ambiguity of meaning is removed.

For example, a reasoned argument as to why it is necessary to have written workshop procedures on the management (care and control) of tools and to have those to ensure the correct identification and fitting of hardware parts and components, might be reinforced by providing examples from research showing the subsequent detrimental effects on aircraft airworthiness, in the event of misinterpretation or non-compliance.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms.

For D2, learners will continually ensure throughout their mechanical and electrical hardware inspection and fitting activities that the hardware component being removed and fitted is returned to full serviceability. Learners will also ensure that the surrounding structure or systems affected are, through appropriate stage checks and rectification, kept and remained in a fully airworthy condition. For example, when replacing a pulley wheel in an aircraft flying control cable run, the pulley wheel will be replaced accurately and correctly. Inspection checks will also be carried out on the disassembled cable run to ensure the integrity and serviceability of all other components, replacing those that are unserviceable, with the requisite checks being carried out on the whole system as well as on the pulley wheel, post replacement.

Overall, the evidence will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer.

For D3, learners will provide evidence in their analysis of how improvements have been made throughout the activity to the serviceability and integrity of the component and/or system or structure, in order to meet with professional laid-down airworthiness and safety standards.

Learners will demonstrate consistently good technical understanding of all aspects of the allotted activity, including the application of relevant behaviours and engineering skills to a professional standard. For example, learners will take responsibility for their own actions and safety, before, during and after the inspection and fitting of an electrical cable loom to a pre-prepared circuit board, ensuring that all relevant electrical safety precautions and pre- and post-quality checks have been accurately completed for the cable loom and for the circuit into which it is fitted.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Safe Working Practices and Suitable Component Selection	An activity requiring learners to research safe working practices and suitable component selection.	A report focusing on the nature and use of information sources, including safety procedures and standards covering aircraft workshop mechanical and electrical working practices, together with the results from recognition exercises to select aircraft hardware and consumable components.
P3, P4, M2, M3, D2	Inspecting and Fitting Aircraft Mechanical and Electrical Hardware	Learners inspect and fit aircraft mechanical and electrical hardware.	A series of practical workshop tasks to safely undertake mechanical and electrical inspection and fitting processes. Evidence will include: finished components, observation records/ witness statements, annotated photographs and drawings and completed record of quality control measures needed to complete the fitting processes.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M4, D3	Lessons Learned from Personal Performance in Aircraft First-line Maintenance Operations	Learners review their performance while carrying out workshop inspection and fitting processes, what they have learned and what aspects of their performance could be improved.	The evidence will focus on what went well and what did not go so well when carrying out mechanical and electrical inspection, safe working practices and suitable component selection processes, and a conclusion of improvements that could be made. The portfolio of evidence will be generated while exploring and reviewing aircraft workshop inspection and fitting processes and reflecting on own performance.

Essential resources

For this unit, learners must have access to:

- appropriate information sources, including relevant maintenance and repair manuals, EASA, CAA or equivalent military publications, workshop safety procedures, notices and safety drills
- a range of consumable parts and related hardware suitable for performing the fitting, installing and repair methods as required by the learning outcomes and unit content
- hand tools, and pneumatic or electrical power tools, precision measuring equipment, workshop machines and equipment suitable for performing the fitting, installing and repair methods as required by the learning outcomes and unit content
- electrical circuit boards, test and measurement instruments and cable crimping tools and equipment
- a range of mechanical and fluid system training rigs and selected aircraft structure or a light aircraft suitably equipped to enable fitting, installing and repair methods to take place.

Unit 100: Aircraft Propulsion Systems

Level:	**3**
Unit type:	**Optional in Aerospace Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

With the increasing range of scheduled aircraft flights, and extended twin-engine operations over greater distances, the reliability and safe operation of the propulsion systems that support the aircraft power plant is essential.

In this unit, learners will examine the function and operation of the major systems and their components associated with the aircraft engine power plant, including the external fuel supply and internal engine fuel distribution systems. They will examine the function and operation of electromechanical and electronic engine control systems. Learners will then examine the function and operation of the engine lubrication and air systems, and their components. Finally, they will examine the function and operation of the fire and ice protection systems and learn how all these systems assist aircraft propulsion.

A study of the aircraft and engine systems that support aircraft propulsion is considered essential if learners want to work in the aeronautical sector. This unit will help to prepare them for an aircraft engineering apprenticeship, or to gain employment in an aircraft technician role. Alternatively, learners could choose to continue their studies in higher education.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation

2 Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation

3 Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation.

Unit content

1 Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation

Aircraft fuels and fuel supply systems

- Types, function and properties of fuels and fuel additives, including:
  - aviation gasoline (AVGAS)
  - JET A1 (AVTUR), an aviation jet turbine kerosene fuel
  - JET B (AVTAG), a wide-cut jet turbine gasoline/kerosene fuel
  - fuel flash point temperature, auto-ignition temperature and density
  - additives, ice and corrosion inhibitors, antioxidants and anti-static agents.
- Fuel supply system component identification, function and layout, including:
  - fuel storage tanks, rigid, integral, flexible
  - booster, jettison and transfer pumps
  - engine fuel, cross-feed, bypass, vent and jettison valves
  - fuel plumbing, heat exchangers
  - fuel level, temperature and pressure sensors and switches, related cabin/cockpit indications and warnings.
- Fuel system operation, including:
  - fuel engine feed, pressurisation and inerting
  - fuel jettison, venting, refuelling and defuelling.

Engine fuel systems

- Airframe and engine fuel system interaction requirements, including:
  - avoidance of suction operation
  - priming, re-priming and relight facility
  - avoidance of fuel contamination.
- Component identification, function and layout, including:
  - low- and high-pressure fuel pumps
  - low- and high-pressure filter assemblies
  - fuel heaters and heat exchangers
  - fuel drains tank
  - pressure and flow control valves, flow meters
  - fuel manifold and fuel spray nozzles.
- Function and operation of a hydro-mechanical fuel metering unit, including main valve assemblies, inputs and outputs.
- Function and operation of typical engine fuel system, from input at low pressure fuel pump to fuel spray nozzles.

Engine electromechanical and electronic control systems

- Electromechanical engine control systems.
  - Identification, function and layout of engine mechanical control system components and system operation, including:
    - teleflex and bowden cables, tension regulators, turnbuckles, cable control stops, control pulley box, start/thrust cable control drum, feedback cables
    - control rods, eye and fork end fittings
    - cable grommets, pressure seals
    - forward and reverse thrust levers, fuel control levers.
  - Electrically actuated fuel shut-off valves, directional control valves, control switches.
  - Function and operation of auto-throttle, including regulation and switching, flight/ground idle control.
- Electronic engine control systems.
  - Identification and function of typical electronic engine control system components including electronic engine controller, power demand and feedback sensors, fuel pumps and fuel metering controller.
  - Function and operation of a full authority digital electronic control (FADEC) control system, including:
    - electronic engine controller (EEC)
    - FADEC fuel metering unit (FMU), metering control and interaction with EEC
    - FADEC control of, for example, minimum pressure rise, fuel shut-off, over speed shut-off, manifold draining on shut down, pump unloading and fuel return to tank control
    - function and integration of the engine health monitoring (EHM) system with the EEC system.

2 Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation

Engine lubrication systems

- Engine lubricant types and properties, including:
  - mineral-based, diester-based and polyol ester-based oils
  - viscosity, flash point, adhesion and cohesion.
- Oil additive types and function, including anti-foaming agents, thickeners, anti-oxidants.
- Oil identification and grading systems, including:
  - commercial aviation number
  - MIL and AN specification (military)
  - SAE system.
- Functions of engine oil systems including lubrication, cooling, cleaning, corrosion protection.

- Component identification, function and layout, including:
  - oil reservoirs, deaerators
  - constant displacement oil pumps (gear, vane and gerotor), scavenge pumps
  - oil filters, filter ratings
  - chip detectors (indicating and pulsed)
  - relief valves, check valves
  - oil jets, distributors, vents
  - fuel/oil heat exchanger, air/oil cooler
  - pressure and temperature gauges.
- Operation of recirculatory gas turbine engine lubrication systems, including:
  - pressure relief system
  - full flow system
  - pressure feed and distribution, scavenge and vent, sub-systems.

Engine internal air systems

- Functions of gas turbine engine's air system, including cooling, bearing chamber and flow path sealing, bearing axial load control.
- Function and operation of air cooling system, including:
  - turbine blade and vane convective, film and transpiration cooling
  - turbine disc, shaft and casing cooling.
- Identification, function and nature of air system seals and sealing methods, e.g.:
  - labyrinth, brush and leaf, carbon, ring and hydraulic rotating seals
  - static seals and sealing
  - effects of external bleed air requirements on internal air system.

3 Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation

Fire protection systems and components

- Fire detection.
  - Fire detection zones, including engines, auxiliary power unit (APU), jet pipes.
  - Function and operation of fire/overheat detector systems, including:
    - unit detector systems, e.g. thermal switch, thermocouple, inertia switches, crash switches, detector circuit, alarm circuit, test circuit
    - continuous loop detector systems, e.g. Fenwal and Kidde resistance sensing systems, dual-loop systems, pneumatic sensing systems, fire detection control unit.
  - Function and operation of smoke, carbon monoxide and flame detection systems, including:
    - smoke and carbon monoxide detectors, e.g. light refraction, ionisation, electronic, chemical colour change
    - flame detectors, e.g. optical infrared, optical ultraviolet.
  - Nature of flight deck and cabin fire warnings, including location indicators, red lights, claxons, overheat indicators.

- Fire extinguishing.
  - Classes of fire, including Class A fires involving ordinary combustible materials, Class B fires involving flammable liquids, Class C fires involving energised electrical equipment, Class D fires involving combustible metals.
  - Use of on-board and ground extinguishing agents, including carbon dioxide, halogenated hydrocarbons and water.
  - Identification, function and layout of on-board fire extinguishing system components, including extinguisher bottles, discharge valves, cartridges, extinguisher plumbing, two-way check valves, bottle pressure and thermal discharge indicators.
  - Pilot and automatic operation of a multi-engine fire extinguishing system.

Ice protection systems

- Nature and effects of ice formation, including rim ice, glaze ice, hoar frost and snow.
- Operation of ice detector systems, e.g. probes, vanes, intake sensors, electronically activated, mass activated.
- Function and operation of engine intake, cowling and propeller anti-icing and de-icing systems, including electrical resistance heaters, spray mats, engine bleed air and chemical propeller slinger ring systems.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the function and operation of fuels, fuel supply and engine fuel systems and their components, identifying the contribution of each system to power plant operation **P2** explain the function and operation of electromechanical and full authority electronic engine control systems and their components, identifying the contribution of each system to power plant operation	**M1** analyse the function and operation of aircraft fuel supply and engine fuel systems and their components, identifying the contribution of each system to power plant operation **M2** analyse the function and operation of electromechanical and full authority electronic engine control systems and their components, identifying the contribution of each system to power plant operation	**D1** evaluate the function and operation of aircraft fuel supply and engine fuel, electromechanical and full authority electronic engine control systems and their components, assessing the contribution of each system to efficient power plant operation
P3 explain the function and operation of an engine's recirculatory pressure relief and full flow lubrication systems and their components, identifying their contribution to power plant operation	**M3** analyse the function and operation of an engine's recirculatory pressure relief and full-flow lubrication and air systems and their components, identifying their contribution to power plant operation	**D2** evaluate the function and operation of an engine's recirculatory pressure relief and full flow lubrication and air systems and their components, assessing the contribution of each system to efficient power plant operation

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 explain the function and operation of an engine's internal air system and its components, identifying their contribution to power plant operation		
P5 explain the function and operation of an aircraft fire protection system and its components, identifying their contribution to power plant operation **P6** explain the nature of ice formation and the operation of engine ice protection system and its components, identifying their contribution to power plant operation.	**M4** analyse the function and operation of an aircraft fire and engine ice protection system and their components, identifying their contribution to power plant operation.	**D3** evaluate the function and operation of an aircraft fire and engine ice protection system and their components, assessing the contribution of each system to efficient power plant operation.

Essential guidance for tutors

Assessment

For P1, learners will explain the function and properties of fuels and fuel additives, the function and operation of an airframe fuel supply system and engine fuel system and their components, identifying the effect each of these systems have on safe power plant operation. For example, learners will explain how the operation of the engine fuel system and the function of its components that ensure a safe fuel supply to the engines, result from the pilot's throttle settings.

For P2, learners will explain the function and operation of electromechanical control, FADEC systems and components, identifying the effect each system has on safe power plant operation. The explanation will include the operation of an electromechanical system and the function of its components used to control pilot throttle inputs, fuel flow and pressure and auto throttle regulation. In addition, the operation of a FADEC system, the function of its components and an EHM system, will be explained.

Overall, the evidence should be logically structured but may be basic in parts and contain minor technical omissions or inaccuracies. For example, learners missing or incorrectly identifying one or two of the functions of the EEC or FMU, when explaining the FADEC engine control system.

For P3, learners will explain the types, requirements and characteristics of engine lubricating oils, the function and operation of aircraft recirculatory engine internal relief valve and full flow lubrication systems and their components, and identify the contribution made by each of these systems and their sub-systems to safe power plant operation. For example, when examining a full flow lubrication system, the function and operation of the pressure feed and distribution, scavenge and vent sub-systems will be explained and their contribution to the safe operation of the lubrication system, identified.

For P4, learners will explain the function and operation of a gas turbine engine's internal air system and its components, and identify the contribution it makes to safe power plant operation. The analysis will include the function and operation of turbine cooling, airflow seals and sealing, bearing axial load control, equipment cooling and external services bleed air feeds. For example, when examining the operation of the turbine air cooling system, the function and operation of the turbine blade, disk and casing cooling and sealing methods, will be explained and the contribution made by the engine turbine cooling system to the safe operation of the power plant, will be identified.

Overall, the evidence should be logically structured but may be basic in parts and contain minor technical omissions or inaccuracies. For example, learners may miss or incorrectly identify a particular seal or sealing method, when explaining the seals and sealing method in a turbine cooling system.

For P5, learners will explain the operation of fire detection and extinguishing systems and the function of their components, and identify the systems contribution to safe power plant operation. The analysis will include the nature and use of extinguishing agents, the function and operation of fire, heat and smoke detection systems, flight deck and cabin fire warnings and fire extinguishing systems. For example, when examining an engine and jet pipe fire wire detection and extinguishing system, learners will explain the function of the fire wire and control components, the nature of the cabin warning indications, together with the manual and automatic actuation of the extinguisher bottles. The contribution the system makes to the safe operation of the power plant will also be identified.

For P6, learners will explain the operation of ice protection systems and the function of their components, and identify the systems contribution to safe power plant operation. The nature and effects of ice formation and the operation of ice detection, engine intake, cowling and propeller anti-icing and de-icing systems and the function of their components, will be explained.

For example, when examining an electrical resistance cowling heater anti-icing system, the operation of the system, learners will explain the function of the ice detectors and heaters, and the nature of the cabin warnings. The contribution of the anti-icing system to the safe operation of the power plant will also be identified.

Overall, the evidence should be logically structured but may be basic in parts and contain minor technical omissions or inaccuracies. For example, learners incorrectly identifying the priority of the cabin fire or icing warning.

For M1, learners will analyse the function and properties of fuels and fuel additives, the function and operation of an airframe fuel supply system and an engine fuel system and their components, identifying the effect each of these systems have on safe power plant operation. For example, learners' analysis will include the operation of the engine fuel system pumps, control valves and hydromechanical FMU to ensure a safe fuel supply to the engines that result from the pilot's throttle settings.

For M2, learners will analyse the function and operation of electromechanical control, and FADEC systems and components, identifying the effect each of these systems have on safe power plant operation. The analysis will include the function and operation of electromechanical and hydro-mechanical system components to control pilot throttle inputs, fuel flow and pressure and auto throttle regulation. In addition, the function and operation of the FADEC system and components including, the engine electronic controller, the FMU and the integration of the EHM system with the FADEC system, will be analysed.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For M3, learners will analyse the function and operation of aircraft recirculatory engine internal relief valve and full flow lubrication systems and their components, and identify the contribution made by each of these systems to safe power plant operation. The types, requirements and characteristics of engine lubricating oils, the function and operation of the pressure feed and distribution, scavenge and venting sub-systems and their components, will be analysed. For example, when examining the operation of the pressure feed and distribution sub-system, learners will identify the function and operation of the reservoir, filters and heat exchanger components and their contribution to the safe operation of the engines recirculatory lubrication system.

Learners will analyse the function and operation of a gas turbine engine's internal air system and its components, and identify the contribution it makes to safe power plant operation. The analysis will include the function and operation of turbine cooling, airflow seals and sealing, bearing axial load control, accessory equipment cooling and external services bleed air feeds. For example, when examining the function and operation of the gas turbine air cooling system, the turbine construction, airflow pathways, sealing and cooling methods will be analysed. Learners will also identify the contribution of the turbine air cooling system to the safe and efficient operation of the power plant.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For M4, learners will analyse the function and operation of fire detection and extinguishing systems and their components, and identify the systems contribution to safe power plant operation. The analysis will include the nature and use of extinguishing agents, the function and operation of fire, heat and smoke detection systems, flight deck and cabin fire warnings and fire extinguishing systems. For example, when examining an engine and jet pipe unit detection and extinguishing system, learners will analyse the function and operation of the detectors, the nature of the cabin warnings, together with the manual and automatic actuation of the extinguisher bottle. The contribution the system makes to the safe operation of the power plant, will also be identified.

Learners will analyse the operation of ice protection systems and the function of their components, and identify the systems contribution to safe power plant operation. The nature and effects of ice formation and the operation of ice detection, engine intake, cowling and propeller anti-icing and de-icing systems and the function of their components, will be analysed. For example, when examining an electrical resistance cowling heater anti-icing system, learners will analyse the operation of the ice detection, control and warning and heater systems and the function of their components. The contribution of these systems to the safe operation of the power plant, will also be identified.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For D1, learners will provide a balanced evaluation of the function and properties of fuels and fuel additives, the operation of an airframe fuel supply system, its interaction with the engine fuel system and its components, assessing the effect of the combination of these systems on safe and efficient power plant operation. For example, learners will evaluate the interaction between the pilot's throttle input and the operation of the engine fuel pumps, control valves and hydro-mechanical FMU, ensuring a safe and efficient supply of fuel to the engine for all power settings.

Learners will provide a balanced evaluation of the function and operation of electromechanical control, and FADEC systems and components and will assess the combined contribution of the systems. The evaluation will include the function and operation of electromechanical and hydromechanical system components to control pilot throttle inputs, fuel flow and pressure and auto throttle regulation. In addition, the function and operation of the FADEC system and components, including the EEC, the FMU and the integration of the EHM system with the FADEC system, and the relative merits between electromechanical and FADEC engine control systems, will be evaluated.

Overall, the evidence presented will be easy to read and understand by a third party, who may or may not be an engineer. The evidence will be logically structured and use correct engineering terms.

For D2, learners will evaluate the function and operation of aircraft recirculatory engine internal relief valve and full flow lubrication systems and their components, and the assessment of the contribution made by each of these systems to safe and efficient power plant operation. The types, requirements and characteristics of engine lubricating oils, the function and operation of the pressure feed and distribution, scavenge and venting sub-systems and their components, and the relative merits between the relief valve and full-flow recirculatory lubrications systems, will be evaluated. For example, when examining the pressure feed and distribution and scavenge sub-systems and their components, the relative merits between scavenge pump sizing and pressure feed for both internal relief and full-flow lubrication systems, will be evaluated.

Learners will evaluate the function and operation of a gas turbine engine's internal air system and its components, and assess the contribution it makes to safe power plant operation. The evaluation will include the function and operation of turbine cooling, airflow seals and sealing, bearing axial load control, accessory equipment cooling and external services bleed air feeds. For example, learners will evaluate the airflow pathways, turbine blade, disk and casing design, turbine sealing and cooling methods and the contribution of the turbine air cooling system to the safe and efficient operation of the power plant.

Overall, the evidence presented will be easy to read and understand by a third party, who may or may not be an engineer.

For D3, learners will evaluate the function and operation of fire detection and extinguishing systems and their components, and assess their contribution to safe and efficient operation of the power plant. The evaluation will include the function and operation of fire, heat and smoke detectors, flight deck and cabin fire warnings, fire extinguishing bottles, igniter heads and discharge pipes, and the nature and use of extinguishing agents.

For example, when examining an engine bay fire wire detection and extinguishing system, the operation of the fire wire detector, its control and warning circuitry, together with the manual and automatic actuation and prioritisation of the extinguisher bottles will be evaluated. Learners will also assess the contribution of the system and its components to the safe and efficient operation of the power plant.

Learners will evaluate the function and operation of ice protection systems and their components, and assess their contribution to safe and efficient operation of the power plant. The nature and effects of ice formation and the function and operation of ice detectors, engine intake, cowling and propeller anti-icing and de-icing systems and their components, will be evaluated. For example, when examining the function and operation of a hot air pre-emptive intake anti-icing system, the operation of the ice detector, its control and warning system and the compressor bleed hot air system, will be evaluated and their contribution to the safe and efficient operation of the power plant, assessed.

Overall, the evidence presented will be easy to read and understand by a third party, who may or may not be an engineer. The evidence will be logically structured and use correct engineering terms. In particular, the evaluation will cover concisely and consistently the function and operation of fire and ice protection systems and their components, assessing the combined contribution of these systems to safe and efficient power plant operation.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Aircraft Fuel and Engine Control Systems	An activity requiring learners to research aircraft fuel and engine control systems.	A report covering the properties of aircraft fuels, the function and operation of aircraft fuel supply systems, engine fuel and control systems and their components, and their contribution to power plant operation.
P3, P4, M3, D2	Engine Lubrication and Internal Air Systems	An activity requiring learners to research engine lubrication and internal air systems.	A report covering the nature of aircraft engine lubricants, the function and operation of engine lubrication and internal air systems and their components, and their contribution to power plant operation.
P5, P6, M4, D3	Aircraft Fire and Ice Protection Systems	An activity requiring learners to research aircraft fire and ice protection systems.	A report covering the function and operation of aircraft fire and ice protection systems and their components, and their contribution to safe aircraft power plant operation.

Essential resources

For this unit, learners must have access to the following specialist physical resources:

- an aircraft gas turbine engine cutaway or otherwise, which includes sight of external and internal lubrication, fuel, control and air systems and components
- a training aircraft or otherwise with installed power plant complete with:
  - intake, cowls and fairings and/or pod, fan, propeller, as available
  - sight of intake and engine fire and ice protection systems and components
  - sight of aircraft engine fuel supply system and components
- data books, manufacturers' specifications and servicing manuals
- appropriate textbooks.

Please note that some or all of the required physical resources identified above may not necessarily be directly available at the centre delivering the unit but will be made readily available on the premises of a partner or other related organisation.

Unit 101: Aircraft First Line Maintenance Operations

Level:	**3**
Unit type:	**Optional in Aerospace Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

Military, general aviation and civil airline organisations operate aircraft in a variety of roles. For such aircraft operations organisations need suitably qualified aircraft maintenance technicians to ensure the continued serviceability of their aircraft, in an operating environment.

In this unit, learners will examine the all-important safety measures that are foremost in all aspects of aircraft maintenance operations, as well as understand the mandatory procedures to be followed for the operations themselves. They will then consider the administrative procedures and quality processes that underpin the function, role, frequency and documentation needed for the maintenance operations. The final part of the unit requires learners to put into practice what they have learned and carry out a number of practical first-line maintenance operations. They will reflect on the processes undertaken, and on their own personal performance, so they can make improvements next time.

This unit will help prepare learners for an aircraft engineering apprenticeship, as well as more specifically assisting them in gaining employment in an aircraft maintenance technician role. Alternatively, they could choose to continue their studies in higher education.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Examine aircraft safe maintenance operations in a first-line engineering environment

2 Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations

3 Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition

4 Review aircraft first-line maintenance operations and reflect on personal performance.

Unit content

1 Examine aircraft safe maintenance operations in a first-line engineering environment

Safety procedures for aircraft first-line maintenance operations

Safety procedures, or other relevant international equivalents, and actions to be followed, including:

- compliance with the Electricity at Work Regulations (EWR)
- awareness of local aircraft electrical safety hazards and procedures for earthing and bonding, radio transmission and connection/disconnection of aircraft ground power
- care and safe handling of pressurised gases, air, oxygen and nitrogen in accordance with the Dangerous Substances and Explosive Atmospheres Regulations (DSAER) and amendments
- Control of Substances Hazardous to Health Regulations (COSHH), including Personal Protective Equipment (PEE) at Work Regulations, aircraft fuel, engine and hydraulic oils,
  de-icing fluids, liquid oxygen (LOX)
- procedures, hazards and precautions when working at height (Work at Height Regulations) and working in confined spaces, e.g. aircraft cockpit,
  engine intakes, and equipment bays
- compliance with local procedures for the operation of ground use fire extinguishers, chocking, blanking, and securing aircraft, anti-deterioration checks.

Types of aircraft first-line maintenance operations

- General maintenance operations**,** including:
  - aircraft movements, towing and marshalling
  - use and connection of, e.g. engine start equipment, passenger services equipment, radio microphones
  - fitment/removal of control locks, blanks and bungs
  - storage and inhibiting of aircraft, engines and major components
  - use, fitment and removal of highway staging, ladder, platforms
  - hoisting and lifting
  - operation of, e.g. air stairs, fuselage doors, cargo bay doors,
    cockpit canopies.
- Specialist maintenance operations, including:
  - walk round inspections for security of attachment of hatches, access doors, panels and fasteners, leaks, tyre condition, general damage
  - abnormal occurrence checks and procedures for, e.g. lightning strike,
    tyre burst, heavy landing, bird strike, flight through turbulence
  - fluid replenishment, e.g. air, oxygen, nitrogen, LOX, engine oils,
    hydraulic oils, component lubrication
  - refuelling and defuelling
  - ground de-icing/anti-icing, cold weather actions
  - connection/disconnection of aircraft ground power, e.g. electrical,
    hydraulic, pneumatic
  - jacking and trestling, wheel change

- avionic – cabin, instrument, navigation or landing light bulb replacement, battery condition checks, pitot-static sense and leak checks.

2 Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations

Maintenance planning and quality processes

- Civil or military maintenance planning, including:
  - approved maintenance programmes and schedules
  - servicing cycles, e.g. check, equalised, opportunity
  - additional maintenance requirements, e.g. minor and major modifications, special technical instructions (STI), servicing instructions (SI), airworthiness directives (AD) and notices.
- Civil or military quality processes, including:
  - functions and roles of quality departments – quality control and assurance processes, inspection processes
  - function and roles of checks, e.g.:
    - first, second, third and fourth line check system
    - A, C, D, ramp and transit system
    - scheduled and unscheduled checks
    - authorisations, duplicate inspections, independent checks
  - control of life limited components and equipment, e.g. hard-time, on-condition, condition monitoring.

Administrative procedures for aircraft maintenance

Civil or military administration, including:

- content and purpose of documentation:
  - maintenance manuals, repair manuals
  - records and recording documents including historical record cards, serial and part numbers, logbooks
  - certification, e.g. certificate of release to service (CRS), Ministry of Defence (MOD) form 700
- stores systems:
  - layout, procedures
  - parts and equipment tracking and record keeping
  - quarantine stores, bonded stores
  - parts classification, e.g. aircraft general spares (AGS), A, B, C stores, consumables, life-limited items
  - issue of parts and equipment, hard copy and computer based parts manuals.

3 Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition

Preparation for aircraft first-line maintenance operations

Preparation activities, including:

- consult the appropriate documentation and/or supervisor to determine the nature and type of maintenance operation required
- ensure appropriate entries are and have been made in the aircraft log or job card
- comply with relevant operational procedures, job card instructions and safety procedures
- obtain all tools and equipment necessary for safe completion of the maintenance operation.

Aircraft general first-line maintenance operations

General maintenance operations, e.g.:

- assist with aircraft moving, towing or marshalling operations
- connect and disconnect engine start equipment or passenger services equipment
- fit and remove control locks, blanks and bungs
- assist with securing and preparing aircraft for inclement weather
- assist with safe handling or inhibiting and storage of aircraft engine or airframe or avionic components and equipment
- fit and remove highway staging, ladders or platforms
- assist with hoisting, winching or lifting operations
- operate air stairs, fuselage doors, cargo bay doors or aircraft canopies.

Aircraft specialist first-line maintenance operations

Prepare, administer and carry out specialist first line maintenance operations, e.g.:

- walk round checks
- assist with abnormal occurrence checks
- lubricate aircraft components, equipment and linkages
- drain and replenish fluid systems
- assist with aircraft refuelling and/or defuelling
- assist with aircraft ground de-icing
- assist with aircraft anti-deterioration checks and tests
- connect and disconnect aircraft electrical ground power
- connect and disconnect aircraft hydraulic or pneumatic power rigs
- assist with jacking and trestling aircraft
- change an aircraft wheel or brake unit
- replace a cabin instrument, navigation or landing light filament
- check battery charging and condition
- perform sense and leak checks on a pitot static system
- remove and fit an avionic line replaceable unit (LRU).

4 Review aircraft first-line maintenance operations and reflect on personal performance

Lessons learned from aircraft first-line maintenance operations

Scope of the lessons learned should cover:

- health and safety skills, to include – familiarity and compliance with laid down health and safety procedures and hazard prevention actions when ground handling aircraft and equipment and when carrying out aircraft maintenance operations in a first line area or hangar
- aircraft first line maintenance skills, e.g. interpreting maintenance information sources and procedures, selection care and control of tools and equipment for each particular maintenance operation, post maintenance checks and tests and the raising and completion of appropriate maintenance documentation.

Personal performance while carrying out aircraft first-line maintenance operations

Understand the relevant behaviours when working in an aircraft maintenance environment, including:

- taking initiative and responsibility for own actions when applying knowledge and practical skills to aircraft maintenance operations that are safe, efficient and independent, e.g. awareness and use of appropriate maintenance manuals and documentation and the selection and use of appropriate tools and equipment for the particular maintenance operation
- communication and literacy skills to interpret and comply with aircraft safety and maintenance procedures and to ensure the correct and accurate entries are completed in the relevant documentation
- problem solving issues as they occur, e.g. overcoming the logistical and safety problems of aircraft access and use of servicing equipment such as oxygen or engine oil replenishment trolleys, in a first line operational environment.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain what safety procedures and actions are required to complete general and specialist maintenance operations	**M1** assess what safety procedures and actions are required to reduce the hazards present when completing general and specialist maintenance operations	**D1** evaluate how safety procedures, planning, quality processes and administrative procedures combine to impact on the safe and efficient delivery of aircraft maintenance operations
P2 explain the functions and roles of planning and quality processes on aircraft maintenance operations **P3** explain the functions and roles of the administrative procedures used to support aircraft maintenance operations	**M2** assess the functions and roles of planning, quality processes and administrative procedures on aircraft maintenance operations, including the impact on efficiency of the work undertaken	
P4 complete three general and three specialist aircraft maintenance operations safely and using the correct processes, including appropriate inspections, checks and tests	**M3** complete safely, accurately and efficiently three general and three specialist aircraft maintenance operations using the correct processes, including appropriate inspections, checks and tests	**D2** refine, while using the correct processes, three general and three specialist maintenance operations safely to ensure aircraft serviceability and integrity, including appropriate inspections, checks and tests

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 explain how health and safety procedures and aircraft maintenance operations were applied effectively in an aircraft maintenance environment **P6** explain how relevant behaviours were applied effectively to aircraft maintenance operations.	**M4** recommend improvements to the aircraft maintenance operations and to the relevant behaviours applied.	**D3** demonstrate consistently good technical understanding and analysis of the aircraft maintenance operations, including the application of relevant behaviours to a professional standard.

Essential guidance for tutors

Assessment

For P1, learners will explain the safety and operational procedures that must be followed to complete different types of specialist and general first-line maintenance operations. For example, the safety zones, when approaching, working on or marshalling aircraft with running engines are required to reduce or eliminate the hazards associated with engine intake ingestion or hot exhaust emissions.

They should also explain, for P2 and P3, the functions and roles of planning and quality processes and administrative procedures. For example, explaining the need for planned inspections and the release of work cards from the planning department, to ensure that the maintenance operations are carried out during aircraft down time and are accompanied by the appropriate documentation to ensure their safe delivery.

Overall, the explanations will be logically structured, although basic in parts and they may have one or two omissions. For example, when considering the type of maintenance activity related to gaining access to and exiting the aircraft, they may omit the procedures to be followed when carrying out ground handling operations on cargo doors, having previously covered only the main aircrew passenger doors and emergency doors.

For P4, learners will complete safely three general and three specialist first-line maintenance operations. Evidence of the safe completion of these maintenance operations may be obtained by those witnessing or testifying to learners' understanding and compliance with relevant safety procedures and precautions, as well as with the identification and use of the correct maintenance tools, equipment, operational procedures and documentation. Learners will need to complete all appropriate entries in the relevant documentation, including appropriate inspections, checks and tests. For example, that all maintenance activities have been carried out and signed for on the job cards, including the need to clear entries for any inspections, checks or tests directly related to the specific maintenance operation being carried out and the need to call for over signatures, as required.

Overall, any supporting evidence may be limited, for example there may be little evidence of preparation activities and the inspection documentation, although complete, may not be detailed.

For P5, learners will detail in their evidence (such as a technical report of around 500 words in length) the lessons learned during each of the three general and three specialist maintenance operations. The evidence will explain the actions taken to ensure their own personal safety and the safety of others in aircraft operational and maintenance areas, such as the use of personal protective clothing and pre-use checks on equipment. For example, the wearing of a face visor, protective gloves, apron and footwear, the positioning of a fire appliance and carrying out pre-use checks on a liquid oxygen (LOX) trolley prior to recharging the aircraft LOX system. For P6, the evidence will further detail relevant behaviours that were applied when working in an aircraft maintenance operational environment, for example time management to ensure completion of work to deadlines and good husbandry to ensure cleanliness and a maintenance environment that is free of foreign object debris (FOD).

Overall, the evidence will be well organised and laid out clearly so that a third party would be able to understand how learners' skills have been applied. Efforts will be made to use some technical language where appropriate, although there may be some inaccuracies with spelling and grammar. Also, some parts of the evidence may be considered in greater depth than others.

For M1 and M2, learners will assess the most relevant safety and operational procedures, and the actions required to undertake first-line maintenance operations safely. They will consider the consequences of not taking the appropriate action. Learners will assess the most relevant planning, quality processes and administrative procedures when undertaking aircraft first-line maintenance operations and how the efficiency of the operation is affected. For example, the management of stores and tool control reduce the hazards associated with lost or mislaid spares or tools. This reduces the potential harm to objects, including the aircraft, and improves the efficiency of the maintenance operations being undertaken as spares and tools are more likely to be available when required.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For M3, learners will provide evidence of the safety, accuracy and efficiency of the three general and three specialist aircraft first-line maintenance operations being undertaken. The evidence may be gauged by the standard of the documentation presented in the evidence. Also by those witnessing or testifying to the logical approach adopted by learners with respect to information gathering, the handling and completion of documentation, as well as the order of the maintenance operations and sequence and nature of the inspections, checks and tests.

Overall, the evidence presented for the maintenance operations undertaken should be logically presented, technically accurate and easily understood.

For M4, learners will make recommendations as to where improvements could be made. For example, the management of health and safety to decrease the risk of harm to self and others, for example posting warning notices and/or cordoning-off the area before commencement of a lifting operation that takes place at height, posing a drop hazard to those working or walking below. The logic in the order of the steps and checks taken throughout the maintenance operation, for example, ensuring that a complete walk round inspection is carried out before making entries in the documentation for any faults found. Thus ensuring that all appropriate entries are made at the same time, rather than piecemeal, which will result in more efficient maintenance actions being taken. There will be the application of relevant behaviours to ensure that time goals are met and maintenance operations are completed in a more efficient manner.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For D1, learners will evaluate how the combined effect of safety procedures, planning, quality processes and administrative procedures impact on the efficient and safe delivery of first-line maintenance operations. For example, they will evaluate how planned servicing cycles and quality procedures improve the efficiency and safe delivery of inspections of lifted components by clearly identifying the frequency and type of checks these components require, during a first-line turn round, before flight or after flight maintenance operation. The evaluation will also include how the effects of hazards during maintenance operations can be minimised and the consequences that could result. For example, not refuelling the aircraft at the same time as replenishing oxygen during a turn round inspection reduces the risk of an explosion.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct engineering terms.

For D2, learners will refine, during the process, three general and three specialist aircraft maintenance operations to ensure aircraft serviceability and integrity, by undertaking thorough and comprehensive pre and post maintenance inspections, checks and tests. For example, before completing a wheel change, resulting from a worn or damaged tyre initial inspection of the undercarriage bay, the brakes and the under wing area will be carried out to ascertain if there is any foreign object debris damage, hydraulic fluid leakage or other physical damage, that has occurred. Also, for example, post maintenance checks will be carried out on wheel brake operation as well as on the wheel for correct fit, security of attachment and function.

Overall, the evidence will be presented clearly in a way that would be understood by a third party, who may or may not be an engineer. There will be a comprehensive record of the safety and operational procedures followed, together with accurately and correctly completed documentation for each of the maintenance operations completed.

For D3, learners will, in their analysis, demonstrate consistently good technical understanding, including the application of relevant behaviours. For example, learners will take responsibility for their own actions and safety, before, during and after the connection of electrical ground power to an aircraft. Ensuring that all relevant documentation checks to ascertain the maintenance state of the aircraft have been carried out, ensuring that aircraft bonding and earthing measures are taken, other technicians working in or around the aircraft are informed and all switches, circuit breakers and other isolation devices are correctly and safely positioned before, during and after electrical ground power is connected and disconnected.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be an engineer. For example, learners should consistently demonstrate a good technical understanding of aircraft first-line maintenance operations that includes correct technical engineering terms and information about improvements.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Planning, Administrative and Safety Procedures and Quality Processes Involved in First-line Maintenance	An activity requiring learners to research the function, use and compliance with the necessary procedures and processes.	A report focusing on operational maintenance procedures and the function, use and compliance with planning, administrative and safety procedures and quality processes necessary to restore the aircraft to a serviceable condition in a first-line engineering environment.
P4, M3, D2	Preparing For and Carrying Out Aircraft General and Specialist First-line Maintenance Operations	Learners carry out general and specialist maintenance operations, including the necessary preparations.	A series of practical tasks to complete aircraft maintenance operations safely. Evidence will include: a record of the procedures followed, observation records and correctly completed servicing documents, with witness signatures against each completed task.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M4, D3	Lessons Learned from Personal Performance in Aircraft First-line Maintenance Operations	Learners review their performance in carrying out aircraft first-line maintenance, what they have learned and what aspects of their performance could be improved.	The evidence will focus on what went well and what did not go so well when carrying out aircraft first-line maintenance operations and a conclusion of improvements that could be made. The portfolio of evidence generated while exploring and reviewing aircraft maintenance operations and reflecting on own performance.

Essential resources

Please note that the required physical resources may not necessarily be directly available at the centre delivering this unit, but could be made available on the premises of a partner organisation.

For this unit, learners must have access to:

- appropriate information sources, including relevant maintenance manuals, operational procedures and work recording documentation, such as job cards, maintenance logs and servicing schedules; EASA, CAA or equivalent military publications, first-line maintenance safety procedures, notices and safety drills
- appropriate tools, and ground servicing equipment suitable for the general and specialist maintenance operations identified in the content
- a minimum of one training aircraft and its associated ground support equipment, with the capacity for first line maintenance operations, for example: ground handling operations, moving, marshalling, jacking, connection of ground power, component lubrication, fluid system replenishment, fluid, mechanical and electrical systems/equipment maintenance including functional checks and tests.

Unit 102: Industrial Process Measurement

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will introduce learners to the principles involved in the operation, selection and calibration of transducers and signal processors used to measure a range of common industrial process variables. The methods of system and device construction and their specifications are investigated along with relevant calibration and documentation processes.

Learners will consider the performance, operation and application of industrial transducer systems and the relationship between the physical principles of a transducer to its selection and application. Often there are requirements for signal processing once a transducer has been selected to ensure that the measurement system output meets specification. This unit provides a thorough background in the operation of signal processors and details the current systems that are available.

In many industrial process plants the process being measured can be some distance from the display systems, for example in a control room. Therefore signal transmission is required over distance. This unit identifies the variety of transmission systems and standards that are used within industrial plant.

The unit relates to the requirements and techniques of system calibration. Learners will be able to use industrial procedures and standards in order to correctly calibrate such process measurement systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about industrial transducer systems and their applications

2 Know about the operation and application of signal processing systems

3 Know about a range of signal transmission and recording systems

4 Be able to select and use a range of equipment to test and calibrate instruments on process plant.

Unit content

1 Know about industrial transducer systems and their applications

System performance: accuracy; error; linearity; reliability; sensitivity; resolution; range; static and dynamic characteristics, e.g. dead time, time constant, hysteresis, steady state

Transducer types and operation: pressure, e.g. diaphragm capsule, bellows, Bourdon tube, piezo-electric, manometers; level, e.g. pressure gauges, DP cell transmitters, purged dip pipes, capacitive probes, ultrasonic, nucleonic, load cells, level switches; temperature, e.g. thermocouples, metallic resistance thermometers, thermistors; flow, e.g. Venturi, orifice plate, Pitot static tube, DP cell, conventional/smart electronic and pneumatic types, variable area, vortex, ultrasonic; nucleonic analysers, e.g. alpha, beta, gamma, neutron; speed, e.g. tachogenerator, radar; position, e.g. linear/rotary potentiometer, absolute/incremental digital encoder, Linear Variable Differential Transducer (LVDT), resolver

Applications: selection of appropriate transducer in terms of process variable, system performance, environment and constraints

2 Know about the operation and application of signal processing systems

Signal converter types and operation: resistance to voltage, e.g. potential divider, Wheatstone bridge; voltage to current; pressure to current; current to pressure; analogue to digital, e.g. counter type, integrator type

Signal conditioner systems and operation: signal standards, e.g. 4-20mA, 1-5V, 3-15 psi, 20-100Kpa; amplification, e.g. simple op-amp arrangements, difference amplifier; attenuation; lineariser, e.g. square root extractor; filters, e.g. low pass, high pass

Applications: selection of appropriate signal processing system to meet system specification in terms of signal input and signal output

3 Know about a range of signal transmission and recording systems

Transmission requirements: systems, e.g. pressure transmission, analogue electrical transmission, digital transmission; electrical standards, e.g. RS232, RS422; transmission devices, e.g. multiplexers; selection of appropriate medium for transmission

Recording and display devices: analogue meters, e.g. voltmeter, ammeter, pressure gauge; trend indicators, e.g. hand-held oscilloscope, chart recorder; computer system, e.g. Supervisory Control and Data Acquisition (SCADA), Distributed Control Systems (DCS); specifications, e.g. acquisition time, update speeds, resolution

4 Be able to select and use a range of equipment to test and calibrate instruments on process plant

Selection and use of equipment: instrumentation specifications to determine the system inputs and outputs (range, zero requirements, span); test and calibration equipment, e.g. multi-meters, oscilloscope, data acquisition system

Test and calibrate: calibration of process transmitters, e.g. pressure, level, temperature, flow, nucleonic, position, speed; calibration parameters (component specification, system requirements); recording and presentation of test and calibration results; calibration process, e.g. standards, accuracy, methods, documentation

Systems: process measurement, e.g. vessel level, vessel pressure, air-flow supply in a bubbler system, furnace temperature

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain each of the terms relating to system performance		
P2 explain transducer types and their operation for each of the process variables	**M1** justify the choice of a transducer to meet a given specification	**D1** evaluate the choices of transducer to meet a given specification
P3 explain the operation and application of five different types of signal converter used in process measurement		
P4 explain the operation and application of two common signal conditioning systems that can be found within process measurement	**M2** design a signal processing system to meet a given specification	
P5 explain the signal transmission requirements for two different types of transducers		
P6 explain why two common recording and display devices will meet given specifications		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 explain the equipment required to test and calibrate a given process measurement system	**M3** justify the choice of equipment selected for the testing and calibration of a given process measurement system	
P8 test and calibrate a given process measurement system		**D2** evaluate the overall error in the process measurement system

Essential guidance for tutors

Assessment

For P1, learners need to explain each of the eight terms relating to system performance – accuracy, error, linearity, reliability, sensitivity, resolution, range, and static and dynamic characteristics. Each of the terms must be explained in the context of transducer systems.

