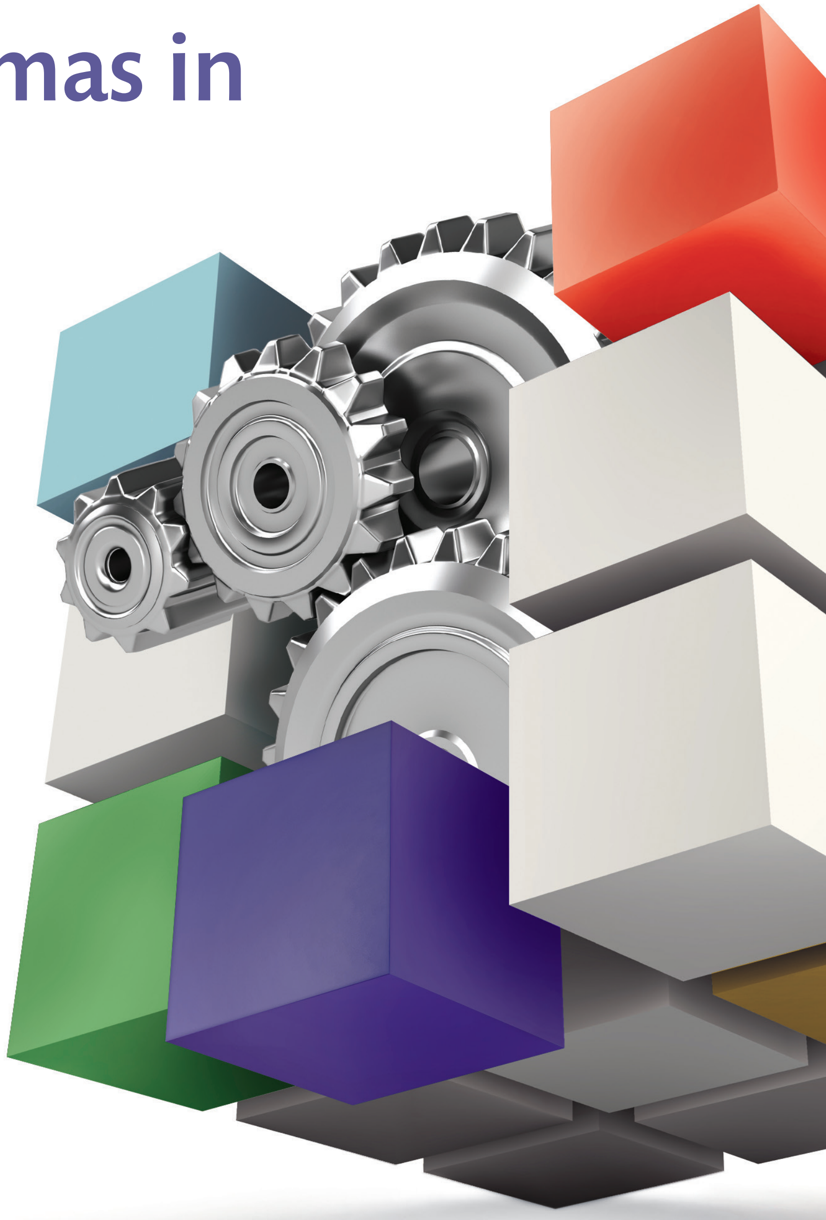
Pearson BTEC

Pearson
BTEC Level 3 National Extended Diplomas in
Engineering

Engineering
Electrical and Electronic Engineering
Mechanical Engineering
Computer Engineering
Manufacturing Engineering
Aeronautical Engineering



Specification

First teaching from September 2016

First certification from 2018

Issue 9

Pearson
BTEC Level 3 National Extended Diplomas in Engineering

Engineering

Electrical and Electronic Engineering

Mechanical Engineering

Computer Engineering

Manufacturing Engineering

Aeronautical Engineering

Specification

First teaching September 2016

Issue 9

About Pearson

We are the world's learning company operating in 70 countries around the world with more than 22,500 employees. We provide content, assessment and digital services to schools, colleges and universities, as well as professional and vocational education to learners to help increase their skills and lifelong employability prospects. We believe that wherever learning flourishes so do people.

This specification is Issue 9. We will inform centres of any changes to this issue. The latest issue can be found on our website.

References to third-party material made in this specification are made in good faith. We do not endorse, approve or accept responsibility for the content of materials, which may be subject to change, or any opinions expressed therein. (Material may include textbooks, journals, magazines and other publications and websites.)

ISBN 978 1 446 95114 9

Welcome

With a track record built over 30 years of learner success, BTEC Nationals are widely recognised by industry and higher education as the signature vocational qualification at Level 3. They provide progression to the workplace either directly or via study at a higher level. Proof comes from YouGov research, which shows that 62% of large companies have recruited employees with BTEC qualifications. What's more, well over 100,000 BTEC students apply to UK universities every year and their BTEC Nationals are accepted by over 150 UK universities and higher education institutes for relevant degree programmes either on their own or in combination with A Levels.

Why are BTECs so successful?

BTECs embody a fundamentally learner-centred approach to the curriculum, with a flexible, unit-based structure and knowledge applied in project-based assessments. They focus on the holistic development of the practical, interpersonal and thinking skills required to be able to succeed in employment and higher education.

When creating the BTEC Nationals in this suite, we worked with many employers, higher education providers, colleges and schools to ensure that their needs are met. Employers are looking for recruits with a thorough grounding in the latest industry requirements and work-ready skills such as teamwork. Higher education needs students who have experience of research, extended writing and meeting deadlines.

We have addressed these requirements with:

- a range of BTEC sizes, each with a clear purpose, so there is something to suit each learner's choice of study programme and progression plans
- refreshed content that is closely aligned with employers' and higher education needs for a skilled future workforce
- assessments and projects chosen to help learners progress to the next stage. This means some are set by you to meet local needs, while others are set and marked by Pearson so that there is a core of skills and understanding that is common to all learners. For example, a written test can be used to check that learners are confident in using technical knowledge to carry out a certain job.

We are providing a wealth of support, both resources and people, to ensure that learners and their teachers have the best possible experience during their course. See *Section 10* for details of the support we offer.

A word to learners

Today's BTEC Nationals are demanding, as you would expect of the most respected applied learning qualification in the UK. You will have to choose and complete a range of units, be organised, take some assessments that we will set and mark, and keep a portfolio of your assignments. But you can feel proud to achieve a BTEC because, whatever your plans in life – whether you decide to study further, go on to work or an apprenticeship, or set up your own business – your BTEC National will be your passport to success in the next stage of your life.

Good luck, and we hope you enjoy your course.

Collaborative development

Students completing their BTEC Nationals in Engineering will be aiming to go on to employment, often via the stepping stone of higher education. It was, therefore, essential that we developed these qualifications in close collaboration with experts from professional bodies, businesses and universities, and with the providers who will be delivering the qualifications. To ensure that the content meets providers' needs and provides high-quality preparation for progression, we engaged experts. We are very grateful to all the university and further education lecturers, teachers, employers, professional body representatives and other individuals who have generously shared their time and expertise to help us develop these new qualifications.

Employers, professional bodies and higher education providers that have worked with us include:

Cisco Systems

Engineering Council

Network Rail

Nottingham Trent University

Parafix

Royal Academy of Engineering

University of Exeter

University of Northampton.

These qualifications have been approved by the engineering professional bodies on behalf of the Engineering Council as contributing to the requirements for professional registration as an Engineering Technician (EngTech).

The professional bodies include:

The Institution of Engineering and Technology (IET)

The Institution of Mechanical Engineers (IMechE)

The Society of Operations Engineers (SOE).

In addition, universities, professional bodies and businesses have provided letters of support confirming that these qualifications meet their entry requirements. These letters can be viewed on our website.

Summary of Pearson BTEC Level 3 National Extended Diplomas in Engineering Specification Issue 9 changes

Summary of changes made between the previous issue and this current issue	Page number
The *Structures of the qualifications at a glance* table has been updated to include units that have been added to the Extended Certificate, Diploma and Extended Diploma.	Pages 10 and 13
Unit 59: Principles of Electrical Machines and *Unit 60: Autonomous Mobile Robotics* have been added to the specification to provide additional optional unit choices for learners. (*Unit 59: Principles of Electrical Machines* is a barred combination with *Unit 15: Electrical Machines* due to duplicate content.)	Pages 13, 30, 31, 33, 35, 687 and 699
Removal of references to MyBTEC, as that service is retiring.	Pages 711, 716, 721, 737, 738

Summary of Pearson BTEC Level 3 National Extended Diplomas in Engineering Specification Issue 8 changes

Summary of changes made between Issue 7 and Issue 8	Page number
The last paragraph of the *Qualification and unit content* section has been amended to allow centres delivering the qualification above to alter the content to reflect the context of the country where it is being delivered.	Page 14
Changes made to *Unit 16: Three Phase Electrical Systems* Content and Assessment criteria for Learning aim C to replace 'domestic' with 'industrial/commercial' and clarify the wording in criterion C.D3.	Pages 211 and 212
Changes made to *Unit 19: Electronic Devices and Circuits* Content for B3, Assessment criteria for Learning aim B and Essential information for assessment decisions section Learning aim B Distinction and Merit standard.	Pages 242, 244, 247
Changes made to *Unit 54: Aircraft Electrical and Instrument Systems* Assessment criteria and Essential information for assessment decisions for Learning aim C to replace 'assemble' with 'inspect'.	Pages 643 and 647
A new unit *Unit 57: Sustainable Transport* has been added to the Pearson BTEC Level 3 National Extended Diploma in Engineering in this specification.	Pages 13, 30 and 669-676
A new unit *Unit 58: Energy Management* has been added to the Person BTEC Level 3 National Extended Diploma in Engineering in this specification.	Pages 13, 30 and 677-685

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

Contents

Introduction to BTEC National qualifications for the engineering sector

This specification contains the information you need to deliver the Pearson BTEC Level 3 National Extended Diplomas in Engineering. The specification signposts you to additional handbooks and policies. It includes all the units for these qualifications.

These qualifications are part of the suite of engineering qualifications offered by Pearson. In the suite there are qualifications that focus on different progression routes, allowing learners to choose the one best suited to their aspirations.

All qualifications in the suite share some common units and assessments, allowing learners some flexibility in moving between qualifications where they wish to select a more specific progression route. The qualification titles are given below.

Within this suite are BTEC National qualifications for post-16 learners wishing to specialise in a specific industry, occupation or occupational group. The qualifications give learners specialist knowledge and technical skills, enabling entry to an Apprenticeship or other employment, or progression to related higher education courses. Learners taking these qualifications must have a significant level of employer involvement in their programmes.