For P2, learners need to explain transducer types and their operation for each of the seven process variables (pressure, flow, level, temperature, nucleonic, speed and position).

For M1 and D1, learners must be provided with a system specification that includes criteria to cover the required transducer system performance.

For M1, learners will justify the choice of a specific transducer that meets all of the different criteria in the system specification. The justification will include definitive reasons for why it is the best choice.

For D1, learners will evaluate at least two possible choices of transducer against the different criteria in the system specification and will then provide definitive reasons why they would choose one over the other. The evaluation will be detailed and will address aspects including process variable, system performance, environment and constraints.

For P3, learners must explain the operation and application of five different types of signal converter used in process measurement. They must cover the signal conversions required to enable five different transducers to provide specific signal output types. These will include voltage, current (from both voltage input and pressure input), pressure and digital.

For P4, learners should be provided with the specifications of two systems that require the signal outputs to be conditioned to a predefined state. A range of typical systems is given in the *Unit content* for learning outcome 2. In each case, learners must explain the operation and application of the common signal conditioning system. Signal standards must be covered in the response.

For M2, learners must design a signal processing system to meet the requirements of one of the specifications provided for P4. The design may be in the form of a block, signal or circuit diagram but must be fit for purpose in relation to one of the given specifications.

For P5, learners must explain the signal transmission requirements for two different types of transducers. The range of transducers that could be covered for criterion P6 is given in the *Unit content* for learning outcome 1.

For P6, learners must explain why two common recording and display devices will meet the given specifications for each of the two systems covered in their response for P4.

For P7, P8, M3 and D2, assessment evidence must be produced based on a practical testing and calibration activity for a given process measurement system. Suitable examples of process measurement system are ranged in the *Unit content* for learning outcome 4. The process measurement system must be on process plant and must include instrumentation.

For P7, learners must explain the equipment required to test and calibrate a given process measurement system. The requirement for and use of each piece of equipment for the testing and calibration activity must be explained.

For P8, learners must both test and calibrate the given process measurement system. Learners must show they are capable of appropriately carrying out both parts of the activity and must document their results. Annotated photographs and an observation record or witness statement could be used, in addition to the documented results, to prove that the testing and calibration activity was appropriately carried out.

For M3, learners must justify the choice of equipment selected for the testing and calibration activity. Learners could generate evidence for this criterion as an extension of that provided for P8. The justification will include definitive reasons why the equipment selected was the most appropriate when compared to other equipment that could have been used.

For D2, learners must evaluate the overall error in the process measurement system. Having tested and calibrated a given process measurement system, learners must evaluate the documented results and determine the overall system error performance relative to known/ideal system parameters. Learners must cover where the inaccuracies are in each element of the system and must provide an appropriate reasoning for the inaccuracies.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Industrial Transducer Applications	You are an apprentice engineer and have been asked by your supervisor to provide a report on industrial transducers. They want you to consider the possible types of transducer for given specifications and to offer choices so your company can meet the needs of their customers.	A written report with diagrams as required
P3, P4, P5, P6, M2	Signal Processing, Transmission and Recording Systems	You are an apprentice engineer and have been asked by your supervisor to provide a report on signal processing systems. They also want you to design a signal processing system to meet a given specification provided by a customer. As part of this, you need to provide a range of information on signal conversion, signal conditioning, transmission requirements and recording and display devices.	A written report with diagrams as required. A block, signal or circuit diagram to show the design of the signal processing system
P7, P8, M3, D2	Testing and Calibrating a Process Measurement System	In your role as an apprentice engineer, your supervisor has asked you to test and calibrate a process measurement system and to evaluate its accuracy. As part of this, you must document your results and justify your selection of suitable equipment to carry out the testing and calibration activity.	A practical assignment evidenced by a report that includes documented results, annotated photographs and an observation record/witness statement

Essential resources

Industrial process measurement, calibration and test equipment is essential for this unit. Learners should have access to a relevant workshop or laboratory facilities including:

- industrial plant, rigs or system simulators
- signal processing hardware or simulation software
- signal transmission hardware
- data books and manufacturers' specifications
- paper-based or IT-based data logging systems
- appropriate tools.

Indicative reading for learners

Textbooks

Anderson N – *Instrumentation for Process Measurement and Control* (CRC Press, 1998) ISBN 9780849398711

Fraser R – *Process Measurement and Control* (Prentice Hall, 2000) ISBN 9780130222114

Johnson C – *Process Control Instrumentation Technology*, 8th edition (Pearson, 2013) ISBN 9781292026015

Unit 103: Understanding and Using Fabrication Skills for Blacksmithing and Metal working

Level:	**3**
Unit type:	**Optional**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

This unit aims to introduce learners to fabrication skills for blacksmithing and metalworking, and how these can be applied in practice. It is designed for learners in centre-based settings looking to progress into the sector or on to further/higher education.

A blacksmith's work can consist of producing single, forged items but, invariably, it will involve the connection of two or more pieces of material to realise its final shape. Knowledge and skill in fabrication are therefore an intrinsic part of the metalworker's craft in any situation involving the assembly of components.

This unit gives learners the opportunity to gain and develop the knowledge and skills needed to produce a variety of fabrications in sheet metal. It includes the interpretation of a specification, identification of materials, measuring, marking out and cutting to diagrams and/or drawings, forming metal, joining of materials and the evaluation of the production processes.

Learning outcome 1 addresses the range of materials available and the forms they might be supplied in. While most of the experience gained in this unit will be in the use of carbon steel, the range of metals and their various forms of supply to suit differing situations will also be covered.

Learning outcome 2 is concerned with marking out and cutting appropriately to produce components to a specified accuracy.

Learning outcomes 3 and 4 cover the use of manual bending and forming machines and the common joining methods used in fabrication processes.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the metals and associated forms of supply commonly used in fabrication processes

2 Be able to mark out and cut to a parallel line development specification

3 Be able to use fabrication bending and forming methods, equipment and machinery to produce a parallel line development sheet fabrication

4 Be able to use fabrication joining methods and equipment to create a parallel line development sheet fabrication.

Unit content

1 Know the metals and associated forms of supply commonly used in fabrication processes

Metals: ferrous, e.g. plain carbon steels, alloy steels; non-ferrous, e.g. brass, bronze, copper, aluminium; physical properties of commonly used metals, e.g. mass, density, thermal conductivity; mechanical properties of the commonly used metals, e.g. tensile strength, compressive strength, hardness, toughness, malleability, ductility; advantages and limitations of different commonly used metals; forms of supply, e.g. sheet, plate, rolled steel sections; costs; sources of supply

2 Be able to mark out and cut to a parallel line development specification

Methods and equipment for marking out and cutting metals: appropriate use of diagrams/drawings/templates/patterns; parallel line method of surface development; marking out equipment, e.g. pencils, scriber, rules, squares, dividers, trammels; cutting out/material removal equipment, e.g. snips, chisels, manual and powered guillotines, hand saws, nibblers, hand shears; setting up, use and maintenance of equipment; relevant current legislation and codes of practice; health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements; personal protective equipment (PPE); risk assessment

3 Be able to use fabrication bending and forming methods, equipment and machinery to produce a parallel line development sheet fabrication

Methods and equipment for bending and forming: manual bending, e.g. using hammers, stakes, folding bars and methods of use; forming using machinery, e.g. rolling, hammering, drawing and methods of use; accuracy, e.g. joint fit up, assembly sequence, edge treatment; finish, e.g. selection, techniques, equipment, tools; setting up, use and maintenance of equipment; relevant current legislation and codes of practice; health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements; personal protective equipment (PPE); risk assessment including hazards, risks, control measures, recording method

4 Be able to use fabrication joining methods and equipment to create a parallel line development sheet fabrication

Methods and equipment for joining: self-securing joints; rivets; skin adhesion processes; spot welding; brazing; related equipment and materials; advantages and limitations of methods; uses of each method; costs; relevant current legislation and codes of practice; health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements; personal protective equipment (PPE); risk assessment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the physical and mechanical properties of the ferrous and non-ferrous metals that blacksmiths use in fabrication processes	**M1** justify why a specific metal and form of supply are the most suitable for a given component	
P2 safely use appropriate methods and equipment to mark out a component to meet a given parallel line development specification	**M2** justify the methods and equipment chosen to mark out a component to meet a given parallel line development specification.	
P3 safely use appropriate methods and equipment to cut out a component to meet a given parallel line development specification		
P4 safely use appropriate manual fabrication bending methods and equipment when producing a component to meet a given parallel line development specification		
P5 produce a risk assessment for the use of a specified piece of fabrication machinery		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 safely use appropriate fabrication forming methods and machinery when producing a component to meet a given parallel line development specification		
P7 safely use appropriate fabrication joining methods and equipment when producing a component to meet a given parallel line development specification.		**D1** evaluate the use of the chosen cutting, bending, forming and joining methods in the production of a component to meet a given parallel line development specification and provide valid reasons for choices.

Essential guidance for tutors

Assessment

The assessment for this unit is based on the production of a component to meet a given parallel line development specification. The specification should cover the usual factors that would be found in industry (such as design criteria, features, measurements, materials, finish tolerances and any relevant standards) and should be provided to learners when the assessment commences. The component to be produced must offer learners a full opportunity to use a range of appropriate fabrication methods, equipment and machinery to mark out, cut, bend, form and join.

For P1, learners must explain the physical and mechanical properties of the ferrous and non-ferrous metals that blacksmiths use in fabrication processes. Learners must cover at least two ferrous metals and at least two non-ferrous metals. One physical property and two mechanical properties of each material must also be covered. The response must be technically accurate.

For M1, learners must justify why a specific metal and form of supply are the most suitable for a given component. The justification must be based on the provided parallel line development specification. Learners must give accurate reasons that are both valid and show technical understanding when considering the final use of the component and how it will be made.

For P2, learners must safely use appropriate methods and equipment to mark out a component to meet a given parallel line development specification. The marking out must be accurate when considering the requirements of the parallel line development specification and must enable the subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of methods, for example templates and patterns, and a range of equipment, for example, squares, dividers and trammels.

For M2, learners must justify the methods and equipment chosen to mark out a component to meet a given parallel line development specification. Learners must consider the requirements of the parallel line development specification and show applied understanding when providing valid reasons why the methods and equipment chosen to mark out were the most suitable in comparison to other methods/equipment that could have been used.

For P3, learners must safely use appropriate methods and equipment to cut out a component to meet a given parallel line development specification. The cutting out must be accurate when considering the requirements of the parallel line development specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of equipment, including, for example, guillotines, hand saws, nibblers and shears.

For P4, learners must safely use appropriate manual fabrication bending methods and equipment when producing a component to meet a given parallel line development specification. The bending must be accurate when considering the requirements of the parallel line development specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of equipment, including, for example, hammers, stakes and folding bars.

For P5, learners must produce a risk assessment for the use of a specified piece of fabrication machinery. The risk assessment must be for one of the pieces of machinery to be used when assessing P6. The risk assessment must be populated into a standard industry template and must cover, as a minimum, the full range of hazards and risks and suitable control measures.

For P6, learners must safely use appropriate fabrication forming methods and machinery when producing a component to meet a given parallel line development specification. The forming must be accurate when considering the requirements of the parallel line development specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use at least two pieces of machinery, for example for rolling or drawing.

For P7, learners must safely use appropriate fabrication joining methods and equipment when producing a component to meet a given parallel line development specification. The joining must be accurate when considering the requirements of the parallel line development specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of a range of equipment, including, for example, for riveting and spot welding.

For D1, learners must evaluate the use of the chosen cutting, bending, forming and joining methods in the production of a component to meet a given parallel line development specification and provide valid reasons for choices. Learners must review and assess the comparative advantages and disadvantages of the methods, equipment and machinery used against others that could have been used when considering the requirements of the given parallel line development specification. A conclusion should be evident that gives valid reasons why the fabrication methods, equipment and machinery that were chosen or could have been chosen to cut, bend, form and join the component were the most appropriate, improved the efficiency/accuracy of production and reduced wastage.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Metals Used in Fabrication	You are an apprentice metalworker and your supervisor has asked you to report on the physical and mechanical properties of materials, so you can make material recommendations for components that customers need.	Written report
P2, M2	Safely Marking Out a Component to Meet a Given Parallel Line Development Specification	As an apprentice metalworker, your supervisor has asked you to mark out a component to meet a given parallel line development specification and then report on the methods and equipment you chose to use, so they can check your technical understanding.	Annotated photographs, observation record and written report with diagrams and images
P5	Risk Assessment for a Piece of Fabrication Machinery	You are an apprentice metalworker and your workshop has just taken delivery of a new fabrication machine. Your supervisor has asked you to produce a risk assessment to ensure it is used safely.	Risk assessment on an industry template

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P6, P7, D1	Safely Produce a Component to Meet a Given Parallel Line Development Specification and Review	As an apprentice metalworker, your supervisor has asked you to cut, bend, form and join a component to meet a given parallel line development specification and then report on the methods, equipment and machinery you chose to use, so they can check your technical understanding and whether you can review appropriately to improve the efficiency/accuracy of production and reduce wastage.	Annotated photographs, observation record and written report with diagrams and images

Essential resources

Learners will need supervised access to sufficiently resourced workshops appropriate to their specialist pathways. Workshops should offer a comprehensive range of sheet metal and fabrication tools, machinery and equipment so that learners can progress through the unit, for example guillotines, saws, pillar drills, bending/folding machines, other ancillary equipment and hand tools.

Learners must also have access to a sufficiently diverse range of stock sizes/sections.

Library and IT facilities should be available to enable research techniques, materials, equipment and examples of work.

Additional health and safety information and support should be provided.

Tutors delivering this unit should have vocationally-specific craft knowledge.

Indicative reading for learners

Textbooks

Weygers A – *The Complete Modern Blacksmith* (Random House, 1997)
ISBN 9780898158960

Unit 104: Understanding and Using Fabrication Techniques for Blacksmithing and Metal working

Level:	**3**
Unit type:	**Optional**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

This unit aims to introduce learners to fabrication techniques for blacksmithing and metalworking, and how these can be applied in practice. It is designed for learners in centre-based settings looking to progress into the sector or on to further/higher education.

The ability to fabricate sheet and plate steel in relatively complex situations is an important skill for those working in the blacksmithing and metalworking industries.

This unit gives learners the knowledge and skills needed for fabrication work at the level required by a metalworker/fabricator when setting up their own workshop or when seeking employment in a professional metalworking environment.

Learning outcome 1 covers the design aspects of fabrication in relation to the effective use of material to produce a component that is fit for purpose whilst optimising weight, shape, strength and aesthetics.

Learning outcome 2 addresses the wide range of cutting and material removal methods used in these processes and their selection to suit various tasks.

Learning outcomes 3 and 4 cover the wide range of ways in which the materials might be formed, bent and joined and their selection to suit various tasks.

In this unit, learners will develop their ability to study a specification, make appropriate informed choices based on experience and show their capability to carry out practical activities.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use materials effectively

2 Be able to cut complex components to specification within a product-based task

3 Be able to form and bend complex components to specification within a product-based task

4 Be able to join complex components to specification within a product-based task.

Unit content

1 Be able to use materials effectively

Principles: design; forming methods; load carrying efficiency; product weight; product structure; product use; process requirements; effective use of materials; optimum use of weight, size, aesthetics; relevant current legislation and codes of practice, e.g. health and safety at work legislation; environmental issues

Stiffening and strengthening methods and treatments: sheet; plate; orientation of material; integral methods, e.g. grooved seams, flared holes, stretching the profile; edge treatments, e.g. edge bending, hemming a wire edge; applied devices e.g. tabs, brackets, gussets; advantages and disadvantages of using applied devices

Layout: nesting arrangements

2 Be able to cut complex components to specification within a product-based task

Cutting equipment, tools, machinery and processes: tin snips; hand and/or powered guillotines; powered hand tools; cold saws; band saws; croppers; thermal cutting processes; methods of use; factors affecting selection of material removal process; health and safety; risk assessment; relevant current legislation and codes of practice, e.g. health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements

3 Be able to form and bend complex components to specification within a product-based task

Forming and bending equipment, tools, machinery and processes: hand tools (stakes, folding irons, hammers); machines (flat, flange and swaging rolls, fly press, folding machines); methods of use; health and safety; risk assessment; relevant current legislation and codes of practice, e.g. health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements

4 Be able to join complex components to specification within a product-based task

Joining equipment, tools and processes: sheet metal locks; skin adhesion; mechanical fastening; riveting; non-fusion welding, e.g. soldering, brazing, spot welding; factors affecting choice and use of joining method; methods of use; health and safety; risk assessment; relevant current legislation and codes of practice, e.g. health and safety at work legislation, provision and use of work equipment regulations, control of substances hazardous to health regulations current requirements

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 safely produce a complex fabricated component using a stiffening and strengthening method to meet a given specification	**M1** analyse how a different integral method and edge treatment could be used to stiffen and strengthen a complex fabricated component	**D1** assess the advantages and disadvantages of using applied devices when producing a complex fabricated component.
P2 safely produce a complex fabricated component using an edge treatment to meet a given specification		
P3 safely produce a complex fabricated component using cutting processes to meet a given specification		
P4 safely produce a complex fabricated component using forming and bending processes to meet a given specification	**M2** justify reasons for the choice of cutting, forming, bending, joining and welding processes used to produce a complex fabricated component.	
P5 safely produce a complex fabricated component using fabrication machinery to meet a given specification		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 safely produce a complex fabricated component using mechanical joining processes to meet a given specification		
P7 safely produce a complex fabricated component using a non-fusion welding process to meet a given specification.		

Essential guidance for tutors

Assessment

The assessment for this unit is based on the production of a complex component to meet a given specification. The specification should cover the usual factors that would be found in industry, such as features, measurements, materials, finish tolerances and any relevant standards, and should be provided to learners when the assessment commences. The complex component to be produced must offer learners a full opportunity to use a range of appropriate cutting, forming, bending, joining and welding processes and must also require them to use stiffening and strengthening methods and edge treatments.

For P1, learners must safely produce a complex fabricated component using a stiffening and strengthening method to meet a given specification. Learners must show their ability to accurately produce at least one feature when considering the requirements of the given specification, such as a flared hole or a stretched profile, and it must be possible for any subsequent practical activities to be completed accurately.

For P2, learners must safely produce a complex fabricated component using an edge treatment to meet a given specification. Learners must show their ability to accurately produce at least one feature when considering the requirements of the given specification, such as an edge that has been folded back or a hemmed wire edge, and it must be possible for any subsequent practical activities to be completed accurately.

For P3, learners must safely produce a complex fabricated component using cutting processes to meet a given specification. The cutting out must be accurate when considering the requirements of the given specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of equipment during the cutting processes, including, for example, tin snips, guillotines and croppers.

For P4, learners must safely produce a complex fabricated component using forming and bending processes to meet a given specification. The forming and bending must be accurate when considering the requirements of the given specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of equipment during the forming and bending processes, including, for example, stakes, folding irons and hammers.

For P5, learners must produce a complex fabricated component using fabrication machinery to meet a given specification. The opportunity to achieve this criterion could be incorporated into the activities for P3 and P4, for example by requiring learners to use a band saw when cutting and a fly press when forming. Learners must show that they can safely and accurately use at least two pieces of fabrication machinery.

For P6, learners must produce a complex fabricated component using mechanical joining processes to meet a given specification. The joining must be accurate when considering the requirements of the given specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use a range of methods during the joining processes, including, for example, sheet metal locks, skin adhesion and riveting.

For P7, learners must produce a complex fabricated component using a non-fusion welding process to meet a given specification. The non-fusion welding must be accurate when considering the requirements of the given specification and must enable any subsequent practical activities to be completed accurately. Learners must show that they can safely use at least one process, for example, brazing or spot welding.

For M1, learners must analyse how a different integral method and edge treatment could be used to stiffen and strengthen a complex fabricated component. Learners must cover how one other integral method and other one edge treatment could be used to stiffen and strengthen the complex fabricated component and must detail the advantages and disadvantages of each when compared to those used for P1 and P2. In their response, the learner must show consideration of the manufacturing process and the final use of the complex fabricated component as a minimum.

For D1, learners must assess the advantages and disadvantages of using applied devices when producing a complex fabricated component. Learners must cover how at least two applied devices could be used to stiffen and strengthen the complex fabricated component and must then detail the advantages and disadvantages of using these devices. As a minimum, learners must show consideration of aesthetics, structural requirements, manufacturing complexity (such as extra joining processes), material consumption and mass and the whether the trade-offs are justifiable given the final use of the complex fabricated component.

For M2, learners must justify reasons for the choice of cutting, forming, bending, joining and welding processes used to produce a complex fabricated component. Learners must consider the requirements of the given specification and show applied understanding when providing valid reasons why the cutting, forming, bending, joining and welding processes used were the most suitable in comparison to other cutting, forming, bending, joining and welding processes that could have been used.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, P6, P7	Producing a Complex Fabricated Component	As an apprentice metalworker, your supervisor has asked you to produce a complex fabricated component to meet a given specification. The component is for a customer so it must be produced accurately and efficiently.	Annotated photographs, observation records and inspection results
M1, D1, M2	Stiffening and Strengthening Methods and Process Review	You are an apprentice metalworker and your supervisor has asked you to report on different stiffening and strengthening methods as part of a fabricated component design review. They also want you to report on the processes you used when producing the complex fabricated component so they can check your technical understanding.	Written report with diagrams and images

Essential resources

Learners will need supervised access to sufficiently resourced workshops appropriate to their specialist pathways. Workshops should offer a comprehensive range of sheet metal and fabrication tools, machinery and equipment so that learners can progress through the unit, for example croppers, guillotines, band saws, pillar drills, bending/folding machines, rolling machines, other ancillary equipment and hand tools. Learners must also have access to a sufficiently diverse range of stock sizes/sections.

Library and IT facilities should be available to enable learners to research techniques, materials, equipment and examples of work.

Additional health and safety information and support should be provided.

Tutors delivering this unit should have vocationally specific craft knowledge.

Indicative reading for learners

Textbooks

Weygers A – *The Complete Modern Blacksmith* (Random House, 1997)
ISBN 9780898158960

Unit 105: Motorsport Workshop Practices

Level:	**3**
Unit type:	**Optional in Motorsport pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The aim of this unit is to develop learner understanding of the safety procedures applicable in a motorsport workshop and to enable them to disassemble and reassemble motorsport vehicle components and select materials for motorsport applications.

This unit is designed to prepare learners for trackside operations and reinforce their understanding of the need for safe working practices. Learners will develop an understanding of how actions can reduce the risk to employees, others and vehicles in a temporary workshop at an outdoor motorsport event. In addition, learners will gain an appreciation of the procedures required to deal with trackside incidents.

Learners will also develop the skills needed to use tools and equipment, including hand and power tools, through carrying out disassembly and reassembly tasks. This will involve an understanding of fasteners and materials used in motorsport vehicle construction, and their appropriate usage.

Finally, the unit introduces learners to the properties of engineering materials and their specific applications for motorsport engine and chassis components.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how to maintain good housekeeping and health and safety procedures at a motorsport event

2 Be able to use appropriate tools and equipment for the disassembly and reassembly of motorsport vehicle components

3 Know how and why temporary and permanent fasteners are used for specific motorsport applications

4 Be able to select appropriate materials for specific motorsport applications.

Unit content

1 Understand how to maintain good housekeeping and health and safety procedures at a motorsport event

Actions to reduce risk: risk to employees, e.g. correct use of personal protective equipment (PPE), safe use of tools and equipment, safe use of fuels and lubricants; others, e.g. containment of hazardous substances, warning signs correctly used and clearly visible; vehicles, e.g. correct use of lifting and supporting equipment; housekeeping, e.g. relevant regulations/codes of practice (Health and Safety at Work Act, Control of Substances Hazardous to Health (COSHH)), work areas kept separate from public areas at all times

Dealing with incidents: emergencies, e.g. personal injury, fire, spillage, equipment failure, area evacuation, inhalation of noxious fumes; accidents, e.g. slips, trips, falls, collision; immediate actions, e.g. evacuate/cordon off area, report/fight fire, quarantine emergency; follow-up actions, e.g. clear away spillage and dispose of waste, document incident, administer first aid, inform emergency services

Motorsport event: e.g. rallying, go-karting, closed-circuit competition, off-road racing, motocross, sprint, hill climbs

2 Be able to use appropriate tools and equipment for the disassembly and reassembly of motorsport vehicle components

Tools and equipment: hand tools, e.g. spanners, screwdrivers, ratchets and sockets (metric and imperial); tool size recognition; power tools relevant to speed and efficiency at trackside, e.g. pneumatic/electric ratchets, drills; measuring tools, e.g. micrometer, vernier callipers, gauges; lifting and stabilising equipment, e.g. pneumatic/mechanical lifts, hydraulic jacks, axle/vehicle stands

Disassembly/reassembly: components, e.g. body and chassis components in the event of a crash (panels and steering components), engine disassembly and reassembly; tasks, e.g. maintenance, servicing and repair of consumable components during an event

3 Know how and why temporary and permanent fasteners are used for specific motorsport applications

Temporary fasteners: for components requiring frequent maintenance or replacement, e.g. 'R' clips, split pins, nuts and bolts, quick release fasteners

Permanent fasteners: for components that do not require regular replacement or removal for maintenance, e.g. rivets, locking nuts, stretch bolts, shear bolts; alternative methods, e.g. the bonding of polymers, glass/carbon fibre and plastic welding, adhesives

4 Be able to select appropriate materials for specific motorsport applications

Material selection: mechanical properties, e.g. strength, hardness, ductility, durability, density and mass; performance versus weight; finish, e.g. professional appearance for chassis components, weight and aerodynamic properties; aesthetic, ergonomic and durable properties; types of material, e.g. metallic alloys and non-metallic materials, Kevlar, glass/carbon fibre; special treatments to obtain required properties, e.g. shot/laser peening, heat treatment, specialised coatings; effects of loading, e.g. compressive/ tensile stress, fatigue, stress corrosion

Motorsport engine component: e.g. pistons, connecting rods, crankshafts, camshafts, valves, engine mounting brackets

Motorsport chassis components: e.g. steering components (such as steering racks and columns), braking components (such as callipers and discs), suspension components such as wishbones, pushrods, uprights, body panels and wings

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the ways that actions can reduce the risk to employees, others and vehicles in a temporary workshop at a motorsport event	**M1** take the necessary action to deal with an incident at a motorsports event	**D1** evaluate a temporary workshop at a motorsport event for potential hazards and recommend action to be taken
P2 describe the immediate and follow-up actions to be taken to deal with two different types of incidents at a motorsport event	**M2** justify the use of two different fasteners for use in motorsport competition critical applications	**D2** compare the differences in the material selection criteria for a specific vehicle component used on both production and motorsport vehicles.
P3 select and use the most appropriate tools and equipment to efficiently disassemble a motorsport vehicle component	**M3** justify the differences in surface finishing techniques used for a motorsport engine compared to a mass produced engine.	
P4 select and use the most appropriate tools and equipment to efficiently reassemble a motorsport vehicle component		
P5 describe the use of three different temporary fasteners with regard to suitability for purpose in motorsport applications		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe the use of three different permanent fasteners with regard to suitability for purpose in motorsport applications		
P7 select an appropriate material for a given motorsport engine component application		
P8 select an appropriate material for a given motorsport chassis component application		

Essential guidance for tutors

Assessment

Assessment of this unit is likely to be through the use of four assignments, one for each learning outcome.

The first assignment could cover learning outcome 1 and the related criteria (P1 and P2). The assignment could also be designed to provide an opportunity to work towards M1 and D1.

To achieve P1, learners must be able to explain the ways in which actions can reduce the risk to employees, others and vehicles in a temporary workshop or motorsport event. The evidence for this criterion could be achieved through a time-constrained test. However, it is recommended that learners produce their own observation record during one or more actual events. The record could be in the form of a logbook in which learners record their observations in such a way as to cover risks to employees, others and vehicles and housekeeping.

P2 could be dealt with in a similar way to P1. Although learners might have had experience of, or witnessed an emergency/accident, the use of role play or a 'what if' scenario is a much more likely means of gathering evidence.

M1 can be linked to P1 and P2 and evidence is likely to be in the form of tutor observation of learner performance during a particular incident (which could be real or simulated). There is a further link through to D1, for which learners need to use their understanding from P1, P2 and M1 to carry out a risk assessment. It is important that the situation used provides learners with an opportunity to make recommendations for action to be taken (ie there needs to be some real or simulated problems in the temporary workshop). In order to gain D1, learners must attend a competition event and carry out the risk assessment. Centres must therefore make adequate provision for this to happen.

The two pass criteria associated with learning outcome 2 (P3 and P4) cover the disassembly and reassembly of components. For P3, learners will require a specific task to be set for them to disassemble a motorsport vehicle component. The tools that learners select and use will be determined by the task and therefore, not all the unit content is necessarily going to be covered. Centres should, however, ensure that the choice of component demands the use of a reasonable number of the items listed in the unit content (for example hand tools, power tools, measuring tools, lifting and stabilising equipment). The same would apply to P4 but for reassembly.

The evidence for P3 and P4 is likely to be in the form of a tutor observation record supported by the learner's own records of how they dealt with the tasks. This could be in the form of a technical report or logbook.

P5 and P6 relate to learning outcome 3, which covers temporary and permanent fasteners. Learners will need to describe the use of three different temporary fasteners and three different permanent fasteners with regard to suitability in motorsport applications. Although it would be possible to assess these criteria using a written test, a more practical approach is recommended. There is an opportunity to link the work undertaken for P3 and P4 with this learning outcome, since it is likely that when disassembling and reassembling components learners will experience such fastenings.

An integrated approach could also be used to assess M2. An extension task could be built onto the work for P3, P4, P5 and P6 requiring learners to justify fastenings used within a maintenance or repair task.

Learning outcome 4 is covered by P7 and P8, which also link to M3 and D2. In order to meet P7 and P8, evidence of independent research of the materials involved must be shown. For both P7 and P8, learners are expected to select a material for a given motorsport engine and chassis component application, respectively. The components selected for this task must enable learners to investigate the mechanical properties of a material, issues of performance versus weight, the material's finish, and any aesthetic, ergonomic and durable properties as appropriate to the component. The types of material investigated could be chosen from the list of examples in the content (for example metallic alloys and non-metallic materials used in engine tuning, Kevlar, glass fibre) or any other relevant material. It is expected that special treatments to obtain required properties and the effects of loading will be dealt with for at least one of the components (i.e. either for the engine component or chassis component). This could then be linked through to M3 and D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Housekeeping and Health and Safety Procedures	A technician needs to carry out a risk assessment for a motorsport workshop	Written report
P3, P4	Assembling and Disassembling Motorsport Vehicle Components	A technician is required to disassemble and reassemble a motorsport vehicle component	Practical work evidenced through records/log of work carried out and tutor observation records
P5, P6, M2	Applications of Temporary and Permanent Fasteners	A technician needs to describe the use of different fasteners to a new member of a motorsports team	A written report
P7, P8, M3, D2	Motorsport Applications of Materials	A technician needs to select materials for motorsport engine and chassis components	Practical work evidenced through records/log of work carried out and observation records

Essential resources

Learners will need access to outdoor motorsports events at which they can take an active part in field/temporary workshops. Centres will also need workshop facilities fitted with a range of the tools and equipment listed in the unit content. A range of fastenings and components (engine and chassis) will need to be available for demonstration purposes and for learners to work with.

Learners will also need access to sufficient data and research resources to enable them to study and research different engineering materials for motorsports applications.

Indicative reading for learners

Textbooks

Health and Safety Executive – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Health and Safety Executive – *Five Steps to Risk Assessment* (HSE Books, 2006) ISBN 9780717661893

Health and Safety Executive – *A Short Guide to Personal Protective Equipment at Work Regulations 1992* (HSE Books, 2005) ISBN 9780717661411

Unit 106: Motorsport Vehicle Preparation and Inspection

Level:	**3**
Unit type:	**Optional in Motorsport pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The aim of this unit is to enable learners to prepare a motorsports vehicle for competition, including completing relevant documentation, and carrying out vehicle inspections before, during and after a motorsport event.

The preparation and inspection of motorsport vehicles plays a vital part in their overall safety, performance and reliability. Any motorsport vehicle must be prepared to withstand the forces it is subjected to, the environment that it is used in and to conform to relevant standards.

The correct preparation of a vehicle's chassis, braking, suspension, steering, engine and transmission systems is imperative if it is going to perform at its best. Preparation is also a vital aspect in maintaining the safety requirements of a vehicle involved in competitive activities.

Each form of motorsport requires specific types of preparation but there are also aspects of preparation that span the whole spectrum of the sport. Vehicle inspection is a critical part of the process, ensuring conformity to both set standards and safety requirements. It also goes a long way in ensuring a vehicle's reliability, which is an extremely important factor for any motorsport vehicle. Inspections should be carried out post- build, pre-competition, during competition and post- competition.

This unit focuses on both the technical and practical aspects of preparation and inspection. It will enable learners to gain the skills required of a competent member of a motorsport team. The areas covered will include preparing a motorsport vehicle to a given standard and ensuring that the correct documentation has been gathered and completed during the inspection process. It will also cover the documentation required by the sport's governing bodies.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to record and collate documentation required to compete at a motorsports event

2 Be able to prepare a competition vehicle to a recognised specification

3 Be able to carry out inspections before, during and after a motorsports event.

Unit content

1 Be able to record and collate documentation required to compete at a motorsports event

Vehicle documentation: ministry of transport (MOT) test (if required); Motorsports Association (MSA) logbooks; road tax; vehicle and competition insurance; driver and vehicle licensing agency (DVLA) log books, pre-inspection documentation, set-up sheets; collation of competition data, e.g. from DVLA, MSA, manufacturer

Competitor documentation: club/membership cards; MSA licences, e.g. clubman, national A, international, race, rally, speed medical certificate; doctor's medical report; collation of competition data, e.g. entry applications and acceptances, final instructions, road books, circuit diagrams

Motorsport event documentation: e.g. MSA permits, insurance waivers, land registry, final instructions, regulations (race/rally)

2 Be able to prepare a competition vehicle to a recognised specification

Vehicle preparation: tool use, e.g. spanners, sockets, screwdrivers, torque wrenches, pressure gauges; specialist tools, e.g. camber, caster, tracking, spring compression gauges, gas analysers; equipment use, e.g. hoists and stands, auxiliary engine starting devices; safe operation of tools and equipment, e.g. serviceable condition, correctly stored and accounted for (shadow boards, tool control methods), correct tool/equipment used in an appropriate manner; preparation routines, e.g. conformation of class, scrutineering

Specifications: MSA blue yearbook, FIA regulations, e.g. technical regulations, competitor safety (cage mountings, cage design, fire extinguishers); yellow book, e.g. technical regulation, homologation (type of vehicle, year of make); single make and class regulations, e.g. engine cubic capacity (cc), design type

3 Be able to carry out inspections before, during and after a motorsports event

Health and safety: safe use and handling of lubricants/fluids, e.g. fuel, oil, solvents, grease; safe use of lifting equipment and handling techniques, e.g. tested and calibrated lifting equipment, Manual Handling Regulations; safe working practices, e.g. motorsport specific applications of regulations and legislation (Health and Safety at Work Act, Control of Substances Hazardous to Health (COSHH) Regulations, Provision and Use of Work Equipment Regulations (PUWER); safe disposal of waste materials and components, e.g. cleaning cloths, hydraulic fluids, contaminated fuel, scrap components (tyres, brake and clutch linings)

Personal protective equipment (PPE): overalls, safety-shoes, gloves, specialist motorsports equipment, e.g. fire protection, hearing and eye protection, communications equipment

Pre-competition inspection: scrutineering; security of fastenings using a torque wrench, e.g. nuts, bolts, critical securing devices; fuelling vehicle, e.g. correct capacity, type of fuel; tyres, e.g. suitability, condition, pressures; lubrication and coolant system levels and pressures, e.g. warm up, operating temperature; testing throttle settings and operation, e.g. idle, full throttle; hydraulic fluid system levels, check for leaks and operation, e.g. for clutch, steering, brakes; vehicle brake balance settings; setting suspension dampers to suit event; transmission system operation, e.g. function of clutch and gearbox through all gears; electrical system operation; running gear, e.g. spherical bearings, wheel bearings; reporting of faults, e.g. loss of fluid, abnormal pressure, excessive wear

Pre-competition set-up: event analysis, e.g. data from previous event used to provide a set-up sheet for setting-up the vehicle for an event including gearing, cambers, springs, anti-roll bars, other suspension geometry adjustments, corner weights, aerodynamic elements and steering geometry

Inspections during an event: scheduling of inspections within certain timeframes; types of inspections, e.g. fuel draining/weighing, fluid level checks, spanner checks, visual checks for leaks/damage, brake condition/temperature checks and bodywork security/condition

Post-competition inspection: initial post-competition assessment; set-down of vehicle; engine condition, e.g. compression/leak tests; cleaning of bodywork/removal of track debris

Post-competition vehicle rectification: using job sheets, type of rectification, e.g. repair, adjustment, replacement

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 record and collate vehicle, competitor and event documentation for a motorsport event	**M1** compare the specifications required between two different classes of motorsport events	**D1** compare the differences in the tools and equipment used in a motorsports workshop against those used at a competitive event
P2 use tools and equipment to prepare a competition vehicle to a given specification	**M2** carry out a survey of a service/pit area and identify strengths and threats to the health and safety of self and others	**D2** evaluate your own and your team's performance after a motorsports event and recommend an improvement strategy.
P3 describe the health and safety procedures to be followed when inspecting a motorsports vehicle	**M3** produce a 'set-down' schedule and checklist for post-competition inspection and rectification.	
P4 use appropriate personal protective equipment when inspecting a motorsport vehicle		
P5 carry out pre-competition vehicle inspection and set-up		
P6 carry out vehicle inspections during a motorsports event		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 carry out a post-competition inspection following a motorsports event		
P8 identify and record vehicle rectification work required.		

Essential guidance for tutors

Assessment

Assessment of the unit should predominantly focus on learners demonstrating their skills and knowledge during motorsports events. It is expected that each learner will prepare their own portfolio of evidence to cover all the assessment criteria through participation in real motorsport activities. Centres will need to consider how this can be supported and managed on an individual basis. Some simulation may be appropriate for assessment purposes, although this should be kept to an absolute minimum wherever possible.

The three learning outcomes cover documentation, pre-motorsport activity vehicle preparation and pre/during/post- event inspection. Assessment is likely to follow this order although this is not essential. It should be noted that learning outcomes 1 and 2 only have one related pass criterion each, with the bulk of assessment relating to learning outcome 3, with six pass criteria.

For learning outcome 1, learners must be able to record and collate vehicle, competitor and event documentation for a motorsport event (P1). It is important that this criterion is not fragmented and that the assessment activity that is used allows learners to collect all the required documentation at one event. The actual documentation will depend on the nature/type of event used, but centres must ensure that the chosen event provides sufficient coverage of the unit content for the assessment to be valid and reliable.

Learning outcome 2 requires learners to use tools and equipment to prepare a competition vehicle to a given specification (P2). This is one of the criteria that could be simulated. However, whether simulation is used or the vehicle is actually being prepared for an event, learners must be able to demonstrate their ability to select appropriate general tools, specialist tools and equipment and use them safely following a given specification. Evidence for this criterion is likely to be in several forms. Firstly, a tutor observation record of the learner's selection and use of tools and equipment, plus a logbook record (maintained by the learner) of the work carried out together with any data/information gathered. Finally, it is likely that the tutor will carry out an observation/inspection of the success of the vehicle's preparation against the specification together with the use of oral questioning of the learner.

Merit criterion M1 can be effectively linked to P2. One of the specifications used for the comparison is likely to be that used for the vehicle preparation undertaken for P2. A second, and quite different, specification should be used to add depth and breadth to the learner's assessment evidence.

All the remaining pass criteria relate to learning outcome 3. It is expected that P4, P5, P6, P7 and P8 will be undertaken and assessed under actual motorsport activity conditions.

To achieve P3 learners must describe the health and safety procedures to be followed when inspecting a motorsports vehicle. This must include safe use and handling of lubricants/fluids, safe use of lifting equipment and handling techniques, safe working practices and safe disposal of waste materials and components. Examples of each of these are given in the unit content but it is the actual task(s) undertaken that will determine which of these examples is most appropriate. It is for the centre to determine sufficiency of evidence but, clearly, the task(s) used will need to be chosen carefully to include opportunities to meet all the requirements of the unit content. Since this is a descriptive criterion, a paper-based response could be used, although it might be more appropriate for evidence to be gathered through oral questioning of learners as they carry out relevant tasks.

M2 is related to P3 and provides an opportunity for learners to demonstrate and apply the knowledge. Evidence for M2 could be a written report of the learner's findings or feedback from their survey in the form of a briefing. The tutor will need to ensure that there are a number of typical health and safety issues (specifically created for the purpose of assessment if necessary) for learners to report back on under the heading 'threats'.

For P4, learners should be observed using the range of personal protective equipment listed in the unit content. With respect to the specialist equipment, it would not be unreasonable to expect all the examples to be used but as a minimum learners should select and use at least two under the appropriate conditions.

It is expected that P5, P6, P7 and P8 will be assessed during an actual motorsport activity. Ideally, the criteria should not be fragmented and should all be covered at one event. Once again, the assessment evidence for all of these criteria will be a mix of tutor observation and logbook records and data collection. It is essential for the achievement of P8 that the motorsport vehicle requires rectification. For this reason, it may be that this criterion cannot be assessed at the same event as the others. Although it is likely that some rectification will be required following an event, the question for the tutor will be one of sufficiency.

M3 could be linked to the work of P7 and P8. The 'set down' schedule must cover the post-competition inspection and rectification and is expected to include timetables, checklists, job cards, parts requisitions and invoicing/costing information.

It is likely that the evidence for D1 and D2 will come from the overview that the learner has gained during their work towards P5, P6, P7 and P8. Although D1 could be covered at the same event as that used at pass, it is more likely that a completely different event is used when learners are less involved and can stand back and take a broader view of the event. It is intended that the evidence for D1 will come from an analytical exercise that allows learners to compare motorsport workshop equipment with the type of tools and equipment used in the field during an event. Typically, this would include lists of the type of tools and equipment used and the related costs, safety and security considerations. It should also include an evaluation of which tools can double up for both purposes and the reasons behind the choices.

Finally, for D2, learners should carry out a full evaluation of their team's performance following an event. The evaluation might include the learner's reflection on the team's preparation, inventories, scheduling, loading lists, movements and individual personal performance. The evaluation must include a strategy for how the team can do things better and this is likely to touch on the cost efficiencies that can be made.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Motorsport Documentation	A motorsport technician needs to collate the relevant documentation for an event	Practical assignment evidenced through observation records and records of information collated
P2, M1	Preparing a Motorsport Vehicle to Specification	A technician needs to prepare a motorsport vehicle	Practical assignment evidenced through observation records and learner's record/ logbook
P3, M2	Health and Safety in a Motorsport Service Area	A technician needs to explain to a new apprentice the health and safety procedures to be followed when inspecting a motorsports vehicle	A written report
P4, P5, P6, P7, P8, M3	Inspecting Motorsport Vehicles	A technician needs to inspect a vehicle before, during and after a motorsport event	Practical assignment evidenced through observation records and learner's record/ logbook
D1, D2	Evaluating a Motorsports Event	A technician needs to report on a motorsports event and suggest possible improvements	A written report

Essential resources

Learners will need access to actual motorsport activities and events. In addition, centres will need to provide learners with access to a realistic motorsport vehicle preparation and inspection area, including relevant tools and equipment. Relevant health and safety documentation and regulations relating to motorsport activities will also need to be available for learners.