In the engineering sector these qualifications are:

Pearson BTEC Level 3 National Diploma in Engineering (720 GLH) 601/7580/1

Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering (720 GLH) 601/7579/5

Pearson BTEC Level 3 National Diploma in Mechanical Engineering (720 GLH) 601/7583/7

Pearson BTEC Level 3 National Diploma in Computer Engineering (720 GLH) 601/7578/3

Pearson BTEC Level 3 National Diploma in Manufacturing Engineering (720 GLH) 601/7582/5

Pearson BTEC Level 3 National Diploma in Aeronautical Engineering (720 GLH) 601/7577/1

Pearson BTEC Level 3 National Extended Diploma in Engineering (1080 GLH) 601/7588/6

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering (1080 GLH) 601/7587/4

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering (1080 GLH) 601/7590/4

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering (1080 GLH) 601/7586/2

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering (1080 GLH) 601/7589/8

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering (1080 GLH) 601/7585/0.

Other BTEC National qualifications in this sector provide a broad introduction that gives learners transferable knowledge and skills. These qualifications are for post-16 learners who want to continue their education through applied learning. The qualifications prepare learners for a range of higher education courses either by meeting entry requirements in their own right or by being accepted alongside other qualifications at the same level and adding value to them. Learners may progress to one of the qualifications in this specification having completed a smaller qualification that provides suitable fundamental knowledge and skills.

In the engineering sector these qualifications are:

Pearson BTEC Level 3 National Certificate in Engineering (180 GLH) 603/1197/6

Pearson BTEC Level 3 National Extended Certificate in Engineering (360 GLH) 601/7584/9

Pearson BTEC Level 3 National Foundation Diploma in Engineering (540 GLH) 601/7591/6.

This specification signposts all the other essential documents and support that you need as a centre in order to deliver, assess and administer the qualification, including the staff development required. A summary of all essential documents is given in *Section 7*. Information on how we can support you with these qualifications is given in *Section 10*.

The information in this specification is correct at the time of publication.

Total Qualification Time

For all regulated qualifications, Pearson specifies a total number of hours that it is estimated learners will require to complete and show achievement for the qualification: this is the Total Qualification Time (TQT). Within TQT, Pearson identifies the number of Guided Learning Hours (GLH) that we estimate a centre delivering the qualification might provide. Guided learning means activities, such as lessons, tutorials, online instruction, supervised study and giving feedback on performance, that directly involve teachers and assessors in teaching, supervising and invigilating learners. Guided learning includes the time required for learners to complete external assessment under examination or supervised conditions.

In addition to guided learning, other required learning directed by teachers or assessors will include private study, preparation for assessment and undertaking assessment when not under supervision, such as preparatory reading, revision and independent research.

BTEC Nationals have been designed around the number of hours of guided learning expected. Each unit in the qualification has a GLH value of 60, 90 or 120. There is then a total GLH value for the qualification.

Each qualification has a TQT value. This may vary within sectors and across the suite depending on the nature of the units in each qualification and the expected time for other required learning.

The following table shows all the qualifications in this sector and their GLH and TQT values.