Indicative reading for learners

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology 6th Edition* (Nelson Thorne, 2010) ISBN 978-1408515181

Nunney M – *Light and Heavy Vehicle Technology* (Butterworth-Heinemann, 2006) ISBN 9780750680370

Unit 107: Professional Practice and Logistics for Motorsports

Level:	**3**
Unit type:	**Optional in Motorsport pathway only**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

The aim of this unit is to develop learner knowledge of the organisation, administrative procedures and professional bodies associated with motorsport activities. It will also enable them to communicate with the media and plan motorsport logistics, sponsorship and team finances.

This unit examines the appropriate behaviour expected of high-profile drivers, including their responsibilities to the media, fans, sponsors, officials, team members, agents and managers. Learners will examine ways of dealing with the media, both in terms of using the media to their advantage and minimising media intrusion. Learners will also develop the skills needed to carry out an effective media interview.

Learners will also look at the logistics and transportation associated with motorsport competitions both at national and international level. Some motorsport disciplines demand that participants are involved in travelling considerable distances. This can range simply from an individual driving to (and from) an event with a single vehicle, to being a member of a large, multi-vehicle team. The unit will also look at transport movement schedules, route planning, costing and motorsport team logistics.

The financial responsibilities of a motorsports team will also be looked at, as will the potential sources of finance available through sponsorship for a full-time driver/team.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Know the organisation, administrative structure and associated professional bodies of motorsport activities
2. Be able to communicate with the media to provide information about a motorsport activity
3. Be able to plan motorsport vehicle transportation
4. Be able to plan the sponsorship and financial management of a motorsport team.

Unit content

1 Know the organisation, administrative structure and associated professional bodies of motorsport activities

Organisation: types of organisation, e.g. local motor club, regional associations, national associations, international associations; level of competition, e.g. local, regional, national, international championships; forms of motorsport activity, e.g. motocross, rallying, formula 1 (F1), saloon racing, formula ford

Administrative structure: organisation, e.g. structured administration charts, officials and their responsibilities, related rules, regulations; schedules/frequency of events; marketing methods

Professional bodies: e.g. Motorsports Association (MSA), Federation Internationale de l'Automobile (FIA), Auto Cycle Union (ACU), National Association for Stock Car Auto Racing (NASCAR)

2 Be able to communicate with the media to provide information about a motorsport activity

Media: e.g. television, radio, internet, press (local, national, specialist magazines)

Media interview: planning, e.g. purpose/aims/objectives, data research (available resources, information gathering, use of information and communication technology), content/message to be conveyed; preparation, e.g. scripts/prompt sheets, rehearsals, evaluation (strengths/weaknesses, use of feedback, video analysis, modifications to improve and/or change performance); delivery, e.g. speech (technical vocabulary, pace, tone, clarity) communication style, body language, presentation methods, appearance, timing

3 Be able to plan motorsport vehicle transportation

Transport vehicles: purpose, e.g. number/size, weight and types of vehicles to be transported, spares, equipment, people/accommodation (cooking, eating, sleeping), workshop facilities; types, e.g. tow vehicle and trailer, adapted and purpose-built light goods vehicle (LGV), passenger service vehicle (PSV); vehicle construction, e.g. materials, steel, aluminium, wood, glass-fibre, carbon fibre, sheeting; wheels and tyres; chassis, e.g. maximum weights (nose, axle, train, towing); characteristics, e.g. types of hitch, braking systems, loading methods, positioning, centre of gravity, load security and limiting factors, bulk loads and relative densities

Legislation: weight, dimensions (length, width, height), speed; security of load; driving, e.g. licence requirements, driving hours, insurance; lighting and markers; health and safety, e.g. weight distribution, risk assessments (responsibilities, safe lifting, manual handling aids)

Transport schedule and route planning: human and physical resource requirements, e.g. accommodation, equipment, vehicles, staffing; schedules, e.g. depart/arrival time, work loading, loading sheets, tool list and inventories, ancillary equipment sheet, spares and consumable requirements; route plan, e.g. use of route planning software, alternative routes, costs (fuel, wages, tolls)

4 Be able to plan the sponsorship and financial management of a motorsport team

Sources of income: prize money, loans, endorsed clothing/equipment, advertising, e.g. vehicles, clothing, equipment; sponsorship, e.g. use, purpose, advantages and limitations; types of sponsorship, e.g. clothing and equipment, individual and corporate sponsorship

Business planning: team structure, income and expenditure, e.g. capital expenditure, wages, fees; financial management, e.g. investments, royalties, tax, expenses, insurance; use of experienced personnel to manage finances, e.g. accountant, financial adviser

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the organisation, administrative structure and associated professional bodies of two different forms of motorsport activity	**M1** compare two different motorsport professional governing bodies	**D1** evaluate the influence of a professional governing body for a motorsport activity and its effect on professional drivers and teams
P2 plan, prepare and deliver a media interview	**M2** compare the legislation relating to driver's hours and the respective codes of practice relating to vehicle construction for two given motorsport activities	**D2** evaluate the effectiveness of a media interview, providing recommendations for change and/or amendments.
P3 select appropriate transport vehicles for two different types of motorsport activity	**M3** evaluate a transport schedule and route plan for a specific motorsport activity and identify and justify possible areas where improvements could be made.	
P4 interpret the legislation relating to a specific transport vehicle and driver		
P5 produce a transport schedule and route plan for a specific motorsport activity		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe the sources of income that are available for a professional motorsport team		
P7 prepare and present a sponsorship proposal for a motorsport activity		
P8 prepare a business plan to operate a professional motorsport team for a twelve month season.		

Essential guidance for tutors

Assessment

Because there are no direct links between the learning outcomes they can be assessed in any order. The unit does not necessarily require learners to have access to motorsport events for assessment and most of the evidence produced will probably be paper based in one form or another (for example reports, plans, schedules, etc). Exceptions to this might be the use of tutor observation for the presentations for P2 (media interview) and P7 (sponsorship proposal). However, observation should be suitably recorded and supported by additional written evidence prepared by the learner (for example the interview plan and preparation notes, the data collected for the proposal).

Learning outcome 1 has only one associated pass criterion (P1). This could be assessed through an activity in which learners are required to research two motorsport activities, which they could choose or which could be set by the tutor. The main issue for tutors will be to ensure that a sufficient range of motorsport activities is covered by any one group of learners to ensure authenticity of the evidence presented for assessment. Evidence is likely to be collated and presented as a portfolio. Learners should also be encouraged to work towards the related merit and distinction criteria (M1 and D1), which could form a natural extension to the work for P1.

Learning outcome 2 also only has one related pass criterion (P2) and learners need to show that they can communicate with the media to provide information about a motorsport activity. There is sufficient scope within this learning outcome to ensure that each learner is preparing a different interview (for example TV, radio, internet, press) and as such, authenticity of evidence should be less of an issue. However, it is important that each learner provides evidence of their planning and preparation for the interview as well as its actual delivery. The interview could be carried out by the tutor or one of the learner's peers. In addition to paper-based evidence of planning and preparation, tutor observation records of the final interview will also be required (for example the learner's use of appropriate technical vocabulary, the pace, tone and clarity of speech, communication style, body language, presentation methods, appearance and timing).

A further task could be added to the assessment activity used for P2, giving learners an opportunity to work towards D2. The interview being evaluated could be one delivered by one of their peers for P2. However, it is recommended that learners evaluate the results of an interview carried out by a well-known motorsports driver/personality (for example a pre-recorded interview or an article from a newspaper or magazine). This would give tutors more control over the potential for critical evaluation and would avoid any issues that might arise from peer-on-peer evaluation.

Learning outcome 3 is covered by P3, P4 and P5 and it is recommended that a single assignment be designed to cover all three criteria. Learners could choose one of the two different types of motorsport activities considered for P3 and use it for P4 and P5. However, tutors should check that learners' choice of motorsport activity provides sufficient scope to cover the requirements of the unit content for these criteria. The assessment instrument used should also provide learners with an opportunity to work towards M2 and M3, which build on P4 and P5 respectively.

The remaining pass criteria cover learning outcome 4, which deals with financial management and sponsorship. For P6, learners need to describe the sources of income that are available for a professional motorsport team. It is expected that evidence for this criterion would be drawn from a real example of a professional motorsport team and should cover the key aspects of the unit content relevant to that team (for example what prize money is available, is it typical for the team to use loans, what about endorsed clothing/equipment and what opportunities are there for sponsorship?).

P7 requires learners to prepare and present a sponsorship proposal for a motorsport activity. The scenario for this is likely to be set using a relevant case-study that includes sufficient background information for learners to build a case for a sponsor to consider backing their team. The proposal should make clear how the team is prepared to promote the sponsor (for example clothing, equipment, vehicles). The presentation could be either a short oral presentation using visual aids or a written proposal. Where an oral presentation is used, tutors should ensure that learners are assessed on the content of their presentation and not the quality of the presentation methods (for example how good specific images look, whether a presentation package has been used or just handwritten overhead transparencies/flipchart notes).

Finally, P8 requires learners to prepare a business plan to operate a professional motorsport team for a 12-month season. This could be an extension of the scenario used for P7. The business plan should include information on team structure, income and expenditure, financial management and the use of experienced personnel to manage finances (examples of each of these are given in the unit content).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Motorsport Organisation, Structure and Professional Bodies	An investigation of motorsport professional bodies	A written report
P2, D2	Delivering a Media Interview	A member of a motorsports team needs to give a media interview	Role play observation
P3, P4, P5, M2, M3	Motorsport Vehicle Transportation	A member of a motorsports team needs to plan the transport for an upcoming event	Presentation of proposals
P6, P7, P8	Motorsport Sponsorship and Financial Management	A proposal is required to present to potential sponsors	A presentation and financial plan

Essential resources

There are no essential resources for this unit.

Indicative reading for learners

Textbooks

Hillier V – *Hillier's Fundamentals of Motor Vehicle Technology 6th Edition* (Nelson Thornes, 2010) 9781408515181

Nunney M – *Light and Heavy Vehicle Technology* (Butterworth-Heinemann, 2006) ISBN 9780750680370

Unit 108: Industry 4.0

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning hours: 60

Unit introduction

Industry 4.0 is the term that has been adopted to describe the fourth industrial revolution that is reshaping manufacturing. It is not based solely on the mechanical and then electronic technologies that dominated previous industrial revolutions but on the integration of physical systems with internet connectivity and cloud computing. In manufacturing, this integration of cyber-physical systems and the Internet of Things (IoT) has enabled more efficient and responsive production systems.

The aim of this unit is to give learners an understanding of the factors enabling Industry 4.0 and how smart factories are changing the face of manufacturing. Learners will look at how a series of industrial revolutions have led up to Industry 4.0, as well as the characteristics of smart factories and the technology that enables them. Learners will then consider what is involved in the transition from Industry 3.0 to 4.0 and will have the opportunity to look at real-world case studies of organisations that have made the change.

Learners will gain a broad understanding of the technologies, systems and benefits of Industry 4.0 production systems. The unit is suitable for all engineering learners from a wide range of disciplines and could lead to further study of engineering, an apprenticeship or employment in the manufacturing sector.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the factors shaping the fourth industrial revolution and the characteristics of an Industry 4.0 smart factory
2. Understand the role that the Internet of Things (IoT) plays in an Industry 4.0 smart factory
3. Understand the range of technologies that enable Industry 4.0 and their benefits
4. Understand the factors that manufacturers need to consider when transitioning from Industry 3.0 to 4.0.

Unit content

1 Understand the factors shaping the fourth industrial revolution and the characteristics of an Industry 4.0 smart factory

Technologies enabling industrial revolutions: 1.0 mechanisation, water and steam power, transport; 2.0 work sharing, mass production, assembly lines, oil, gas and electrical power; 3.0 information technology, electronics, automation, computerisation; 4.0 (current) cyber physical systems, the Internet of Things (IoT), cloud computing; 5.0 (future) cognitive computing, Artificial Intelligence (AI), mass customisation/personalisation

The impact of successive industrial revolutions on manufacturing: workforce; skills; efficiency; flexibility; processes; integrated techniques, quality, repeatability

Characteristics of a smart factory: connectivity; flexibility; scalability; agility; autonomous systems; efficiency; intelligent automation, e.g. self-optimisation, self-diagnostics; robotics; workforce skills; collaborative systems; cobots; systems monitoring

Systems that underpin the operations of smart factories: data analytics; forecasting; data visualisation; quality control

2 Understand the role that the Internet of Things (IoT) plays in an Industry 4.0 smart factory

Internet of Things (IoT) technologies: wireless connectivity; radio frequency identification (RFID); sensors; system monitoring; cloud computing; data analysis; mobile devices; 5G

Benefits of the use of IoT to improve manufacturing systems: productivity; safety and security; efficiency and effectiveness; quality; flexibility; responsiveness

Application of IoT systems in manufacturing: energy monitoring and control; motion tracking; workforce monitoring; real-time machine monitoring, control and optimisation; RFID in supply chain management; warehouse management systems; inventory and materials management; manufacturing applications, intelligent scheduling, geo-fencing

Principles that underpin IoT systems and services: sensor technology; data collection and analysis; cloud computing; internet and telecommunications infrastructure; wireless connectivity

Important considerations when using IoT: risks, e.g. security threats, hacking, ethics, data protection, cybercrime; sustainability, e.g. 'always on' systems, data storage; benefits, e.g. efficiency, productivity gains, waste reduction, optimisation, real-time responsiveness

3 Understand the range of technologies that enable Industry 4.0 and their benefits

Characteristics, applications, importance and benefits of technologies that enable Industry 4.0: Cyber-Physical Production Systems (CPPS); Internet of Things (IoT); Artificial Intelligence (AI); digital twin technology; telecommunications and internet infrastructure; wireless connectivity, e.g. RFID, Bluetooth, Wi-Fi; data analytics; big data; cloud computing; cyber-security; additive manufacturing; computer-aided design (CAD); computer-aided manufacturing (CAM); simulation; augmented reality; autonomous robotics; collaborative robotics; blockchain, e.g. traceability, compliance, audit trail

4 Understand the factors that manufacturers need to consider when transitioning from Industry 3.0 to 4.0

Key factors that need to be considered and their potential impact when transitioning to Industry 4.0: technologies, e.g. selection, implementation, appropriateness to manufacturing needs; infrastructure, e.g. networking, wireless connectivity, sensors; data management, e.g. collection, storage, analysis, visualisation; cyber-security, e.g. integrated security, encryption, risk analysis, authorisation to collect and store data; processes, e.g. managing optimisation; supply chains; customers; workforce, e.g. new roles, skills gap, training, re-deployment, redundancy; change management; restructuring of organisations; employment demographics; health and safety, e.g. safety of autonomous robotic systems

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the impact and enabling technologies of the industrial revolutions that shaped Industry 4.0	**M1** analyse how the impact and enabling technologies of industrial revolutions have shaped the characteristics of an Industry 4.0 smart factory	**D1** evaluate how the impact and enabling technologies of industrial revolutions have shaped the characteristics of an Industry 4.0 smart factory
P2 describe the characteristics of an Industry 4.0 smart factory		
P3 describe the technologies enabling the Internet of Things (IoT)	**M2** analyse how Internet of Things (IoT) technologies are applied in an Industry 4.0 smart factory and their benefits	**D2** evaluate how Internet of Things (IoT) technologies are applied in an Industry 4.0 smart factory and their benefits
P4 describe a range of manufacturing applications of the Internet of Things (IoT) in an Industry 4.0 smart factory		
P5 describe a range of technologies that enable Industry 4.0	**M3** analyse how Industry 4.0 technologies are applied in a smart factory and their benefits	**D3** evaluate how Industry 4.0 technologies are applied in a smart factory and their benefits
P6 describe a range of manufacturing applications of Industry 4.0 technologies in a smart factory		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 describe a range of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.	**M4** analyse the potential impact of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.	**D4** evaluate the potential impact of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.

Essential guidance for tutors

Assessment

P1, P2, M1, D1

Learners will provide a historical overview of the four industrial revolutions that have shaped manufacturing industry, including their enabling technologies and their impact.

For distinction standard, learners will:

- evaluate, with examples, how at least three technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time. A written conclusion should justify the most important and influential of these technologies.
- evaluate, with examples, how at least four successive technologies have helped to shape Industry 4.0. For example, steam power, electricity generation, the development of electronics and computing were all vital steps in the development of internet connectivity that is now crucial to Industry 4.0. A written conclusion should justify the most important and influential series of successive technologies.
- evaluate, with examples, at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies. A written conclusion should justify the most important technologies that underpin and enable these characteristics.
- use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- analyse, with examples, how at least three technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time.
- analyse, with examples, how at least three successive technologies have helped to shape Industry 4.0.
- analyse, with examples, at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies.

For pass standard, learners will:

- describe how at least two technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time.
- describe how at least two successive technologies have helped to shape Industry 4.0.
- describe at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies.

P3, P4, M2, D2

For distinction standard, learners will:

- use suitable examples derived from case studies to evaluate how at least three IoT technologies and their applications can be used in an Industry 4.0 smart factory and the benefits they provide. A written conclusion should justify the IoT application that has the most impact and provides the greatest benefits in a specific manufacturing context.
- use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- use suitable examples derived from case studies to analyse how at least three IoT technologies and their applications can be used in an Industry 4.0 smart factory and the benefits they provide.

For pass standard, learners will:

- describe at least three IoT technologies and their applications as used in an Industry 4.0 smart factory.

P5, P6, M3, D3

Learners must not use IoT technologies and examples for learning outcome 3, as IoT is the focus of learning outcome 2.

For distinction standard, learners will:

- use suitable examples derived from case studies to evaluate how at least three Industry 4.0 technologies (not including IoT technologies) are applied in an Industry 4.0 smart factory and the benefits they provide. A written conclusion should identify the Industry 4.0 technology and application that has the most impact and provides the greatest benefits in a specific manufacturing context.
- use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- use suitable examples derived from case studies to analyse how at least three Industry 4.0 technologies (not including IoT technologies) are applied in an Industry 4.0 smart factory and the benefits they provide.

For pass standard, learners will:

- describe at least three Industry 4.0 technologies and their applications (not including IoT technologies) as used in an Industry 4.0 smart factory.

P7, M4, D4

For distinction standard, learners will:

- use suitable examples derived from case studies to evaluate the potential impact of at least three factors (such as data management, supply chains and workforce) that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory. For example, when considering the impact on the workforce (one factor), aspects such as skills development, re-training, re-deployment and potentially redundancy need to be addressed before significant changes to processes or infrastructure can be made. A written conclusion should justify which of the three factors must take precedence during the transition, given the specific manufacturing context.
- use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- use suitable examples derived from case studies to analyse the potential impact of at least three factors that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory.

For pass standard, learners will:

- describe at least three factors that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Industrial Revolutions and the Industry 4.0 Smart Factory	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The first in this collection of training materials will consider how a series of industrial revolutions and enabling technologies led up to this point and the characteristics of an Industry 4.0 smart factory.	A written report or presentation
P3, P4, M2, D2	The Technology and Industrial Applications of the Internet of Things (IoT)	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The second in this collection of training materials will consider the technologies enabling the Internet of Things (IoT) and their applications in an Industry 4.0 smart factory.	A written report or presentation
P5, P6, M3, D3	The Technologies Enabling Industry 4.0	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The third in the series of training materials will consider a range of other non-IoT technologies that are important to the operation of an Industry 4.0 smart factory and their applications.	A written report or presentation

Criteria covered	Assignment title	Scenario	Assessment method
P7, M4, D4	Transitioning from Industry 3.0 to Industry 4.0	You are a second-year production engineering trainee and have undergone training on the development of Industry 4.0 and its enabling technologies and applications. Your manufacturing facility is planning the transition to a smart factory over the next 2–3 years. Your training supervisor has asked you to prepare a report evaluating the key factors to be considered during this transition and to justify which of these factors should take precedence.	A written report or presentation based on a given case study

Essential resources

Learners will need access to a range of Industry 4.0 case studies.

Indicative reading for learners

Textbooks

Barkai J – *The Outcome Economy: How the Industrial Internet of Things is Transforming Every Business* (CreateSpace Independent Publishing Platform, 2016) ISBN 9781530381463

Gilchrist A – *Industry 4.0: The Industrial Internet of Things* (Apress, 2016) ISBN 9781484220467

Windpassinger N – *Digitize or Die: Transform your Organization, Embrace the Digital Evolution, Rise above the Competition* (IoT Hub, 2017) ISBN 9791097580032

Yanez F – *The Goal is Industry 4.0: Technologies and Trends of the Fourth Industrial Revolution* (Independent Publisher, 2017) ISBN 9781973413172

Yanez F – *The 20 Key Technologies of Industry 4.0 and Smart Factories: The Road to the Digital Factory of the Future* (Independent Publisher, 2017) ISBN 9781973402107

Websites

dc-gb.resource.bosch.com/media/gb/trends_and_topics_7/industry_4_0/white_paper/BOR1359_-_Industry_4.0_whitepaper_-_AW-HR.pdf	A practical roadmap for the implementation of Industry 4.0
kingstar.com	KingStar: Industry 4.0: Key Design Principles (Article)
new.siemens.com/global/en/company/stories/industry/why-are-there-still-so-many-jobs.html	Siemens 4.0 – The Future of Industry (Article on the effects of Industry 4.0 on employment)
www.advantech.eu/resources/case-study/d51a6016-bc07-4024-bbe2-691a09dfb47c	AdvanTech: Building a Wireless Remote Monitoring and Management System for China's Leading Electrical Appliance Manufacturer (Case study)
www.amfg.ai	Industry 4.0: 7 Real-World Examples of Digital Manufacturing in Action
www.analog.com	Analog Devices: Functional Safety and Industry 4.0 (Article)
www.avnet.com	Industry 4.0 in Manufacturing: 26 Applications Driving Real Business Value
www.epicor.com	What is Industry 4.0 – the Industrial Internet of Things (IIoT)?
www.eurogeography.eu	Eurogeo: Depots (General Reference)
www.industrial-devops.org	The Smart Factory and the Internet of Things – An Industry 4.0 Case Study
www.infineon.com	Infineon: Discoveries, Cloud Computing, Safety and Security with Robots, Industry 4.0, Big Data (General Reference)
www.machinemetrics.com	Ford Case Study: Industry 4.0 Can Improve Safety
www.plattform-i40.de	Plattform Industrie 4.0: Network Based Communication for Industry 4.0 (Article)
www.supplychaingamechanger.com	Supply Chain Game Changer: The Industrial Revolution – From Industry 1.0 to Industry 5.0! (Article)

www.thedigitaltransformationpeople.com	Renault – An Industry 4.0 Case Study
www.trcontrolsolutions.com	TR Control Solutions – Industry 4.0 Case Studies

Unit 109: Data Analytics/Big Data

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Learners will explore how engineering organisations use data and models to make decisions, develop products and improve performance.

Engineering organisations collect vast amounts of data from a wide range of sources about their operations, products and customers, and much of this data is unplanned and/or unstructured. The resulting datasets can be so large that they are now known as big data. For example, airlines and aircraft/engine manufacturers use sensors that can capture data during flights, which enables them to predict issues and optimise the operation and maintenance of aircraft, while sensors linked to production machines can be used for real-time management of engineering processes. Big data and data analytics are also used to improve engineering systems and products, such as using telematic information from vehicles to allow congestion to be avoided and allowing real-time data to be available on smart phones and similar devices.

Learners will investigate how and why engineering organisations collect data and the methods they use to store and analyse it. They will explore a range of methods to present data for different audiences and purposes, and statistical methods used to analyse data. They will use software to analyse a dataset to provide information that could be used, for example, to identify potential causes of failure for an engineering system or product.

The analytical and problem-solving skills and knowledge that learners develop in this unit will prepare them for entry to higher education or higher-level engineering roles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the role of big data and data analytics to improve performance, for benchmarking and/or to trigger innovation in engineering organisations
2. Know about the statistical software tools and techniques used to analyse data in engineering organisations
3. Be able to carry out analysis of statistical data to meet the needs of an engineering organisation.

Unit content

1 Understand the role of big data and data analytics to improve performance, for benchmarking and/or to trigger innovation in engineering organisations

Organisation information:

- The tools and systems that play a key role in the decision-making process in an engineering organisation. The reasons why engineering organisations analyse data, including:
  - strategy planning and implementation, e.g. to identify market trends, to identify technological advances and developments, to inform production planning, to allow for more accurate preventative maintenance, to understand the behaviour of products/systems over time
  - improving departmental productivity, e.g. research and development, design, manufacture, supply chain management, production planning, maintenance, quality assurance and control
  - product and/or service benchmarking, development and triggering innovation, e.g. to increase output, to gain a competitive edge, to develop new or improved products and/or services, to improve product/service quality, to produce more accurate simulations of products/systems in use.
- General challenges of analysing data, including:
  - high costs of design and implementation to gather, store and analyse the data
  - staff skills and training needs
  - data security compliance and maintenance.
- Legislative, ethical and security issues, including:
  - current and relevant legislative issues, including the data protection legislation or other international equivalents
  - ethical issues, including individual and organisational rights and responsibilities, e.g. guaranteeing individual anonymity while maintaining the quality of data, access to personal and sensitive data
  - security of commercial and personal data, e.g. accidental or malicious loss, damage or corruption of data, password policy, data encryption, and maintenance of IT systems.

Data analytics infrastructure and types and storage of data:

- Types of data, including:
  - qualitative data: descriptive information, not a number (NaN) data
  - quantitative data: numerical information
  - internal data: data created by the functions of an engineering organisation, e.g. sales, production, maintenance, customer service department and/or embedded electronic devices, e.g. sensors and actuators (via The Internet of Things [IoT])
  - external data: data that originates from outside the organisation, e.g. data from suppliers, data from embedded sensors/RFID tags, data from end customers, data collected during use of products, maintenance records, warranty and rectification records, data from on-board diagnostics in vehicles.

- Storing data, including:
  - structured data: data in a fixed field in a record or file, e.g. data contained in relational databases and spreadsheets
  - unstructured data: data not in a relational database, e.g. text and/or email messages, photographs, graphs/charts, web pages, data captured by sensors on IoT
  - system-based factors, including:
    - volume: the quantity of data that is generated
    - velocity: the speed of generation of data
    - variety: the mixture of data to be processed
    - variability: inconsistencies in data
    - veracity: the quality and cleanliness of the data
  - security of data, e.g. password protection, data encryption, secure processes, and sufficient maintenance of IT systems
  - data warehouse, including:
    - holds very detailed information on multiple subject areas
    - works to integrate data from multiple sources
    - transforms data into meaningful and useful information
  - data mart, including:
    - often holds only summarised data on one subject area, e.g. machining, fuel consumption or capacity
    - concentrates on integrating information from a given subject area or a set of source systems
    - stand-alone data mart: focuses on one subject area and it is not designed in a whole organisational context, e.g. manufacturing have their data mart, research and development have theirs and so on
    - conformed data mart: facts and measures are categorised and described in the same way across multiple data marts, ensuring consistent reporting across an engineering organisation.
- Accessing data, including:
  - sharing data across an engineering organisation
  - ensuring that the right people have readily available access to:
    - data
    - analytical software, e.g. spreadsheet, database, commercial statistical application, e.g. JMP®, Python
    - data-management processes.

Analysing big data:

Specific challenges analysing big data (large datasets) to aid engineering organisations in making future decisions, including:

- the need for high-level skills in using specialised software tools, e.g. JMP, Python and applications for predictive analytics, data mining, text mining, forecasting and data optimisation to analyse large amounts of data
- online analytical processing (OLAP) technology to analyse multidimensional data quickly (manage volume, velocity, compatibility of datasets, accessing all data), e.g. to complete complex calculations, carry out 'what if' scenarios, produce reports in different formats
- ensuring that data is valid, accurate, current, relevant, sufficient.

Types of data analytics:

Four stages (or levels) of data analytics:

- descriptive analytics (or data mining) analyses data to uncover patterns. It can use data in real time to give a current picture, e.g. using real-time data from sensors in aircraft engines to monitor performance
- diagnostic analytics uses techniques, including data mining, to identify the reasons for past success and failure
- predictive analytics uses data mining and statistical modelling to analyse past and current data to identify potential challenges and opportunities for an organisation to make forecasts
- prescriptive analytics uses data mining, statistical modelling and forecasts to identify actions to be taken to improve performance.

2 Know about the statistical software tools and techniques used to analyse data in engineering organisations

Statistical techniques:

- Routine operations, including:
  - discrete data, continuous data, ungrouped data, grouped data
  - presentation of data: bar charts, pie charts, histograms, spectra diagrams
  - use of spreadsheet and industry-standard software to present data in appropriate formats for audience and purpose
  - measures of central tendency: arithmetic mean, median, mode.
- Non-routine operations, including:
  - measures of dispersion: variance, standard deviation, range, interquartile and inter-percentile ranges
  - use of spreadsheet and industry-standard software to calculate measures of dispersion.

Probability distributions:

- Routine operations, including:
  - normal distribution: shape, symmetry, mean.
- Non-routine operations, including:
  - areas under the normal distribution curve relating to integer values of standard deviation
  - use of industry-standard software, including spreadsheets and specialist software, e.g. JMP, Python and MATLAB®, to determine if data represents a normal distribution
  - comparison of the mean of two samples using software to carry out a t-test.

Mathematical modelling of data to find a goodness of fit:

- Linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ graphically.
- Use of spreadsheet and industry-standard software to calculate an equation of the line of regression and the correlation coefficient.
- Use of spreadsheet and industry-standard software to identify the most appropriate type of regression line for a non-linear relationship.

3 Be able to carry out analysis of statistical data to meet the needs of an engineering organisation

Selecting data for analysis:

Selection of a suitable dataset to produce information to support an organisational decision. The process will involve:

- identifying the objectives of the analysis and framing a clear, specific, well-defined question to identify what you want to know
- defining the system requirements
- defining other factors to be considered, e.g. constraints, access, security issues, e.g. data protection and reliability
- identifying valid, accurate, current, relevant and sufficient big data
- use of data and data analytics to complete a cause–effects model.

Evaluating a dataset and presenting the outcomes:

Use of appropriate software techniques to analyse datasets for a defined audience or purpose, including:

- preparation of the data for analysis, where data should be:
  - 'clean' – the data is consistent, accurate and complete
  - 'formatted' – the data is in a standard format that most commercial software is capable of interpreting, and suitable for data interchange and transformation
  - use of industry-standard software to analyse the data to produce appropriate reports for different audiences and purposes
- the need for the outcomes of the analysis to be:
  - valid: conclusions and recommendations correctly drawn from the analysis of the dataset
  - accurate: values are exact and correct
  - relevant: conclusions and recommendations address the initial question(s)
- presentation of the outcomes from the dataset analysis in an appropriate format for the audience and purpose, including:
  - the ability to convey intended meaning, e.g. written and verbal
  - graphical and numerical data
  - recording documentation, reports, visual aids for presentation use; verbal communication requirements (one-to-one and group informal and formal situations)
  - use of tone and language for verbal and written communications to convey intended meaning and make a positive and constructive impact on audience, e.g. positive and engaging tone, technical/vocational language suitable for intended audience, and avoidance of jargon
  - responding constructively to the contributions of others, e.g. supportive, managing.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain why engineering organisations use data analytics and big data, including the benefits and challenges that they may bring	**M1** assess how an engineering organisation can use data analytics and big data to improve performance, benchmark and/or innovate	**D1** evaluate how an engineering organisation can use data analytics and big data to improve performance, benchmark and/or innovate
P2 explain how an engineering organisation can use data analytics to improve performance, benchmark and/or innovate		
P3 solve problems for a given engineering dataset involving routine central tendency, dispersion and probability distribution operations, using appropriate software	**M2** solve problems accurately for a given engineering dataset involving routine and non-routine central tendency, dispersion and probability distribution operations, using appropriate software	**D2** evaluate the correct synthesis, and accurate application of, routine and non-routine statistical and probability operations, using calculations and appropriate software to solve problems for a given engineering dataset
P4 solve problems for a given engineering dataset involving routine linear regression operations, using appropriate software	**M3** solve problems accurately for a given engineering dataset involving routine and non-routine regression operations, using appropriate software	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 prepare an appropriate raw dataset to meet the needs of an engineering organisation	**M4** prepare effectively an appropriate raw dataset to meet the needs of an engineering organisation	**D3** present concise, valid and relevant conclusions and recommendations from an accurate evaluation of the effectively cleansed and formatted dataset that are fit for different audiences and purpose to meet the needs of an engineering organisation.
P6 analyse, using appropriate software, the dataset by applying routine statistical, probability and mathematical operations	**M5** analyse accurately, using appropriate software, the dataset by applying routine and non-routine statistical, probability and mathematical operations	
P7 present conclusions from the analysis of a dataset to meet the needs of an engineering organisation.	**M6** present concise and valid conclusions and recommendations from the accurate analysis of the dataset that are fit for different audiences and purpose to meet the needs of an engineering organisation.	

Essential guidance for tutors

Assessment

Evidence of achievement of the criteria can be collected from written reports and practical data analysis activities. Case studies might also be used to support assessment activities that allow learners to explore how big data and data analytics are used by engineering organisations to improve efficiencies or to innovate.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require evidence that demonstrates additional depth and/or breadth of knowledge and understanding.

This unit could be assessed through three assignments.

The first assignment should offer learners an opportunity to meet the assessment requirements of P1, P2, M1 and D1.

To achieve a pass, learners will explain why engineering organisations use big data and data analytics, including the benefits and challenges that they may bring, and they must cover ethical and legislative factors, access to and storage of data. They will identify alternative types of data and sources available to engineering organisations and how they may be used. Learners' explanations will need to cover data analysis infrastructure challenges faced by engineering organisations that use and process data, including big data (P1). Learners will also define different types of data analytics, the type of information that may be generated by each type of data analytic and how engineering organisations may use that information. They will explain the benefits to engineering organisations that may arise from the collection, storage and analysis of data in terms of improving performance, benchmarking and/or innovation (P2).

Evidence for merit and distinction will build on that presented for pass. For merit, learners will also assess how engineering organisations use big data and data analytics, for example to improve processes or efficiency. They will assess how the alternative types of data listed in the unit content for learning outcome 1 are used by engineering organisations and the infrastructure choices based on the volume, variety and velocity of data (M1). For distinction, learners will develop their assessment of the use of big data and data analytics by evaluating the types of data and sources available to engineering organisations and the infrastructure challenges associated with the use and processing of big data. They will make valid, accurate and relevant judgements on the usefulness of descriptive, diagnostic, predictive and prescriptive analytics and give examples of where each could be used in a real-world engineering application, for example to improve the efficiency of an aircraft engine (D1).

For the second assignment, covering P3, P4, M2, M3 and D2, learners will need to be given a dataset related to an engineering activity or process, for example mean time to failure data for a sample of components, measurements from an engine oil temperature sensor or data related to tolerances for a manufacturing operation. The dataset should include information for learners to be able to draw conclusions and identify potential problems with the process or product.

For pass, learners will solve problems for the given engineering dataset using routine central tendency, dispersion and probability distribution operations, using industry-standard software. They will tabulate data, present data graphically and calculate representative values for central tendency (mean, mode and median) (P3). They will also use software to solve problems for the given dataset involving routine linear regression operations and will use data to determine the equation of linear regression and the correlation coefficient (P4).

For merit, learners will accurately solve problems for the given engineering dataset using routine and non-routine operations. For example, they will tabulate grouped data and generate annotated charts. In addition to accurately calculating representative values for central tendency, they will calculate variance, standard deviation, range, interquartile and inter-percentile values of normally distributed data. Learners will carry out a t-test on two sets of given data and draw a simple conclusion from the result (M2). They will also accurately determine the equation of linear regression and correlation coefficient, predicting the value of the dependent variable for a non-measured value. Learners will compare the value with the corresponding value from the graph. They will select and use a suitable type of regression for a non-linear relationship, such as a power relationship. Each calculation will be supported by a brief explanation of the method used (M3).

For distinction, learners will complete all calculations with accuracy and evaluate the correct synthesis of results obtained by the accurate application of routine and non-routine statistical and probability operations, using industry-standard software to solve problems. They will evaluate the accuracy of the predicted value of the dependent variable with the value obtained from the graph for a non-measured value, in relation to the value of the correlation coefficient (D2).

For the third assignment, covering P5, P6, P7, M4, M5, M6 and D3, learners will need to be given a dataset related to an engineering process or service, but the data must be 'as collected' and not be sorted or classified in any way. The data should be provided electronically and must include at least 500 records.

For pass, learners will need to prepare the large dataset by cleaning and formatting it, for example by removing some unwanted data and formatting some of the units, such as voltage or current values (P5). They will use industry-standard software to analyse the supplied dataset by applying routine statistical, probability and mathematical operations. For example, they will present data, calculate central measures (mean, mode and median) and calculate the line of best fit of a linear relationship (P6). Learners will then present straightforward conclusions from the analysis of the dataset that are fit for audience and purpose to meet the needs of an engineering organisation. They will state the purpose of the analysis and the intended audience (P7).

For merit, learners will develop their work for pass, for example by removing most of the unwanted data and formatting the units for the dataset (M4). They will apply routine and non-routine statistical, probability and mathematical operations accurately (M5) in order to arrive at conclusions and recommendations from the accurate analysis of the dataset that are appropriate for the intended audience and an engineering organisation (M6).

For distinction, learners will evaluate the outcomes and produce accurate, valid and relevant judgements from the analysis of the effectively cleansed and formatted dataset. The analysis must include appropriate and accurate presentation of data, calculations of central measures, dispersion and probability functions, comparison of datasets and regression. Overall, the evidence will be easily understood by a third party with a mathematical background. There will be correct use of mathematical terminology and application of relevant units (D3).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	The Role of Big Data in Engineering	You are an apprentice engineer and your manager has asked you to produce a report about how using big data and data analytics could benefit your engineering organisation, as well as some of the challenges it brings.	A written report that covers the role of big data and data analytics in engineering organisations, with clear referencing to the use of data for performance improvements, benchmarking and/or innovation
P3, P4, M2, M3, D2	Data Analysis	You are an apprentice engineer and your manager has given you an engineering dataset to study. Your manager wants you to use the dataset to draw conclusions and solve problems.	A report that analyses a given engineering dataset and includes supporting calculations, charts and tables, engineering sketches and diagrams

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M4, M5, M6, D3	Using Data Analytics to Meet the Needs of an Engineering Organisation	You are an apprentice engineer and your manager has asked you to report on your findings from an investigation into faults in a piece of engineering equipment or an engineering process, based on a large, collected dataset.	A report that includes the interpretation and presentation of data in order to provide conclusions/ recommendations for an engineering organisation

Essential resources

For this unit, learners must have access to:

- a wide range of research resources, largely text and internet based. There are many free-to-use large datasets available
- at least two different pre-selected datasets (one for learning outcome 1, the other for learning outcome 2)
- industry-standard software, such as spreadsheets and specialist software, e.g. JMP, MATLAB®, and access to sufficient secure storage space to complete the analysis.

Indicative reading for learners

Textbooks

Bird J – *Bird's Basic Engineering Mathematics*, 8th edition (Routledge, 2021) ISBN 9780367643676

Crickard P – *Data Engineering with Python* (Packt, 2020) ISBN 9781839214189

Marr B – *Big Data in Practice* (Wiley, 2016) ISBN 9781119231387

Websites

www.ibm.com/downloads/cas/ONBGKB82	How big data is used in manufacturing
www.jmp.com	Website for JMP data analysis software – trial downloadable version available
http://www.linkedin.com/pulse/big-data-analytics-tesla-inc-bipin-karki?articleId=6623446918821404672	Article about how Tesla uses big data
www.machinemetrics.com/blog/big-data-in-manufacturing	Use of big data in the manufacturing sector
www.rolls-royce.com/products-and-services/civil-aerospace/intelligentengine.aspx	Rolls-Royce – how the IoT and data are used for aircraft engines

Unit 110: Simulation and Digital Twinning

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the application of simulation and digital twinning as used in advanced manufacturing and the skills needed to produce and simulate digital manufacturing process or system models.

Digital twinning allows manufacturing organisations to test modifications or innovations virtually without the need to suspend production or set up additional test assembly lines. For example, the use of 3D modelling software helps create digital twins for physical objects where connected sensors can collect the data from a physical system and update the digital twin with physical model dynamic conditions. Therefore, a digital twin can be used for monitoring and diagnostics to optimise process or system performance.

This unit will give learners an understanding of recent advances in new technologies and their applications for advanced manufacturing. Learners will also develop an understanding of the benefits and limitations of digital twinning, and will consider the software and data collection implications for digital twinning. They will have the opportunity to produce and simulate a digital twin model of a manufacturing process or system and will consider how to adjust parameters to improve its performance.

The unit encompasses both theoretical teaching and practical work. It aims to enhance learners' awareness of the general concepts and principles associated with the use of digital twinning simulation software for advanced manufacturing.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the benefits and limitations of using digital twinning during advanced manufacturing

2 Understand the software and data collection implications for digital twinning

3 Be able to produce and simulate a digital twin for a manufacturing process or system.

Unit content

1 Understand the benefits and limitations of using digital twinning during advanced manufacturing

Industry 4.0: enabling technologies including the Internet of Things (IoT), cloud computing, cyber physical systems

Digital twinning: use of simulation software to produce a 3D digital twin model and how it is used to enhance quality and efficiency and justify a range of improvements during advanced manufacturing, e.g. simulating small amendments to a range of parameters in a manufacturing process or system digitally and observing the positive and negative effects to decide whether to implement the modifications or make further/different modifications to help reach the desired effect

Benefits of using digital twinning: a lower-cost alternative to physical solutions, e.g. 'what if' analysis in virtual factories to observe the impact on manufacturing processes, data analytics, forecasting, improved human factors such as compliance with health and safety regulations, workforce combined with machine efficiency, decision-making support, data visualisation, enhancing quality and efficiency

Limitations of using digital twinning: the possibilities of inaccurate modelling, e.g. disassembly of machinery to accurately replicate all features of it, inaccurate representation of an object, unrealistic/theoretical nature of the simulation, not accounting for unprecedented future scenarios in the workplace

2 Understand the software and data collection implications for digital twinning

Characteristics of a smart factory: features of advanced manufacturing, e.g. connectivity, flexibility, scalability, agility, autonomy, efficiency, sensors and actuators, IoT featuring Artificial Intelligence, wireless communication protocols, cloud computing

Digital twinning software: definition, use and selection of digital twinning simulation software for a manufacturing process or system, e.g. 2D and 3D CAD modelling, Solidworks, Autodesk, 3D animation software, SAP PEI, Mindsphere, Ansys, Matlab/Simulink, etc

Data collection: evaluation of the accuracy and appropriateness of data collection and use for successful digital twinning, e.g. sensors, cameras, other interface devices, reference to the digital virtual product, the physical product and the connection between both the digital and the physical product, AI, machine learning, IoT, health and safety, communication protocols (NFC, RFID, Bluetooth, Zigbee, Wi-Fi)

3 Be able to produce and simulate a digital twin for a manufacturing process or system

Utilisation of digital twin modelling software: using virtual and augmented reality as well as 3D graphic and data modelling to accurately produce a virtual model of a manufacturing process or system, enhanced by real-time process data and analytics based on accurate configurations

Simulating digital twin models: checking the model for accurate replication of all process or system activities from the physical to the digital world by collating all live application data from application logs and devices to then replicate all live application issues in test, using logs which will enable the analysis of the effects of adjusting parameters for the future prediction and prevention of system failures and the optimal function of the manufacturing process or system.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe how digital twinning is used during advanced manufacturing	**M1** explain the use of digital twinning to enhance quality and efficiency during advanced manufacturing	**D1** analyse how digital twinning is used to justify a range of improvements during advanced manufacturing
P2 describe the limitations of digital twinning during advanced manufacturing		
P3 explain how simulation software can be used to create a digital twin	**M2** justify the choice of digital twinning simulation software for an advanced manufacturing process or system	**D2** evaluate the collection and use of appropriate data for a digital twin of an advanced manufacturing process or system
P4 explain why successful digital twinning is based on the collection and use of appropriate data		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 produce a 3D digital twin model of a manufacturing process or system	**M3** produce accurately a 3D digital twin model of a manufacturing process or system.	**D3** analyse the effect of changing parameters when using the 3D digital twin model to simulate the operation of a manufacturing process or system, and recommend improvements that will optimise the function of the manufacturing process or system.
P6 simulate the operation of a manufacturing process or system using the 3D digital twin model, determining the effect of changing parameters.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

The first assignment could cover P1, P2, M1 and D1 holistically.