Qualifications, sizes and purposes at a glance

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Certificate in Engineering	180 GLH (260 TQT) Equivalent in size to 0.5 of an A Level. 2 units of which both are mandatory and 1 is external. Mandatory content (100%). External assessment (67%).	This qualification is intended for post-16 learners who want to continue their education through applied learning and who aim to progress to higher education and ultimately employment. It aims to provide a coherent introduction to study of the engineering sector.
Pearson BTEC Level 3 National Extended Certificate in Engineering	360 GLH (465 TQT) Equivalent in size to one A Level. 4 units of which 3 are mandatory and 2 are external. Mandatory content (83%). External assessment (67%).	This qualification provides a broad basis of study for the engineering sector. It has been designed to support progression to higher education when taken as part of a programme of study that includes other appropriate BTEC Nationals or A Levels.
Pearson BTEC Level 3 National Foundation Diploma in Engineering	540 GLH (740 TQT) Equivalent in size to 1.5 A Levels. 7 units of which 4 are mandatory and 2 are external. Mandatory content (67%). External assessment (44%).	This qualification has been designed as a one-year, full-time course that supports progression to an apprenticeship in engineering or to a further year of study at Level 3. If taken as part of a programme of study that includes other BTEC Nationals or A Levels, it supports progression to higher education.
Pearson BTEC Level 3 National Diploma in Engineering	720 GLH (975 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).	This qualification is aimed at learners preparing for roles in engineering, for example engineering technician or engineering operative. Learners gain relevant skills and knowledge from studying a range of content focused on electrical/electronic and mechanical disciplines, for example electrical machines and maintenance of mechanical systems. The qualification has been designed to be the substantive part of a 16–19 study programme for learners who want a strong core of sector study and a focus on the wider engineering industry. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering	720 GLH (980 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).	This qualification is aimed at learners preparing for roles in electrical and electronic engineering, for example electrical engineering technician or electronic engineering operative. Learners gain relevant skills and knowledge from studying a range of units, for example in electronic devices and circuits, power and energy systems and printed circuit board design and manufacture. The qualification is designed to be the substantive part of a 16–19 study programme for learners wanting a strong core of electrical and electronic engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.
Pearson BTEC Level 3 National Diploma in Mechanical Engineering	720 GLH (985 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).	This qualification is aimed at learners preparing for roles in mechanical engineering, for example mechanical engineering technician or mechanical fitter. Learners gain relevant skills and knowledge from studying a range of units, for example in metallic and non-metallic materials, fluid mechanics and/or thermodynamic practices. The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of mechanical engineering. The qualification may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Diploma in Computer Engineering	720 GLH (985 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).	This qualification is aimed at learners preparing for roles in computer engineering, for example computer engineering technician or computer support analyst. Learners gain relevant skills and knowledge from studying a range of units, for example in computer programming, website design and/or cyber security. The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of knowledge in computer engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.
Pearson BTEC Level 3 National Diploma in Manufacturing Engineering	720 GLH (980 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).	This qualification is aimed at learners preparing for roles in manufacturing engineering, for example manufacturing engineering technician or welding operative. Learners gain relevant skills and knowledge from studying a range of units, for example in computer-aided manufacturing, modern manufacturing systems, additive manufacturing and machining. The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of knowledge of manufacturing engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Diploma in Aeronautical Engineering	720 GLH (990 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).	This qualification is aimed at learners preparing for roles in aeronautical engineering, for example aeronautical engineering technician or aerospace fitter. Learners gain relevant skills and knowledge from studying a range of units, for example in aircraft workshop principles, gas turbine engines, airframe construction and first-line maintenance. The qualification is designed to be the substantive part of a 16–19 study programme for learners who want to focus on the specific aspects that relate to the aeronautical industry. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.
Pearson BTEC Level 3 National Extended Diploma in Engineering	1080 GLH (1475 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in engineering. Learners gain relevant skills and knowledge from studying a range of content focused on electrical/electronic and mechanical disciplines, for example electrical machines and maintenance of mechanical systems. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in electrical and electronic engineering, such as a power engineering technician. Learners gain relevant skills and knowledge from studying a range of units, for example in electronic devices and circuits, power and energy systems, printed circuit board design and manufacture, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.
Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners who want to progress to employment in mechanical engineering, such as a mechanical maintenance technician. Learners gain relevant skills and knowledge from studying a range of units, for example in metallic and non-metallic materials, fluid mechanics, thermodynamic practices, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Computer Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in computer engineering, such as a computer support technician. Learners gain relevant skills and knowledge from studying a range of units, for example in computer programming, microcontrollers, website design, cyber security, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.
Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering	1080 GLH (1475 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in manufacturing engineering, such as a quality control technician. Learners gain relevant skills and knowledge from studying a range of units, for example in computer-aided manufacturing, modern manufacturing systems, microcontrollers, additive manufacturing, and machining. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering	1080 GLH (1495 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in aeronautical/ aerospace engineering, for example in aerospace manufacturing or as a systems fitter or aircraft maintenance operative. Learners gain relevant skills and knowledge from studying a range of units, for example in aircraft workshop principles, microcontrollers, calculus, gas turbine engines, airframe construction and first-line maintenance. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Structures of the qualifications at a glance

This table shows all the units and the qualifications to which they contribute. The full structure for this Pearson BTEC Level 3 National in Engineering is shown in *Section 2*. **You must refer to the full structure to select units and plan your programme.**

Key

	Unit assessed externally	**M**	**Mandatory units**	**O**	**Optional units**		
E	**Engineering**	**EE**	**Electrical/Electronic**	**ME**	**Mechanical**	**C**	**Computer**
MA	**Manufacturing**	**AE**	**Aeronautical**				

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
1 Engineering Principles	120	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
2 Delivery of Engineering Processes Safely as a Team	60	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
3 Engineering Product Design and Manufacture	120		M	M	M	M	M	M	M	M	M	M	M	M	M	M
4 Applied Commercial and Quality Principles in Engineering	60			M	M	M	M	M	M	M	M	M	M	M	M	M
5 A Specialist Engineering Project	60				M	M	M	M	M	M	M	M	M	M	M	M
6 Microcontroller Systems for Engineers	120										M	M	M	M	M	M
7 Calculus to Solve Engineering Problems	60		O	O	O	O	O	O	O	O	M	M	M	M	M	M
8 Further Engineering Mathematics	60				O	O	O	O	O	O	O	O	O	O	O	O
9 Work Experience in the Engineering Sector	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O
10 Computer Aided Design in Engineering	60		O	O	O		O	O	O	O	O		O	O	O	O
11 Engineering Maintenance and Condition Monitoring Techniques	60		O	O	O		O	O	O	O	O		O	O	O	O
12 Pneumatic and Hydraulic Systems	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
13 Welding Technology	**60**			O	O		O		O	O	O		O		O	O
14 Electrical Installation of Hardware and Cables	**60**				O	O		O			O	O		O	O	
15 Electrical Machines**	**60**			O	O	O	O	O		O	O	O	O	O		O
16 Three Phase Electrical Systems	**60**				O	O		O	O	O	O	O		O	O	O
17 Power and Energy Electronics	**60**				O	O					O	O				
18 Electrical Power Distribution and Transmission	**60**				O	O		O			O	O	O	O		
19 Electronic Devices and Circuits	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
20 Analogue Electronic Circuits	**60**				O	O	O	O			O	O	O	O		
21 Electronic Measurement and Testing of Circuits	**60**			O	O	O	O	O			O	O	O	O	O	O
22 Electronic Printed Circuit Board Design and Manufacture	**60**			O	O	O		O	O		O	O		O	O	
23 Digital and Analogue Electronic Systems	**60**				O	O					O	O				
24 Maintenance of Mechanical Systems	**60**			O	O	O	O	O	O		O	O	O	O	O	
25 Mechanical Behaviour of Metallic Materials	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
26 Mechanical Behaviour of Non-metallic Materials	**60**				O		O		O	O	O	O	O		O	O
27 Static Mechanical Principles in Practice	**60**			O	O	O	O	O	O		O	O	O	O	O	
28 Dynamic Mechanical Principles in Practice	**60**				O		O		O		O	O	O		O	O
29 Principles and Applications of Fluid Mechanics	**60**				O		O			O	O		O		O	O
30 Mechanical Measurement and Inspection Technology	**60**		O	O	O	O	O		O		O	O	O	O	O	

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
31 Thermodynamic Principles and Practice	**60**				O		O			O	O		O			O
32 Computer System Principles and Practice	**60**				O			M			O			M		
33 Computer Systems Security	**60**				O	O		O			O	O	O	O		
34 Computer Systems Support and Performance	**60**				O	O	O	O	O		O	O	O	O	O	
35 Computer Programming	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
36 Programmable Logic Controllers	**60**			O	O	O	O	O	O	O	O	O	O	O	O	O
37 Computer Networks	**60**				O	O		O			O	O		O		
38 Website Production to Control Devices	**60**				O	O		O			O	O		O		
39 Modern Manufacturing Systems	**60**				O				M		O				M	
40 Computer Aided Manufacturing and Planning	**60**				O			O	O		O		O	O	O	
41 Manufacturing Secondary Machining Processes	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
42 Manufacturing Primary Forming Processes	**60**				O		O		O		O		O		O	
43 Manufacturing Computer Numerical Control Machining Processes	**60**			O	O	O	O	O	O	O	O	O	O	O	O	O
44 Fabrication Manufacturing Processes	**60**		O	O	O	O	O		O		O	O	O		O	O
45 Additive Manufacturing Processes	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
46 Manufacturing Joining, Finishing and Assembly Processes	**60**				O				O		O				O	
47 Composites Manufacture and Repair Processes	**60**				O				O	O	O				O	O

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
48 Aircraft Flight Principles and Practice	**60**									M						M
49 Aircraft Workshop Methods and Practice	**60**									O						O
50 Aircraft Gas Turbine Engines	**60**									O						O
51 Aircraft Propulsion Systems	**60**									O						O
52 Airframe Construction and Repair	**60**									O						O
53 Airframe Mechanical Systems	**60**									O						O
54 Aircraft Electrical and Instrument Systems	**60**									O						O
55 Aircraft First Line Maintenance Operations	**60**									O						O
56 Industrial Robotics	**60**				O	O	O	O	O	O	O	O	O	O	O	O
57 Sustainable Transport	**60**			O	O						O					
58 Energy Management	**60**				O						O					
59 Principles of Electrical Machines**	**60**				O	O					O	O				
60 Autonomous Mobile Robotics	**60**				O	O	O				O	O	O			

** Learners may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, they cannot take both.

Qualification and unit content

Pearson has developed the content of the new BTEC Nationals in collaboration with employers and representatives from higher education and relevant professional bodies. In this way, we have ensured that content is up to date and that it includes the knowledge, understanding, skills and attributes required in the sector.

Each qualification in the suite has its own purpose. The mandatory content provides a balance of breadth and depth ensuring that all learners have a strong basis for developing technical skills required in the sector. Learners are then offered the opportunity to develop a range of technical skills and attributes expected by employers with some opportunity to select between optional units where a degree of choice for individual learners to study content relevant to their own progression choices is appropriate. It is expected that learners will apply their learning in relevant employment and sector contexts during delivery and have opportunities to engage meaningfully with employers.

The proportion of mandatory content ensures that all learners are following a coherent programme of study and acquiring the knowledge, understanding and skills that will be recognised and valued. Learners are expected to show achievement across mandatory units as detailed in *Section 2*.

BTEC Nationals have always required applied learning that brings together knowledge and understanding (the cognitive domain) with practical and technical skills (the psychomotor domain). This is achieved through learners performing vocational tasks that encourage the development of appropriate vocational behaviours (the affective domain) and transferable skills. Transferable skills are those such as communication, teamwork, planning and completing tasks to high standards, which are valued in both the workplace and in higher education.

Our approach provides rigour and balance, and promotes the ability to apply learning immediately in new contexts. Further details can be found in *Section 2*.

Centres should ensure that delivery of content is kept up to date. Some of the units within the specification may contain references to legislation, policies, regulations and organisations, which may not be applicable in the country you deliver this qualification in (if teaching outside of England), or which may have gone out-of-date during the lifespan of the specification. In these instances, it is possible to substitute such references with ones that are current and applicable in the country you deliver subject to confirmation by your Standards Verifier.

Assessment

Assessment is specifically designed to fit the purpose and objective of the qualification. It includes a range of assessment types and styles suited to vocational qualifications in the sector. There are three main forms of assessment that you need to be aware of: external, internal and synoptic.

Externally-assessed units

Each external assessment for a BTEC National is linked to a specific unit. All of the units developed for external assessment are of 120 GLH to allow learners to demonstrate breadth and depth of achievement. Each assessment is taken under specified conditions, then marked by Pearson and a grade awarded. Learners are permitted to resit external assessments during their programme. You should refer to our website for current policy information on permitted retakes.