To achieve P1, learners need to describe how digital twinning is used during advanced manufacturing. Learners are expected to describe in detail how modelling a potential modification to a manufacturing process or system using digital software can be beneficial to companies in terms of saving time, money and resources. When describing the benefits, learners should also cover the environment in which the manufacturing process or system operates, the capital required to maintain effective operation and examples of potential modification requirements.

For P2, learners must describe at least two limitations of digital twinning during advanced manufacturing. Learners could refer to inaccurate/simplistic modelling of the real system, the theoretical nature of the simulation or not accounting for unprecedented future scenarios in the workplace. Learners must also cover the possible implications of both limitations during advanced manufacturing.

For M1, the explanation must demonstrate a good understanding of the reasons why, in a global market environment, a manufacturing organisation can maximise the quality and efficiency of its processes or systems by incorporating digital twinning applications into its developmental processes, with particular reference to the specific effects on productivity.

To achieve D1, learners must provide a detailed analysis of the ways in which digital twinning is used to justify a range of improvements to a manufacturing process or system. For example, learners should cover how a manufacturing organisation can make small amendments to a range of parameters in a manufacturing process or system digitally, and can then observe the positive and negative effects, which can then provide evidence to either implement those modifications (if they produce the desired effect) or make different/further modifications to help reach the desired effect. Specific examples must be provided.

A second assignment could cover P3, P4, M2 and D2 holistically.

To achieve P3, learners must explain how simulation software can be used to create a digital twin model of a manufacturing process or system. This could include the use of 2D and 3D CAD modelling, Solidworks, Autodesk, 3D animation software, SAP PEI, Mindsphere, Ansys, Matlab/Simulink, etc. Learners need to give a detailed, step-by-step explanation of how the software functions to produce the digital twin model of a manufacturing process or system. For example, this may include defining the process or system that is being digitised, geometry, and the appropriate utilisation of strategically placed sensors to replicate/simulate the physical process or system in real time.

In order to achieve P4, learners will need to explain why successful digital twinning is based on the accurate collection and use of appropriate data. Learners need to explain the effectiveness of at least two data acquisition methods used (such as sensors and cameras) to collect the appropriate data accurately. As part of this, learners must also cover how the data collected is used, for example to simulate simple process or system modifications or to build a longer-term picture to predict where failures may occur.

For the merit and distinction criteria, learners must be given a specific example of an advanced manufacturing process or system (such as a detailed flow diagram for a manufacturing cell or a production line producing a component) so that they can justify and evaluate in context.

The achievement of M2 requires learners to select the digital twinning software that they deem the most suitable for producing a digital twin of the given advanced manufacturing process or system and then justify their choice. This justification could include the benefits of the specific software, the limitations of other software and the ease of producing a digital twin with the chosen software.

For D2, learners must evaluate the collection and use of appropriate data for a digital twin of the given advanced manufacturing process or system. Learners should evaluate different methods of acquiring accurate and appropriate data for the given advanced manufacturing process or system to minimise the inaccuracies of the digital twin model compared to the real process or system. They must also evaluate how the data collected could be used, by providing specific examples of potential process or system modifications that could be simulated using the digital twin model.

A third assignment could cover P5, P6, M3 and D3 holistically.

For this assignment, learners must be given the details of a manufacturing process or system and it should not be overly complex – for example, a manufacturing cell or a production line producing a standard component.

To achieve P5, learners must produce a 3D digital twin model of the given manufacturing process or system using simulation software. For M3, learners are required to *accurately* produce a 3D digital twin model of the given manufacturing process or system using simulation software. For P5, the model will function but may be too simplistic, with some errors that affect the way it operates, meaning that when process or system parameters are amended, the model may not produce results that can be trusted. For M3, the model should be appropriately detailed and should function well, with only minor errors present, meaning that when process or system parameters are amended, the model can be analysed so that the function of the manufacturing process or system can be optimised.

In order to achieve P6, learners need to determine the effect of changing parameters by simulating the operation of the produced 3D digital twin model to ensure that it is a suitable representation of the given physical manufacturing process or system. For example, they need to test whether the digitised objects are the same size and design as the physical objects, and whether the function is identical to truly replicate the dynamic conditions of the given manufacturing process or system. Learners should also determine where changing parameters can improve the accuracy of the operation of the digital twin in order to function identically to the real system.

The achievement of D3 links to M3. For D3, learners need to analyse the effects of changing parameters when using the 3D digital twin model to simulate the operation of the given manufacturing process or system, and recommend improvements that will optimise the function of the given manufacturing process or system. For example, if the production time is slower than initially predicted, the learner may choose to remove a stage from the production process and simulate this to see if it works better, or amend other parameters to optimise the agility of the given manufacturing process or system. The learner must include what-if analysis of this choice and the possible impacts (both positive and negative) that it could have on the given manufacturing process or system, in order to recommend suitable improvements.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Using Digital Twinning during Advanced Manufacturing	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering how the use of digital twinning could enhance quality and efficiency during manufacturing. They want you to do this because they are aware that a range of improvements could be implemented.	A written report
P3, P4, M2, D2	Software and Data Collection Implications for Digital Twinning	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the use of software and data collection/use for digital twinning. They want you to do this to help identify improvements that could be made to enhance the suitability of digital twin models.	A written report
P5, P6, M3, D3	Produce and Simulate a Digital Twin Model of a Manufacturing Process or System	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to produce and simulate a digital twin model of a given manufacturing process or system. They want you to do this because they want to understand the effects of changing parameters to improve the function of the manufacturing process or system.	A written report/portfolio based on practical activities supported by annotated photos and observation records

Essential resources

Centres should have sufficient facilities so that learners can carry out practical activities associated with digital twinning. Relevant software packages should be available to permit simulation and modelling.

A visit to an engineering company that utilises digital twinning applications would be a good way for learners to see how the applications work in practice and to gather research information. This could involve talking to a CAD designer/3D modeller and being shown the processes of specifying, producing and simulating digital twin models to give learners a basis of knowledge and understanding before they produce their own models.

Indicative reading for learners

Gilchrist A – *Industry 4.0: The Industrial Internet of Things* (Apress, 2016) ISBN 9781484220467

Tao F, Zhang M, Nee A – *Digital Twin Driven Smart Manufacturing* (Academic Press, 2019) ISBN 9780128176306

Yanez F – *The 20 Key Technologies of Industry 4.0 and Smart Factories: The Road to the Digital Factory of the Future* (Independent Publisher, 2017) ISBN 9781973402107

Websites

www.control.com/technical-articles/digital-twinning-leaders-in-the-emerging-technology/	Digital Twinning: Leaders in the Emerging Technology
www.challenge.org/insights/digital-twinning/	What is the meaning of digital twinning and how it is applied
www.ibm.com/topics/what-is-a-digital-twin	What is a digital twin?
www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/digital-twins/	Digital Twin: rise of the digital twin in Industrial IoT and Industry 4.0
www.networkworld.com/article/3280225/what-is-digital-twin-technology-and-why-it-matters.html	What is a digital twin and why it's important to IoT

Unit 111: Cyber Security in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Learners will investigate the cyber security of engineering computer systems, and will install and configure security measures to protect a system from malicious threats.

Cyber security is an important issue for the economy and for engineering organisations. For example, engineering organisations undertake cutting-edge research and need to invest in sophisticated systems to protect information and intellectual property with passwords, security passes and sophisticated physical locks. Organisations have a responsibility to create secure products, so all the engineers involved in the development and testing process must have an understanding of security issues.

Learners will investigate a range of computer security threats, computer system vulnerabilities, and security-protection measures that are used in the industry. They will also investigate the legal requirements placed on organisations to protect information and systems. They will plan for and then install and configure protection measures for an engineering computer system and test the effectiveness of the measures.

All engineers need to understand why cyber security is important and how it can be implemented in products and systems of all types. This unit helps learners prepare for an engineering apprenticeship, for higher education and for technician-level roles, such as an information technology (IT) technician, engineering technician or IT operations technician.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the threats to computer systems in engineering organisations and the organisations' legal responsibilities

2 Know computer system vulnerabilities and protection measures used in engineering organisations

3 Be able to plan security measures to protect an engineering computer system from threats

4 Be able to implement security measures to protect an engineering computer system from threats.

Unit content

1 Understand the threats to computer systems in engineering organisations and the organisations' legal responsibilities

Computer system security threats:

- All computer systems are vulnerable to attack from external and internal threats.
- Internal threats include:
  - employee sabotage and theft, e.g. changing parameters via remote access causing machine failure, theft of physical equipment or data, and damage, such as fire, flood, power loss, terrorism or other disaster
  - unauthorised access by employees and other users to secure areas and administration functions, including security levels and protocols, e.g. to remote systems, to engineering machines controlled by computer
  - weak security measures and unsafe practices, e.g. security of computer equipment, engineering machines and storage devices, security vetting of visitors, visiting untrusted websites, limited encryption
  - accidental loss or disclosure of data, e.g. poor staff training on system access and engineering device operation, limited internal protocols and monitoring of equipment and access.
- External threats include:
  - malicious software (malware) and how it functions, including viruses, worms, spyware, adware, rootkits and Trojan horses
  - hacking, e.g. commercial, government or individuals
  - sabotage, e.g. commercial, government, terrorism, individuals
  - social-engineering techniques used to obtain secure information by deception.
- The impact of a successful threat to an organisation is some form of loss, such as operational loss, e.g. manufacturing output; financial loss, e.g. organisational, compensation and liability; reputation loss, e.g. lack of service and employee or customer information; and intellectual property loss, e.g. new product design.

Legal responsibilities:

United Kingdom legislation or other relevant international equivalents, including:

- data protection legislation and amendments, requirements for organisations to keep data secure such as General Data Protection Regulations (GDPR)
- computer misuse legislation and amendments, its definitions of illegal practices and applications
- Telecommunications (Lawful Business Practice) (Interception of Communications) regulations and amendments, requirements to allow companies to monitor an employee's communication and internet use while at work
- EU Cyber Security Directive
- fraud legislation and amendments, requirements to deal with services using IT-based methods to steal information for fraudulent purposes.

2 Know computer system vulnerabilities and protection measures used in engineering organisations

Computer system vulnerabilities:

- Understand that different types of computer system are exposed to different threats and contain different vulnerabilities. Possible vulnerabilities include:
  - network, e.g. open firewall ports, Wi-Fi passwords, encryption
  - organisational, e.g. inappropriate file permissions or privileges, password policy
  - software, e.g. from an untrusted source, torrent-downloaded software, illegal copies, insecure product software
  - operating system, e.g. unsupported versions, updates not installed
  - physical, e.g. theft of equipment, USB storage devices with sensitive data, collection of passwords and other information by social-engineering methods
  - process of how people use the system, e.g. leaks and sharing security details.
- Different security threats exploit different computer/system vulnerabilities, e.g. hackers can exploit open firewall ports to obtain sensitive information, such as passwords, or to manipulate engineering process and/or products.

Physical security measures:

Physical security measures and their effectiveness, including:

- site security, e.g. locks, card entry, biometrics, closed circuit television (CCTV)
- data storage, data protection and backup procedures, including planned automated backup, on- and off-site data storage, cloud storage.

Software and hardware security measures:

Software security measures and their effectiveness, including:

- anti-virus software and detection techniques, including virus signatures, heuristics techniques used to identify potentially suspicious file content, techniques for dealing with identified threats
- software and hardware firewalls and the filtering techniques they use, including packet filtering and inspection, application layer awareness, inbound and outbound rules, and network address
- user authentication, including user log-on procedures; strong password; text and graphical password; biometric authentication; two-step verification; security tokens, e.g. USB-based keys; knowledge-based authentication, e.g. question and response pairs; Kerberos network authentication for Windows and Linux-based operating systems; certificate-based authentication
- access controls and the methods to restrict authorised/unauthorised users' access to resources, e.g. user groups and the access rights allocated to resources, such as folders, files and physical resources including printers, automated PLCs and/or microprocessor controller systems on the network
- the principles of encryption, including shift ciphers, one-time pads, hashing, symmetric and public key encryption, file/folder encryption, disk encryption products

- precautions that can be taken to protect a wireless local area network (LAN) from unauthorised access, e.g. MAC address filtering and hiding the service set identifier (SSID); wireless encryption such as Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA) and Wi-Fi Protected Setup (WPS), mitigating known wireless vulnerabilities
- consideration of security issues during network and system design, and remote access product design, to ensure security is built in from the development stage.

Policy security measures:

Policy security measures and their effectiveness, including:

- organisation policies and their application, including policies on internet and email use, security and password procedures, staff responsibilities, staff IT security training
- security audits and their application to check compliance against policies
- backup of data
- ensuring no detrimental impact on the safe use of engineering equipment and processes.

3 Be able to plan security measures to protect an engineering computer system from threats

Assessment of computer system vulnerabilities:

- Tools and methods to assess the vulnerabilities in computer systems, including port scanners, e.g. NMAP, Angry IP scanner; checkers (Windows Registry Checker Tool, CCleaner); website vulnerability scanners, e.g. Acunetix, w3af; general vulnerability detection and management software, e.g. OpenVAS, QualysGuard, Firesheep; and assessing user vulnerabilities, e.g. training and staff vetting.
- Audits of system and network designs prior to implementation.
- Penetration testing for common threats, e.g. those in the OWASP (Open Web Application Security Project) top 10, including Structured Query Language (SQL) Injection.

Assessment of the risk severity for each threat:

- A risk is a threat that could result in some form of loss at some point in time.
- Risk severity = probability of the threat occurring × expected size of the loss.
- Measures for risk severity include:
  - risk severity = low, medium, high and extreme
  - probability of the threat occurring = unlikely (e.g. every two years), likely (e.g. every month) and very likely (e.g. once or more a day)
  - size of the loss = minor (e.g. under one hundred pounds), moderate (e.g. hundreds or thousands of pounds) and major (e.g. tens of thousands of pounds).
- The resultant risk severity is illustrated in the following matrix:

Probability of threat occurring	Very likely	Medium	High	Extreme
	Likely	Low	Medium	High
	Unlikely	Low	Low	Medium
		Minor	Moderate	Major
	Size of the loss			

- Risk assessment approach:
  - risk assessments are undertaken during system design and at regular intervals or following a security breach, as threats are constant and ever changing
  - a risk assessment method should:
    - identify possible threats and assess the probability of different threats occurring
    - assess the vulnerabilities of a computer or engineering technology system to specific threats
    - determine the risk severity (low, medium, high and extreme)
    - identify ways to prevent severe risks (medium, high and extreme) from occurring and reduce the severity of the risk if it does occur.

A security plan for a computer system:

A plan for a computer system, including:

- a risk assessment
- system protection measures for the most severe risks, including:
  - a summary of how the system will be protected
  - user security policy, e.g. with access rights and information and functional change availability
  - hardware protection measures, e.g. firewalls, routers, wireless access points
  - software protection measures, e.g. anti-malware, firewall, port scanning
  - a description of policies, e.g. scheduled backups and running anti-virus scans
  - alternative solutions, including risk transfer to a third party, risk avoidance by stopping an activity, and risk acceptance, e.g. a low risk
  - any technical and financial constraints, e.g. software licence costs
- a test plan to check that the protection measures work as intended
- methods to detect security breaches, response plans.

4 Be able to implement security measures to protect an engineering computer system from threats

Installation and configuration of security measures for a computer system:

- Consideration of security issues during the design and development of the engineering system.
- Installation and configuration of security software, e.g. anti-virus, firewall.
- Hardware and/or operating system-embedded firewalls, including configuration of:
  - inbound and outbound rules to control network connections that are allowed and prevent all other unauthorised connections
  - firewall events and interpretation of log entries.
- Wireless security, including:
  - wireless encryption methods, e.g. WEP, WPA (1 and 2)
  - configuration of wireless router security settings
  - adding clients to a wireless network.

- Access control, including:
  - design and implementation of hardware and software access-control regimes, including permission settings on files, folders, functional control changes and resources
  - defining legitimate users, groups and the resources they need to access and the levels of access they need (read, modify, delete)
  - defining password policies, e.g. length, complexity, age and reuse
  - white listing of applications' trusted signed binaries
  - data hiding when viewing logs and visibility of sensitive data
  - defining users with special privileges, e.g. administrator rights.

  Testing a computer system's security measures:

  Test the effectiveness of the protection measures and make recommendations for further improvement, including:
  - firewall testing using penetration-testing software to check that the firewall blocks unauthorised traffic and allows legitimate traffic through
  - wireless penetration testing using stumblers to find and identify access points, cracking software to test passwords
  - viewing and interpreting activity logs
  - checking that the normal operation of the computer system/engineering system is not hindered.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the different security threats that may affect contrasting engineering computer systems and the impact of any loss	**M1** assess the different security threats, the impact of any loss, and legal requirements that apply to contrasting engineering computer systems, including how they interrelate	**D1** evaluate the effectiveness of security measures used to protect vulnerabilities in contrasting computer systems from threats, considering the impact of loss and the legal requirements that apply
P2 explain the legal responsibilities that at least one engineering organisation has for the security of its computer systems		
P3 explain what vulnerabilities exist in contrasting engineering computer systems	**M2** justify how the physical, software, hardware and policy security measures protect vulnerabilities in contrasting engineering computer systems from loss	
P4 explain how the physical, software, hardware and policy security measures protect contrasting engineering computer systems from loss		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 produce a plan to protect an engineering computer system from possible threats	**M3** produce a detailed plan to protect an engineering computer system from possible threats, justifying the recommendations	**D2** optimise the effectiveness of the plan and of the protected engineering computer system safely, testing how well the system is protected by the measures and that users are not unreasonably hindered by the measures.
P6 undertake security measures safely to protect an engineering computer system	**M4** undertake security measures safely to fully protect severe vulnerabilities in an engineering computer system, testing how well the system is protected by the measures.	
P7 test how well the engineering computer system is protected by the measures.		

Essential guidance for tutors

Assessment

Learning outcomes 1 and 2

For distinction standard (D1**)**, learners will evaluate the vulnerabilities in two contrasting computer systems. The evaluation will be detailed, well balanced and comprehensive, and will cover the full range of internal and external threats and suitable protection measures. Learners' evaluation will consider protection measures that are likely to be effective and those that are not, explaining why each measure would or would not be effective, or what factors might reduce its effectiveness. For example, choices made in the selection of a password policy will dictate the effectiveness of the policy. Learners will also cover the impact of the loss and the legal requirements that apply.

Overall, the evidence, such as a report, will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms.

For merit standard (M1, M2), learners will assess the threats, the likely impact of the threat and legal requirements for contrasting engineering computer systems, and will assess how they interrelate. For example, an engineering organisation is required by data protection legislation to keep sensitive information, such as customer bank details, secure, thereby assuring customers that any malware threat to obtain sensitive information would be unsuccessful.

Learners will justify how the physical, software, hardware and policy measures would protect vulnerabilities in contrasting engineering computer systems, which would prevent loss. For example, anti-malware software can protect against malware threats either by scanning incoming files and blocking threats it identifies or by scanning existing files in a computer system, identifying any suspicious files for deletion, thereby preventing loss.

Overall, the evidence must be technically accurate and demonstrate good-quality written communication.

For pass standard (P1, P2, P3, P4), learners will provide evidence that describes what security threats commonly apply to contrasting engineering computer systems and they will cover at least three internal and external threats to each system. They will also describe the impact of the threat should it succeed, for example employee theft of sensitive information – for example, designs for a new product or changes to equipment parameters leading to productivity or system failure could result in financial loss to the organisation from lost revenue and compensation to and reputational loss with customers.

Learners' evidence will explain the legal responsibilities covering contrasting engineering computer systems, and they will cover at least one requirement from all five of the pieces of legislation and regulations. For example, data protection legislation and amendments place a requirement on organisations to keep data about customers secure and stored for no longer than is necessary for the purpose for which it was provided.

Learners will explain the possible vulnerabilities in contrasting engineering computer systems. For example, insufficient file permissions control could be exploited to obtain information by employees working in an organisation, which may result in financial fraud or disruption to an engineering process, which may affect productivity or cause loss.

Learners will also explain the physical, software, hardware and policy measures that are available to protect contrasting engineering computer systems from threats. For example, an employee policy that outlines access rights and information availability would help to prevent fraud.

Overall, the evidence will be logically structured. It may be basic in parts, for example the requirements of the regulations may not be fully explained, or may contain minor technical inaccuracies relating to terminology. For example, the difference between 'rootkits' and 'worms' may not be clear.

Learning outcomes 3 and 4

For distinction standard (D2), learners will optimise the effectiveness of the plan and of the protected engineering computer system safely. For example, they might adjust virus-scanning schedules to avoid scanning the system when it is heavily used. The testing will demonstrate that the system is protected and that users are not unduly hindered by the measures. For example, if specific access controls are applied for certain users, they would need to show how effective the measure is in terms of granting access to the right users and preventing access to others. Other examples include setting scheduled virus scans at appropriate times, and password policies to balance protection of the engineering system with the convenience of the remote monitoring and control. If the measures implemented are ineffective then learners must also mention what they would do differently next time.

Overall, the evidence will be logically structured, technically accurate and easy to understand by a third party who may or may not be an engineer.

For merit standard (M3, M4), learners will provide a detailed plan to protect an engineering computer system that covers all the severe risks and they will include a suitable test plan. The plan will also provide a clear, reasoned justification of the recommendations made to protect the system. This must include technical reasons why particular protection methods and configurations were selected and others were rejected. For example, learners might justify the Wi-Fi configuration choices they have made.

Learners will implement and configure a coherent set of computer-security measures safely as outlined in the plan. As demonstrated by the test results, the measures will protect the system from the severe risks. For example, learners should set firewall settings to allow legitimate programs to operate and place user accounts in groups that provide appropriate levels of access and restriction and balance protection of the engineering system with the convenience of remote monitoring and control.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard (P5, P6, P7), learners will produce a plan to protect an engineering computer system from a range of possible threats. The plan may not identify all the severe risks and some of the protection measures may be unsuitable to fully protect the system. For example, learners may omit to mention how a firewall can be effectively configured to prevent unauthorised access to the system. The evidence will also include a test plan.

Learners will undertake security measures safely to protect the engineering computer system from threats by implementing the plan. For example, they will install and configure anti-malware software to protect a network computer system. The system may be a mock-up or virtualised version of a real networked engineering system.

Learners will test that the computer system is protected by the measures implemented and configured safely. For example, they will test that shared folder permissions are set correctly and work as intended.

Overall, the evidence will be logically structured, although it may be basic in parts, for example supporting evidence may lack detail and it may unnecessarily hinder the operation of users. File or folder permissions may unnecessarily restrict users' ability to save or update files.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	System threats and Vulnerabilities: Legal Requirements and Methods of Protection	You are an apprentice security engineer and your supervisor has asked you to review two contrasting computer systems and to carry out an investigation into the effectiveness of the security measures used to protect the vulnerabilities from threats. They also want you to consider the impact of any potential loss and the legal requirements that apply.	A detailed report
P5, P6, P7, M3, M4, D2	Planning and Implementation of Security Measures	You are an apprentice security engineer and your supervisor has asked you to produce a structured plan to protect an engineering computer system from threats. You must also implement the plan and test how effectively the system is protected.	Written plan Written report, annotated photographs, screenshots, etc and an observation record related to the practical demonstration of the implementation and testing

Essential resources

For this unit, learners must have access to:

- case study materials from different organisations describing the purpose of some of the computer systems, the configuration and security protection measures
- appropriate legislation and regulations as listed in the unit content
- computer systems (real, mock-up or virtualised) to which security measures can be applied
- appropriate security software such as anti-virus and firewall software.

Indicative reading for learners

Textbooks

Colbert E – *Cyber-security of SCADA and Other Industrial Control Systems: 66 (Advances in Information Security)* (Springer, 2018) ISBN 9783319812038

Diogenes Y, Ozkaya E – *Cybersecurity – Attack and Defense Strategies: Counter Modern Threats and Employ State-of-the-Art Tools and Techniques to Protect Your Organization Against Cybercriminals,* 2nd edition (Packt Publishing, 2019) ISBN 9781838827793

Easttom C – *Computer Security Fundamentals*, 4th edition (Pearson IT Certification, 2019) ISBN 9780135774779

Hodson C – *Cyber Risk Management: Prioritize Threats, Identify Vulnerabilities and Apply Controls* (Kogan Page, 2019) ISBN 9780749484125

Russell B – *Practical Internet of Things Security: Design a Security Framework for an Internet Connected Ecosystem*, 2nd edition (Packt Publishing, 2018) ISBN 9781788625821

Thames L – *Cybersecurity for Industry 4.0: Analysis for Design and Manufacturing* (Springer, 2017) ISBN 9783319506593

Websites

www.cisa.gov	United States of America CyberSecurity, Infrastructure & Security Agency equivalent to UK GCHQ – overviews, education, advice and guidance
www.insidetechlaw.com/internet-of-things	Overview of IoT and world legal requirements, including publications and blogs
www.ncsc.gov.uk	UK Government site for GCHQ and cyber security – overviews, education, advice, and guidance

Unit 112: Additive Manufacturing Processes

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Learners cover the principles and practical methods used in additive manufacturing (AM) and develop a component using additive processes.

Additive manufacturing (AM) processes are set to revolutionise the manufacturing industry and provide mass customisation of products and components for consumers. For example, a human jawbone can be manufactured to the exact specification of a patient needing a transplant. In addition, additive processes are more sustainable than traditional subtractive manufacturing processes, such as computer numeric controlled machining.

In this unit, you will examine the technology and characteristics of the additive and finishing processes that are needed to manufacture a product or component. You will investigate design changes required to move from a traditional manufacturing process, such as machining and casting, to an additive process and the additional finishing processes that may be needed as a result. Finally, you will design a component that is suitable for manufacture using an additive process and manufacture your component using a 3D printer.

Technology is transforming our lives; therefore as an engineer it is important that you understand the new manufacturing processes that are providing opportunities in product design, mass customisation and sustainability. In the United Kingdom, additive AM processes have been estimated to be worth around £6 billion per annum and are expected to employ 63000 people by 2020. This unit helps to prepare you for employment, for example as a manufacturing engineering technician, for an apprenticeship, or for entry to higher education to study, for example, manufacturing engineering.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Examine the technology and characteristics of additive manufacturing processes as used in industry
2. Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes
3. Develop a component using additive manufacturing processes safely.

Unit content

1 Examine the technology and characteristics of additive manufacturing processes as used in industry

AM processes

- Technology and characteristics, such as complexity, surface texture, and tolerances, of AM processes, including:
  - material extrusion – fused deposition modelling (FDM)
  - powder bed fusion – electron beam melting, laser powder bed, plasma powder bed, laser sintering
  - photo polymerization – Selective Laser Sintering (LS), stereolithography (SLA), Digital Light Processing (DLP)
  - material jetting – binder jetting
  - wire deposition (wire arc manufacturing), including plasma, electron beam and laser.
- Capacity of AM processes, including:
  - component size is limited by the capacity of the AM machine, including physical machine footprints and base size and working area and swept volume
  - manufacturing volume is determined by the processing speed of the machines, e.g. wire deposition has a relatively high throughput speed (at several kilograms of material per hour but geometrical accuracy reduces at faster speeds) and powder bed fusion processes have relatively low throughput speed (around 0.1 kilograms per hour).
- Sustainability of the processes, including:
  - the recycling of metallic powder and polymer-based materials as part of the powder bed fusion process
  - limited waste material is produced as a result of the process
  - less energy is required to manufacture components
  - localisation of manufacturing reduces the need for transportation.
- Applications of AM processes, including:
  - manufacture of aerospace and automotive components – using powder bed technologies and wire deposition processes
  - rapid prototyping of products and components – using FDM and LS processes
  - moulds and tooling, e.g. moulds – for casting near net shapes, patterns, jigs – using FDM and LS
  - digital manufacturing, e.g. industrial components, consumer products – using powder bed technologies and wire deposition
  - personalised fabrication, e.g. customisation, personal products, home and machine repairs – using FDM
  - biomedical, e.g. dental, prosthetics, hearing aids and human tissue – using FDM.
- Typical materials, including:
  - polymers, e.g. Acrylonitrile Butadiene Styrene (ABS), polylactic acid (PLA), polyamides
  - metals, e.g. titanium (Ti), aluminium (Al), steel, gold, silver

- composites, e.g.: glass fillers within polymers, cermets, carbon fibre, epoxy resins.

Safe working practices for AM processes

- Key features of health and safety regulations, or other relevant international equivalents, including:
  - Control of substances hazardous to health (COSHH) regulations, e.g. requirements on the safe storage and use of hazardous substances, manufacturers' safety data sheets, hazard symbols, protection from contact with hazardous substances
  - Personal protective equipment (PPE) at work regulations, e.g. employer responsibility to provide appropriate equipment, e.g. eye protection, heat-resistant apparatus, disposable gloves, protective clothing, dust masks, respirators.
- Safety hazards, including x-rays, ultraviolet rays, metal powders (e.g. flammability, explosions), handling materials, e.g. polymer wire, powders (polymers and metals) and high temperatures.

2 Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes

Design considerations for AM processes

- Advantages of AM processes over traditional manufacturing processes, e.g. machining and casting, including:
  - reduction in mass and cost by redesigning the component for AM processes, whereas using traditional processes, e.g. machining from billet, requires a different design approach
  - further reduction in mass and an improvement in part performance can be achieved by using a mathematical approach called topology optimisation
  - the integration of parts, the ability to manufacture assembled items together that cannot be manufactured together using traditional processes without multiple operations
  - reduced time to manufacture as specialist tooling, e.g. moulds, are typically not required
  - reduced costs as there is typically no need for expensive tooling, e.g. moulds
  - design freedom comes at no extra cost
  - material properties are similar to those achieved using forging and casting processes.
- The disadvantages of AM processes over traditional manufacturing processes, e.g. secondary machining and casting, including:
  - products and components need to be redesigned to realise the advantages
  - materials choice can be limited
  - the process is currently only suitable for jobbing or small batch manufacturing volumes (unless the product or component is high value)
  - the initial capital cost is quite high
  - slow process speed, high part cost, innovations to overcome these factors to create high volume production of parts on AM.

- Design considerations required for additive processes, including:
  - distortion, including warping, shrinkage
  - surface finish considerations, including aliasing (stepping), creation of edges, effect on radii, and sharp corners
  - support structures required to maintain rigidity during manufacture that need to be removed after manufacture
  - scanning existing or modelled physical components to capture the shape in a computer-aided design (CAD) system for manipulation and manufacture using AM processes.

  Component finishing processes post-additive manufacturing

  Characteristics of common finishing processes, including:
  - shot blasting involves directing a high-speed stream of particles, e.g. plastic, glass, or ceramic, at the product to clean, strengthen (peen) and polish a product
  - vibro-energy grinding involves vibrating products with cylindrical or ball shape material, e.g. wet and dry, surfactants, chemicals, powder dispersion
  - chemical processes, e.g. vapour smoothing involves exposing a part to vaporised solvent for a few seconds to melt its outer layer to give it a smooth, glossy finish
  - hot isostatic processing (HIPping) involves heating components to an elevated temperature under pressure to remove internal porosity and voids. The benefits include removing residual stresses, densifying and eliminating voids and occlusions
  - machining (traditional subtractive process) involving the removal of material by cutting, e.g. milling. The benefits include improving the surface texture and dimensional accuracy.

  A limitation of some component finishing processes, e.g. shot blasting, is that they require line of sight to work.

3 Develop a component using additive manufacturing processes safely

Component design for additive manufacture

- Design a component or product suitable for an AM process, including:
  - form complexity, to include a hollow section and section needing support/powder removal during manufacture
  - material, e.g. suitable mechanical properties, single or multiple materials, availability, multiple colours
  - consideration of the structural integrity, including:
    - laminar build-up of layer structure
    - shrinkage allowed for and warping tolerances
    - cooling of the finished product
    - support of overhanging surfaces
  - functionality of the product, e.g. moving parts operate as intended

- additive machine characteristics, including:
  - swept volume and the capacity of the machine
  - stepping (aliasing) surface finish with regards to resolution
  - accuracy within machine parameters
  - resolution within machine parameters
  - processing time considerations to achieve the desired quality and resolution
- transfer of data, e.g. Wi-Fi, direct link, SD card, program file size
- multiple components.

- Creation of a component drawing suitable for transfer to an AM system, including:
  - 3D model created on a CAD software package
  - image created in a photo-editing software package
  - a component scanned in three dimensions and uploaded into a CAD or photo-editing software package
  - process the CAD or photo-edited image into a file suitable for manufacturing on an additive system.

Manufacture of a component using an AM process

- Manufacturing process set up and implemented, including:
  - data transfer – CAD to a programming language (standard tessellation language, STL), resolution within machine parameters, transfer rate and memory size
  - component set-up to include physical size, swept volume, scale, orientation and datum
  - safe working practices, including:
    - use of personal protective equipment (PPE), e.g. overalls, safety glasses, safety boots
    - in place and secure machine guards
  - additive machine set-up, to include single or multiple materials, binders, fillers and support structures
  - additive machine parameters during operation, e.g. infill, layer height, feed rate, travel feed rate, temperature, resolution
  - finishing processes, e.g. chemically rated, sanded, and shot blasted.
- Quality control checks, including:
  - components to be free from burrs, and sharp edges
  - checks for accuracy, e.g. external micrometer.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably	**M1** compare the technology and characteristics of at least two additive processes used to manufacture components safely and sustainability	**D1** justify, using vocational language, the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably
P2 explain how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes	**M2** analyse how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes, including a justification for the finishing processes required	**D2** evaluate how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes, including a justification for the finishing processes required
P3 explain what finishing processes could be applied to two components if they were manufactured using additive processes instead of traditional manufacturing processes		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P4 design a component encompassing a hollow section and/or a support that can be manufactured safely using an additive process	**M3** design a component encompassing a hollow section and/or a support that can be manufactured safely and effectively using an additive process.	**D3** optimise the development of a component encompassing a hollow section and/or a support using additive manufacturing and finishing processes safely, effectively and efficiently, while checking the finished component for dimensional accuracy.
P5 manufacture a component encompassing a hollow section and/or a support, safely using an additive and suitable finishing process	**M4** manufacture a component encompassing a hollow section and/or a support safely and effectively using an additive and suitable finishing processes, while checking the finished component for dimensional accuracy.	
P6 check the finished component for dimensional accuracy against the original design.		

Essential guidance for tutors

Assessment

Learning outcome 1

For distinction standard, learners will provide a balanced justification of at least two AM processes. For example, the evidence may cover why some prototype component manufacturers choose binder jetting for prototype manufacture instead of Fused Deposition Modelling (FDM), because binder jetting enables the manufacture of prototypes using different materials, such as steels, polymers and glass, while the latter process is limited to polymers. Therefore, it can better meet customer needs through using a range of materials. Also, binder jetting requires little support during manufacture due to the binder, while FDM often requires structural support, which means that it requires more post-processing. Learners will also cover the accuracy and surface finish capabilities of the processes and will justify the sustainability of the process and the safe working practices applied.

Overall, the evidence will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will compare the characteristics and technology of at least two AM processes, breaking them down into logical topics. For example, learners investigating the wire deposition and powder bed fusion processes will determine that the former process has a relatively high throughput speed (several kilograms per hour) and is more suited to larger components (well over a metre in length is possible) and the latter process has a low throughput speed (around 0.1 kilograms per hour) and is limited to smaller components (up to 500 × 500 × 500mm build volume).

Learners must also cover typical sustainability considerations and safe working practices. For example, when metal powder is being manipulated full face respirators should be used with high-efficiency particulate arrestance (HEPA) air cartridges to protect the technician.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain how at least two AM processes are used to manufacture components safely and sustainably. For example, the wire deposition process uses a high-powered laser to deposit molten material layer by layer into the shape of a component and inert gas is used to shield the material. Appropriate machine guarding is needed to protect operators during the process.

Overall, the evidence, such as a report, will be logically structured although basic in parts. Evidence may contain minor technical inaccuracies relating to engineering terminology such as mentioning ‘subtractive processes’ instead of ‘additive processes’.

Learning outcome 2

For distinction standard, learners will provide a balanced evaluation of the design of at least two components that could be adapted and improved if they were manufactured using additive processes. For example, learners could suggest that the machines are calibrated to produce accurate results and recalibrating or refining the design to accommodate improvements. Learners will justify how the components would be finished so that they meet the design requirements. For example, a component manufactured by wire deposition processes could be milled and polished following manufacture to ensure that critical dimensions and surface finish requirements are met.

Overall, the evidence should be easy to read and understand by a third party who may or may not be an engineer. It will be structured and presented in a logical way and will use the correct technical engineering terms. Also, it will show all design suggestions and modifications, for example component form, material choice, and suggested and rejected ideas, including the reasons why.

For merit standard, learners will analyse how the design of at least two components manufactured using traditional processes could be improved and adapted using additive processes. Learners will be methodical and break down the design considerations into smaller parts and examine them one at a time. For example, learners will specify an additive process that is capable of manufacturing the components, including the physical dimensions of the component and the required accuracy. Learners will then justify the type of finishing processes required and what is involved in these processes.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain how the design of two components manufactured using traditional processes, such as machining and casting, could be improved and adapted using additive process. Suitable components include automotive and aerospace brackets and automotive valves. For example, learners will explain that the additive process reduces the amount of waste material compared to the traditional machining process.

Learners will also explain what finishing processes are required on the two components if they were manufactured using additive processes. For example, hot isostatic processing may be used to reduce internal porosity and voids in components, which would improve the in-service performance of the component in safety-critical aerospace applications.

Overall, the evidence, such as a report, will be logically structured although basic in parts. Evidence may contain minor technical inaccuracies relating to engineering terminology, such as mentioning 'sodium chloride' instead of 'sodium hydroxide'.

Learning outcome 3

For distinction standard, learners will optimise the design and manufacture of a component or product, including a hollow section and/or support using additive and finishing processes. An optimised component will be one that is designed and manufactured safely, effectively and efficiently. Efficiency mainly applies to the manufacturing process, for example learners will have set the machine parameters, such as layer height, so that the manufacturing time is reasonable while ensuring dimensional tolerances and surface finish are within the machine's capabilities.

Overall, the evidence should be presented clearly and in a way that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will design a component, including a hollow section and/or support that can be manufactured effectively using additive processes. They will use an iterative process to adapt and improve the design of the component, for example by reducing the mass or by combining components together.

Learners will manufacture a component safely and effectively using an additive process. They will also apply an appropriate finishing process, for example to remove any 'aliasing' by sanding. The effectiveness of the process will be demonstrated by checking the critical dimensions against the design.

Overall, the evidence, including observation records, will clearly demonstrate how learners worked safely throughout the process, for example by using appropriate personal protective equipment.

For pass standard, learners will consider the design of a component that will be manufactured using the available AM process and include a hollow section and/or support. For example, learners should take account of the machines swept volume and that support would be needed, such as the wings of a model aeroplane. Suitable components include 3D jewellery, a scale model car, a scale model aeroplane, a scale architectural model, a child's model figurine and scale models of larger components or products are also acceptable.

Learners will use AM and finishing processes to create the component or product and will check the accuracy of critical dimensional against the design. Finishing processes will include the appropriate removal of supports. The final artefact may have some dimensional errors, for example a model may be distorted due to the heat generated during manufacture.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results. For example, learners will show all design iterations, modifications to size, material, suggested ideas and rejected ideas, and the reasons why each decision was taken.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Additive Manufacturing Processes in Industry	You are employed as an apprentice machinist at an engineering firm producing a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems. As part of your training within the company you have been asked to perform an investigation into additive manufacturing processes to better understand their benefits, the technology involved and typical applications, with a view to developing the use of additive manufacturing within the company.	Technical report including diagrams where applicable, giving a balanced justification of the technology and characteristics of additive machining when operated safely and used sustainably

Criteria covered	Assignment title	Scenario	Assessment method
P2, P3, M2, D2	Design Considerations for Additive Manufacturing Processes in Industry	You are employed as an apprentice machinist at an engineering firm producing a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems. As part of your training within the company you have been asked to perform an investigation into additive manufacturing processes to find out how designs for traditionally manufactured components need to be changed if they are produced using AM processes.	Technical report, and diagrams where appropriate, to cover the design considerations and finishing processes of additive machining

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3, M4, D3	Design and Manufacture of a Component Using Additive Manufacturing	You are employed as an apprentice machinist at an engineering firm that produces a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems and processes. As part of your training within the company you have been asked to perform an investigation of additive manufacturing processes to better understand the benefits. In order to support this, you are now going to design and manufacture a product using additive manufacturing system and processes.	An optimised design for a component and the manufacture of the component or product. Annotated photographs, screen shots, sketches, CAD or photo editing software screen shots and drawings. Inspection documents, log book, records of QC checks, observation records or witness statements.

Essential resources

For this unit, learners must have access to:

- AM machine, for example FDM
- software suitable to produce and process 3D models, for example AutoCAD, AutoCAD Inventor, Tinkercad, Adobe Photoshop, Adobe Illustrator, Google SketchUp, plus post-processing software and software to control the AM process
- auxiliary equipment, for example that required to finish the components or for the AM process
- a range of equipment suitable for measuring the dimensional accuracy, for example vernier callipers
- a range of health and safety regulations, as required by the learning outcomes and unit content.

Indicative reading for learners

Textbooks

Barnatt C, *3D Printing* (CreateSpace, 2016) ISBN 9781539655466

Hopkinson N et al, *Rapid Manufacturing: An Industrial Revolution for the Digital Age* (Wiley, 2005) ISBN 9780470016138

Websites

www.caduser.com	Information and up to date articles related to Computer Aided Design
www.renishaw.com/en/additive-manufacturing-case-studies-44452	Case studies related to additive manufacturing across several engineering sectors
www.stratasys.com	Information on additive manufacturing machines, materials, applications and industries

Unit 113: Autonomous Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit aims to give learners an understanding of the increasing role autonomous systems play in advanced manufacturing, how the software and hardware are integrated in autonomous systems, and the skills needed to build and test an autonomous system.

Autonomous systems can adapt by making decisions based on the information gathered about their environment, removing the need for human intervention. In a manufacturing context, an autonomous system may control a particular aspect of the production process or even the whole supply chain. Autonomous systems have the capability to work collaboratively with machines, humans or other autonomous systems using artificial intelligence (AI) and machine learning, which can significantly advance manufacturing capabilities.

Learners will develop an understanding of the benefits and limitations of these types of systems and how software and hardware can be utilised to design and realise autonomous system solutions that meet advanced manufacturing requirements.

Learners will build and test an autonomous bot, which is a type of autonomous system, and will develop some skills in microcontroller programming, hardware assembly and problem solving.

The unit encompasses both theoretical teaching and practical work. It aims to enhance learner awareness of the general concepts and principles associated with the use of autonomous systems in advanced manufacturing.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the concept, applications, benefits and limitations of autonomous systems used in advanced manufacturing
2. Understand the integration of software and hardware to design and realise autonomous system solutions to meet advanced manufacturing requirements
3. Be able to develop an autonomous bot for an advanced manufacturing application.