The styles of external assessment used for qualifications in the Engineering suite are:

- examinations – all learners take the same assessment at the same time, normally with a written outcome
- set tasks – learners take the assessment during a defined window and demonstrate understanding through completion of a vocational task.

Some external assessments include a period of preparation using set information. External assessments are available once or twice a year. For detailed information on the external assessments please see the table in *Section 2*. For further information on preparing for external assessment see *Section 5*.

Internally-assessed units

Most units in the sector are internally assessed and subject to external standards verification. This means that you set and assess the assignments that provide the final summative assessment of each unit, using the examples and support that Pearson provides. Before you assess you will need to become an approved centre, if you are not one already. You will need to prepare to assess using the guidance in *Section 6*.

In line with the requirements and guidance for internal assessment, you select the most appropriate assessment styles according to the learning set out in the unit. This ensures that learners are assessed using a variety of styles to help them develop a broad range of transferable skills. Learners could be given opportunities to:

- demonstrate practical and technical skills using appropriate processes, devices, components, equipment, materials, consumables
- complete realistic tasks to meet specific briefs or particular purposes
- write up the findings of their own research
- use case studies to explore complex or unfamiliar situations
- carry out projects for which they have choice over the direction and outcomes.

You will make grading decisions based on the requirements and supporting guidance given in the units. Learners may not make repeated submissions of assignment evidence. For further information see *Section 6*.

Synoptic assessment

Synoptic assessment requires learners to demonstrate that they can identify and use effectively, in an integrated way, an appropriate selection of skills, techniques, concepts, theories and knowledge from across the whole sector as relevant to a key task. BTEC learning has always encouraged learners to apply their learning in realistic contexts using scenarios and realistic activities that will permit learners to draw on and apply their learning. For these qualifications we have formally identified units which contain a synoptic assessment task. Synoptic assessment must take place after the teaching and learning of other mandatory units in order for learners to be able to draw from the full range of content. The synoptic assessment gives learners an opportunity to independently select and apply learning from across their programmes in the completion of a vocational task. Synoptic tasks may be in internally or externally assessed units. The particular unit that contains the synoptic tasks for this qualification is shown in the structure in *Section 2*.

Language of assessment

Assessment of the internal and external units for these qualifications will be available in English. All learner work must be in English. A learner taking the qualifications may be assessed in British or Irish Sign Language where it is permitted for the purpose of reasonable adjustment.
For information on reasonable adjustments see *Section 7*.

Grading for units and qualifications

Achievement in the qualification requires a demonstration of depth of study in each unit, assured acquisition of a range of practical skills required for employment or progression to higher education, and successful development of transferable skills. Learners achieving a qualification will have achieved across mandatory units, including external and synoptic assessment.

Units are assessed using a grading scale of Distinction (D), Merit (M), Pass (P), Near Pass (N) and Unclassified (U). The grade of Near Pass is used for externally-assessed units only. All mandatory and optional units contribute proportionately to the overall qualification grade, for example a unit of 120 GLH will contribute double that of a 60 GLH unit.

Qualifications in the suite are graded using a scale of P to D*, **or** PP to D*D*, **or** PPP to D*D*D*. Please see *Section 9* for more details. The relationship between qualification grading scales and unit grades will be subject to regular review as part of Pearson's standards monitoring processes on the basis of learner performance and in consultation with key users of the qualification.

UCAS Tariff points

The BTEC Nationals attract UCAS points. Please go to the UCAS website for full details of the points allocated.

1 Qualification purpose

In this section you will find information on the purpose of these qualifications:

Pearson BTEC Level 3 National Extended Diploma in Engineering

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering

On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Pearson BTEC Level 3 National Extended Diploma in Engineering

In this section you will find information on the purpose of this qualification and how its design meets that purpose through the qualification objective and structure. We publish a full 'Statement of Purpose' for each qualification on our website. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Engineering is for learners who want to pursue a career in engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or employment as an engineering technician or can choose to progress to higher education to study for an engineering degree. The qualification is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study seven mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- design and manufacture of products
- microcontroller systems design and programming.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills**: communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- reading technical texts
- effective writing

- analytical skills
- creative development
- preparation for assessment methods used in degrees.

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering

In this section you will find information on the purpose of this qualification and how the design of the qualification meets that purpose through the qualification objective and structure. On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering has primarily been designed for learners who want to pursue a career in electrical/electronics engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or to employment as an engineering technician, or can choose to progress to higher education to study for an engineering degree. The qualification is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study seven mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- design and manufacture of products
- microcontroller systems design and programming
- calculus to solve engineering problems.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills**: communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- reading technical texts
- effective writing
- analytical skills
- creative development
- preparation for assessment methods used in degrees.

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering

In this section you will find information on the purpose of this qualification and how the design of the qualification meets that purpose through the qualification objective and structure. On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering has primarily been designed for learners who want to pursue a career in mechanical engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or to employment as an engineering technician or can choose to progress to higher education to study for an engineering degree. It is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study seven mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- microcontroller systems design and programming
- calculus to solve engineering problems.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills**: communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- reading technical texts
- effective writing
- analytical skills
- creative development
- preparation for assessment methods used in degrees.