Unit content

1 Understand the concept, applications, benefits and limitations of autonomous systems used in advanced manufacturing

Concept: systems and machines that are capable of performing a series of operations where the sequence is determined by the outcome of the previous operation or by reference to external circumstances that are monitored and measured within the system itself; systems and machines that can adapt to changes by making decisions based on the information gathered about their environment, which removes the need for human intervention, e.g. building blocks of autonomous systems, gathering information from sensors, analysing that information to plan an action, executing an action to achieve a goal; autonomous bots, humanoids and drones

Applications: understanding the applications of autonomous systems to meet Industry 4.0 expectations and for advanced manufacturing, e.g. ability to compensate for system failures, self-regulation in uncertain situations, condition monitoring, gripping, picking and packing bots, dealing with obstacles, materials, parts or product recognition, transportation of parts and products to and from the assembly line

Benefits of autonomous systems: the improvements that autonomous systems offer for advanced manufacturing, e.g. enhancing efficiency, effectiveness, agility, productivity, repeatability, reproducibility, flexibility, ability to compensate for ageing workforce, minimising waste, ability to augment capabilities of human workforce, less human intervention needed, augmenting collaborative working with both humans and other autonomous systems leading to advances in physical and intelligent capabilities, safety improvements by deploying autonomous systems for dangerous tasks

Limitations of autonomous systems: the drawbacks of autonomous systems for advanced manufacturing, e.g. expensive, not accurately meeting the desired system requirements, malfunctions, costs of fault-finding and correction, highly skilled human maintenance may be required to ensure the smooth functioning of the system, building public acceptance, meeting health and safety regulations, costs of training, workforce morale, streamlining all aspects of production to be sustainable in order to please customers and avoid negative publicity, cybersecurity risks, compliance with standards.

2 Understand the integration of software and hardware to design and realise autonomous system solutions to meet advanced manufacturing requirements

Characteristics of a smart factory: definition and features of advanced manufacturing processes, e.g. connectivity, flexibility, scalability, agility, autonomy, efficiency, sensors and actuators, autonomous robots, Internet of Things (IoT) featuring artificial intelligence (AI), wireless communication protocols, cloud computing, 5G, 6G, HoloLens, augmented reality (AR), virtual reality (VR), mixed reality

Software and hardware: integration of software and hardware for an autonomous system to learn, make decisions, adapt and autocorrect to improve flexibility and reconfigurability, combining sensors and control systems to enable sequences of operations, e.g. AI, machine learning, neural network, fuzzy logic, software (e.g. Raspberry Pi OS, Arduino software [IDE], MPLAB [IDE], GENIE Studio, Atmel studio, Tinkercad, Matlab/Simulink),

microcontrollers (e.g. Raspberry Pi, Arduino, PIC, Beagle Board), PLCs, microprocessors, sensors and actuators, human-machine interface (HMI), block chain, data acquisition, data security

Improvements to autonomous systems: methods that can be used to improve the functionality, performance and efficiency of autonomous systems, e.g. using AI and machine learning to train autonomous machines via repetitive tasks to eliminate the occurrence of faults, data collection and analysis and using deep learning-based algorithms for decision-making tasks

Model-based and data-driven approaches: using the knowledge and understanding of data to develop accurate models that can help select the most suitable solution, e.g. using model predictive controllers, deep learning, reinforcement learning, neural networks, statistical analysis, pattern recognition, simulating uncertainties, integrating machine learning and mathematical programming for more efficient data-driven optimisation frameworks.

3 Be able to develop an autonomous bot for an advanced manufacturing application

Build an autonomous bot: build simple autonomous bot for useful advanced manufacturing applications using an educational kit, e.g. grip bot, picking and packing bots, materials, parts or products recognition bots, transportation bots for delivering parts and products to and from the assembly line

Assembly of an autonomous bot: the assembly of hardware structures that make an autonomous bot from the available educational kit, e.g. protective/aesthetic shell, chassis/framework, axles, wheels; microcontrollers that can read from input devices (e.g. sensors) and control output devices (e.g. actuators, motors) and can store and process data (e.g. Raspberry Pi, Arduino, PIC, Atmel AT89C52, Beagle Board); input devices, e.g. light-dependent resistors, touch sensors, switches, accelerometers, infrared sensors, potentiometers, sound sensors, touch sensors, temperature sensors, position-sensing circuit, colour-sensing circuit, cameras, tilt sensors; output devices, e.g. LEDs and LED arrays, lights, motors (e.g. servo and stepper), actuators, audio/sound emitters (e.g. piezo speakers, buzzers, amplifiers), solenoids, relays (e.g. H-bridge integrated circuits (ICs) for motor control); power source, e.g. photovoltaic cells and batteries; data storage, e.g. solid-state storage device

Software development: production of original code using a development environment and editing of a program and adapting library code snippets – suitable languages include flowchart, C (including derivatives) and basic, e.g. Raspberry Pi OS, Arduino software [IDE], MPLAB [IDE], GENIE Studio, Atmel Studio, Tinkercad, Matlab/Simulink; programming construction techniques including: program flow and control, e.g. using program libraries, subroutines/functions, control structure (sequence, selection, iteration – if, else, switch, case, for, do, while, until, end), delays and timing; logic and arithmetic functions, e.g. variables, comparative operators (equal, not equal, less than, more than, less than or equal, more than or equal); Boolean operators (AND, OR, NOT); arithmetic operations (adding, subtracting, multiplication, division, increment, decrement, random); development and refinement of control programs using suitable programming language constructions and techniques; annotation of code to allow effective repair/debugging of the program and for maintainability.

Test, debug and analyse: testing an autonomous bot for functionality against the expected outcome, producing formal documentation of the test results, analysing test results to identify where faults can be corrected and where improvements can be made to the performance and efficiency of the autonomous bot to meet the original requirements, recording changes that improve the software program and/or hardware.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe two applications of autonomous systems in advanced manufacturing	**M1** explain how an autonomous system can be used to enhance the efficiency and productivity of a given advanced manufacturing application	**D1** analyse how autonomous systems are effectively utilised in two given advanced manufacturing applications
P2 describe the benefits and limitations of using autonomous systems in advanced manufacturing		
P3 describe how software and hardware are used in an autonomous system for an advanced manufacturing application	**M2** explain how an autonomous system for an advanced manufacturing application can be improved using AI and machine learning	**D2** analyse how model-based and data-driven approaches can be combined to enhance the functionality and performance of an autonomous system for a given advanced manufacturing application
P4 design an adequate high-level control program for an autonomous bot in an advance manufacturing application	**M3** develop an autonomous bot safely for an advanced manufacturing application that functions as intended.	**D3** optimise the performance and/or efficiency of an autonomous bot for an advanced manufacturing application.
P5 build and program a partially functioning autonomous bot safely for an advanced manufacturing application, using a microcontroller and at least two input devices, and one output device		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 test a partially functioning autonomous bot safely for an advanced manufacturing application, recording the outcomes of the tests.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

The first assignment could cover P1, P2, M1 and D1 holistically.

To achieve P1, learners need to describe two applications of autonomous systems in advanced manufacturing, for example a gripping bot, a picking and packing bot, a transportation bot to and from an assembly line, or a material, part or product recognition bot. Learners may choose any two applications of autonomous systems and the response must be explicitly linked to a specific purpose in advanced manufacturing.

For P2, learners must describe in detail the benefits and limitations of using autonomous systems in advanced manufacturing. Learners should use their examples of applications from P1 to contextualise their response. Learners could refer to the improvements that autonomous systems provide for advanced manufacturing, such as improved efficiency, productivity, flexibility, agility and functionality. At least four benefits should be described. For the limitations, learners may cover the high initial costs, fault-finding and self-correction issues/costs, possibilities of malfunctions, the impact they have on workforce morale, cybersecurity risks and enhanced maintenance requirements. At least four limitations should be described. Learners should also cover the possible implications of each of the limitations during advanced manufacturing. When describing both the benefits and limitations, learners must also refer to the environment in which the autonomous systems operate and the capital required to maintain effective operation.

For M1, learners need to give a detailed explanation of how an autonomous system can be used to enhance the efficiency and productivity of an advanced manufacturing application. This explanation should be based on a given application and an industry-specific case study given to the learner, around which the learner should contextualise their response. The explanation must demonstrate a good understanding of why, in a global market environment, a manufacturing company can maximise the quality and efficiency of its systems and processes by incorporating an autonomous system into its production processes. Learners must provide detail related to the specific effects on efficiency (in terms of time, money and resources) and productivity (both of the human workforce and the production process in general).

For D1, learners are expected to provide a detailed analysis of how autonomous systems are effectively utilised in two given advanced manufacturing applications. This analysis should be based on given applications and industry-specific case studies given to the learner, around which the learner should contextualise their response. One of the two given applications can be the same as the given application for M1. Learners should refer to aspects like greater productivity, efficiency, agility, scalability and accuracy for each given advanced manufacturing application, but they must also refer to other more technical aspects, such as the ability to compensate for system failures, self-regulation and condition monitoring. The learner’s response must clearly show how the autonomous system is utilised to make each specific advanced manufacturing application more effective.

A second assignment could cover P3, M2 and D2 holistically.

To achieve P3, learners must describe how software and hardware are used in an autonomous system for an advanced manufacturing application. The application could be a gripping bot, a picking and packing bot, a transportation bot to and from an assembly line, or a material, part or product recognition bot. Learners need to give a detailed step-by-step description of how elements of software and hardware are combined in the autonomous system. For example, they might describe how the software and hardware are integrated to enable an autonomous system to learn, make decisions, adapt and autocorrect to improve flexibility and reconfigurability, and how control systems are linked to sensors to enable sequences of operations.

For M2, learners need to explain how an autonomous system for an advanced manufacturing application can be improved using artificial intelligence (AI) and machine learning. Learners could give examples of how AI can be utilised to help machines respond better to unprecedented changes in the environment and to monitor conditions themselves, meaning there is even less need for human intervention. They could give examples of how machine learning can be incorporated into autonomous systems to help machines adapt, monitor parameters and make appropriate corrections to meet the manufacturing system/process functional requirements so that the set goal is achieved.

To achieve D2, learners must give a detailed analysis of how model-based and data-driven approaches can be combined to enhance the functionality and performance of an autonomous system for a given advanced manufacturing application. This analysis should be based on a given application and an industry-specific case study given to the learner, around which the learner should contextualise their response. Learners could refer to the use of model predictive controllers, deep learning, reinforcement learning, neural networks, statistical analysis, pattern recognition, simulating uncertainties and integrating machine learning and mathematical programming. Learners also need to cover why a combination of model-based and data-driven approaches is more effective for enhancing the functionality and improving the performance of the autonomous system instead of just one approach.

A third assignment could cover P4, P5, P6, M3 and D3 holistically.

The specification and minimum functionality of the autonomous bot must be defined for learners so that they are able to test whether it meets requirements set. Learners should assemble the autonomous bot from the educational kit available at the centre. Note that learners must not use ‘visual block and text’ programming languages, such as Scratch and Picaxe Blockly, to program the bot.

To achieve P4, learners will design an adequate control program for the bot, by using a flow chart and/or pseudocode. An adequate design will show the key areas of functionality (inputs, outputs and processes) and how they link together with some commentary. The design of the control program may have some elements of functionality omitted and may be at a high level.

To achieve P5, learners are expected to build and program an autonomous bot safely for an advanced manufacturing application using a microcontroller and at least two input devices and one output device. As a minimum the bot will partially function, for example a bot may not always avoid obstacles, or it may not transport products in an assembly line as it should do. The annotation of the control program may also be inconsistent and patchy. Overall the assembled autonomous bot will function but may have some errors that affect the way it operates, or some elements of required functionality may have been omitted.

To achieve P6, learners should test their autonomous bot for an advanced manufacturing application safely, recording the outcomes of the tests. Learners must highlight where there are any faults or where the bot only partially functions given the requirements of the specification. They must also cover how the errors could be resolved.

For M3, learners will develop, by designing an appropriate control program, building and programming appropriately an autonomous bot safely for an advanced manufacturing application. The bot will function as intended, as throughout the development process the learner will correct software and hardware faults identified during the testing. Learners will also compare the functionality of their autonomous bot against the specification and update it accordingly. They will annotate the code appropriately to explain how the program works. The updated autonomous bot will be appropriately detailed and should work well, with only minor errors present, meaning that when the autonomous bot operates it functions as intended.

The achievement of D3 links to M3. For D3, learners will optimise the performance and/or efficiency of the autonomous bot for an advanced manufacturing application. For example, learners could implement at least one hardware change and one software change that would improve the efficiency and performance of the autonomous bot overall. This could involve learners using a more sensitive input device, or by changing the program codes to increase the velocity of the bot.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Applications of Autonomous Systems for Advanced Manufacturing	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the benefits and limitations of autonomous systems, with examples of how they could be effectively utilised in advanced manufacturing applications. They want you to do this because they are aware that a range of improvements could be implemented to the current manufacturing systems and processes.	A written report
P3, M2, D2	Software and Hardware for Autonomous Systems	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the use of software and hardware for autonomous systems, with specific reference to AI, machine learning and model-based and data-driven approaches. They want you to do this in order to help to identify improvements that can be made to ensure that the autonomous systems used in their advanced manufacturing applications meet their requirements.	A written report

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6 M3, D3	Develop an autonomous bot to solve a problem for an advanced manufacturing application	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to build, program and test a prototype autonomous bot. They want you to do this because they are aware that autonomous systems, such as bots, have the potential to improve efficiency and productivity, and to increase profitability, and they want examples that can be shown to more senior staff.	A written report/portfolio based on practical activities, including evidence of the control program code, annotated photographs/video of the functioning autonomous bot, test results, updated documentation and photographs/ video showing optimisation and changes and observation records

Essential resources

A visit to a factory that utilises autonomous systems would be a good way for learners to see how these systems work in practice and to gain insight.

The centres delivering this unit must be equipped with, or have access to, educational programmable bot kits or centres could alternatively develop, including testing, their own bot kit for each learner to assemble and use.

Learners are expected to build/assemble bots and undertake programming exercises to replicate advanced manufacturing applications.

Educational bot kits

www.uk.rs-online.com/web/c/raspberry-pi-arduino-development-tools/stem-education/stem-robot-kits	STEM educational robot kits www.amazon.co.uk/Robot-Kit/s?k=Robot+Kit	Robot kits
www.nvidia.com/en-gb/autonomous-machines/embedded-systems/jetbot-ai-robot-kit/	AI robot kits from NVIDIA Jet Bot Partners www.ti.com/tool/TIRSLK-EVM	TI-RSLK MAX low-cost robotics system learning kits

Indicative reading for learners

Textbooks

Blokdyk G – *Autonomous Systems, a Complete Guide* (5STARCooks, 2021) ISBN 9780655821601

Blum R – *Arduino Programming in 24 Hours – Sams Teach Yourself* (Sams, 2014) ISBN 9780672337123. A good, detailed guide to programming using the Arduino IDE.

Buckenham A, et al – *BTEC National Engineering Student Book: For the 2016 Specifications* (Pearson, 2017) ISBN 9781292141008

Ibrahim D – *PIC Microcontroller Projects in C: Basic to Advanced*, 2nd edition (Newnes Elsevier, 2014) ISBN 9780080999241. This book demonstrates how to develop a range of microcontroller applications using a project-based approach.

Mouloua M, Hancock P – *Human Performance in Automated and Autonomous Systems: Emerging Issues and Practical Perspectives* (CRC Press, 2019) ISBN 9781138312296

Sauceda S, Cruz J, Perez O – *Manufacturing 4.0: The Use of Emergent Technologies in Manufacturing* (Palibrio, 2018) ISBN 9781506526188

Siegesmund M – *Embedded C Programming: Techniques and Applications of C and PIC MCUS* (Newnes Elsevier, 2014) ISBN 9780128013144. A hands-on introductory course on concepts of C programming using a PIC® microcontroller and CCS Compiler.

Upton E J – *2 IN 1: Rasberry Pi Master Series: Beginner's Guide + Projects Workbook, Rasberry Pi 4 Updated 2020* (independently published, 2019) ISBN 9781672837019

Van Dam B – *PIC Microcontrollers: 50 Projects for Beginners and Experts* (Elektor Electronics, 2008) ISBN 9780905705705. This book has a hands-on approach to projects and gives several useful examples for assessor and learner.

Wodecki –A - *Artificial Intelligence in Management: Self-learning and Autonomous Systems as Key Drivers of Value Creation* (Edward Elgar Publishing Ltd, 2020) ISBN 9781839104947

Websites

www.global.hitachi-solutions.com/blog/industry-4-0-technologies-outcomes-and-the-future-of-manufacturing	Industry 4.0: technologies, outcomes, and the future of manufacturing
www.ottomotors.com/blog/5-industry-4-0-technologies	Five key In ustry 4.0 technologies
www.new.siemens.com/us/en/company/press/siemens-stories/corporate-technology/ai-enhanced-robotics-and-the-future-of-manufacturing.html	Robotics and the future of manufacturing, Siemens
www.arduino.cc/en/Main/Software_	Site for learners to download Arduino IDE, access documents to conduct research
www.i-scoop.eu/industry-4-0/	Industry 4.0: the fourth industrial revolution
www.manufacturing.net/technology/blog/21207750/how-autonomous-manufacturing-will-step-beyond-industry-40	How autonomous manufacturing will step beyond Industry 4.0
www.microsoft.com/en-gb/ai/autonomous-systems	Autonomous systems – Microsoft AI
www.microsoft.com/en-gb/ai/autonomous-systems-solutions?activetab=pivot1%3aprimaryr5	Case studies: bringing autonomy to industrial control systems – Microsoft AI
www.microchip.com	Site for learners to download the free MPLAB® IDE and conduct research
www.nokia.com/networks/insights/autonomous-systems-their-place-in-our-future/	Autonomous systems: their place in our future
www.raspberrypi.org/software/	Site for learners to download Raspberry Pi OS (previously called Raspbian) and access books and magazines to conduct research
www.tinkercad.com/	Site for learners to design, build, test circuits, program and simulate microcontrollers

Videos

www.youtube.com/watch?v=S1QCZW92fU4	Tutorial to support using MPLAB® IDE
www.youtube.com/watch?v=PhJKhV5l-i4	Tutorial to support creating a project in MPLAB® IDE
www.youtube/BpJCAafw2qE	Raspberry Pi 4: getting started
www.youtube.com/watch?v=fJWR7dBuc18	Arduino Tutorial 1: Setting up and programming Arduino for absolute beginners

Unit 114: Environmental Engineering and Sustainability

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

In this unit, learners will gain an understanding of environmental engineering and sustainability in their sector and will cover analyses that can be used to reduce the environmental impact of an engineering process, product or system.

They will learn about the environmental issues that face engineers, from the use of finite resources and materials, through the ways in which products are manufactured, to the disposal of engineered products at the end of their useful life. Learners will look at the approaches that can be taken to reduce the environmental impact of engineering processes, products and systems, for example through redesigning a component to allow it to be manufactured using a different process that reduces material and energy usage.

Learners will also gain an understanding of the processes involved when completing a life cycle analysis and a system analysis. They will apply these approaches to assess a product or system that is manufactured or serviced in the workplace and then redesign a component or part of the product or system in order to reduce its environmental impact.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about sustainability in engineering

2 Understand design, system and product-based approaches to reducing environmental impact

3 Be able to carry out an environmental impact analysis of an engineered product or system

4 Be able to carry out a redesign of an engineered product or system to reduce environmental impact.

Unit content

1 Know about sustainability in engineering

Environmental issues facing engineers: climate change, pollution, energy use, carbon emissions/capture, use of finite natural resources

Natural resources: materials, fossil fuels, water resources

Principles and approaches to reduce the impacts of engineering activities: international protocols and agreements: Paris Agreement, Kyoto Protocol, UN Climate Change Conference; government policies: Climate Change Act

Sustainable approaches and solutions in engineering: low-carbon solutions, reductions in material and energy use, recycling, energy recovery, sustainable supply chains, methods of reducing pollution

Alternative and renewable energy sources: solar, wind, tidal, HEP, nuclear, waste-to-energy

Energy storage methods: batteries, mechanical storage, flywheels, pumped storage

Energy demand: trends, changes in demand for energy, changes in energy use, capacity for energy generation

Energy reduction: energy-saving schemes, smart meters, incentives, approaches to energy efficiency

Energy management: energy management audits, energy use, monitoring and targeting energy savings

Alternative fuels and power sources for vehicles: hydrogen fuel cells, biodiesel, natural gas, electricity, solar energy, hybrid vehicles, electrified railways, synthetic jet fuels

2 Understand design, system and product-based approaches to reducing environmental impact

Life cycle analysis: raw material extraction, processing/manufacturing/ production, transportation, use/reuse, end of life/recycling

Types of life cycle analysis: cradle to grave, cradle to gate, cradle to cradle, well to wheel

Systems analysis: inputs to the system, system components, connections between components, outputs from the system, consumables, connections to other systems

Energy-based approaches to sustainable design: increased efficiency of plant and equipment, use of renewable energy sources, reduction in energy losses

Materials-based approaches to sustainable design: use of renewable materials, use of recycled/recyclable materials, selecting materials with desirable properties to allow for a long service life, reduction in waste

Product-based approaches to sustainable design: e.g. utilising new parts with lower energy requirements, simplifying systems or products so there are fewer moving parts to lessen the need to cool and/or use oil-based lubrication, building flywheel energy storage into processes, reducing the number of components or parts, designing for recycling

Technology-based approaches: e.g. use of advanced manufacturing techniques, use of newly developed materials, use of innovative technologies, use of modern manufacturing systems

3 Be able to carry out an environmental impact analysis of an engineered product or system

Life cycle assessment stages: raw material extraction; processing and manufacturing; transportation; use, repair and maintenance; end of life

System analysis stages: inputs; processes, components, mechanisms; connections with other systems; outputs; operating principles and parameters

System analysis techniques: block diagrams, event trees, cause-consequence diagrams, SWOT analysis

Parameters of the analysis: identification of a product/system to analyse, system boundaries, factors to include, expected outcomes

Scope of the analysis: which stages to include, which components/processes to include

Environmental impact analysis processes: define the scope of the analysis, analyse the problem, analyse the requirements of the system/product, design/redesign the system/product, assess designs, propose a solution

Results of the analysis: e.g. meeting objectives, identification of trends, opportunities to reduce environmental impacts, graphical representations of results; interpretation of results to produce a design specification for the redesign of a product or system

4 Be able to carry out a redesign of an engineered product or system to reduce environmental impact

Identification of potential approaches to reduce environmental impact of an engineering product or system: e.g. reduction in waste, reduction in processes/processing, improved life span of the product/system, improved efficiency, design for manufacture, design for recycling/reuse

Design specification/criteria: e.g. quantity, maintenance, finish, materials, weight/mass, capacity, aesthetics, product life cycle, sustainability, carbon footprint, reliability, safety, ergonomics, usability, manufacturing, system parameters

Initial and developed ideas and solutions to reduce the environmental impact of an engineering product or system: technical design criteria; idea generation; initial design proposals (fitness for purpose, refinements, meeting design criteria); developed design idea/chosen solution (purpose and function, mechanical/electronic principles, material requirements, manufacturing processes, assembly arrangements)

Communication of designs: freehand sketching and diagrams (2D and 3D, illustrations, technical); CAD; annotations; documentation (detail and assembly drawings, specifications, parts list, material lists)

Reporting: evaluation of the outcomes; assessment of reduced environmental impact; presentation of solution to third parties

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe environmental issues faced by engineers and sustainable approaches that can be used to address them	**M1** compare the benefits of alternative sustainable solutions to address environmental issues	**D1** evaluate alternative sustainable solutions to address environmental issues and suggest improvements that might make each solution more effective
P2 explain why engineers need to consider energy use, demand and storage when developing sustainable solutions		
P3 describe how engineers can use life cycle analysis and systems analysis to reduce the environmental impact of an engineering process or product	**M2** explain how engineers can use life cycle analysis, systems analysis and approaches to sustainable design to reduce the environmental impact of an engineering process or product	**D2** evaluate the benefits of completing a life cycle analysis and a systems analysis when selecting approaches to sustainable design for an engineering process or product
P4 describe approaches to sustainable design that can be used to reduce the environmental impact of an engineering process or product		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 define the parameters and scope for an environmental impact analysis for an engineering product or system	**M3** explain the outcomes of a completed environmental impact analysis on an engineering product or system	**D3** evaluate the outcomes of a completed environmental impact analysis with respect to its parameters and scope
P6 carry out an environmental impact analysis on an engineering product or system		
P7 interpret the results of an environmental impact analysis to produce a design specification for the redesign of an engineering product or system	**M4** assess the chosen design solution against the results of an environmental impact analysis and design specification.	**D4** evaluate the chosen design solution against the results of an environmental impact analysis and design specification and suggest further improvements.
P8 produce design proposals that meet the requirements of the design specification		
P9 present, using a range of techniques, details of how the chosen design solution reduces environmental impact.		

Essential guidance for tutors

Assessment

Assessment of this unit will be based both on reports and on practical investigation and design activities. While a theoretical approach is suitable for learning outcomes 1 and 2, the assessment activities for learning outcomes 3 and 4 should be linked to an engineering product or system with which the learner is familiar. Ideally, the product or system would be one that the learner works with regularly, either in a manufacturing or a servicing capacity.

For learning outcome 3, learners might need to add their own sketches, drawings/circuit diagrams, notes, lists, charts, photographs, etc to support their environmental impact analysis. The product or system should be sufficiently complicated to allow for a number of different possible improvements to be made, but should not be excessively complex. For more complicated systems or products, either a component or a sub-system could be considered, and learners will need to make decisions related to the scope of the analysis. For example, for a product, will they cover all stages of a product life cycle or focus on raw material extraction through to transportation to customers? For a system, will all inputs and outputs be considered, or only the ones which are key to the operation of the system?

Employed learners should be encouraged to work closely with their own company/ employer when deciding on a product or system to analyse, so that the activity is meaningful and has sufficient scope to allow access to all the relevant assessment criteria.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require answers that demonstrate additional depth and/or breadth of treatment.

Learning outcome 1

For P1, learners will need to describe at least two environmental issues that face engineers, for example those associated with the use of finite resources or pollution from engineering processes. They will also need to consider sustainable approaches that could be taken with respect to these environmental issues, for example through the use of alternative materials to reduce the need for extraction of finite materials or the use of filtering to remove particulates from emissions. P2 requires learners to explain why engineers need to consider the way that energy is used, both in engineering and in the wider world, including changes such as increased demand for electricity, for example as a result of more electric vehicles being sold. Learners will need to include details of how energy can be stored and the implications of these methods when developing sustainable solutions.

For M1, learners will develop their responses to P1 and P2 by comparing the benefits of different approaches to address at least two environmental issues. For example, for one of the environmental issues learners may consider different energy sources as one solution and different manufacturing processes as a second solution. Learners will need to do something similar for the second environmental issue.

To achieve D1, learners will need to evaluate the alternative solutions that have been identified for M1 and suggest further possible improvements that would make each of their selected sustainable solutions more effective.

Learning outcome 2

For P3, learners will need to describe how engineers can use life cycle analysis and systems analysis to reduce the environmental impact of an engineering process or product. As part of this they will consider the five main stages of a life cycle assessment and what is focused on during these stages; they will also describe the stages of a systems analysis, for example for a piece of equipment that they use in their workplace. They will give details of different approaches to carrying out the analyses and give brief reasons why, for example, an engineering organisation might consider cradle to gate as being more appropriate for the products they produce. For P4, learners will describe examples of energy-based, materials-based, product-based and technology-based approaches that can be used to achieve sustainable designs. Again, these could be associated with a process or product that learners have experience of in their workplace; however, not all the approaches need to relate to the same process or product.

To achieve M2, learners will need to develop their responses for P3 and P4 to explain how the life cycle and systems analyses can be used in combination with the four different approaches to achieving sustainable design for an engineering process or product in order to reduce environmental impact.

For D2, learners will need to evaluate the benefits of carrying out a life cycle analysis and a systems analysis, for example being able to identify the stages in the process where there are the greatest opportunities to implement sustainable design solutions, or where the greatest benefit could be achieved, and how the outcomes of an analysis can inform decisions as to which sustainable design approach to take.

Learning outcome 3

Learners will need to select either an engineering product or system on which to carry out an analysis. The product or system should allow them to identify a number of possible opportunities to redesign features and reduce the environmental impact (for learning outcome 4). The product or system should be something that the learner is familiar with, and not overly complex. For example, learners should not investigate a car as a product, but might consider the lighting system or wheels.

For P5, learners will need to define the parameters and scope for an environmental impact analysis. For example, they might decide that cradle to gate is appropriate for a car wheel given the relatively long life of such a product, and also what the scope will be, such as focusing on the materials and processes used in making the wheel but not the tyre. For P6, learners will then carry out the environmental impact analysis on their selected product or system, and they will identify which aspects of the product or system have negative effects on the environment.

For M3, learners will need to explain the outcomes of their completed environmental impact analysis, including the implications of the outcomes, for example indicating the stages of the life cycle or system operation that have the greatest negative effects on the environment and should be focused on to reduce the environmental impact of the engineering product or system.

This will need to be developed for D3, where learners will evaluate these outcomes with respect to the parameters and scope of the analysis. For example, they might recognise that there is a large negative impact related to extraction of raw materials for batteries; however, there are no alternative sources so mitigation measures are needed to reduce impacts.

Learning outcome 4

Learners will make use of the outcomes of their environmental impact analysis to redesign part of the product or the system. The redesign should address more than one aspect where the environmental impact of the product or system could be reduced. For example, focusing only on the type of material used would not be sufficient.

For P7, learners will need to interpret the results of their environmental impact analysis to produce a design specification for the redesign of the engineering product or system. The design specification need not cover all the factors in the unit content for learning outcome 4; however, it will be sufficiently detailed to allow objective judgements to be made about the improved/chosen design solution and whether it is fit for purpose. For P8, the design specification will need to be used to produce a range of ideas/proposals for improvements to the design of the engineering product or system. Learners will need to present a portfolio of evidence that includes initial design ideas/proposals and a developed/chosen design solution using freehand sketches, formal drawings and CAD. The developed/chosen design solution should show a reduction in environmental impact and be presented using formal drawings, parts lists and materials lists to a third party (P9).

For M4, learners will need to assess the chosen design solution when compared to the original design, the outcomes of the environmental impact analysis and also the requirements of the design specification, giving reasons as to why their chosen design offers environmental impact improvements and how this is achieved.

This will need to be developed for D4, where learners will evaluate the chosen solution holistically, considering areas where environmental impact improvements have been made and also where further improvements might be possible. For example, developments in additive manufacturing might allow more reductions in the mass of a component if it could be produced with a honeycomb structure that provides the same structural integrity as a solid component.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Environmental Issues Faced by Engineers	You are an apprentice engineer and your supervisor has asked you to investigate environmental issues, including those associated with energy, that are faced by engineers, and to produce a report that includes details of approaches that could be used to address these issues. They want you to do this as reducing environmental impact is a key objective for your company.	A written report containing details of environmental issues faced by engineers and the sustainable solutions that could be used to address them
P3, P4, M2, D2	Approaches to Reducing Environmental Impacts	You are an apprentice engineer and your supervisor has asked you to produce a report investigating the use of life cycle analysis and systems analysis and how both can be used to select suitable approaches to produce sustainable solutions to engineering problems. They want you to do this as reducing environmental impact is a key objective for your company.	A written report containing details of how life cycle analysis and systems analysis can be used by engineers to identify approaches that will reduce the environmental impact of engineering products or processes

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M3, D3	Environmental Impact Analysis	You are an apprentice engineer and you have been asked by your supervisor to identify a product or system that you work with, whose environmental impact you think could be reduced. You then need to complete an environmental impact analysis and present the outcomes to your supervisor. They want you to do this as reducing environmental impact is a key objective for your company.	A report that includes a completed environmental impact analysis of an engineering product or system plus the outcomes from the analysis
P7, P8, P9, M4, D4	Redesigning an Engineering Product or System	You are an apprentice engineer and you have been asked by your supervisor to produce a design specification and to then redesign aspects of the product or system so that it has a reduced impact on the environment. They want you to do this as reducing environmental impact is a key objective for your company.	A portfolio of evidence that includes a design specification, initial proposals/ ideas and a chosen/presented design solution, along with an evaluation that considers further improvements to the product or system

Essential resources

Learners will need access to appropriate engineering products or systems for the completion of the environmental impact analysis. They will need access to CAD and equipment for producing formal drawings for learning outcome 4.

Indicative reading for learners

Textbooks

Allen D, Shonnard D – *Green Engineering* (Prentice Hall, 2016) ISBN 9780132657075

Allen D, Shonnard D – *Sustainable Engineering: Concepts, Designs and Case Studies* (Pearson, 2011) ISBN 9780132756587

Boyle G – *Energy Systems and Sustainability: Power for a Sustainable Future,* 3rd edition (Oxford University Press, 2021) ISBN 9780198767640

Ciambrone, D – *Environmental Life Cycle Analysis* (CRC Press, 2018) ISBN 9781351450430

Gibson A, Johnson A – *Sustainability in Engineering Design* (Elsevier, 2014) ISBN 9780124045910

Gibson J et al – *How to Do Systems Analysis* (Wiley, 2007) ISBN 9780470130582

Klemes, J – *Assessing and Measuring Environmental Impact and Sustainability* (Elsevier, 2015) ISBN 9780128022337

Zindani D, Davim J – *Sustainable Manufacturing and Design* (Elsevier, 2021) ISBN 9780128221617

Websites

www.eao.stanford.edu/research-areas/life-cycle-assessment	Background information about life cycle assessments
www.medium.com/disruptive-design/quick-guide-to-sustainable-design-strategies-641765a86fb8	Article introducing methods for sustainable design that could be applied to engineering systems and products
www.sustainabledevelopment.un.org	United Nations Sustainable Development Knowledge Platform (general reference)
www.carbontrust.com	Carbon Trust: information about carbon footprinting
www.greenspec.co.uk/life-cycle-assessment-lca	Background information about life cycle assessments
www.tutorialspoint.com/system_analysis_and_design/system_analysis_and_design_overview.htm	Overview of methods of completing a systems analysis

Unit 115: Aircraft Materials and Hardware

Level:	**3**
Unit type:	**Optional in Aerospace Engineering pathway only**
Assessment type:	**Internal**
Guided learning hours:	**90**

Unit introduction

This unit will develop learners' knowledge and understanding of the materials and hardware used in the construction, maintenance and repair of aircraft.

An understanding of aircraft materials and hardware is a fundamental requirement for those wishing to practice as aircraft engineering technicians, no matter what their chosen specialisation.

This unit will provide learners with an understanding of the processing, identification, microstructure, properties and use of ferrous and non-ferrous metals, as well as composite materials. In particular, steels and light alloys are considered in detail, as are polymers and polymer matrix composites, since it is these materials that are most widely used in aircraft construction. The mechanical testing of steels and light alloys is considered, as a way of determining their properties. The nature of corrosion and the recognition of the types of corrosion that may occur on aircraft metallic structures, are also covered.

A general electro-mechanical approach has been adopted with respect to the types of hardware covered in the unit. Aircraft fastening and locking devices are first covered, followed by fluid plumbing, riveting, transmission and aircraft mechanical controls hardware. Then finally, a further outcome is devoted to understanding the types, construction, characteristics, identification methods and use of aircraft electrical cables and connectors.

This unit covers part of the knowledge required for those taking the European Aviation Safety Agency (EASA) Part 66 examinations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the methods of producing and treating ferrous and non-ferrous metals and alloys

2 Understand the effect of microstructure on the macroscopic properties of ferrous and non-ferrous metals and alloys

3 Know the nature of corrosion and how the properties of ferrous and non-ferrous materials are determined using testing techniques

4 Know about the structure and properties of non-metallic materials

5 Know the types, characteristics and applications of aircraft fasteners and general hardware

6 Understand the construction, characteristics and applications of aircraft electrical cables and connectors.

Unit content

1 Know the methods of producing and treating ferrous and non-ferrous metals and alloys

Ferrous metals and alloys: iron and plain carbon steel production, e.g. blast furnace, open hearth, basic oxygen, and electric-arc process; heat treatments, e.g. annealing, normalising, hardening, tempering, case hardening, surface hardening (such as flame, induction, nitriding) iron-carbon diagram; steel alloys and properties, e.g. with chromium, molybdenum, manganese, vanadium, tungsten, nickel; identification methods, e.g. SAE classification, MIL-Spec, part number, colour code; applications, e.g. engine rotary and static parts, engine mounts, landing gear struts, axles and bearings, flap and slat track mechanisms, heat shields, hinges, fasteners

Non-ferrous metals and alloys: aluminium production (Bayer process bauxite to alumina, smelting process); heat treatment and processing, e.g. annealing, solution treatment, anodising, precipitation treatment, age hardening, cold working (such as rolling, cladding, drawing, forging); alloying and properties, e.g. aluminium with copper, manganese, silicon, magnesium, zinc, lithium, chromium, nickel; other non-ferrous metals and alloys such as (titanium, tungsten, copper, magnesium and nickel); identification, e.g. SAE, AMS, BS, DTD, ASN specifications, aluminium association incorporated alloy group series method, non-heat treatable and heat treatable codes; applications, e.g. flying control surfaces, fuselage structure and skin, empennage structure and skin, cabin floors, cowlings, panels, fixtures and fittings

2 Understand the effect of microstructure on the macroscopic properties of ferrous and non-ferrous metals and alloys

Macroscopic properties: mechanical properties, e.g. density, strength, stiffness/elasticity, specific strength, specific stiffness, plasticity, toughness, hardness, brittleness, ductility, malleability; other properties, e.g. heat resistance, expansivity, conductivity, resistivity, durability, passivity, ease of fabrication and manufacture

Microstructure: atomic lattice packing (body-centred cubic [BCC], face centre cubic [FCC], closed packed hexagonal [CPH]); features of grain structure, e.g. formation, boundary, size, crystal defects (such as point, line or dislocation, planar), slip planes; effect of grain structure, lattice packing and alloying on, e.g. ductility, brittleness, toughness, fracture toughness, hardness and strength, of parent material

3 Know the nature of corrosion and how the properties of ferrous and non-ferrous materials are determined using testing techniques

Corrosion: chemical fundamentals, e.g. the corrosion cell, rust reactions, dry corrosion, formation by galvanic action, microbiological mechanisms and stress, the redux table and metal potential, active and passive materials, material susceptibility to corrosion; types of corrosion, their recognition and cause, e.g. microbiological, hydrogen embrittlement, mercury contamination, surface, crevice, exfoliation, intergranular, bimetallic, pitting, fretting, stress and fatigue corrosion

Testing techniques and properties: tensile test (strength, ductility and stiffness; hardness test, e.g. Brinell, Vickers pyramid, Rockwell, shore scelerscope; impact tests, e.g. Charpy, Izod; fatigue tests (toughness), e.g. rotary machine, full fatigue rig (S/N curve, fatigue limit, endurance limit)

4 Know about the structure and properties of non-metallic materials

Structure: microstructure of polymers (thermoplastics, thermosets, elastomers); structural make-up and use for plastic, Perspex, glass fibre reinforced plastic (GFRP), ceramic matrix composite (CMC), polymer matrix composite (PMC) and metal matrix composite (MMC) materials

Properties: of, e.g. composite material reinforcing fibres, matrix and core materials (such as strength, stiffness/elasticity, specific strength and stiffness, toughness, ductility, fatigue resistance)

Characteristics of polymers and composites: e.g. directional and non-directional strength and stiffness in tension, compression, shear and bending, cost, environmental degradation, weathering, ageing, reaction to ultra-violet light, heat and chemical attack

Use and identification: of, e.g. reinforcing fibres and cloths (such as glass cloth, aromatic-polyamide aramid/Kevlar, boron, ceramic fibres), matrix materials (such as thermosets, thermoplastics, metals) and core materials (such as paper and metal honeycomb, balsawood, Styrofoam, methane foam, PVC foam, cellulose acetate)

5 Know the types, characteristics and applications of aircraft fasteners and general hardware

Aircraft fasteners: e.g. screws, nuts, wing nuts, bolts, studs, (type, thread form, markings, identification codes, dimensions), rivets (such as materials, dimensions, tolerances, allowances, spacing and pitch, solid, chobert, avdel, jo-bolts, blind), locking devices (such as lock nuts, tab and spring washers, friction devices, specialist fasteners (such as lock wired devices, quick release, toggle, bayonet)

Aircraft general hardware: e.g.

- fluid plumbing hardware (such as solid and flexible pipes, unions, olives, fittings, bayonet and threaded connectors)
- transmission hardware (such as springs, bearings, belts, chains, pulleys, sprockets)
- flexible control cables (such as aircraft control cables, bowden cables, teleflex cables, swaged, bolted and pinned end fittings, swaging methods and checks for integrity, turnbuckles, turn barrels, handling)

6 Understand the construction, characteristics and applications of aircraft electrical cables and connectors

Aircraft electrical cables: e.g. performance, current and voltage rating, construction, classification, insulation, screens, types (such as nyvin, tersial, fepsil, kapton, high-tension, co-axial), coding, crimped terminations, cable sleeves, cable supports, clamps, blocks, grommets)

Aircraft electrical connectors: e.g. terminal blocks, high density module blocks, pins, ground/earth points, threaded and bayonet multi-pin couplings, plugs, rack and panel connectors

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the production process of plain carbon steel and a heat treatment after production that will add hardness to the surface of this steel		
P2 use a given sample and a given identification method to identify the type of an alloy steel and give two aircraft structural applications for this material		
P3 describe the production process for aluminium and a heat treatment process that may be used to return the aluminium to a malleable state after cold working		
P4 identify the type of an alloy using a given sample and the alloy group series method, and give two aircraft structural applications for this material		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 describe the mechanical properties and other properties of two metal alloys that make them suitable for fuselage structure and skin	**M1** compare the mechanical and other properties of steel alloys, titanium alloys and magnesium alloys and give two examples of the best use of each of these alloys in aircraft production	
P6 explain how BCC, FCC, and CPH lattice packing and features of grain structure affect the ductility and brittleness of parent metallic materials	**M2** explain what is meant by a passive material and for two different passive metallic materials used on aircraft, explain how this property is advantageous	
P7 describe the action of a corrosion cell that occurs between rivets and the aircraft skin and explain the circumstances under which corrosion is accelerated	**M3** explain the effect on the microstructure and therefore the parent metal of coldworking and alloying	
P8 identify three types of corrosion with the aid of preprepared illustrations	**M4** explain the significance of the S/N curve with respect to the measurement and testing of fatigue and discuss the differences between fatigue limit and endurance limit.	
P9 explain why inter-granular corrosion is considered dangerous in aircraft metallic structures		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P10 carry out a tensile test using standard steel and aluminium alloy test pieces and determine the strength and ductility properties of these alloys from test results		
P11 describe the differences in the microstructure of thermosets, thermoplastics and elastomers and describe the structural makeup of GFRP, CMC, PMC, and MMC materials		**D1** compare the properties and characteristics of aluminium-lithium alloys and polymer matrix composites and explain their use and effectiveness for aircraft construction
P12 describe the properties and characteristics and explain the use and methods of identification, for two reinforcing fibres, two matrix materials and two core materials used in the production of aircraft composite structures		**D2** choose appropriate metallic and/or non-metallic materials for the sandwich construction of an aircraft floor panel and give reasons for your choice.
P13 use an approved method to identify each of a range of given aircraft standard and specialist fasteners, rivets and locking devices, detail their characteristics and give an example of the use for each		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P14 use an approved method to identify each of a range of given aircraft fluid plumbing, transmission, control cable and fittings hardware, detail their characteristics and give an example of the use for each		
P15 identify the cable type of a range of given aircraft electrical cables, state their current and voltage rating and give an aircraft circuit use for each type		
P16 explain the importance of aircraft earthing and the care and safety precautions necessary for aircraft earthing points and electrical connectors.		

Essential guidance for tutors

Assessment

It is expected that a range of assessment methods will be used for this unit. Evidence may be gathered from written responses to assignments and formal assessments. Evidence from laboratory reports and observation records will also be appropriate particularly in order to achieve the assessment criteria associated with the materials testing element of learning outcome 3.

Five assignments could be used to assess this unit, although opportunities exist to combine or split the suggested assessment activities, as centres see fit.

The first assignment could consist of written tasks that require learners to describe the production of steel (P1) and aluminium (P3) and relate these production methods to a qualitative understanding of the microstructure obtained in the material as a result of the production processes and any subsequent heat treatments. Learners must also demonstrate an understanding of the identification methods used for steel and aluminium and their associated alloys, as well as the aerospace uses to which these materials may be put (P2, P4).

The second assignment is also likely to consist of formal written tasks. Learners must be able to describe the properties associated with two metal alloys that make them suitable for fuselage and aircraft skin production (P5). Their description must mention the structural efficiency properties that make these alloys suitable for this application. They must be able to relate and explain how the different forms of lattice packing, the associated number of slip planes and the nature of the grain structure impact on the ductility and brittleness of the parent metallic material (P6). To achieve the related merit criteria, learners need to build on their knowledge of material properties and microstructure in order to be able to compare the properties of steel, titanium and magnesium alloys and provide appropriate examples in aircraft production (M1). They must also be able to explain the meaning of passive metallic materials and detail the uses to which this advantageous property may be put, during aerospace manufacture and maintenance (M2).

A third assignment could cover P7, P8, P9, P10, M3 and M4. To achieve P7, learners must understand the mechanisms and necessary components that produce a corrosion cell and relate this understanding to a real life application where an aircraft skin is riveted using two materials of differing potential. Learners must identify three types of corrosion from pre-prepared drawing or actual physical examples (P8) and explain the dangers associated with inter-granular corrosion within aircraft structures (P9). They must be able to carry out a standard tensile test on both an aluminium and steel alloy test piece and be able to establish the alloys' strength and ductility properties from the test itself and from the test results (P10).

M3 and M4 require further tasks enabling learners to explain the effect on the microstructure and therefore the parent material of cold working and alloying (M3). In particular mention must be made of the increases in dislocation density and strain energy within and around the grains that results in increased hardness and strength in the parent material. With respect to the results of a series of fatigue tests and/or fatigue data collected from live aircraft, learners must be able to explain the significance of the S/N curve produced and the meaning of the parameters identified on the curves, including fatigue limit and endurance limit, related to different metallic materials (M4).

A fourth assignment could be used to assess P11, P12, D1 and D2. Learners must describe the differences in microstructure between thermoplastic and thermoset polymers and elastomers and describe the structural make-up of the most common composite materials (P11). They must also describe the properties and characteristics and explain the use and methods of identification for two reinforcing fibres, matrix materials and core materials, used in the production of aircraft composite structures (P12). It is suggested that learners are steered towards two different variants of PMC, when making their choice on suitable reinforcing fibres, matrix materials and core materials.

The two distinction grade criteria can also be built into this assignment and would require learners to compare and contrast the properties and characteristics of aluminium-lithium alloys and polymer matrix composites and be able to debate (set up an argument) for their use and effectiveness in aircraft construction (D1). They must also be able to assess the mechanical and physical properties and characteristics required of an aircraft composite material floor panel and argue for the choice of appropriate materials for its construction based on the materials ability to meet the required properties and so be fit for purpose (D2).

A fifth assignment could cover the aircraft hardware learning outcomes. Learners must be able to detail the characteristics and identify a range of mechanical fasteners, locking devices and rivets, using an approved method. This may include but not be exclusively confined to the reading of part numbers and other codes on correctly labelled packaging and being able to confirm from features of the give codes or numbers, that the correct hardware is contained within the packing (P13). Learners must also be able to carry out a similar identification exercise for a given selection of fluid plumbing, transmission, control cables and fittings and electrical cables and as before, they must be able to detail their characteristics (P14, P15). Learners must finally be able to explain the importance of aircraft earthing and detail the care and safety precautions necessary to maintain earth points and fittings in a serviceable condition (P16).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4	Production, Identification, Heat-treatment and Application of Ferrous and Non-ferrous Metals and Alloys	A formal assignment requiring learners to respond to written tasks.	Written responses to set written tasks.
P5, P6, M1, M2	Macroscopic Properties and Microstructure of Metallic Materials	A formal assignment requiring learners to respond to written tasks.	Written responses to set written tasks.
P7, P8, P9, P10, M3, M4	Corrosion and Metallic Materials Testing	A two-part assignment, consisting of set written tasks followed by a metallic materials testing exercise.	Written responses to set tasks and a written laboratory report resulting from materials testing.
P11, P12, D1, D2	Non-metallic Materials	A formal assignment requiring learners to respond to written tasks (*Note*: evidence for successful completion of criteria D1 and D2 may be gathered here as part of this assignment or a separate investigative assignment could be set).	Written responses to set written tasks (If suggestion as per *Note* is followed, then a written report resulting from the investigation could be used to provide evidence).

Criteria covered	Assignment title	Scenario	Assessment method
P13, P14, P15, P16	Aircraft Mechanical and Electrical Hardware	A two-part assignment consisting of a multiple-choice test and an oral identification exercise.	Written response to multiple-choice test questions and oral response to identification exercise given under controlled conditions.

Essential resources

The following resources are considered the minimum required to effectively deliver the unit content:

- a bench or other type of tensile test machine
- example of aircraft metallic and composite materials and structural components
- good quality illustrations of different types of corrosion, identified on aircraft or preferably some physical examples of corrosion types
- a good range of aerospace fasteners, locking devices, rivets, transmission, fluid plumbing and manual control cables and fixtures hardware
- a good selection of electrical cables, cable looms and electrical connectors and ancillary fittings.

Although not essential, access to a chemistry laboratory to investigate the nature of corrosion and additional testing machines such as hardness testers, Izod and/or Charpy impact and some form of rotary bench mounted fatigue tester would most definitely encourage interest and enhance the learning experience.

Indicative reading for learners

Textbooks

Black B – *Workshop Processes, Practices and Materials*, 5th edition (Routledge, 2015) ISBN 9781138784727

Bolton W – *Materials for Engineering*, 2nd edition (Routledge, 2016) ISBN 9781138136168

Crane D – *Airframe Volume 1: Structures*, 3rd edition (Aviation Supplies and Academics, 2008) ISBN 9781560277125

Unit 116: Installing and Commissioning Engineering Equipment

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit will give learners the knowledge and skills needed to correctly install, commission and hand over a range of mechanical and electrical engineering systems.

The correct installation and commissioning of engineering equipment is a vital aspect in preventing its failure at a later date. This unit gives learners an insight into how both mechanical and electrical/electronic equipment is installed and commissioned. Learners will have a chance to demonstrate their practical skills in installing and commissioning a piece of engineering equipment used on an engineering system. The system worked on can be from any of a variety of industry sectors, ranging from traditional mechanical systems to one found in the medical sector.

Before an installation/commissioning engineer leaves the equipment in the hands of its new owner, they need to ensure correct handover has taken place. The last part of this unit will give learners the opportunity to show that they are aware and know about this process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how to install and commission mechanical equipment

2 Know how to install and commission electrical/electronic equipment

3 Be able to install and commission equipment used on an engineered system

4 Know how to hand over an installation after commissioning an engineered system.

Unit content

1 Know how to install and commission mechanical equipment

Installation procedure: procedures to include:

- pre-installation activities, e.g. site accessibility, utilities availability, installation consumables, documentation availability
- during installation activities, e.g. adhering to risk assessment, COSHH and other relevant safety standards, authority to carry out the installation activities, providing safe access and working arrangements, safe isolation of services, disposing of waste items in a safe and environmentally acceptable manner, leaving the work area in a safe condition
- methods and techniques, e.g marking out of locating and securing positions, drilling and hole preparation, fitting inserts, positioning equipment, aligning equipment, levelling equipment, shimming and packing, fitting anti-vibration mountings, securing by using mechanical fixings, applying screw fastening locking devices
- using moving equipment, e.g. slings, cranes, fork lift, portable lifting devices, block and tackle, rollers/ skates, hoists, jacks
- using instruments, e.g. straight edges and feeler gauges, engineer's levels, dial test indicators, measuring instruments, plumb lines and taut wires, alignment telescopes, laser equipment, self-diagnosis equipment
- making connections, e.g. mechanical, electrical wired, fluid power, utility service
- testing that the installation works
- checking and testing activities, e.g. six point, half-split, input-to-output, functional testing, self-diagnostics, emergent problem sequence, injection and sampling, unit substitution
- completing relevant paperwork, e.g. installation records, company specific paperwork, job card

Types of mechanical equipment: e.g. machine tools, industrial compressors, conveyors, turbines, elevators, processing plant, hoppers or large storage vessels, lifting and handling equipment, engines, process control equipment

Commissioning procedure: procedures to include:

- pre-commissioning activities, e.g. site accessibility, checking installation, ensure documentation is available
- using methods and techniques, e.g. start-up procedures, confirming that the equipment/system meets specifications, running equipment at the recommended initial settings, checking for leaks during operations, making sensory checks, running through the operating sequence, checking for correct functioning, loading the system incrementally, making any necessary adjustments to settings to achieve the specification parameters, conducting a trial run of the equipment at full power/speed/flow, confirming that the final product/process outcomes meet specifications, monitoring and recording measurements and observations, shutting down/isolating the equipment/installation to a safe condition
- using instruments/devices, e.g. alignment, levelling, linear measuring, speed measuring, multimeter, continuity tester, bleeding equipment, pressure testing, flow testing, diagnostic aids, PLC/PC equipment
- completing relevant paperwork, e.g. commissioning log/record, job sheet, company specific paperwork, handover report

2 Know how to install and commission electrical/electronic equipment

Installation procedure: procedures to include:

- pre-installation activities, e.g. site accessibility, utilities availability, installation consumables, documentation availability
- during installation activities, e.g. adhering to risk assessment, COSHH and other relevant safety standards, authority to carry out the installation activities, providing safe access and working arrangements, safe isolation of services, disposing of waste items in a safe and environmentally acceptable manner, leaving the work area in a safe condition
- methods and techniques, e.g. marking out of location positions for components/modules, positioning and securing of equipment and components, securing by using mechanical fixings, securing by using masonry fixings, drilling and hole preparation, levelling and alignment
- connecting to electrical supplies, e.g. single phase, three phase, direct current, low voltage (up to 115v), combination power circuits
- using test instruments, e.g. multimeter, watt meter, voltmeter, ammeter, insulation resistance tester, light meter, earth-loop impedance tester
- making cable terminations, e.g. sealing and protecting cable connections, making mechanical/screwed/ clamped connections, soldering and de-soldering, attaching suitable cable identification, routeing and securing wires and cables, heat shrinking, crimping, stripping cable insulation/protection, adding cable end fittings
- testing that the installation works
- checking and testing activities, e.g. six point, half-split, input-to-output, functional testing, self-diagnostics, emergent problem sequence, injection and sampling, unit substitution
- completing relevant paperwork, e.g. installation records, company specific paperwork, job card

Types of electrical/electronic equipment: module/components, e.g. switchgear, alarm devices, programmable controllers, power factor correction devices, motors and starters, luminaries, panels or sub-assemblies, control devices, communication equipment, cable connectors, encoders or resolvers, conduit, bus bars, safety devices, emergency/standby batteries, overload protection devices, sensors and actuators, electronic modules/units, trunking, tray work; cable types, e.g. mineral, armoured, data/communication, fibre optics, PVC, screened, loom/harness

Commissioning procedure: procedures to include:

- pre-commissioning activities, e.g. site accessibility, checking installation, ensuring documentation is available
- methods and techniques, e.g. start-up procedures, confirming equipment/system meets specification, running equipment at recommended initial settings, checking electrical integrity, making sensory checks, running through the operating sequence, checking for correct functioning, loading the system incrementally, making necessary adjustments to settings to achieve specification parameters, conducting a trial run of the equipment at full power/speed/flow, monitoring and recording measurements and observations, shutting down/isolating the equipment/installation to a safe condition; using instruments/devices, e.g. multimeter, watt meter, voltmeter, ammeter, insulation resistance tester, light meter, earth-loop impedance tester
- completing relevant paperwork, e.g. commissioning log/record, job sheet, company specific, handover report

3 Be able to install and commission equipment used on an engineered system

Installation activity: activities to include:

- methods and techniques, e.g. marking out positions, drilling and preparing holes, moving and positioning, aligning and levelling, shimming and packing, fitting anti-vibration mountings, securing items
- using test instruments, e.g. alignment devices, linear measuring devices, electrical measuring equipment, fluid/power testing equipment, instrumentation test equipment, PLC/PC test equipment
- checking and adjusting, e.g. making visual checks of the installation for completeness and freedom from damage, topping up fluid/oil reservoirs, ensuring that all bolts are correctly torqued and locking devices are fitted to fasteners, ensuring that all electrical connections are correctly made, earth bonding is secure and connections covered, ensuring that all pipe connections are correctly made, secure and leak free, ensuring that all moving parts are guarded and clear of obstruction, checking that the system operates to the installation specification, making sensory checks of the system
- checking and testing activities, e.g. six point, half-split, input-to-output, functional testing, self-diagnostics, emergent problem sequence, injection and sampling, unit substitution
- completing relevant paperwork, e.g. installation records, company specific paperwork, job card

Engineering system: equipment/components, e.g. mechanical (such as machine tool, processing plant, turbine engine, transfer equipment, heat and ventilation), electrical/electronic (such as switchgear, distribution panels, motors, starters, luminaries), fluid power (such as compressors, pumps, accumulators, filters, regulators), process controller (such as PLCs, data communication links), instrumentation and control (such as pressure, flow, temperature, speed, weight), medical (such as cardiovascular, physiological monitoring and infusion, anaesthetic and ventilation, medical imaging, mechanical and electromechanical assistive technology)

Commissioning activity: activities to include:

- pre-start up, e.g. checking for damage, correct positioning, correctly secured, utilities operative, appropriate fluid levels, clear of obstructions, correct labelling, guards, fences and safety systems operative
- methods, techniques and procedures, e.g. running system (low speed), checking for leaks, sensory checks, incrementally load, conducting trial run, monitoring and recording measurements, shutting down and isolating
- using instruments, e.g. devices (such as alignment, measuring), testing, electrical measurement
- completing relevant paperwork, e.g. commissioning log/report, corrective action report, job sheet, customer-specific documentation, handover report

4 Know how to hand over an installation after commissioning an engineered system

Handover procedures: run the installation; confirm all safety procedures are working; give instructions, e.g. modifications, unusual features, operating instructions, service/maintenance requirements; handover documentation; people involved, e.g. commissioning engineer, maintenance supervisor, production/process supervisor; complete all relevant paperwork, e.g. job card, installation and commissioning report, handover paperwork; confirm handover of responsibility for the equipment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe an installation procedure for a given type of mechanical equipment		
P2 describe a commissioning procedure for a newly installed given type of mechanical equipment		
P3 describe an installation procedure for a given type of electrical/ electronic equipment containing five different modules/components and two different types of cable		
P4 describe a commissioning procedure for a given newly installed type of electrical/ electronic equipment		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P5 carry out an installation activity for a given piece of equipment used on an engineering system	**M1** explain the differences and similarities when installing mechanical and electrical/ electronic types of equipment, including safety considerations	
P6 carry out a commissioning activity for a given piece of equipment used on an engineering system	**M2** describe how a given piece of equipment used on an engineering system was installed and commissioned.	
P7 describe how to hand over an engineering system after installation and commissioning.		**D1** explain the importance of correct installation, commissioning and handover procedures.

Essential guidance for tutors

Assessment

Evidence can be generated through a variety of methods such as assignments, practical activities and in-class written assessments.

To achieve a pass grade, learners must be able to describe installation and commissioning procedures for both mechanical and electrical/electronic types of equipment. They will also need to demonstrate, through a practical activity, that they can install and commission a simple piece of equipment as used on an engineering system. Finally, they need to demonstrate that they know how to hand over an engineering system that has been installed and commissioned, although actual handover is not required. The criteria associated with learning outcomes 1, 2 and 4 relate to equipment in its wider sense, whereas the criteria associated with learning outcome 3 relate to simpler equipment that is likely to be found on more complex engineering systems.

To achieve a merit grade, learners must show that they understand the differences and similarities when installing mechanical and electrical/electronic types of equipment, including safety considerations. They will also be able to describe how a given piece of equipment used on an engineering system was installed and commissioned. This piece of equipment and installation and commissioning could relate to that carried out as a practical activity for some of the pass criteria requirements.

To achieve a distinction grade, learners must show they understand the importance of correct installation, commissioning and handover procedures.

This unit could be assessed through the use of three assignments. The first assignment could cover the pass criteria associated with learning outcomes 1 and 2 (P1, P2, P3 and P4). Written tasks could be given that ask learners to describe an installation procedure for a given type of mechanical equipment and describe a commissioning procedure for a given newly installed type of mechanical equipment (P1 and P2). Because the type of mechanical equipment is given, different learners can be given different types of mechanical equipment according to their preferred area. Whilst examples are given in the unit content, this list is not exhaustive.

A similar set of tasks could be given for P3 and P4. Whilst again there is freedom of choice for the type of electrical/electronic equipment given, it must include five different modules/components and two different types of cable.

For all four criteria evidence is likely to be in the form of a written response. If any descriptions are given verbally then a very detailed record of this needs to be kept, supported by a witness statement/observation record.

A second assignment could address criteria P5, P6, M1 and M2. Again, individual tasks could be set to target each criterion. Physical resources need to be made available to support the practical activity carried out for P5 and P6. Again, the given engineering system can be based on the learner's preferred area of work. Whilst examples are given in the unit content this list is not exhaustive. Centres should not make the practical task too complex.

Evidence for P5 and P6 is likely to be in the form of a witness statement/observation record supported by supplementary records such as pre-start check sheets, annotated photographs and completed documentation etc.

Further written tasks could be set to cover criteria M1 and M2. Responses and evidence are likely to be in the form of a written report.

The final assignment could address criteria P7 and D1. This could ask learners to describe how to hand over an engineering system after installation and commissioning (P7). This could be based on the practical activity carried out in the second assignment. The assignment could also ask them to explain the importance of correct installation, commissioning and handover procedures (D1). It is important that this assignment is attempted last as it relies on understanding gained from the other assignments and activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3 and P4	Part 1: Installing Mechanical Systems Part 2: Installing Electrical Systems	Learners need to describe to a new member of staff the common installation and commissioning techniques for mechanical and engineering systems.	A written report setting out the common techniques and procedures for a range of different systems and describing the installation and commissioning procedures for a newly installed mechanical and electrical system.
P5, P6, M1 and M2	Installation and Commissioning in an Engineering System	A practical activity installing a simple, learner-selected system.	A record of observation by the tutor of the learner's installation activity. A witness statement/ observation record supported by written supplementary records such as pre-start check sheets, annotated photographs and completed documentation This could be included in a written report completed by the learner.

Criteria covered	Assignment title	Scenario	Assessment method
P7 and D1	Handing Over	Written activity based on the previous, practical assignment requiring learners to describe the handover of the specific engineering system.	A written report describing the handover procedures appropriate as follow-up to the practical activity, explaining the importance of correct installation, commissioning and handover procedures.

Essential resources

Centres delivering this unit will require access to a variety of instruments used in installation and commissioning work along with relevant industrial standard documentation. A range of both mechanical and electrical/electronic equipment types are required, particularly engineering system equipment/components as listed in the unit content.

Indicative reading for learners

Textbooks

Allan D, Blaus J – *Electrical Installations*, 2nd edition (Heinemann, 2008)
ISBN 9780435467043

Linsley T – *Advanced Electrical Installation Work* (Newnes, 2005)
ISBN 9780750666268

Unit 117: Battery Manufacturing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit covers electric and hybrid vehicle batteries as well as battery manufacturing systems and processes. Learners will explore the range of batteries that have been developed and used in hybrid and electric vehicle applications and how they provide power for the vehicle relevant to its demands. Learners will review how batteries interact with vehicle systems in both hybrid and electric situations, how batteries interact with existing carbon fuel systems in hybrids and how the traditional mechanical systems are powered by the battery in an electric vehicle. Learners will look at the operation of common battery types and be able to describe the chemical reactions that occur to generate and store the needed electrical power.

The unit continues on to cover the manufacturing processes involved in the manufacture and assembly of battery cells, modules and packs. Learners will review the manufacturing processes that are involved in the creation of a variety of battery cell types. The manufacturing sequences will be explored, and the machinery needed to create the cells identified and studied. The unit progresses on to look at the way the cells are combined to create the individual battery modules needed to create the final battery packs. Learners will

look at the construction processes needed to allow the correct power to flow from each cell and then each module. The links through busbar additions and power management circuits will be reviewed, together with the cleaning protocols needed to prevent damage or malfunction after each construction phase. The final assembly process for the battery packs, their framework and circuits will be understood. Throughout the unit learners will develop an understanding of the safety protocols needed in manufacturing and especially within the battery manufacturing environments.

Learning outcomes

In this unit you will:

1 Know about batteries used in electric and hybrid vehicles

2 Understand the operating principles of electric and hybrid vehicle batteries

3 Explore electric and hybrid vehicle battery manufacturing

4 Know about safe working practices when manufacturing electric and hybrid batteries.

Unit content

1 Know about batteries used in electric and hybrid vehicles

Battery types used in electric and hybrid vehicles in own region

- Battery types used in electric and hybrid vehicles:
  - battery type identification used for electric and hybrid vehicle manufactures, e.g.:
    - Toyota hybrid (Nickel-metal hydride),
    - Tesla (Lithium-Ion)
    - Jaguar electric vehicles (Lithium-ion)
  - identification of common batteries used, or have been developed for use, in electric and hybrid vehicles, e.g.:
    - alkaline
    - sodium-nickel chloride, sodium-sulphur
    - lithium-ion
  - battery power sizes, e.g. battery kWh and potential range of the vehicle
  - variety of electric vehicle manufacturers' warranties (vehicle and battery) set out in time and distance measurements, e.g.:
    - Jaguar
    - BMW
    - Hyundai.

Interactions between the vehicle systems and the batteries

- An overview of the electrical systems in a hybrid vehicle that link to the low voltage (LV) and/or the high voltage (HV) systems, e.g.:
  - HV systems, e.g. drive systems, battery management controller, inverters, direct charging system
  - LV systems, traditional circuits, e.g. engine management, lighting, heating, power steering, DC charging systems
  - how the systems are charged, managed and how they co-exist within the vehicle.
- An overview of the electrical systems in an electric vehicle that require different voltage levels, e.g.:
  - HV systems, e.g. direct drive system, battery and power management, regeneration systems
  - LV system identification, e.g. heating and air conditioning, electric brake system, power-assisted steering
  - LV systems: comparisons between hybrid and electric vehicle systems, different operating requirements, input variances, adaptions for operation and impacts, e.g. heat pumps, liquid cooling systems, heat exchangers, servo-assisted to electronically controlled master cylinders.

2 Understand the operating principles of electric and hybrid vehicle batteries

Operating processes of different battery types used in electric/hybrid vehicles

- Working processes of electric and hybrid vehicle batteries:
  - battery types, e.g. Alkaline (Ni-Cad, Ni-Fe, Ni-MH), Sodium-nickel chloride (Na- $NiCl_2$), Sodium-sulphur (Na-S), Lithium-ion (Li-ion)
  - construction of each battery type, e.g. Alkaline (Ni-Cad, Ni-Fe, Ni-MH), Sodium- nickel chloride (Na-$NiCl_2$), Sodium-sulphur (Na-S), Lithium-ion (Li-ion)
  - working cycle of the different battery types, charging, discharging and storage of power, e.g. Alkaline (Ni-Cad, Ni-Fe, Ni-MH), Sodium-nickel chloride (Na-$NiCl_2$), Sodium-sulphur (Na-S), Lithium-ion (Li-ion)
  - battery technical specifications for the following battery types; Alkaline (Ni-Cad, Ni-Fe, Ni-MH), Sodium-nickel chloride (Na-$NiCl_2$), Sodium-sulphur (Na-S), Lithium-ion (Li-ion)
  - battery operating specifications, e.g. specific energy (Wh/kg), specific power (W/kg), amp-hour efficiency, operating temperature (oC), self-discharge (%), life cycles to 80%, recharge time (h)
  - the impacts of the specifications on the battery when in use in the vehicle, vehicle users and potential battery life.

3 Explore electric and hybrid vehicle battery manufacturing

Battery cell construction process

- Anode and cathode chemical and material location and preparation.
- Component coating, e.g. anode material combination, cathode material combination.
- Drying phase: material drying and cooling.
- Electrode completion: e.g. ESD removal, cleaning, sizing, measurement of conformity, re-cleaning.
- Final shaping processes, e.g. cutting, slitting, cleaning, drying, anode and cathode shaping.
- Separator insertion.
- Pouch preparation and installation: cell tab connection, pouch insertion, partial sealing.
- Finishing processes, e.g. electrolyte addition, degassing and final sealing.
- End of line (EOL) and final testing procedures, e.g. charge and shipping voltages, loss rate, visual inspection.

Battery module construction process

- Cell preparation: product identification e.g. barcode scanning; cleaning, e.g. plasma, ionised air cleaning, isobutanol cleaning, surface treatment.
- Tab and connector shaping: tab trimming, tab bending, tape application and cell bending, foam application, glue application, cell testing, e.g. polarity, weighing, quality vision, size checks.
- Frame installation (if needed), e.g. cleaning and taping.
- Stacking, e.g. compression pads, end plates, welding or fixings, compression.

- Busbar addition: fitment; parallel, series and series-parallel connections; tab attachments and welding.
- Welding checks: non-destructive testing, resistance testing.
- Printed circuit board and battery management unit installation.
- Case sealing and welding: thermal exchange plates, sealant addition, welding.

Battery pack construction process

- The pack is designed depending on the vehicle it is being used in and the batteries that are being purchased for use, voltage requirements and location within the vehicle chassis.
- Insertion of the battery modules.
- Interconnection of the individual battery modules.
- Thermal and electric integration including – Busbar system, Battery management system, Cooling system, HV module, HV and LV connections.
- Sealing and leaking testing.
- Charging, flashing and thermal testing.
- End of line testing.
- Connection and integration of the battery module to vehicle chassis and HV and LV systems.

4 Know about safe working practices when manufacturing electric and hybrid batteries

Manufacturing safety protocols

- Risk assessment of manufacturing processes, e.g. individual operation assessments, movement risk assessments, positional risk assessments.
- Specialist assessments for Control of Substances Hazardous to Health (COSHH) Regulations, e.g. chemical storage assessments, chemical movement assessments, chemical usage risk assessments.
- Individual procedural analysis: e.g. single process risk assessments, work position manufacturing operation risk assessment, manual/automatic machine operations risk assessments, maintenance risk assessments.
- Visual management in manufacturing, e.g. caution signs, exit and entry signs, moving vehicle signs, walkways, protective equipment signage, chemical signs, mandatory action signs, prohibition signs.
- Manufacturing guidelines for correct equipment use.
- Safety managers, line inspections and safe working practice monitoring.
- Production line safety systems, e.g. infrared monitoring, movement sensors, torque trips.

Battery handling safety protocols

- Potential hazards related to battery handling:
  - electrical, e.g. shocks, insulation testing procedures, electro-static build up
  - heat, e.g. burns, cooling failures, component damage, welding arcs
  - chemical, e.g. coat materials, powder coating, respiratory challenges.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Identify battery types used in electric and hybrid vehicles	**M1** Explain interactions between different battery types and electric and hybrid vehicle power systems	**D1** Evaluate different types of battery used in electric and hybrid vehicles in terms of operating principles, vehicle interactions, energy efficiency and suitability of application
P2 Describe different interactions between batteries and vehicle power systems in electric and hybrid vehicles.		
P3 Explain the operation of two typical types of electric/hybrid battery.	**M2** Analyse in detail the operation of two typical types of electric/hybrid battery within different vehicles.	
P4 Describe the battery cell construction process for a commonly used type of electric/hybrid battery.	**M3** Explain the manufacturing process of a common battery cell, module and pack used in electric and hybrid vehicles.	**D2** Assess the efficiency of processes and testing during the manufacture of electric and hybrid battery modules.
P5 Describe the battery module construction process for a commonly used type of electric/hybrid battery.		
P6 Describe the battery pack construction process for a commonly used type of electric/hybrid battery.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Describe key safety protocols used in manufacturing environments.	**M4** Explain key safety protocols in a general, and battery-specific, manufacturing environment.	**D3** Compare safety protocols in general manufacturing, and a battery manufacturing, environments and the potential safety measures that could reduce the risks.
P8 Describe the use of additional safety protocols needed in battery handling environments.		

Essential guidance for tutors

Assessment

1 Know about batteries used in electric and hybrid vehicles; and

2 Understand the operating principles of electric and hybrid vehicle batteries

For Distinction standard, learners will need to demonstrate they have researched and understood the various hybrid and electric vehicle batteries that are available for common use. They must evaluate the operation of two types of electric and hybrid vehicle battery and the levels of interaction they have with other vehicle systems. Learners must also include in their evaluation evidence of the use of data to allow judgements to be made
about efficiency, output levels and lifespan of the two types of battery.

For Merit standard, learners need to explain the interactions and links between electric vehicle and hybrid vehicle battery types and wider vehicle power systems, for example start/charge systems, electric steering, electronic brake systems. Learners must then analyse how two different battery types operate under different scenarios to produce
drive and ancillary functions, for example stop-start traffic or constant speed cruising on highways.

For Pass standard, learners must show that that they can identify examples of a range of battery types that are used in electric and hybrid vehicles, based on information such as their chemical components or through manufacturers' descriptions. Learners also need to describe the common interactions between vehicle systems and the main power battery. This must include details of one interaction with hybrid vehicles and two interactions within electric vehicles. Learners need to also include information about the changes needed in some traditionally mechanical and/or fluid-based systems that cannot function correctly within electric vehicle systems. Learner should then select two of the available battery types and explain their construction and operating processes in terms of their working cycles.

3 Explore electric and hybrid vehicle battery manufacturing

For Distinction standard, learners need to assess a full battery manufacturing process, reviewing the construction processes that make up each stage of the cell, module and pack build. Learners will need to assess each main process stage, including the machinery and equipment needed to complete each construction stage and why they are used. Learners should highlight the human interactive stages, the semi-automatic stages and the fully automated stages. Learners should comment on the suitability of these processes and their efficiency during the manufacture and testing of the electric and hybrid battery modules.

For Merit standard, learners need to review a suitable manufacturing process for a full battery end to end process. The learner must cover the three levels of production: cell, module and battery pack. The learner should explain what happens at each point of the process and how this is completed. The explanation should include details of operator and automated processes.

For Pass standard, learners need to describe the manufacturing process and equipment needed to produce a battery cell for an electric or hybrid vehicle. All main construction steps should be described including the equipment and machinery used in the process. Learners should review the module construction process and the pack construction process in a similar manner. Learners should describe the automatically and manually completed operations and how the products are tested at each stage.

4 Know about safe working practices when manufacturing electric and hybrid batteries

For Distinction standard, learners must review safety protocols used in manufacturing and in the battery handling and manufacturing process. Learners should then compare the protocols in both production environments and identify the similarities and the differences. The learner should clearly identify any safety measures that specifically reduce risks in the battery manufacturing environment and justify why these measures are needed.

For Merit standard, learners must explain the key safety protocols used in general manufacturing environments and also in battery handling and manufacturing environment. Learners should clearly explain the reason for the protocol in these environments and the impact on the process and operators if these protocols fail.

For Pass standard, learners need to describe the key safety protocols used in manufacturing settings. Learners should include details of why they are in place and who they affect, making references to appropriate regulations. Learner should use their understanding of manufacturing protocols to describe the additional safety measures that need to be in place for battery handling and manufacturing environments.

Essential information for assignments

There is a maximum number of two summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcomes: 1 and 2 (P1, P2, P3, M1, M2, D1)

Learning outcome: 3 (P4, P5, P6, M3, D2)

Learning outcome: 4 (P7, P8, M4, D3)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Know about batteries used in electric and hybrid vehicles	A report that details the different types of battery used (at least two) in electric and hybrid vehicles, and covers: • operating principles • interactions with power systems • energy efficiency, output levels and lifespan • operation and suitability of their application within different vehicles, including for drive and ancillary functions. Annotated diagrams/images should support the written evidence.
2 Understand the operating principles of electric and hybrid vehicle batteries	
3 Explore electric and hybrid vehicle battery manufacturing	A report that details each of the different stages in a manufacturing process for a common battery cell, module and pack used in electric and hybrid vehicles, and also: • covers the machinery and equipment used • includes information about the human interactive stages, the semi-automatic stages and the fully automated stages • makes judgements about the efficiency of the construction processes and testing. Annotated diagrams/images/charts should support the written evidence.

Learning outcome	Recommended assessment approach
4 Know about safe working practices when manufacturing electric and hybrid batteries	A presentation with detailed notes that compares the specific safety protocols and regulations in battery manufacturing environments with the safety protocols and regulations in general manufacturing environments, covering: • the similarities and differences • why the specific safety measures used to reduce risks in a battery manufacturing environment are needed • the possible impact on processes and operators if the protocols fail. Relevant diagrams/images/charts should be used to enhance the presentation.

Resource requirements

For this unit, learners must have access to a range of information sources related to battery types, operational information and construction processes. It would benefit learners if the manufacturers and battery types were those that they have access to and are more likely to gain experience working with. Learners would also benefit from details of the manufacturing layouts and processes at each stage and how the components are tested before and after full assembly.

Indicative reading for learners

Textbooks

Perdontis M – *Battery Manufacturing & Electric & Hybrid Vehicles* (*Energy Science, Engineering and Technology: Electrical Engineering Developments*) (Nova Science, 2012) ISBN 9781614705833

Li J – *Advances in Battery Manufacturing, Service, and Management Systems* (Wiley-IEEE Press, 2016) ISBN 9781119056492

Unit 118: Electric and Hybrid Vehicle Motors

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit covers the main types of motor that are used in electric and hybrid vehicle drive systems. Learners will develop an understanding of the use of different varieties of AC and DC drive motors, and the positioning of single and in-wheel motor drive systems in relation to the vehicle and the advantages and disadvantages these placements provide. The structure of the in-wheel motors and their operating process will be evaluated. The single motor drive system will be explained together with the additional component requirements to support this drive type. The internal structure of the motor and the different wiring and operating systems will be examined. This will include the variety of rotor types and the manufacturing process differences needed to create these varieties. The stator wiring systems will be explored, and the operation of the various types explained. The manufacturing process for the variety of rotors and stators will be explained and evaluated for efficiency of design, ergonomically measured using lean manufacturing tools. Safety issues will be reviewed and evaluated. The common and specialist manufacturing equipment used in the construction process will be identified and explained. A case study could be used to show a typical construction line for rotors, stators and complete motor units.

Learning outcomes

In this unit you will:

1 Know about the design and functioning processes of hybrid and electric vehicle motor drive systems

2 Know about electric vehicle motor types, construction and operation

3 Know about electric vehicle motor manufacturing equipment and processes

4 Understand safety and manufacturing ergonomics relevant to electric vehicle motor manufacturing.

Unit content

1 Know about the design and functioning processes of hybrid and electric vehicle motor drive systems

Power and drive systems used in hybrid vehicles

- Drive system:
  - in gearbox motors:
    - location: in gearbox powerline, link to output shaft, electrically variable transmission assembly
  - flywheel motors:
    - location: between engine and gearbox, within flywheel.
- Operating layout:
  - in gearbox motors:
    - construction: rotor, stator, cooling components, inverter, mechanical gearbox
  - Flywheel motors:
    - construction: rotor, stator, cooling components, flywheel components, housing, disconnection clutch, hydraulic system.
- Component function:
  - gearbox motor:
    - rotor function, stator function, housing systems, driveshafts, drive gears
  - flywheel motor:
    - rotor, stator, damper, one way clutch, disconnection clutch actuator, cooling channel.

Power and drive systems used in electric vehicles

- Drive system:
  - direct drive: motors are located at each drive wheel, rotor, stator, wheel bearing, operating electronics, cooling system
  - indirect drive single motor systems: single motor fitment, locations, fixed ratio gearbox, driveshafts, differential and constant velocity joints.
- Operating layout:
  - direct drive:
    - rotor positioning, e.g. fixed to wheel, mounted on the wheel bearing
    - stator: mounted on backplate/suspension components, contains electronics
  - indirect drive single motor systems: rotor, centrally mounted, gear drive to drive output shaft;
    - Stator: mounted around the rotor in the gearbox casing, linked to electronic controls, inverter, epicyclic geartrain, diff drive, output shafts.
- Component function:
  - direct drive:
    - rotor, stator, electronics, cooling system, bearings
  - indirect drive:
    - rotor, centrally mounted, gearing systems, cooling systems, differential system.

2 Know about electric vehicle motor types, construction and operation

Commonly used electric vehicle motor types and their operation

- AC motors:
  - asynchronous motor: squirrel cage type, wound rotor type; slip between speed and magnetic field
  - synchronous motor: synchronous induction, permanent magnet, rotor and magnetic field speed
  - rotor winding: hairpin or stranded wire
  - operating principles: asynchronous, synchronous.
- DC motors:
  - brushless: electronically commutated motor, permanent magnet rotor
  - brush type: series wound, separately excited shunt wound
  - operating principles.

Stator construction types and operation

- Stator construction types.
- Star wound construction.
- Delta wound construction.

Rotor construction types and operation

- Rotor construction types:
  - squirrel cage, permanent magnet, wound synchronous rotor, hairpin, stranded wire.

3 Know about electric vehicle motor manufacturing equipment and processes

Commonly used manufacturing equipment

- Common machinery, e.g. wire feeding and straightening tools, bending tools; laser welding tools, moulding machines, presses, lathes, demoulding and cleaning machines, heating and cooling machines, gasket machinery, drilling.
- Specialist tools, e.g. hairpin insertion tools, winding machines, stator lacing tools; resin application machinery; powder coating machines; potting machines, balancing machine.

Electric motor manufacturing processes

- Rotor construction processes, e.g. paper preparation, shaft press, slot insulation, star disc assembly, winding, paper and slot wedges insertion, cup assembly, connection and welding, electrical testing, impregnation, balancing, machining slip ring, electrical test.
- Stator construction processes, e.g. slot insulation, winding, insertion, int. form, connection, lacing, final forming, testing, impregnation, testing.
- Unit construction processes, e.g. housing heating rotor mounting, bearing and gear assembly and fitting, drive cover assembly, leak pressure testing, final assembly, electrical testing

4 Understand safety and manufacturing ergonomics relevant to electric vehicle motor manufacturing

Safety in electric vehicle motor manufacture

- Potential threats related to motor production:
  - electrical, e.g. shocks, insulation testing procedures, electro-static build up
  - heat, e.g. burns, cooling failures, component damage, welding arcs
  - chemical, e.g. coat materials, powder coating, respiratory challenges.

Ergonomic layouts and processes in electric vehicle manufacture

- Ergonomic design: e.g. lean manufacturing processing, workplace organisation, kaizen pods, access points, parts delivery systems, shortest distance travelled, process balancing.
- Machine placement, e.g. power supply, line position, material delivery, safety risks, heat and light generation, chemical management and use.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe one common motor drive system used in a hybrid vehicleapplication.	**M1** Explain the design and functioning processes of two motor drive systems for one hybrid and one electric vehicle.	**D1** Evaluate the efficiency and use of two motor drive systems types for one hybrid and one electric vehicle applications.
P2 Describe one common drive system used in an electric vehicle application.		
P3 Describe commonly used motor types for AC and DC drive motors.	**M2** Explain the construction and operation of AC and DC motors, including stator and rotor types, used in electric vehicles.	**D2** Evaluate construction and operation of AC and DC motors, rotor and stator types, in electric and hybrid vehicle applications.
P4 Describe the construction and operation of stator and rotor type motors used in electric vehicles.		
P5 Describe commonly used and specialist manufacturing equipment used to construct electric or hybrid vehicle motors.	**M3** Explain one electric or hybrid vehicle motor manufacturing process including the commonly used and specialist equipment used in its construction.	**D3** Analyse the manufacturing process and equipment used to construct an electric or hybrid vehicle motor system.
P6 Describe one electric or hybrid motor manufacturing process.		
P7 Explain safety issues that can occur within vehicle motor manufacturing for use in electric drive systems.	**M4** Analyse safety and ergonomic factors which must be considered when creating a manufacturing process for electric and hybrid vehicle motors.	**D4** Evaluate an electric vehicle drive system manufacturing process for its safety procedures and use of ergonomic production layouts
P8 Describe ergonomic factors that need to be considered when manufacturing electric and hybrid vehicle motors.		

Essential guidance for tutors

Assessment

1 Know about the design and functioning processes of hybrid and electric vehicle motor drive systems

For Distinction standard, learners will need to locate information on a motor drive system for an electric and for a hybrid vehicle. Learners can choose the types of motor and their locations; however their evaluations must include details of the efficiency of their chosen motor drive system and include comparisons with alternatives, including alternative motor locations.

For Merit standard, learners need to explain the design and construction of two motor drive systems. They must include one electric vehicle and one hybrid vehicle motor drive system. The explanation can be either single or at wheel motors for an electric vehicle. For a hybrid vehicle motor this could either increase the torque or fully power the vehicle. Learners will need to explain the working processes of each of the motors and associated components and how they provide drive for the two vehicle types.

For Pass standard, learners must describe a commonly used motor drive system for one electric vehicle and one hybrid vehicle. For the electric vehicle this can be from either a single motor system or a multi-motor type. Learners will need to describe the location and operation of each motor, including the components they are attached to. Learners will need to also describe a hybrid vehicle motor drive system. Learners can describe a motor that delivers additional driving torque or one that drives the vehicle independently. The description should include the position and operation of each drive system component, its location and how it links to any mechanical systems.

2 Know about electric vehicle motor types, construction and operation

For Distinction standard, learners will evaluate the construction and efficiency data available for the four different types of motor that have been researched for both electric and hybrid vehicles. Learners should make comparisons between the operation of each type and torque delivery at all speed ranges, giving advantages and disadvantages of the different motors when used in electric and hybrid vehicles.

For Merit standard, learners need to explain the construction of AC and DC motors used in both electric and hybrid motors. They will need to include details of AC synchronous and asynchronous motors including their rotor and stator wiring methods and DC brushless and brushed motors. They need to included details of the components of the motors, explaining their purpose and how they work with other components to make the motor function correctly. Learners need to explain the operating applications of each of these four types of motor and why they have been used in that situation

For Pass standard, learners need to describe at least one example of each type of motor included in the unit content that are used commonly on both electric and hybrid vehicles. For AC motors they need to include descriptions of synchronous and asynchronous motors and their rotor and stator wiring methods. For DC motors they must include both brushless and brushed motors, again with details of rotor and stator wiring methods. Learners need to describe the operation of a synchronous and asynchronous AC motor and a brushless and brushed DC motor, including their internal wiring systems. Learners should include details of magnetic impacts, permanent magnets rotors, slip between the magnetic field and rotor speed and how these affect motor performances.

3 Know about electric vehicle motor manufacturing equipment and processes

For Distinction standard, learners must choose a type of AC or DC motor that is used in electric or hybrid vehicles. Learners should analyse the manufacturing process that is used to construct the motor system from rotor and stator construction to final assembly within the drive placement. Learners should analyse the use of commonly used equipment and automation within the manufacturing process including any specialist equipment. Learners should give reasons why these processes and equipment are used instead of alternatives.