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering

In this section you will find information on the purpose of this qualification and how the design of the qualification meets that purpose through the qualification objective and structure. On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Computer Engineering has primarily been designed for learners who want to pursue a career in computer engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or to employment as an engineering technician or can choose to progress to higher education to study for an engineering degree. It is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study eight mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- microcontroller systems design and programming
- data representation and manipulation, hardware and software, computer architecture and computer programming.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills**: communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- reading technical texts
- effective writing
- analytical skills
- creative development
- preparation for assessment methods used in degrees.

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering

In this section you will find information on the purpose of this qualification and how the design of the qualification meets that purpose through the qualification objective and structure. On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering has primarily been designed for learners who want to pursue a career in manufacturing engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or to employment as an engineering technician or can choose to progress to higher education to study for an engineering degree. It is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study eight mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- design and manufacture of products
- microcontroller systems design and programming
- manufacturing principles and systems.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills**: communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- reading technical texts
- effective writing
- analytical skills
- creative development
- preparation for assessment methods used in degrees.

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering

In this section you will find information on the purpose of this qualification and how the design of the qualification meets that purpose through the qualification objective and structure. On our website we publish a full 'Statement of Purpose' for each qualification. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification that is suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering has primarily been designed for learners who want to pursue a career in aeronautical engineering, and who want to be able to collaborate across and apply knowledge, skills and understanding in other branches of engineering. They can either progress directly to an apprenticeship or to employment as an engineering technician or can choose to progress to higher education to study for an engineering degree. It is equivalent in size to three A Levels at 1080 GLH and is intended to be a Tech Level qualification. It has also been designed to meet the Tech Bacc measure when studied alongside Level 3 mathematics and the Extended Project Qualification (EPQ).

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas including electrical and electronic, mechanical, and others for example manufacturing.

Learners study eight mandatory units including the following topics:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- design and manufacture of products
- an engineering project
- the theory of aircraft flight.

Through the optional units, learners will study a mix of electrical/electronic, mechanical and other engineering specialist areas. They could include: electronic devices and circuits, electronic measurement and testing of circuits, behaviour of metallic materials, maintenance of mechanical systems, programmable logic controllers, secondary machining processes.

The content of this qualification has been developed in consultation with employers and professional bodies to ensure relevance to current industry practice in engineering occupational disciplines. In addition, academics have been consulted on the content development to ensure the qualification supports progression to higher education.

What could this qualification lead to?

This qualification supports progression to job opportunities in the engineering sector at a variety of levels. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative
- engineering technician
- electronics technician
- IT support technician
- mechatronics technician.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering technician or as an engineering operative.

After this qualification, learners can progress directly to technician roles, but it is likely that many will do so via higher education study. This qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BEng (Hons) in Aerospace Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How do these qualifications provide employability and technical skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem solving skills**: use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills:** communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

Many of the mandatory and specified optional units encourage learners to develop the specific practical skills that employers are looking for.

How do these qualifications provide transferable knowledge and skills for Higher Education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university or other higher study either immediately or for career progression. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- practical engineering skills
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can become prepared for life-long learning through:

- analytical and problem-solving skills
- reading technical texts
- effective writing
- preparation for assessment methods used in degrees.

2 Structure

Qualification structure

The structures for the qualifications in this specification are:

Pearson BTEC Level 3 National Extended Diploma in Engineering

There are seven mandatory units, three external and four internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least eight optional units. Learners must take a minimum of two units from each of groups C, D and E. Learners take two further units from groups C, D or E.

Pearson BTEC Level 3 National Extended Diploma in Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 2 - 4 units			
14	Electrical Installation of Hardware and Cables	**60**	**Optional**	Internal
15	Electrical Machines**	**60**	**Optional**	Internal
16	Three Phase Electrical Systems	**60**	**Optional**	Internal
17	Power and Energy Electronics	**60**	**Optional**	Internal
18	Electrical Power Distribution and Transmission	**60**	**Optional**	Internal
19	Electronic Devices and Circuits	**60**	**Optional**	Internal
20	Analogue Electronic Circuits	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
22	Electronic Printed Circuit Board Design and Manufacture	**60**	**Optional**	Internal
23	Digital and Analogue Electronic Systems	**60**	**Optional**	Internal
58	Energy Management	**60**	**Optional**	Internal
60	Autonomous Mobile Robotics	**60**	**Optional**	Internal
	Optional units group D – learners complete 2 - 4 units			
24	Maintenance of Mechanical Systems	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
26	Mechanical Behaviour of Non-metallic Materials	**60**	**Optional**	Internal
27	Static Mechanical Principles in Practice	**60**	**Optional**	Internal
28	Dynamic Mechanical Principles in Practice	**60**	**Optional**	Internal
29	Principles and Applications of Fluid Mechanics	**60**	**Optional**	Internal
30	Mechanical Measurement and Inspection Technology	**60**	**Optional**	Internal
31	Thermodynamic Principles and Practice	**60**	**Optional**	Internal
57	Sustainable Transport	**60**	**Optional**	Internal
	Optional units group E – learners complete 2 - 4 units			
8	Further Engineering Mathematics	**60**	**Optional**	Internal
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
10	Computer Aided Design in Engineering	**60**	**Optional**	Internal
11	Engineering Maintenance and Condition Monitoring Techniques	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems	**60**	**Optional**	Internal
13	Welding Technology	**60**	**Optional**	Internal
32	Computer System Principles and Practice	**60**	**Optional**	Internal
33	Computer Systems Security	**60**	**Optional**	Internal
34	Computer Systems Support and Performance	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
36	Programmable Logic Controllers	**60**	**Optional**	Internal
37	Computer Networks	**60**	**Optional**	Internal
38	Website Production to Control Devices	**60**	**Optional**	Internal
39	Modern Manufacturing Systems	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
40	Computer Aided Manufacturing and Planning	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
42	Manufacturing Primary Forming Processes	**60**	**Optional**	Internal
43	Manufacturing Computer Numerical Control Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal
46	Manufacturing Joining, Finishing and Assembly Processes	**60**	**Optional**	Internal
47	Composites Manufacture and Repair Processes	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal
59	Principles of Electrical Machines**	**60**	**Optional**	Internal