For Merit standard, learners need to explain either a hybrid or electric vehicle motor manufacturing process. This could be for any of the motor types used in these vehicle types. Learners need to explain each stage of the process including the equipment used in the line construction process. Learners need to cover at least three examples of commonly used equipment, three examples of specialist equipment and any special processes that are needed for the construction process.

For Pass standard, learners must investigate and describe commonly used manufacturing equipment that is used to construct electric or hybrid vehicles. The common types should include at least three of the following: drills, lathes, moulding machines and presses. Learners must also consider at least three examples of specialist machinery, for example winding and insertion machines, resin machines, powder coating machines and rotor balancing machines. Learners then need to select either an electric or hybrid motor manufacturing process and describe each of the manufacturing phases used during
the construction of the motor, including details of the equipment used.

4 Understand safety and manufacturing ergonomics relevant to electric vehicle motor manufacturing

For Distinction standard, learners will show an understanding of manufacturing processes and the tools that support the evaluation of ergonomic production layouts. These could include lean principles, workplace organisation and station balance times. Learners should evaluate the whole of the manufacturing process in terms of ergonomic design and safety systems that are in place on the manufacturing line.

For Merit standard, learners will have reviewed a typical electric or hybrid vehicle motor manufacturing environment. They will use this knowledge to explain why safety protocols and ergonomic factors must be considered when creating a new manufacturing line for electric and hybrid vehicle motors. Learners must include details of specific safety protocols that will be required, including those for hazards associated with heat, electricity and chemicals, and the reasons why ergonomics play such an essential role within line design for electric or hybrid vehicle motor manufacturing.

For Pass standard, learners need to use safety data and investigations to identify and describe at least eight common safety issues that can occur within a vehicle motor manufacturing setting. This should cover safety issues created by the machines used, the chemicals used in the process, and sound and sight dangers such as loud repetitive noise
or lights from welding processes. At least one example of safety issues related to heat, electrical and chemicals must be included. Learners need to describe common ergonomic factors that can impact online production and state how and why it is important to take these factors into account when designing a manufacturing system for electric or hybrid vehicle motors.

Essential information for tutors

There is a maximum number of four summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcome: 1 (P1, P2, M1, D1)

Learning outcome: 2 (P3, P4, M2, D2)

Learning outcome: 3 (P5, P6, M3, D3)

Learning outcome: 4 (P7, P8, M4, D4)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Know about the design and functioning processes of hybrid and electric vehicle motor drive systems	A report that details the design/construction, functioning processes, use and efficiency of two motor drive system types, one for a hybrid vehicle application and one for an electric vehicle application. The report should also include specific information about: • the location of the motor drive system types • the associated components they are attached to • alternative motor drive system types, including where they could be located. Annotated diagrams/images should support the written evidence.
2 Know about electric vehicle motor types, construction and operation	A report that details the construction and operation of AC (one synchronous and one asynchronous) and DC (one brushless and one brushed) motors, rotor and stator types, in electric and hybrid vehicle applications. The report should also include specific information about: • magnetic impacts, permanent magnets rotors, slip between the magnetic field and rotor speed and how these affect motor performances • wiring methods/systems • components of the motors, their purpose and how they work with other components • the operation of each type and torque delivery at all speed ranges, along with the advantages and disadvantages of the different motors when used in electric and hybrid vehicles. Annotated diagrams/images should support the written evidence.

Learning outcome	Recommended assessment approach
3 Know about electric vehicle motor manufacturing equipment and processes	A report that details each phase of the manufacturing process and the equipment used to construct an electric or hybrid vehicle motor system from rotor and stator construction to final assembly within the drive placement. The report should also include specific information about: • at least three examples of commonly used equipment, three examples of specialist equipment and any special processes that are needed for the construction process • why these processes and equipment are used instead of alternatives. Annotated diagrams/images should support the written evidence.
4 Understand safety and manufacturing ergonomics relevant to electric vehicle motor manufacturing	A report that details safety procedures and the use of ergonomic production layouts in an electric vehicle drive system manufacturing process. The report should include specific information about: • at least eight common safety issues that can occur within a vehicle motor manufacturing setting (covering machines, chemicals, electrical and heat plus sound and sight dangers) • specific safety protocols required, including those for hazards associated with heat, electricity and chemicals • common ergonomic factors that can impact on line production and how and why it is important to take these factors into account when designing a manufacturing system for electric or hybrid vehicle motors • the suitability of the manufacturing process when considering lean principles, workplace organisation and station balance times. Annotated diagrams/images should support the written evidence.

Resource requirements

For this unit, learners must have access to a variety of information and data sources specific to the use of electric motors in both electric and hybrid vehicles. They will need access to information about motor theory and the variety of motor types used in electric and hybrid vehicles. Access to manufacturing information, including automation, machinery, construction stage information and testing processes, will also be needed.

Indicative reading for learners

Textbooks

Denton T – *Electric and Hybrid Vehicles* (Routledge, 2020) ISBN 9780367273231

Tripathi P – *Handbook on Electric Vehicles Manufacturing* (Niir Project Consultancy Services, 2022) ISBN 9788195676927

Unit 119: Electric Vehicle Drives

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning hours: 60

Unit introduction

This unit covers the electric and hybrid vehicle transmission system. This will include the location of the drive motors in electric vehicles, single motor and multi-motor layouts, the advantages and disadvantages of each and their operating efficiency. The different varieties of hybrid vehicle layouts will be studied, including the various motor assistance layouts and the most popular placements for the motor/mechanical combinations reviewed. Learners will also investigate the three main combination types, parallel, series and power split systems, their sub systems and the variations of each. Learners will explore the operation of the motors and transmission systems to provide electrical assistance at all levels from simple stop-start systems to fully electrical drive systems.

Learners will investigate the manufacturing process and systems that are needed to create electric and hybrid transmission systems. A full production line process will be studied and assessed. Learners will review the product creation stages and the equipment needed to complete these stages. The review will include an overview of each machine type, factory layout and lean manufacturing principles assessment. The complex nature of the construction process can raise safety concerns. This unit will review general and specific
safe working practices, personal protection, the impact of electrostatic discharge can have during the manufacturing process and how to protect from this.

Learning outcomes

In this unit you will:

1 Know about the operating principles of electric vehicle drive systems

2 Know about the operating principles of hybrid vehicle transmission systems

3 Understand electric and hybrid vehicle transmission manufacture and assembly

4 Understand safe working practices when manufacturing electric and hybrid vehicle transmission systems.

Unit content

1 Know about the operating principles of electric vehicle drive systems

Single motor drive systems used in electric vehicles

- Principles of single motor drive systems:
  - potential motor positions in the vehicle structure
  - manufacturer motor positioning variances
  - motor torque outputs, e.g. torque delivery in the speed range, torque multiplication needs
  - single motor drive operation
  - advantages and disadvantages of single motor electric vehicles, e.g. cost of manufacture, reduced vehicle costs, reduced weight, requires gearing, driveshafts and differentials, good sprung weight characteristics, less battery space options, weight distribution, regenerative braking.

Multiple drive motor layouts, at or in wheel

- Principles of multiple drive motor drive systems:
  - potential motor positions in the vehicle structure
  - manufacturer motor positioning variances
  - motor torque outputs, e.g. torque delivery in the speed range, torque multiplication needs
  - advantages and disadvantages of multiple motor electric vehicles, e.g. precise torque delivery, multi-torque level delivery, speed variances at each wheel, reduced component needs, increase available location space for the battery, unsprung weight increase, needs enhanced suspension design to improve ride quality, more complex motor cooling systems.

2 Know about the operating principles of hybrid vehicle transmission systems

Hybrid vehicle drive system layouts

- Hybrid impact levels and the set ups they employ:
  - stop/start: fuel reduction etc
  - mild hybrid
  - strong hybrid
- Common types of hybrid vehicle layout; parallel, series and power split systems.
- Hybrid electric motor standardised categories:
  - P classifications for motor placements:
    - P0 engine front end accessory drive (FAED) locations
    - P1 engine rear locations directly to the crankshaft
    - P2 between the engine and the transmission
    - P3 within the transmission or post- transmission prior to the differential
    - P4 within the axle drive system
    - PS power split device, planetary gearset
  - EE axle drive system.

- Sub system types, layouts and components:
  - parallel hybrid single clutch systems
  - parallel hybrid two clutch system
  - parallel hybrid double clutch transmission
  - axle split parallel hybrid
  - series hybrid
  - series parallel hybrid
  - power-split hybrid.

Hybrid vehicle transmission systems construction and operation

- Hybrid transmission systems:
  - adapted flywheel drive systems
  - transmission motor drive systems
  - axle motor drive systems
  - different drive systems efficiency and torque production.
- Hybrid transmission unit construction:
  - adapted flywheel drive systems
  - transmission motor drive systems
  - axle motor drive systems.
- Hybrid transmission unit operating principles:
  - adapted flywheel drive systems
  - transmission motor drive systems
  - axle motor drive systems

3 Understand electric and hybrid vehicle transmission manufacture and assembly

Transmission unit production processes

- Stages of transmission construction (insertion, load, press, tightening, measuring, marking, apply sealants, rollover, leak test, in process verification).
- EV component production, e.g. rotor, stator and inverter.
- EV component construction process, e.g. housing construction, stator inserting, bearing pressing, rotor insertion, final assembly, testing.
- Line construction: construction flow, efficient line design, lean impacts, robot placement, transportation systems, automated stages, manual task stages, testing zones, reworking areas

Transmission unit construction equipment

- Line machinery, e.g. robotic stations, automated single operation machinery, automated multistage machinery, semiautomated machines, manually-operated machinery.
- Hand tools, e.g. air operated assembly tools, spanners, specialist sockets, spline tools.
- Measuring tools, e.g. pressure testers, torque testers, power testers, electronics testers.

4 Understand safe working practices when manufacturing electric and hybrid vehicle transmission systems

Hazard identification in the manufacturing process

- Risk assessment of manufacturing processes: common dangers, specialist assessments, chemical evaluations, individual process analysis.
- Common hazard signage in manufacturing, e.g. caution signs, exit and entry signs, moving vehicle signs, walkways, protective equipment signage, chemical signs, mandatory action signs, prohibition signs.

Personal protective equipment requirements

- Basic personal protection in manufacturing:
  - Workwear, e.g. risk assessed requirements, safety footwear, protective clothing
  - specialist personal protective equipment, e.g. eye protection, gloves, ear protection, hard hats, breathing equipment, face coverings.
- Anti-static protection:
  - impacts of static in electronic production process, e.g. product failure, system failure, production reworking, estimated costs of electrostatic discharge damage in manufacturing
  - potential damage caused by static in production situations, e.g. circuit damage, component damage, explosions, fires, robotics damage
  - equipment used to prevent static damage, e.g. anti-static benches/line positions, antistatic accessories, antistatic lights, anti-static chairs, anti-static mats, plastic.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the location and operation of a single motor in a front or rear wheel drive electric vehicle.	**M1** Explain the similarities and differences in the location and operation of single and multi-motor drive systems.	**D1** Evaluate electric and hybrid vehicle drive and transmission systems in terms of their efficiencies, motor locations and the need for transmission systems or direct drive.
P2 Describe the location and operation of a multi-motor drive system used in an electric vehicle.		
P3 Identify a range of hybrid vehicle drive system layouts.	**M2** Compare the electric motor assistance given, and the way each system provides drive, for two hybrid vehicle systems.	
P4 Describe the operation of three hybrid vehicle electric motor systems.		
P5 Describe an electric/ hybrid vehicle transmission manufacturing and assembly process.	**M3** Assess the manufacturing and assembly process for an electric/hybrid vehicle transmission in terms of the operations carried out and the equipment used.	**D2** Evaluate the manufacture and assembly process for electric/ hybrid vehicle transmissions, in terms of processing, efficiency in operation and potential improvements.
P6 Explain equipment needed to manufacture and assembly of electric/ hybrid vehicle transmissions.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Explain common and specific safe working practices required in an electric/hybrid drive system manufacturing and assembly process.	**M4** Assess the effectiveness of safety systems, protective equipment and risk management process relevant to an electric/hybrid vehicle drive system production process.	**D3** Evaluate the effectiveness of safety practices and protocols used in an electric/ hybrid drive system production and make recommendations for improvements.
P8 Describe the correct personal protective equipment required when manufacturing and assembling electric/hybrid vehicle drive systems.		

Essential guidance for tutors

Assessment

1 Know about the operating principles of electric vehicle drive systems, and

2 Know about the operating principles of hybrid vehicle transmission systems

For Distinction standard, learners will need to produce an evaluation of electric and hybrid vehicle drive and transmission systems that demonstrates an in-depth understanding of light vehicle electric and hybrid vehicle layouts, motor position options and the advantages and disadvantages of each. Learners will need to evaluate the associated drive systems for suitability and efficiency and the assistance they can offer to hybrid mechanical systems. Learners will need to evaluate advantages and disadvantages of transmission drive systems to the direct drive system. The evaluation should include consideration of weight, unsprung mass, torque delivery, vehicle control and regeneration of energy.

For Merit standard, learners need to demonstrate their understanding of the range of electric motor layouts used in current electric vehicles. They must explain the operations of the single and multi-motor systems, including details of their efficiencies and potential detractions. Learners will need to explain the similarities and differences of single and multi-motor dive systems by comparing the two systems. Learners will investigate the hybrid systems available, comparing motor locations, working processes and the amount of assistance the electrical systems give to the mechanical processes. Learners should review the effect the intervention has and how these interventions are suited to the driving situations.

For Pass standard, learners must show that they can clearly describe the layout of single motor electric vehicles, this can be front or rear mounted motors. Learners will describe how the systems operate and how they link to the mechanical systems of the vehicle. Learners will also describe the layout of multi-motor vehicles and how they compare to the single motor systems. Learners should describe the unique advantages of both single and multi-motor vehicles and their use. Learners must describe the operation of multi-motor electric vehicles and why motors are located at the wheels.

Learners will review a range of hybrid vehicle types and identify their purpose and classification in terms of motor layout, sub system types, layouts and components. Learners need to differentiate between levels of intervention and their associated efficiency gains. Once a range of systems has been identified the learner will need to describe their operation of at least three hybrid vehicle electric motor systems. The description must include details of how the systems provide electrical assistance and the level of assistance that the system can provide.

3 Understand electric and hybrid vehicle transmission manufacture and assembly

For Distinction standard, learners must produce an evaluation that includes a review of the manufacturing and assembly process for an electric or hybrid vehicle transmission. They will consider the assembly line and evaluate the stages of manufacture of the transmission system in terms of the operations being completed. Learners will consider the interaction between human and automated actions in the processes and evaluate the efficiency of these processes before identifying potential improvements to the assembly process.

For Merit standard, learners will assess the manufacturing process for an electric or hybrid vehicle transmission system. The learner will assess the processes used during the construction of the transmission system, the equipment used during the process and movement of the components between stations.

Learners will include details of the function of each machine used and also consider the efficiency of the manufacturing process overall.

For Pass standard, learners need to describe one manufacturing process that is used for the construction of an electric or hybrid transmission system. Learners will describe each stage and the processes used. They will also describe the equipment and machinery used at each station and the processes completed by each of the machines. Learners will describe the functions of each of the pieces of equipment and the efficiency of each in its role. Learners should also describe the differences between robotic equipment, automated machinery and manually operated machines.

4 Understand safe working practices when manufacturing electric and hybrid vehicle transmission systems

For Distinction standard, learners will evaluate the effectiveness of safety practices and protocols. They should demonstrate research of safety practices that are used in a electric/hybrid drive system manufacturing environment. Learners will evaluate the standard and specific safety requirements that would be present in the electric/hybrid production environment, considering the effectiveness of these requirements in reducing incidents and accidents. Learners will need to include particular issues that can occur in electrical/ electronic environments as part of their evaluation. Learners will evaluate all the safety systems and protocols that are in place and make recommendations for improvements that might be necessary.

For Merit standard, learners will assess the need for safety assessments and the processes used to identify and manage the risks that are related to the manufacturing environment for electric and hybrid drive systems. Learners will assess the effectiveness of personal protective equipment as a method for preventing potential harm from the risks identified. Learners should consider a range of risks including general risks and those risks specific to electrical and mechanical equipment construction and manufacturing processes.

For Pass standard, learners must explain the common safety risks that are present when manufacturing and assembling electric/hybrid drive systems. This should include safety management processes and signage use to maintain a safe working environment. Learners should explain key safe working practices, for example with respect to anti- static measures, that are relevant to the production of electric and hybrid vehicle transmission systems. Learners need to explain how risk assessment processes need to be applied to each manufacturing stage. Learners will describe the correct personal protective equipment that is required in a manufacturing setting, including details of its specific use, protections and how to care for equipment.

Essential information for assignments

Assessment

There is a maximum number of three summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcomes: 1 and 2 (P1, P2, P3, P4, M1, M2, D1)

Learning outcome: 3 (P5, P6, M3, D2)

Learning outcome: 4 (P7, P8, M4, D3)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Know about the operating principles of electric vehicle drive systems	A report that details the operating principles of electric vehicle drive systems and hybrid vehicle transmission systems. The report should include specific information about: • the layout of single and multi-motor electric vehicles, how they operate and how they link to the mechanical systems of the vehicle • the unique advantages of single and multi-motor vehicles and their similarities, differences, efficiencies and potential detractions • a range of hybrid vehicle types and their purpose and classification in terms of motor layout, sub system types, layouts and components to differentiate between levels of intervention and their associated efficiency gains in different driving situations • the operation of at least three hybrid vehicle electric motor systems with details of locations, working processes and the amount of assistance the electrical systems give to the mechanical processes • the suitability and efficiency of the electric and hybrid vehicle drive and transmission systems when considering weight, unsprung mass, torque delivery, vehicle control and regeneration of energy. Annotated diagrams/images should support the written evidence.
2 Know about the operating principles of hybrid vehicle transmission systems	

Learning outcome	Recommended assessment approach
3 Understand electric and hybrid vehicle transmission manufacture and assembly	A report that details the manufacture and assembly process for an electric or hybrid vehicle transmission system, considering processing, efficiency in operation and potential improvements. The report should include specific information about: • each stage of the manufacturing process, covering the functions and efficiency of the equipment and machinery used at each station, the processes completed by each of the machines, the movement of the components between stations and the differences between robotic equipment, automated machinery and manually operated machines • the suitability and efficiency of the assembly line in terms of the operations being completed, the interaction between human and automated actions in the processes and potential improvements to the assembly process. Annotated diagrams/images should support the written evidence.
4 Understand safe working practices when manufacturing electric and hybrid vehicle transmission systems.	A presentation with detailed notes that covers the effectiveness of safety practices and protocols used in an electric/hybrid drive system manufacturing environment and recommends improvements. The presentation/notes should include specific information about: • common safety risks, safety management processes, signage and safe working practices • how risk assessment processes need to be applied to each manufacturing stage and how they are used to identify and manage the general risks and those risks specific to electrical/mechanical equipment construction/manufacturing processes • personal protective equipment with details about specific use, protections and how to care for the equipment • the suitability of the specific safety practices and protocols in the electric/hybrid manufacturing environment to reduce incidents and accidents. Relevant diagrams/images/charts should be used to enhance the presentation.

Resource requirements

For this unit, learners must have access to a range of transmission types (clutches, gearboxes and driveline/final drives) and their components. A variety of information and data sources specific to the transmission systems will also be required. Learners will need access to the special tools and equipment needed for investigation and routine maintenance of the selected transmission systems as defined in the unit content and assessment criteria.

Indicative reading for learners

Textbooks

Chau K – *Electric Vehicle Machines and Drives: Design, Analysis and Application* (IEEE Press, 2015) ISBN 9781118752524

Tong W – *Mechanical Design and Manufacturing of Electric Motors* (CRC Press, 2022) ISBN 9780367564285

Unit 120: E-mobility

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning hours: 60

Unit introduction

This unit covers the factors that provide the infrastructure and laws and policies required to allow electric vehicles to grow in popularity, meet the targets set out in international collaborations and to deal with the potential environmental impacts that electric vehicles may have. Starting with the infrastructure requirements, learners will look at the requirements for charging networks to allow electric vehicles to work continuously as transport vehicles and to be recharged in a timely and convenient manner. This will include road network charging systems and home charging requirements. Learners will research and review the various pieces of legislation that control the production and construction requirements of electric vehicles including environmental impact, safety features, component location and driving safety systems. Learners will review the lifecycle of electric vehicles, the impacts of the construction phase on the environment and the location of construction materials. They will also examine the use phase of electric vehicles and the potential life span of components. Learners will learn about the potential end of life processes that can improve battery life and reuse rather than destruction. Learners will look at material salvage if reuse or recycling are not an option.
The final part of this unit looks at the developments within fuel cell technology and its applicability as a power source for electric vehicles. Learners will look at the potential positives and current negatives of fuel cells and the distance they need to travel to be more effective as fuel sources in vehicles.

Learning outcomes

In this unit you will:

1 Know infrastructure necessary to support full electric and hybrid vehicle integration
2 Know policies that manage the transition to environmentally supportive transport
3 Understand end of life requirements of electric and hybrid vehicles
4 Understand other efficient fuel systems available for vehicles

Unit content

1 Know infrastructure necessary to support full electric and hybrid vehicle integration

Charging systems and locations to meet customer needs

- Battery charging methods (current and proposed):
  - AC charging systems: industry acceptance, implementation and usage costs, potential installation sites and customer usage.
  - DC charging methods (low and high): industry acceptance, implementation and usage costs, potential installation sites and customer usage
  - inductive charging: likelihood of acceptance, working process, potential costs, potential positives and negatives
  - battery replacement: likelihood of adoption of the method, need for standardisation, potential journey pause time, storage and the requirements of a change station.
- Charging modes for safe charging and to suit manufacturers' chosen charging plug options, charging power source, maximum charging power, interactive communication processes:
  - mode 1 max power level: electrical input requirement, communication availability and impact, connection types, safety systems
  - mode 2 max power level: electrical input requirement, communication availability and impact, connection types, safety systems
  - mode 3 max power level: electrical input requirement, communication availability and impact, connection types, safety systems
  - mode 4 max power level: electrical input requirement, communication availability and impact, connection types, safety systems.
- Charging system plug variety and application, e.g. type 1 single phase system, type 2 power supply and charging system variation, vehicle receiver variations.
- Wireless power transfer types (stationary, quasi-dynamic and dynamic), power levels (light duty, light duty fast charge and high/heavy duty), benefits, potential development for the future.

Specific vehicle repair networks

- EV repair networks: what do we need them for, will slow growth impede EV take up, staff requirements, additional specialist equipment.
- Safety systems of work when completing repairs on EV and hybrid HV systems.
- Repair staff training/updating requirements (qualifications, typical training scenarios, typical hazards during repairs).
- How existing roadside support and repair systems can adapt to electric and hybrid vehicles (emergency starting, roadside repair methods, recovery and towing, emergency and fire procedures).

2 Know policies that manage the transition to environmentally supportive transport

Environmental regulations affecting electric and hybrid vehicle development

- End of Life Vehicle (ELV) Directive 2000/53/EC and the equivalent regulations outside of the EU, vehicles covered, cars and light vans, recycling targets; 95% of vehicles to be reused, recycled or recovered; authorised recycling centres operations, e.g. vehicle stripping, de-polluting environmentally hazardous components.
- Global agreements ($C0_2$ reduction targets, differences between developed countries and the least developed countries legal targets, 2030 deadlines for change, 2050 targets), e.g. the Paris Agreement.
- Worldwide harmonised light vehicles test procedure; a global standard for vehicle data measurement (pollutant levels, $C0_2$ emissions, fuel or energy consumption and electric range).
- Local and regional regulations that can affect electric and hybrid vehicles.

Vehicle-based laws and policies that effect electric and hybrid vehicle development

- ECE-R100 regulations for the harmonisation of EV systems on vehicle category M and N.
- Requirements from law and policies:
  - safety systems: shock protection, e.g. HV systems in the compartments for passengers and luggage can't be touched, any HV system protection carries a danger symbol, traction battery and powertrain must correctly fused or contain circuit breakers, HV powertrain must be isolated from other EV systems
  - charging processes, e.g. electric vehicles should not be able to move when charging, protection for charging equipment under any circumstance, plug systems should disable vehicle operation
  - general safety and driving requirements, e.g. vehicle starting must be controlled, key removal stops driving ability, notification of movement readiness, early warning of battery discharge, driving mode warning systems, direction changes are managed through switching or double actuations, driver warning systems when vehicle issues occur.

3 Understand end of life requirements of electric and hybrid vehicles

Vehicle life cycle

- Three stages of the vehicle life cycle: production, use and recycling.
- Whole life cycle assessment, measuring $C0_2$ of a vehicle through production, use and recycling, typical vehicle comparison data comparing petrol, diesel and electric vehicles.
- $C0_2$ generation at each stage of vehicle production, e.g. production data for each vehicle type, use data for each vehicle type and recycling data for each vehicle type.

Battery end of life options and environmental impact

- Expected battery life span, e.g. manufacture for vehicle life, minimum capacity levels, e.g. 80%, 8 – 10 years:
  - battery construction materials (low impact, non- hazardous materials (lithium, sodium, copper, aluminum, plastic), high impact, heavy metals (cadmium) and toxic materials (nickel).
- Waste Batteries and Accumulators Regulations 2009: returning batteries to manufacturers, completing the 5R process.
- 5R solution and retained value:
  - recovery of battery from customers
  - repair the battery
  - remanufacture of the battery to return working capacity
  - reuse of batteries for non-automotive applications (household power storage, solar power systems)
  - recycle the battery by reclaiming usable materials.

4 Understand other efficient fuel systems available for vehicles

Use of fuel cells and super capacitors

- Fuel cells: common types (hydrogen, methanol), operating principles of hydrogen fuel cells, infrastructure requirements, potential gains and drawbacks of the hydrogen and methanol systems.
- Super capacitors: types (super, ultra), application within automotive circuits, links to energy recovery systems.
- Benefits of fuel cells and supercapacitors for reducing environmental impacts.

Energy recovery systems

- Regenerative braking: theory of operation, difference in operation when fitted to conventional braking and EV braking systems, motor reversal process and driving impact.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Outline the suitability of different charging systems available for electric and hybrid vehicles in home, work and service station scenarios.	**M1** Compare traditional fossil fuel infrastructures with electric and hybrid vehicle infrastructure.	**D1** Analyse improvements needed to existing automotive infrastructure to support the growth of electric and hybrid vehicle use.
P2 Describe requirements of a repair network sufficient to support electric and hybrid vehicles.		
P3 Describe given environmental policies that affect the production and use of electric and hybrid vehicles.	**M2** Explain the impact of given environmental and vehicle-based laws/policies on the production and use of electric and hybrid vehicles.	**D2** Evaluate the impact of given environmental and vehicle-based laws/policies have on the development and use of electric and hybrid vehicles.
P4 Describe ways that vehicle-based laws that can impact on electric and hybrid vehicles.		
P5 Describe the lifecycle for electric and hybrid vehicles.	**M3** Assess the lifecycle and end of life processes needed to support electricand hybrid vehicles.	**D3** Evaluate the lifecycle planning for electric and hybrid vehicles, vehicle recycling and battery reclamation processes.
P6 Explain the end-of-life process for a range of battery types used in electric and hybrid vehicles.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Explain the use offuel cells, supercapacitors and energy recovery systemsin vehicle fuel efficiency.	**M4** Analyse the operation of energy storage and recovery systems used on current electric and hybrid vehicles.	**D4** Evaluate the use of energy recovery systems on current electric and hybrid vehicles, how that energy is stored and recommend improvements.

Essential guidance for tutors

Assessment

1 Know infrastructure necessary to support full electric and hybrid vehicle integration

For Distinction standard, learners will need to demonstrate their in-depth understanding of the required infrastructures needed for the growth of EV within communities and nations. Learners will need to clearly research each infrastructure need for EVs and then discuss the improvements that will be needed in each infrastructure area, for example with respect to the provision for public EV charging points, that in turn will support the growth of usage of electric and hybrid vehicles.

For Merit standard, learners need to demonstrate their understanding of fossil fuel vehicle infrastructure and the infrastructure needed for EVs. Learners need to investigate the different charging systems that will be required for EVs and compare these needs to the current fossil fuel provision. Learners will need to include information about the potential network changes that will be required for service stations to provide EV charging facilities and vehicle support. Learners need to consider the need for different systems to suit the charging demands of different manufacture's EVs when charging vehicles at home, at a place of work and also at service stations.

For Pass standard, learners must show that they have identified the different aspects of EV charging systems and explained their suitability for charging different vehicles at home, at an office or workplace and in a service station situation. The explanation should cover the different demands place by EV owners and their individual vehicles in each of the situations, such as the need for faster charging in a service station compared to at home. Learners will provide an explanation of the different charging modes used in EV charging, the safety levels for each mode and why they are used. Learners should consider charging times and the use of single and three phase power sources. Learners will include information about the three levels of wireless charging, the benefits of wireless charging and potential developments of this technology for the future. Learners will provide information on the current infrastructure available for EV support in their own region or country. Learners will need to describe each area of the network requirements. This will include describing the safety systems needed within a repair centre, staff training needs and any additional equipment that may be required.

Learners should also provide details of the training needed for active repair staff and typical dangers that can occur in a repair environment. Learners will need to consider the roadside assistance currently available for fossil fuel vehicles and how this will need to change to suit a higher level of EVs on the roads.

2 Know policies that manage the transition to environmentally supportive transport

For Distinction standard, learners will need to evaluate a given environmental policy and a law that are linked to EV development and CO_2 management. Learners should fully evaluate the impacts these policies and laws have on the development and life cycle of electric and hybrid vehicles. Learners need to evaluate the impact of a policy and a law that dictates a range of development, construction and in use measures.

For Merit standard, learners need to review a given policy and a law and explain the main components of each and how they promote safety, conformity. The explanation will also need to provide details of the regulations that control environmental impact for vehicles for the future. Learners need to clearly explain the regulations that manage the design and production of electric and hybrid vehicles and how the vehicle lifecycle can impact on the environment.

For Pass standard, learners need to describe a given policy and a law that currently set out the goals for environmental impact reduction from vehicle pollutants and the impact of CO_2 throughout the vehicle life cycle. This should include a simple comparison between fossil fuel vehicle impact and the environmental impact of EVs through their lifecycle. The learner will then describe regulations that impact the build and use of electric and hybrid vehicles. Learners will need to describe any operational restrictions that are required for these types of vehicle to be used and what they achieve.

3 Understand end of life requirements of electric and hybrid vehicles

For Distinction standard, learners must demonstrate research and evaluation of the current EV life cycle management processes that are currently set out. Learners should make sufficient judgements to determine the suitability of the recycling and reclamation processes that are currently used. They need to include details in their evaluation of the vehicle battery recycling requirements, including who is involved in the process and whether or not it is suitable to prevent further environmental impacts within the lifecycle of electric and hybrid vehicles.

For Merit standard, learners need to discuss the electric and hybrid vehicle life cycle including material sourcing, manufacturing, customer use, main component longevity and the processes and requirements of component reuse and recycling. Learners should give examples of potential battery remanufacturing options and provide information on the importance of remanufacturing as a method to reduce environmental impacts. They should review the potential options for recycling batteries, including the potential impact of each.

For Pass standard, learners need to review electric and hybrid vehicle life cycle examples, describing each stage and the resulting emissions of CO_2. Learners will investigate the processes required at each stage and how this combines to create a lower polluting vehicle. They will also need to describe a development that will continue to lower the environmental impact of road vehicles. Learners need to identify the highest polluting stages of the lifecycle and identify improvements that are planned for implementation. Learners will explain the end-of-life process for a range of battery types used in electric and hybrid vehicles, including their ability to be remanufactured, reused or recycled and the impact each of these can have on the environment. Learners should correctly rank these options from the most environmentally friendly to the least.

4 Understand other efficient fuel systems available for vehicles.

For Distinction standard, learners need to research and evaluate the current energy recovery systems used on electric and hybrid vehicles. Learners should use that research to discuss and propose addition energy collection systems that could work or have been through proof-of-concept trials. Learners need to investigate the use, or potential use, of fuel cell technology and evaluate its potential use in electric and hybrid vehicles. Learners must clearly evaluate the positive and negatives of the use of fuel cells and any reasons that prevent their use in road going vehicles.

For Merit standard, learners need to analyse the use of fuel cells and super capacitors in vehicles to provide short- and long-term storage for recovered power. Learners should consider how the storage system operates in conjunction with available energy recovery systems. This can include current energy recovery systems that link to braking systems and power steering systems.

For Pass standard, learners need to review the current use for alternative fuel options that could be used for electric vehicles. Learners should describe the potential of fuel cell technology, including details of the benefits and restrictions that currently impact on their use in road vehicles. Learners should include information about the potential for environmental impact reductions with this technology and the issues such as heat and gas delivery systems. Learner should also describe the function and operation of a regenerative braking system that is used within electric vehicles and how this works to recharge the battery whilst slowing and stopping the vehicle

Essential information for assignments

Assessment

There is a maximum number of four summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcome: 1 (P1, P2, M1, D1)

Learning outcome: 2 (P3, P4, M2, D2)

Learning outcome: 3 (P5, P6, M3, D3)

Learning outcome: 4 (P7, M4, D4)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Know infrastructure necessary to support full electric and hybrid vehicle integration	A report that details the improvements needed to existing automotive infrastructure to support the growth of electric and hybrid vehicle use. The report should include specific information about: • EV charging systems and their suitability for charging different vehicles at home, at an office or workplace and in a service station situation • the different charging modes used in EV charging, the safety levels for each mode and why they are used • the three levels of wireless charging, the benefits of wireless charging and potential developments of this technology for the future • the current infrastructure available for EV support including the safety systems needed within a repair centre, staff training needs and any additional equipment that may be required • the training needed for active repair staff and typical dangers that can occur in a repair environment, including the roadside assistance currently available for fossil fuel vehicles and how this will need to change to suit a higher level of EVs on the road • the potential network changes that will be required for service stations to provide EV charging facilities and vehicle support when compared to the current fossil fuel infrastructure. Annotated diagrams/images should support the written evidence.

Learning outcome	Recommended assessment approach
2 Know policies that manage the transition to environmentally supportive transport	A presentation with detailed notes that covers the impact that an environmental policy and vehicle-based law, linked to EV development and CO_2 management, have on the development and use of electric and hybrid vehicles. The presentation/notes would include specific information about: • fossil fuel vehicle impact and the environmental impact of EVs through their lifecycle • regulations that control environmental impact in the design, build and use of electric and hybrid vehicles • the main components of the policy/law, how they promote safety and conformity and how they dictate a range of development, construction and in use measures. Relevant diagrams/images/charts should be used to enhance the presentation.
3 Understand end of life requirements of electric and hybrid vehicles	A report that provides details about lifecycle planning for electric and hybrid vehicles, including vehicle recycling and battery reclamation processes. The report should include specific information about: • each stage with examples (material sourcing, manufacturing, customer use, main component longevity and the processes and requirements of component reuse and recycling) of electric and hybrid vehicle life cycles and the resulting emissions of CO_2 • the highest polluting stages of the lifecycle and improvements that are planned for implementation • end-of-life processes for a range of battery types used in electric and hybrid vehicles, including their ability to be remanufactured, reused or recycled and the impact each of these can have on the environment • the suitability of the recycling and reclamation processes that are currently used to prevent further environmental impact. Annotated diagrams/images should support the written evidence.

Learning outcome	Recommended assessment approach
4 Understand other efficient fuel systems available for vehicles	A presentation with detailed notes that covers the use of energy recovery systems in current electric and hybrid vehicles, how the energy is stored and possible improvements. The presentation/notes should include specific information about: • the use fuel cells and super capacitors in vehicles to provide short- and long-term storage for recovered power, with details of the benefits and restrictions/issues that currently impact on their use • how the storage system operates in conjunction with available energy recovery systems • the function and operation of energy recovery systems that link to braking systems and power steering systems • additional energy collection systems that could work or have been through proof-of-concept trials. Relevant diagrams/images/charts should be used to enhance the presentation.

Resource requirements

For this unit, learners must have access to a variety of information and data sources specific to the infrastructure required for EVs to develop in popularity in the learners' national and regional area.

Indicative reading for learners

Textbooks

Kathiresh M et al – *E-Mobility: A New Era in Automotive Technology* (Springer, 2021) ISBN 9783030854232

Filho W et al – *E-Mobility in Europe, Trends and Good Practice* (Springer, 2015) ISBN 9783319365169

Unit 121: Industrial Robotics

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Robotics is at the forefront of the latest industry developments that form part of 'Industry 4.0'. Industrial robots are used to mass produce many everyday objects, such as cars, computers and mobile phones, and their application is industry wide. Learners will investigate the principles and operation of industrial robots used in modern manufacturing. This unit also gives learners an understanding of the health and safety and maintenance requirements associated with modern industrial robots.

The unit covers robot control systems, the different types of sensors and end effectors used, and their application in an industrial robot installation. Learners will learn the programming methods used and will produce a program for an industrial robot to solve an engineering-based problem.

This unit prepares learners for the roles of robotic maintenance engineer, robotic programmer and automation specialist. Learners will develop research and study skills that will prepare them for a higher apprenticeship or for study at university.

Learning outcomes

In this unit you will:

1 Investigate the health and safety and maintenance requirements associated with industrial robots

2 Investigate the operation and design of industrial robots for different applications

3 Investigate the operation of industrial robot sensors and end effectors

4 Produce a program for an industrial robot to solve an engineering problem

Unit content

1 Investigate the health and safety and maintenance requirements associated with industrial robots

Health and safety requirements

- Defining industrial robotics, including:
  - standalone robots
  - manufacturing work cells/robot installations.
- Relevant regulations, e.g. health and safety at work legislation, electricity at work regulations for portable appliance testing, Health and Safety Executive publications, Machine Tool Technologies Association Codes of Practice (MTA Safeguarding Codes of Practice – Industrial Robots parts 1–3).
- Human dangers, e.g. during programming, maintenance and as a result of system faults.
- Safety systems, including their effectiveness, e.g. 'dead man's handle', hold and emergency stop buttons, pressure pads/matting surrounding robot, laser light guards, electromagnetic field barriers.

Maintenance

- Inspection routines, e.g. mechanical condition of all parts, environmental conditions (particulate matter, temperature, ventilation, shock, vibration, electrical noise).
- Spare parts required to sustain continuous operation, e.g. seals, bearing, motors, pneumatic and hydraulic lines and connectors, end effector parts.
- Relevant maintenance tools and test equipment, e.g. safe isolation kit, grease gun, allen keys, spanners, socket sets, multimeter, mastering gauges, tool and base reference points.
- Set-up, maintenance procedures and the overall effectiveness of the maintenance procedures.

2 Investigate the operation and design of industrial robots for different applications

Principles of operation and their applications

- Operational characteristics, e.g. automated, repeatable, tireless, replaces human effort.
- Specifications, e.g. number of axes, payload, size and shape of working envelope.
- Types of controller, manipulator, end effector/tooling, e.g. pneumatic suction cup, hydraulic, electrical and mechanical grippers.
- Workspace organisation, e.g. feed of work, robot-to-robot work, material flow and logistics.
- Applications of robots and their impact, e.g. manufacturing, inspection, palletising, working alongside humans, replacing human workers.

Design principles

- Types of robotic system, e.g. cylindrical spherical, jointed, spherical, Cartesian and Selective Compliant Assembly Robot Arm (SCARA), with associated working envelope.
- Reference frames, e.g. world joint tool.
- Wrist articulations, e.g. yaw, pitch and roll, degrees of freedom in terms of translations and rotations
- Drive mechanisms, e.g. mechanical (ball screws, chain/belt, gears), pneumatic, hydraulic, electrical.

Control systems

- Closed-loop servo controlled systems, e.g. for driving one axis of a robot.
- Input, output and feedback signals, e.g. the sequence that takes place to perform a task.

3 Investigate the operation of industrial robot sensors and end effectors

Sensors

- Sensor types, e.g. tactile (microswitches/piezoelectric/strain gauge/pressure), non-tactile (capacitive/inductive/light/laser), vision (inspection, identification and navigation).
- Sensor applications, e.g. safety, work-cell control, component/part inspection.

End effectors

- Grippers and tools, e.g. parts handling/transfer, assembly, welding, paint spraying, testing.
- Tool centre point, e.g. tool calibration for different applications.

4 Produce a program for an industrial robot to solve an engineering problem

Integrated development environment (IDE)

- Overview of the functions on IDE, e.g. simulator, pure code, available tools.

Programming principles and implementation

- Types of programming, e.g. online, lead through, offline.
- The use of subroutines and subprograms to streamline programming methods.
- Design of programs from a brief, e.g. design specification, flowchart, structured English, safety considerations.
- Writing of programs, including motion commands, e.g. point to point, linear, circular.
- The importance of avoiding singularities during programming.
- Work-cell commands, e.g. wait, signal, delay.
- Program selection, start-up, test, alterations and operation.
- Testing, e.g. running the program in a simulator, code debugging, running of program live with no workpieces, incrementing operating speeds, decreasing operator's level of input.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the health and safety requirements for the safe operation of given industrial robots.	**M1** Justify the benefits of maintenance procedures and the use of a safety system for a specific application of industrial robots.	**D1** Evaluate the maintenance procedures and use of a safety system for a specific application of industrial robots.
P2 Describe maintenance procedures on given industrial robots.		
P3 Explain the operating and design principles of at least two different applications for industrial robots.	**M2** Compare the design, operation and control of at least two different industrial robots, including drive systems.	**D2** Evaluate at least two different industrial robots in terms of their design, operation and control including the use of robotic sensors and end effectors for different applications.
P4 Describe the control systems, including input, output and feedback signals, used in at least two different applications for industrial robots.		
P5 Explain the operating principles of three different types of robotic sensors for different applications.	**M3** Assess the use of robotic sensors and end effectors for different applications.	
P6 Explain the operating principles of two different types of robotic end effectors for different applications.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Design an industrial robot program to solve a problem.	**M4** Develop a functional program for an industrial robot that operates as intended to solve a problem safely.	**D3** Optimise a functional program for an industrial robot by testing that it performs efficiently, safely and operates as intended.
P8 Produce a program for an industrial robot that is tested in simulation mode and which may only partially solve a problem safely.		

Essential guidance for tutors

Assessment

Assessment evidence could be gathered from a variety of tests, assignments, case studies and practical activities involving industrial or training robots. Where possible, where there are clear links between them, assessment instruments should cover multiple assessment criteria, for example P7, P8, M4 and D3.

1 Investigate the health and safety and maintenance requirements associated with industrial robots

For Distinction standard, learners will provide a balanced evaluation of the benefits and limitations of the safety systems and maintenance procedures in place for an industrial robot. They will draw conclusions on the effectiveness of the safety system and maintenance procedure, and advise on how it could be improved. Overall, the evaluation will be logically structured and use correct technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling, consistent referencing of information sources.

For Merit standard, learners will justify the use of a particular safety system and regular maintenance procedures for an industrial robot. For example, safe systems could include the use of a laser light guard instead of a physical barrier entering the work cell. Learners' justification will focus on the benefits only, rather than being balanced. Overall, learners will be able to select and interpret from a range of sources of information, such as Health and Safety Executive (HSE) documentation, manufacturers' literature, textbooks and the internet. The evidence will be logically structured, technically accurate and easy to understand.

For Pass standard, learners will describe the health and safety and maintenance requirements associated with industrial robots. Learners must also make reference to the relevant health and safety legislation.

Overall, the evidence will be logically structured, although it may be basic and unbalanced in parts. Explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology, for example an incorrect name or application for a tool, or 'the robot is networked to the safety system' as opposed to 'the robot controller communicates to the safety system via the PROFIsafe protocol'.

2 Investigate the operation and design of industrial robots for different applications, and

3 Investigate the operation of industrial robot sensors and end effectors

For Distinction standard, learners will demonstrate the ability to evaluate industrial robots in terms of their design, operation and control, including sensors and end effectors. Learners will suggest possible improvements that could be made, with full reasoning behind the use of an alternative. Learners' evidence must demonstrate good interpretation and in-depth use of widely researched sources of information to support and qualify evidence of activities. They will use a wide range of methods to analyse results of research and investigations effectively, and reach well-reasoned conclusions. Overall, the evaluation will be logically structured and use correct technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling, and consistent referencing of information sources

For Merit standard, learners will compare the design, operation and control of at least two different industrial robots, including a more detailed comparison of the benefits and limitations of different drive systems. Evidence on drive systems will cover all the main types: electrical, mechanical, pneumatic, and hydraulic.

Learners will assess the suitability of the use of specific robotic sensors and end effectors in an industrial relevant situation. They will advise on possible alternative solutions, however they might not give full reasoning behind the use of an alternative.

Overall, learners will be able to select and interpret from a range of sources of information, such as manufacturers' literature, textbooks and the internet. In addition, the evidence will be logically structured, technically accurate and easy to understand.

For Pass standard, learners will need to explain the principles of operation of at least two different robots, including types of controller, manipulator, end effector and work space organisation. Learners' explanations also include robot design principles, for example reference frames and wrist articulations.

Learners will need to describe the types and applications of control systems suitable for robots, and they will need to explain the operation of three different sensors, and their different applications. They will also need to provide details of the control an operation of robot end effectors for different applications of industrial robots.

Overall, the evidence will be logically structured, although it may be basic in parts. Learners' explanations may be limited in places and contain minor technical inaccuracies relating to engineering terminology. For example, 'a proximity sensor would be best' as opposed to 'a capacitive proximity sensor would be most suitable as the workpiece is non-metallic'.

4 Produce a program for an industrial robot to solve an engineering problem.

For Distinction standard, learners will design, implement and run a program on an industrial robot. The program will be optimised through the appropriate use of subroutines and will avoid the use of extra motion commands and singularities. Learners will test the program in teach mode at a range of speeds and carry out conformance checks against the original design of their program, confirming the program runs as intended out of teach mode. It will also be accurate enough to be run in a loop in automatic mode.

Overall, the design documentation will be appropriate, the system will operate as intended and it will be safe and efficient to use.

For Merit standard, learners will use industry standard techniques to program a robot. The program produced will be tested in simulation and learners will go on to test the program in the live environment. The robotic solution will solve the problem correctly, however it might not be fully optimised. For example, a pick and place robot may stack components neatly but use extra motion commands to manoeuvre around the work cell or the dispensing robot might apply adhesive accurately but with the unintended use of singularities.

Overall, the evidence will be well structured, with the correct use of appropriate technical language. There will be evidence that learners have taken care to ensure the program runs as accurately as possible.

For Pass standard, learners will, using industry standard software, design a program for an industrial robot to solve an engineering-based problem. For example, suitable problems could be to pick and place components or to apply adhesive to a specified path.

Learners will use industry standard techniques to program a robot. The program produced will be tested in simulation but learners might not go on to test the program in the live environment. The robotic solution might only partially solve the problem, for example a pick and place robot may not stack components neatly or a dispensing robot may apply adhesive unevenly.

Overall, the evidence will be well structured and there will be some use of appropriate technical language, although there may be some inaccuracies with terms used. Also, some parts of the evidence may be considered in greater depth than others.

Essential information for assignments

There is a maximum number of three summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcome: A (P1, P2, M1, D1)

Learning outcomes: B and C (P3, P4, P5, P6, M2, M3, D2)

Learning outcome: D (P7, P8, M4, D3)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriate assignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Investigate the health and safety and maintenance requirements associated with industrial robots	A report or presentation evaluating the safety systems and maintenance requirements in place for an industrial robot or robot work cell.
2 Investigate the operation and design of industrial robots for different applications	A report of findings from research, evaluating an industrial robot installation in terms of its design, operation and control from a case study.
3 Investigate the operation of industrial robot sensors and end effectors	
4 Produce a program for an industrial robot to solve an engineering problem	A program to control a robot that solves an engineering problem.

Resources

Learners will need access to a functioning robot, for example a six-axis, jointed-arm in work cell, a linear robot using a Cartesian system. They will also need some form of industry standard programming software, suitable for an industrial robot or work cell, for example RoboCell, KUKA.Sim, OrangeEdit, Robotics Developer Studio.

Indicative reading for learners

Textbooks

Ross L et al – *Industrial Robotics Fundamentals: Theory and Applications* (Goodheart-Willcox, 2017) ISBN 9781631269417

Craig J – *Introduction to Robotics, Mechanics and Control* (Pearson, 2004) ISBN 9780201543612

Unit 122: Autonomous Mobile Robotics

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

Autonomous mobile robots are at the forefront of the latest 'Industry 4.0' revolution and they promise massive performance gains across industry and society more generally. For example, in warehouses, manufacturing, agriculture and healthcare settings, autonomous mobile robots are being used to improve performance, including operational efficiency, productivity, precision and safety.

An autonomous mobile robot can understand (to a degree) and move through its environment independently to carry out a task. For example, they can avoid colliding with an unexpected obstacle. They differ from standard automated guided vehicles (AGVs), which rely on tracks or predefined paths to carry out a task.

In this unit you will investigate the use of different types of autonomous mobile robot by considering their requirements, environment, benefits and limitations. You will also investigate the sophisticated set of sensors, other hardware, software algorithms and artificial intelligence/machine learning that allow them to interpret and navigate through their environment independently. Finally, you will bring all the learning together to build (using an educational kit) and program an autonomous mobile robot to complete an activity.

This unit prepares you for an electrical, electronic or mechatronic-based engineering apprenticeship, for higher education and for technician-level roles, for example as an electrician or electrical fitter. As an electrical/electronic engineer you may need to safely operate, maintain, repair and even improve autonomous mobile robots, and consequently the requirement for a solid theoretical and practical knowledge and understanding of them is vital.

Learning outcomes

In this unit you will:

1 Investigate the use of different types of autonomous mobile robot

2 Investigate the software and hardware used in autonomous mobile robots

3 Develop an autonomous mobile robot to complete an activity defined in a client brief.

Unit content

1 Investigate the use of different types of autonomous mobile robot

Types and use of autonomous mobile robots

- Definition of autonomous mobile robots, e.g. the capability of a robot to perform a series of activities where the sequence is determined by the outcome of the previous activity or by reference to external circumstances that are monitored and measured by the robot and involve some form of locomotion.
- Traditional robots are programmed to perform a repetitive activity, e.g. welding a car body, standard automated guided vehicles (AGVs) and positioning electronic components on a circuit board. These types of machine and robotic arms lack the autonomy to undertake an activity and require reprogramming to respond to changes in the environment, such as an obstacle or a change to the design of a product, and they may require operator control/oversight of the activity being undertaken.
- Types of autonomous mobile robot, e.g. humanoids, drones, water-based vessels, self-driving cars/vacuum cleaners/construction equipment, picking and packing robots, product recognition, security, healthcare cleaning and disinfecting, agriculture, and movement of components/products (in warehousing and manufacturing).
- Purpose of autonomous mobile robots, e.g. the just-in-time and self-routing movement of components around a manufacturing plant, collaborative product assembly or to clean and prepare medical patient rooms independently.
- Requirements of autonomous mobile robots:
  - behaviours including: object/wall following, standing/balancing, go-to goal, object avoidance, navigation (self-localisation, path mapping and path planning), object recognition, product/component manipulation and collaboration (e.g. assembly, service) and entertainment (e.g. swarm robots)
  - performance including: productivity (e.g. time to complete one activity), reliability, robot mass (with and without a payload), maximum velocity, battery runtime, degree of autonomy, safety, networking (e.g. data sharing and capacity for interconnectivity), agility, rate of acceleration/deceleration, operational terrain type and physical size (form factor).
- Environmental conditions including: alongside humans, radiation, explosion risk, temperature/pressure, without oxygen/air, location (e.g. inside/outside a building and remote), terrain (e.g. flat, undulating, cluttered/uncluttered and dynamic/changing), network connectivity, and degree of visibility.

Benefits and limitations of operating autonomous mobile robots

- Benefits of autonomous mobile robots, e.g. enhancing efficiency, effectiveness, agility, productivity, repeatability, reproducibility, flexibility, minimising waste, ability to augment capabilities of human workforce, less human intervention needed, and safety improvements from undertaking dangerous tasks.
- Limitations of autonomous mobile robots, e.g. expensive, malfunctions, costs of fault-finding and rectification, highly skilled engineers/maintenance, building public acceptance, meeting health and safety regulations, costs of training, workforce morale, cybersecurity risks, and compliance with standards.

2 Investigate the software and hardware used in autonomous mobile robots

Hardware devices and their features used in autonomous mobile robots

- Hardware devices and their features:
  - programmable devices/microcontrollers and their features, e.g. the number of input/output ports (digital and analogue), pulse-width modulation, interrupts, on-board memory, multi-threading, communication (including serial and I2C) and connector types
  - input devices, e.g. temperature sensor, light-dependent resistor, wheel-encoders, infrared sensor, ultrasonic sensor, light detection and ranging (Lidar) sensor, bar code/Quick Response (QR) code reader, and radio-frequency identification (RFID) tagging and the features of each device, e.g. resolution, operating voltage, temperature range, detection range, detection angle and form factor
  - output devices, e.g. light emitting diodes (LEDs), motors, actuators, robotic arms, audio/sound emitters and the features of each device, e.g. resolution, operating voltage, direction of rotation, maximum speed of rotation, torque, detection range, detection angle and form factor
  - power source, e.g. battery, solar cell and the features of each device, e.g. operating voltage and power output.
- Other devices including:
  - mechanical structures, e.g. chassis, bumpers
  - devices for locomotion, e.g. gears, tracks, wheels, propeller, legs
  - object manipulation and robot arms, e.g. end effector like suction cup or electrical or mechanical grippers.

Software and hardware integration used in autonomous mobile robots

- Integration of software and hardware for an autonomous mobile robot including:
  - open loop control of locomotion, e.g. travel a set distance in a straight line
  - closed loop control locomotion, e.g. input, output and feedback signal(s).
- Locomotion algorithms used in autonomous mobile robots, e.g. proportional–integral– derivative (PID) controller, potential fields, A*, grid-based locomotion planning and search-based.
- Methods to improve the performance of autonomous mobile robots including:
  - optimising/tuning the physical robot, e.g. hardware response/calibration time, acceleration and deceleration rates, velocities, wheel slip/inertia, rate of polling sensors
  - using artificial intelligence or machine learning to train autonomous mobile robots via repetitive tasks to eliminate the occurrence of faults, data collection and analysis for decision-making tasks.
- Software libraries/Robot Operating System (ROS) for:
  - command and control, e.g. servomotor
  - navigation object detection and recognition, e.g. sense and avoid, sense and follow
  - basic imaging and signal processing.

3 Develop an autonomous mobile robot to complete an activity defined in a client brief

Design specification and program design for an autonomous mobile robot

- Design specification to include:
  - the intended purpose for an autonomous mobile robot using an educational kit, e.g. wall following and object avoidance robot, picking and packing robot, product recognition robot, transportation robot for delivering parts and products
  - usability and performance requirements, e.g. any user interface requirements for control, starting and stopping, battery charge levels and low battery level action (such as return to charging station, safe power-down), activity completion times, and terrain conditions.
- High-level program design to include:
  - description of the main program tasks in terms of input and output.
  - software program design using recognised techniques, e.g. structured English, flow charts, pseudocode
  - predefined code/algorithms and their sources, e.g. the internet, sensor suppliers
  - test plan and, if appropriate, test data (to test inputs and expected outputs).

Build an autonomous mobile robot

- Assembly of an autonomous mobile robot kit containing at least one programmable device, two input devices and two output devices to include:
  - mechanical structures, e.g. protective/aesthetic shell, chassis/framework, axles, wheels, gears
  - microcontroller/microprocessor programmable devices, e.g. Raspberry Pi, Arduino, PIC, Atmel AT89C52, Beagle Board
  - input devices, e.g. light-dependent resistors, touch sensors, switches, accelerometers, infrared sensors, ultrasonic sensor, light detection and ranging (Lidar) sensor, potentiometers, sound sensors, touch sensors, temperature sensors, position-sensing circuit, colour-sensing circuit, cameras (such as Pixy2), tilt sensors
  - output devices, e.g. LEDs and LED arrays, motors (e.g. servo and stepper), actuators, audio/sound emitters (e.g. piezo speakers, buzzers, amplifiers), solenoids, relays (e.g. H-bridge integrated circuits (ICs) for motor control), seven segment display/ Liquid Crystal Display (LCD)
  - power source, e.g. photovoltaic cells and batteries
  - additional external data storage (if required), e.g. solid-state storage device
  - testing of the kit robot to check basic functionality, e.g. power on.

Development and testing of a control program

- Suitable programming languages include: Flowchart, C (including derivatives), Python and BASIC.
- Use of an Integrated Development Environment (IDE), e.g. Raspberry Pi OS, Arduino IDE, MPLAB IDE, GENIE Studio, Atmel Studio, Matlab/Simulink for:
  - the production and editing of original code
  - adapting library code/snippets, e.g. for the locomotion algorithms, and
  - debugging and compiling code.

- Programming constructs and techniques:
  - program flow and control including:
    - calling program libraries, subroutines/functions/procedures
    - control structures, e.g. sequence, selection, iteration – if, else, switch, case, for, do, while, until, end
    - data structures, e.g. arrays, graphs, matrices
    - timing and delays
  - logic, arithmetic and functions including:
    - variable types, e.g. string, integer
    - arithmetic operations, e.g. adding, subtracting, multiplication, division, increment, decrement, random
    - comparative operators, e.g. equal, not equal, less than, more than,
    - less than or equal to, more than or equal to
    - Boolean operators, e.g. AND, OR, NOT
    - functions, e.g. linear, quadratic, trigonometric, exponential and logarithmic.
- Annotation of code and possibly design documentation to allow effective repair/debugging of the program and for maintainability.
- Test, debug and analyse programs including:
  - to test an autonomous mobile robot for functionality against the expected outcome
  - producing formal documentation of the test results and recording changes that improve the software program and/or hardware
  - analysing test results to identify where faults can be corrected and where improvements can be made to the performance, e.g. speed, precision and safety of the autonomous mobile robot to meet the original requirements.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe adequately how different types of autonomous mobile robot are used.	**M1** Explain adequately how different types of autonomous mobile robot are used, including the benefits and limitations	**D1** Evaluate in detail how different types of autonomous mobile robot are used, including relevant benefits and limitations.
P2 Describe adequately the benefits and limitations of using different types of autonomous mobile robot.		
P3 Describe adequately how software and hardware operate in an autonomous mobile robot for a given purpose.	**M2** Explain adequately how software and hardware operate in an autonomous mobile robot for a given purpose.	**D2** Evaluate how software and hardware operate in an autonomous mobile robot for a given purpose, suggesting improvements.
P4 Produce an adequate specification and high-level program design for an autonomous mobile robot to complete an activity.	**M3** Develop an autonomous mobile robot to successfully complete an activity that functions safely and as intended	**D3** Optimise the performance of an autonomous mobile robot to successfully complete an activity that functions safely and as intended.
P5 Build and program adequately and safely a partially functioning autonomous mobile robot to attempt an activity, using a microcontroller or microprocessor.		
P6 Test adequately and safely a partially functioning autonomous mobile robot to attempt an activity, recording the outcomes of the tests		

Essential guidance for tutors

Assessment

1 Investigate the use of different types of autonomous mobile robot

For Distinction standard, learners will evaluate in detail how two different types of autonomous mobile robots are used. The evaluation will consider varied information sources to provide supported reasons why each robot's behaviour and performance requirements allow it to achieve its purpose given the environmental conditions it operates in and the benefits/limitations that result.

Overall, the evidence will be logically structured and technical engineering terms will be correctly used. The benefits and limitations will be relevant to the purpose of each robot. Learners will also provide a consistent and appropriate amount of detail throughout and reference information sources appropriately.

For Merit standard, learners will explain adequately how two different types of autonomous mobile robots are used. The adequate explanation will include reasons to support why the behaviours and performance requirements of each robot allow it to achieve its purpose given the environment that it operates in and the benefits/limitations that result.

Overall, the evidence will be logically structured, technically accurate and easy to understand. However, the adequate explanations may lack details in some places and the benefits and limitations may not always be relevant to the purpose.

For Pass standard, learners will prepare evidence about how two different types of autonomous mobile robot are used. The descriptions will include adequate details about the purpose and the requirements (behaviours and performance) of the autonomous mobile robots and the intended environmental conditions they operate in.

For the same two types, learners will also describe adequately the benefits and limitations of using the autonomous mobile robots. They should cover at least two different benefits and at least two different limitations of the robots and must consider the environment they operate in when describing the benefits and limitations.

Overall, the adequate descriptions should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

2 Investigate the software and hardware used in autonomous mobile robots

For Distinction standard, learners will evaluate how the software and hardware operate in an autonomous mobile robot for a given purpose. They will methodically deconstruct all key parts of the robot to evaluate how the software, hardware and integration of the software/hardware allow the robot to achieve its purpose. The evidence provided will also include a supported justification about what improvements could be made to the robot being investigated. For example, how specific improvements made to the integration of the hardware/software would improve the performance of the robot in the context of the robot being investigated.

Overall, the evidence will be logically structured and technical engineering terms will be correctly used. Learners will also provide a consistent and appropriate amount of detail throughout and reference information sources appropriately.
For Merit standard, learners will explain adequately how software and hardware operate in an autonomous mobile robot for a given purpose. The explanations will be contextual and will include the programmable devices/microcontroller, input/output devices and power source and also relevant features of these devices, along with explanations for other devices being used. Learners will also explain adequately how software and hardware are integrated together with supported reasons about how the software locomotion algorithm and hardware allow the robot to achieve its purpose.

Overall, the evidence will be logically structured, technically accurate and easy to understand. However, the explanations may lack detail in some places and learners are unlikely to justify why improvements to the autonomous mobile robot are appropriate.

For Pass standard, learners will describe adequately how software and hardware operate in an autonomous mobile robot for a given purpose. The adequate descriptions will include the details of the programmable devices/microcontroller, input/output devices and power source and also some of the features of each of these devices, along with descriptions of other devices being used (such as gears and grippers). They will also describe adequately the locomotion algorithms being used and how the software and hardware are integrated to allow an autonomous mobile robot to achieve its purpose. For example, learners may describe how the robot can make decisions and adapt to changes in the environment to carry a load between two points.

Overall, the adequate descriptions should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology. Meaningful improvements to the robot are unlikely to be given.

3 Develop an autonomous mobile robot to complete an activity defined in a client brief

Learners will build/assemble an autonomous mobile robot from an educational kit and undertake programming exercises to complete an activity. The customer brief will need to scope out the minimum functionality of the autonomous mobile robot, so that learners are able to test whether it meets the requirements set, for example to develop a robot that can follow different configurations of an undulating 3m length wall (made of cardboard boxes) with obstacle avoidance.

For Distinction standard, learners will optimise the performance of the autonomous mobile robot throughout the development process. Learners will provide evidence of hardware and/or software changes that would improve the performance of the robot. For example, this could involve using additional sensors, or changing the program code to increase the velocity of the robot and speed at which navigation decisions are taken. Learners will need to provide evidence of how the autonomous mobile robot was optimised and demonstrate how its performance has been improved.

Overall, the performance of the autonomous mobile robot will be optimised to successfully complete the activity and to make sure it will function safely and as intended. Also, the code will be well structured, annotated and an appropriate range of constructs and techniques will have been used, which means the code is relatively easy to interpret.

For Merit standard, learners will develop an autonomous mobile robot by designing an appropriate control program and building and programming the robot to complete an activity. The robot will function safely and as intended because throughout the development process the learner will correct software and hardware faults identified during suitable testing. Learners will also compare the functionality of their autonomous mobile robot against the purpose, usability and performance requirements and will update their specification accordingly.

Learners will develop the control program with an appropriate range of programming constructs and techniques that have been used correctly. An algorithm to control locomotion will be present and will have been set up correctly. Learners will annotate the code appropriately to explain how the program works.

Overall, the autonomous mobile robot will successfully complete the activity safely and function as intended, with only minor errors present.

For Pass standard, learners will produce an adequate specification including a design for a control program to complete an activity. They will include the purpose, usability and performance requirements for the autonomous mobile robot in their specification. If required, learners may also need to provide details of additional control hardware/circuitry in their specification. The adequate high-level program solution, for example using a flowchart and/or pseudocode, will show the key areas of functionality (inputs, outputs and processes) and how they link together, with some commentary. The design of the control program may omit some elements of functionality. Learners will build and program an autonomous mobile robot safely to attempt the activity using a microcontroller or microprocessor and at least two input and two output devices. If the robot does not function once built, then assistance can be given by the tutor to repair the robot prior to the development of a control program. The control program will contain a narrow range of programming constructs and techniques and some may not be appropriate for the activity or may have been used incorrectly. An algorithm to control locomotion will be present, but it may not have been set up properly or it may contain some errors. The annotation of the control program may also be inconsistent and patchy. Throughout the development process learners will safety test the robot against the purpose, usability and performance requirements. They will record the outcomes of the tests and highlight where there are any faults or where the robot only partially functions given the requirements provided. They must also comment on how any errors were resolved.

Overall, the autonomous mobile robot will partially function, due to some errors that affect the way it operates, or some elements of required functionality may have been omitted. For example, this could mean that the robot may not avoid obstacles as it should do. This means that the robot will attempt the activity, but it may not complete the activity successfully.

Essential information for assignments

There is a maximum number of three summative assignments for this unit.
The relationship of the learning outcomes and criteria is:

Learning outcome: A (P1, P2, M1, D1)

Learning outcome: B (P3, M2, D2)

Learning outcome: C (P4, P5, P6, M3, D3)

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Investigate the use of different types of autonomous mobile robot	A written report with annotated diagrams/photographs.
2 Investigate the software and hardware used in autonomous mobile robots	A written report with annotated diagrams/photographs.
3 Develop an autonomous mobile robot to complete an activity defined in a client brief	A portfolio of evidence, including evidence of the design documentation, control program code, annotated photographs, test results and video showing performance optimisation, and an observation record.

Resource requirements

For this unit, learners must have access to:

- audio-visual resources, expert presenters and/or a site visit demonstrating the uses of and technologies used in autonomous mobile robots
- educational programmable robot kits and other hardware – for example, the following suppliers provide programmable robot kits (there are other suppliers and kits available):
  - RS Components, e.g. Makeblock mBot Robot Kit running Arduino IDE
  - Amazon, e.g. SunFounder Raspberry Pi Pico Robot Car Kit running MicroPython and OSOYOO Model-3 V2.0 DIY Robot Car Kit running Arduino IDE
  - Rapid Electronics Limited, e.g. VexPro running RobotC
  - SparkFun, e.g. JetBot AI Kit v3.0 powered by Jetson Nano.

Notes

1 Centres could alternatively develop, including testing, their own bot kit for learners to assemble and use.

2 Learners must not use 'visual block and text' programming languages, such as Scratch and PICAXE Blockly, to program the robot.

- A range of health and safety guidance documents, data sheets/specifications and relevant tools and equipment should be made available

Indicative reading for learners

Textbooks

Siegwart R et al – *Introduction to Autonomous Mobile Robots* (Intelligent Robotics & Autonomous Agents) (MIT Press, 2011) ISBN 9780262015356

Klancar G et al – *Wheeled Mobile Robotics: From Fundamentals Towards Autonomous Systems* (Butterworth-Heinemann, 2017) ISBN 9780128042045

Unit 123: Aircraft Computers and Electronic Systems

Level:	**3**
Unit type:	**Mandatory**
Assessment type:	**Internal**
Guided learning hours:	**60**

Unit introduction

This unit will develop learners' knowledge and an understanding of the hazards, procedures and aircraft operating environment that influence the handling and associated maintenance of delicate aircraft electronic equipment and systems. Many modern aircraft electronic systems have their own built in test equipment (BITE) and the ability to interrogate these systems using BITE and interpret the resulting information that is displayed, is again an essential skill for aircraft maintenance engineers so, the knowledge and procedures necessary to perform these tasks is covered in the final two outcomes of the unit.

This unit, together with its prerequisite units identified above, covers completely the underpinning knowledge of the European Aviation Safety Agency (EASA) Part-66 module 5. In addition, this unit will also be useful for those pursuing a career as Maintenance Technicians with the armed forces.

Learning outcomes

In this unit, you will:

1 Understand computer data, electronic and fibre optic data buses, computer structure, operation and component interfacing

2 Know the safety hazards and precautions associated with the maintenance and control of microelectronic devices, computer software and electromagnetic environments

3 Understand the principle of operation of electronic flight deck displays and the function of their associated electronic instrument systems

4 Understand the arrangement of electronic aircraft systems and the use of built-in test equipment (BITE) and on-board maintenance systems.

Unit content

1 Understand computer data, electronic and fibre optic data buses, computer structure, operation and component interfacing

Computer data: form of analogue and digital signals; operation and application of analogue to digital (ADC) and digital to analogue (DAC), ADC and DAC data inputs and outputs

Fibre optics: advantages and disadvantages of fibre optic systems; circuit component layout and handling precautions (cable, light guides, couplings, connectors); basic operation of an optical data bus (such as the STANAG 3910 system)

Electronic data buses: format, specification, operation, signal transmission and interfacing of typical aircraft electronic data buses (the aeronautical radio incorporated (ARINC) standards, the military standard (MIL STD) 1553)

Structure, operation and component interfacing: common terms, e.g. software, hardware, integrated circuit (IC), core memory, decoder, language, machine code, routine, byte, bit, PROM; the digital computer, e.g. basic operation, computer component function, operation and interfacing, input section, central processing unit CPU (arithmetic logic unit, register section, control and processing unit and clock), memory and read only memory sections (RAM and ROM), computer outputs; use of medium, large and very large integration

2 Know the safety hazards and precautions associated with the maintenance and control of microelectronic devices, computer software and electromagnetic environments

Electro-static sensitive devices: safety hazards and precautions (handing, static damage, grounding, component labelling, storage and transportation, on-aircraft maintenance precautions)

Software management control: know outline procedures for software certification and modification

Electro-magnetic environment: influence on maintenance of electronic systems, e.g. subject to a high intensity radiated field (HIRF), lighting strike, electromagnetic interference; use of electromagnetic compatibility and lightning protection

3 Understand the principle of operation of electronic flight deck displays and the function of their associated electronic instrument systems

Flight deck displays: operating principles of light emitting diodes (LEDs), liquid crystal displays (LCDs) and cathode ray tubes (CRTs)

Associated electronic instrument systems: function, display modes and display selection methods, e.g. electronic attitude direction indicator (EADI), electronic horizontal situation indicator (EHSI), engine indicating and crew alerting (EICAS), electronic centralised aircraft monitoring (ECAM) systems.

4 Understand the arrangement of electronic aircraft systems and the use of built-in test equipment (BITE) and on-board maintenance systems

Electronic aircraft systems: general arrangement and displays of aircraft electronic systems, e.g. aircrew alerting system (ACAR), ECAM, electronic flight instruments systems (EFIS), EICAS, global positing system (GPS), inertial navigation system (INS), traffic alert and collision avoidance system (TCAS), ground proximity warning system (GPWS), flight data recorder system (FDRS)

System tests: carry out BITE tests on selected systems, e.g. ECAM, EFIS, EICAS, GPS, FDRS systems

On-board maintenance systems: function, layout and operation of, e.g. central maintenance computers, data loading systems, electronic library system, printing, structural monitoring (damage tolerance monitoring), aircraft maintenance analysis system

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Using appropriate sketches showing the input /output signals, describe the operation of an ADC and a DAC converter giving an electronic circuit use for each.	**M1** Explain the function, operation and interfacing of the arithmetic logic unit, control and processing unit, register section, memory sections and clock, within a computer.	**D1** Compare the format, specification, operation, signal transmission, function and interfacing of two ARINC standards and the MIL STD 1553 standard.
P2 Describe the layout, operation and handling precautions for a typical aircraft fibre optic system.		
P3 Define the computing terms software, decoder, integrated circuit, core memory and routine.		
P4 Describe the handling and on-aircraft maintenance hazards/ safety precautions for sensitive electro-static devices and the outline procedures for software certification and modification.	**M2** Explain the nature of the design protection methods used to mitigate the effects of lightning strikes and the subsequent maintenance actions that need to be taken after such a strike.	

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the maintenance procedures that should be adopted when an aircraft electronic system has been subject to an adverse electromagnetic environment.		
P6 Describe with the aid of diagrams the operating principles of LED, LCD and CRT cockpit displays.	**M3** Explain the functions, nature of the displays and the general arrangement of the EICAS system for a modern gas turbine powered transport aircraft.	**D2** Analyse the system arrangement and methods of display, selection and warnings offered by ECAM systems and report on the range and nature of the display functions, the warnings covered and their impact for pilot workload.
P7 State the function and describe the display modes and display selection methods for an electronic attitude direction indicator and an electronic horizontal situation indicator.		
P8 Describe the arrangement and function displays for two electronic aircraft systems.	**M4** With the aid of a schematic block diagram, explain the layout and functions of a typical on-board structural monitoring system.	**D3** Examine the nature, functions, interfacing, communication methods and general operation of the on-board maintenance analysis system and report on your findings.
P9 Carry out a BITE diagnostic test on an aircraft electronic system.		

Essential guidance for tutors

Assessment

1 Understand computer data, electronic and fibre optic data buses, computer structure, operation and component interfacing

For Distinction standard, in addition to the requirements for the Pass and Merit standards, learners will produce a clear, comprehensive and detailed table that compares the format, specification, operation, signal transmission, function and interfacing of two different ARINC standards and the MIL 1553 standard. For example, learners could compare the ARINC 429, ARINC 818 and MIL 1553C standards.

For Merit standard, in addition to the requirements of the Pass standard learners will explain the function, operation and interfacing of the arithmetic logic unit, control and processing unit, register section, memory sections and clock within a computer. Block diagrams showing their interconnections should support the explanation.

For a Pass standard, learners will describe the operation of ADC and DAC converters. They will produce sketches showing the input and output signals for each type of conversion and will give one example of an aircraft systems that uses ADC conversion and one example of an aircraft system that uses DAC conversion. Learners will need to describe the handling precautions when working on aircraft fibre-optic systems and give a basic description of the layout and operation of a typical aircraft fibre-optic system. For example, they could describe the layout and basic operation of a fibre-optic data bus. Learners will also need to define the computing terms software, decoder, integrated circuit, core memory and routine.

2 Know the safety hazards and precautions associated with the maintenance and control of microelectronic devices, computer software and electromagnetic environments

For a Merit standard, learners will expand on what they have produced for the Pass standard and will explain how aircraft systems are protected against the effects of lighting strikes and the maintenance actions that must be undertaken on an aircraft that has been subjected to a lightning strike.

For a Pass standard, learners will describe the safety precautions and hazards associated with working on aircraft systems containing sensitive electro-static devices. They will also describe the precautions that must be employed when handling the electro-static devices. Learners will also give an overview of the procedures that must be followed to ensure that software used in aircraft systems is certified as airworthy throughout its life cycle. In addition, learners will describe the maintenance procedures that must be followed when an aircraft electronic system has been subject to electromagnetic interference. For example, learners could describe the procedures that must be followed following an aircraft being exposed to a high intensity radiated field (HIRF).

3 Understand the principle of operation of electronic flight deck displays and the function of their associated electronic instrument systems

For Distinction standard, in addition to the requirements of the Merit and Pass standards learners, will conduct their own research into aircraft ECAM systems and will produce a technically correct written report that details the functions of the ECAM, the information that it can display to the pilot and how the system helps reduce the pilot workload.

For a Merit standard, in addition to the requirements of the Pass standard, learners will explain with the aid of suitable diagrams, the functions and layout of an EICAS system for a civil airliner such an air Airbus A330. They will explain the types of information that the EICAS displays in the cockpit.

For a Pass standard, learners will describe the operating principles of LED, LCD and CRT cockpit displays. They will produce suitable, labelled sketches that will assist the reader in understanding their principles of operation. They will also provide information about an electronic horizontal situation indicator and an electronic attitude direction indicator giving their respective functions and describing the information that can be displayed on them and how this information is selected.

4 Understand the arrangement of electronic aircraft systems and the use of built-in test equipment (BITE) and on-board maintenance systems.

For Distinction standard, in addition to the requirements of the Pass and Merit standards learners will conduct their own research into aircraft on-board maintenance analysis systems and will produce a technically correct written report that details the system's functions, interfacing, operation and methods of communication.

For a Merit standard, in addition to the requirements of the Pass standard, learners will produce a schematic block diagram of a typical aircraft on-board structural monitoring system and use it to explain the systems layout and functions.

For a Pass standard, learners will describe the arrangement and function displays for two electronic aircraft systems as detailed in the unit content. Their descriptions will include the type(s) of information displayed and the display layout. Learners will also carry out a practical task to undertake a BITE test of a given aircraft system. The learner evidence will consist of annotated photographs showing the test carried out. This will also be supported by an assessor observation record produced by the assessor.

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Understand computer data, electronic and fibre optic data buses, computer structure, operation and component interfacing.	A written report covering the principles of computer data, the function, layout and operation of aircraft fibre-optic and data bus systems and the function, interaction, and operation of computer hardware.
2 Know the safety hazards and precautions associated with the maintenance and control of microelectronic devices, computer software and electromagnetic environments.	A written report covering the requirements when working with and on aircraft systems that contain sensitive electrostatic devices, the principles of aircraft software certification and modification, the procedures that must be observed when an aircraft is subjected to adverse electromagnetic environments and methods/ mitigations and maintenance actions related to the effects of lightning strikes on aircraft.
3 Understand the principle of operation of electronic flight deck displays and the function of their associated electronic instrument systems.	A written report detailing the principles and operation of aircraft electronic cockpit displays and the function and operation of different aircraft flight systems including the information available to the pilots.
4 Understand the arrangement of electronic aircraft systems and the use of built-in test equipment (BITE) and on-board maintenance systems.	A written report detailing the operation and function of aircraft on-board maintenance analysis systems and a practical activity detailing how a BITE test is performed on a given aircraft electronic system.

Essential resources

A considerable amount of computer hardware and access to a live aircraft or simulator will be needed in order for learners to meet the assessment criteria. The following hardware and documentation is considered essential to fully meet the unit aims and to meet the requirements of the external regulatory bodies:

- digital computer equipment and components and associated circuit boards, as detailed in the unit content for learning outcome 1
- operational aircraft/ground engineering simulators
- data books and manufacturers' specifications
- maintenance manuals or air publications.

Indicative reading for learners

Textbooks

Tooley M – *Aircraft Digital Electronic and Computer Systems* (Routledge, 2022) ISBN 9781032104805

Wyatt D et al – *Aircraft Electrical and Electronic Systems* (Routledge, 2018) ISBN 9780415827768

Unit 124: Avionic Systems

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning hours: 60

Unit introduction

The avionic systems installed on modern aircraft have grown significantly over the last few decades in terms of complexity and their level of integration with other aircraft systems. A thorough understanding of avionic systems and their underpinning principles is needed by aircraft technicians involved in the installation and maintenance of these systems.

This unit will familiarise learners with a range of avionic systems and will develop an understanding of fundamental avionic principles, particularly the application of digital techniques in avionic systems. Learners will also know how avionic systems are monitored and tested.

Learners will investigate the operational aspects of key avionic systems and will understand how they interface with other aircraft systems. Learners will start by investigating how logic functions and numbering systems are used as the basis of digital components. This leads to how digital components form the end applications such as electronic displays and computer memory. This is followed by a look at radio frequency (RF) principles and how these are applied to communication and navigation systems.

The theme of navigation develops through area navigation and on to flight management systems. The unit will also cover the operation of automatic flight control systems (AFCS). The final section of the unit looks at methods of troubleshooting avionic systems.

This unit has been designed to provide some of the knowledge required for learners wishing to progress on to the European Aviation Safety Agency (EASA) Part 66 licensing requirements. It will also benefit those seeking employment within the armed forces or the aircraft manufacturing industry.

Learning outcomes

In this unit, you will:

1 Be able to relate digital electronic fundamentals to their end applications

2 Know the purpose of typical aircraft electronic systems

3 Understand the operation of an automatic flight control system

4 Understand the principles of monitoring and testing avionic systems

Unit content

1 Be able to relate digital electronic fundamentals to their end applications

Logic functions: common logic circuit functions, e.g. digital signals, combinational logic, sequential logic.

Numbering systems: principles of numbering systems, e.g. binary, binary codes, octal, hexadecimal, denary.

Hardware: components, e.g. integrated circuits, printed circuit boards, computer memory, microprocessors; electronic displays, e.g. cathode ray tubes, liquid crystal displays, light emitting diodes.

2 Know the purpose of typical aircraft electronic systems

Radio frequency (RF) principles: nature of radio wave transmissions, e.g. electromagnetic spectrum, modulation, amplifiers, transmitters, receivers; frequency bands, e.g. high (HF), very high (VHF), ultra high (UHF).

Communication systems: manual and automatic systems, e.g. flight deck communications, data communications, interphone system, aircraft communications addressing and reporting system (ACARS), satellite communications (SATCOM), cockpit voice recorder (CVR), selective calling (SELCAL).

Navigation systems: radio/radar navigation systems, e.g. automatic direction finder (ADF), VHF omnirange (VOR), instrument landing system (ILS), microwave landing system (MLS), distance measuring equipment (DME), VLF/Omega; self-contained/long-range systems, e.g. inertial navigation system (INS), inertial reference system (IRS), global navigation satellite systems (GNSS), long range navigation (LORAN), Doppler navigation.

Flight management systems: area navigation, e.g. navigation data base, position initialisation, route planning, navigation system management, lateral navigation (LNAV); performance management, e.g. operational database, performance initialisation, flight planner and management, programme pin identification, auto- throttle, vertical navigation (VNAV).

3 Understand the operation of an automatic flight control system

Automatic flight control system (AFCS) components: mode control panel; computer amplifier; servos (roll, yaw, pitch); attitude references; flight director; flight mode annunciator; audible and visual warnings.

Basic operation: pitch modes, e.g. altitude hold; vertical speed select, indicated air speed (IAS) select, mach hold; roll modes, e.g. heading select, LOC/VOR select; auto approach and landing.

4 Understand the principles of monitoring and testing avionic systems

Purpose of monitoring: cost reduction, e.g. reduce unnecessary removals, reduce no fault found; predictive maintenance; simplify troubleshooting.

Test methods: individual line replaceable unit (LRU) testing, e.g. current operation monitoring, built-in test (BIT), built-in test equipment (BITE), go/no test, fault codes; comprehensive system testing, e.g. fault history, centralised maintenance systems.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe where digital electronics including logic functions, numbering systems and hardware are used in avionic systems.	**M1** Explain with the aid of diagrams the operating principles of two types of electronic display.	
P2 Describe the principles of radio frequency transmissions.	**M2** Compare the operation of three aircraft navigation systems and their applications.	**D1** Investigate how a flight management system is initialised with performance and navigation data.
P3 Describe the use of three aircraft communication systems.		
P4 Describe the features of two radio radar navigation systems and two self-contained/long-range systems.		
P5 Describe the basic features of flight management system area navigation and performance management.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 State the function of five AFCS components.	**M3** Explain in detail how an automatic flight control system is used during approach and landing.	**D2** Investigate the interaction of avionic components on the overall performance of an automatic flight control system.
P7 Describe the basic operation of one pitch and one roll mode of an automatic flight control system.		
P8 State the purpose of monitoring and describe a test method for a given avionic system.	**M4** Explain how flight management systems can reduce operating costs with area navigation and flight performance management.	

Essential guidance for tutors

Assessment

1 Be able to relate digital electronic fundamentals to their end applications

For Merit standard, in addition to the requirements of the Pass standard, learners will explain the operating principles of two types of electronic display from the list given in the unit content. For example, learners could explain the operating principles of LED and CRT displays. They will produce suitable, labelled sketches that will assist the reader in understanding their principles of operation.

For a Pass standard, learners will describe common logic circuit functions and the different numbering systems used in electronic systems. They will also describe how hardware components are interconnected to create an electronic circuit giving an example of where such a circuit is used in an avionic system.

2 Know the purpose of typical aircraft electronic systems

For Distinction standard, learners will expand upon their description of the flight management system and after conducting their own research will produce a written report that details how navigation and performance data is loaded into the flight management system of a given aircraft.

For a Merit standard, in addition to the requirements of the Pass standard, learners will produce a clear, comprehensive, and detailed table that compares the operation of three aircraft navigation systems and their applications. For example, learners could compare the inertial Navigation System (INS), Global Navigation Satellite Systems (GNSS) and Long-Range Navigation System (LORAN) giving their relative benefits.

For a Pass standard, learners will describe the nature of radio wave transmissions including the need for amplification, modulation, transmitters and receivers. They will also describe the principles of two types of frequency band as detailed in the unit content giving an example of where each is used in avionic systems. Learners will also describe the function of three aircraft communication systems. For example, they could describe the function of the Cockpit Voice Recorder (CVR), the interphone system and the Aircraft Communications Addressing and Reporting System (ACARS). Learners will also describe the features of two radio/radar navigation systems and two self-contained/long-range systems. Finally, learners will, with the aid of suitable diagrams, describe the basic features of the area navigation and performance management functions of the flight management system.

3 Understand the operation of an automatic flight control system

For Distinction standard, learners will conduct their own research and compile a technically accurate report that details how the components of the AFCS system interact to control the aircraft in a safe flight condition. For example, they could discuss in-built redundancy in the aircraft systems and the use of control laws.

For a Merit standard, learners will expand upon their evidence for the Pass standard and give a comprehensive explanation of how the AFCS system of an airliner controls the aircraft during approach and landing.

For a Pass standard, learners will state the function of five of the AFCS components from the list given in the unit content. They will then describe how a simple AFCS system operates in pitch and roll.

4 Understand the principles of monitoring and testing avionic systems

For a Merit standard, learners will expand upon their evidence produced for the Pass standard and will explain how aircraft operating costs can be reduced by using area navigation and flight performance management systems. For example, learners could explain how the monitoring of the aircraft systems can help engineers predict when in-service failures could occur, allowing component replacements to be proactively managed and scheduled instead of reactive once the component has failed.

For a Pass standard, learners will state the purpose of monitoring of avionic systems and describe one given test method from the list detailed in the unit content.

The table below shows the recommended approach to assessment, detailing suitable forms of evidence for each learning outcome. Centres can use these forms of evidence or other suitable ones. Centres need to provide learners with an appropriateassignment brief to complement the recommended assessment approach.

Learning outcome	Recommended assessment approach
1 Be able to relate digital electronic fundamentals to their end applications	A written report covering the principles of logic circuits and how components are interconnected to produce aircraft avionic systems and the principles and operation of aircraft electronic cockpit displays.
2 Know the purpose of typical aircraft electronic systems	A written report covering the principles of radio wave transmission and the function, layout and operation of different aircraft navigation, communication and flight management systems.
3 Understand the operation of an automatic flight control system	A written report detailing the function and operation of an aircraft AFCS system and how the avionic parts of the AFCS system interact to control the aircraft in safe flight.
4 Understand the principles of monitoring and testing avionic systems	A written report detailing the purpose of avionic system monitoring and how management systems can be used to help operators reduce aircraft operating costs.

Essential resources

To meet the needs of this unit it is essential that centres have access to the following:

- an aircraft and/or simulator with functioning avionic equipment
- representative avionic equipment, e.g. control panels, computers, displays and indicators
- test equipment and measuring instruments
- relevant aircraft technical publications, e.g. maintenance manuals, system schematics, wiring diagram manuals.

Indicative reading for learners

Textbooks

Collinson R – *Introduction to Avionics Systems* (Springer, 2014)

ISBN 9789400792593

Kenney S – *Avionics: Fundamentals of Aircraft Electronics* (Avotek Information Resources, 2013) ISBN 9781933189284

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