** Learners may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, they cannot take both.

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering

Mandatory units

There are seven mandatory units, three external and four internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least eight optional units. Learners must take a minimum of seven units from group C. Learners take one further unit from group C or group D.

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 7 - 8 units			
8	Further Engineering Mathematics	**60**	**Optional**	Internal
14	Electrical Installation of Hardware and Cables	**60**	**Optional**	Internal
15	Electrical Machines**	**60**	**Optional**	Internal
16	Three Phase Electrical Systems	**60**	**Optional**	Internal
17	Power and Energy Electronics	**60**	**Optional**	Internal
18	Electrical Power Distribution and Transmission	**60**	**Optional**	Internal
19	Electronic Devices and Circuits	**60**	**Optional**	Internal
20	Analogue Electronic Circuits	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal
22	Electronic Printed Circuit Board Design and Manufacture	**60**	**Optional**	Internal
23	Digital and Analogue Electronic Systems	**60**	**Optional**	Internal
36	Programmable Logic Controllers	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
59	Principles of Electrical Machines**	**60**	**Optional**	Internal
60	Autonomous Mobile Robotics	**60**	**Optional**	Internal
	Optional units group D – learners complete 0 - 1 unit			
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems	**60**	**Optional**	Internal
24	Maintenance of Mechanical Systems	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
26	Mechanical Behaviour of Non-metallic Materials	**60**	**Optional**	Internal
27	Static Mechanical Principles in Practice	**60**	**Optional**	Internal
28	Dynamic Mechanical Principles in Practice	**60**	**Optional**	Internal
30	Mechanical Measurement and Inspection Technology	**60**	**Optional**	Internal
33	Computer Systems Security	**60**	**Optional**	Internal
34	Computer Systems Support and Performance	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
37	Computer Networks	**60**	**Optional**	Internal
38	Website Production to Control Devices	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
43	Manufacturing Computer Numerical Control Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal

** Learners may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, they cannot take both.

Qualification structure

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering

Mandatory units

There are seven mandatory units, three external and four internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least eight optional units. Learners must take a minimum of seven units from group C. Learners take one further unit from group C or group D. Only two units from group C can be a * unit (either unit 8, 10, 11, 12 or 36).

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 7 - 8 units			
8	Further Engineering Mathematics*	**60**	**Optional**	Internal
10	Computer Aided Design in Engineering*	**60**	**Optional**	Internal
11	Engineering Maintenance and Condition Monitoring Techniques*	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems*	**60**	**Optional**	Internal
24	Maintenance of Mechanical Systems	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
26	Mechanical Behaviour of Non-metallic Materials	**60**	**Optional**	Internal
27	Static Mechanical Principles in Practice	**60**	**Optional**	Internal
28	Dynamic Mechanical Principles in Practice	**60**	**Optional**	Internal
29	Principles and Applications of Fluid Mechanics	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
30	Mechanical Measurement and Inspection Technology	**60**	**Optional**	Internal
31	Thermodynamic Principles and Practice	**60**	**Optional**	Internal
36	Programmable Logic Controllers*	**60**	**Optional**	Internal
	Optional units group D – learners complete 0 - 1 unit			
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
13	Welding Technology	**60**	**Optional**	Internal
15	Electrical Machines	**60**	**Optional**	Internal
18	Electrical Power Distribution and Transmission	**60**	**Optional**	Internal
19	Electronic Devices and Circuits	**60**	**Optional**	Internal
20	Analogue Electronic Circuits	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal
33	Computer Systems Security	**60**	**Optional**	Internal
34	Computer Systems Support and Performance	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
40	Computer Aided Manufacturing and Planning	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
42	Manufacturing Primary Forming Processes	**60**	**Optional**	Internal
43	Manufacturing Computer Numerical Control Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal
60	Autonomous Mobile Robotics	**60**	**Optional**	Internal

* Learners can take only two units.

Qualification structure

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering

Mandatory units

There are eight mandatory units, three external and six internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least seven optional units. Learners must take a minimum of six units from group C. Learners take one further unit from group C or group D. Only two units from group C can be a * unit (either unit 19, 40 or 43).

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
32	Computer System Principles and Practice	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 6 - 7 units			
19	Electronic Devices and Circuits*	**60**	**Optional**	Internal
33	Computer Systems Security	**60**	**Optional**	Internal
34	Computer Systems Support and Performance	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
36	Programmable Logic Controllers	**60**	**Optional**	Internal
37	Computer Networks	**60**	**Optional**	Internal
38	Website Production to Control Devices	**60**	**Optional**	Internal
40	Computer Aided Manufacturing and Planning*	**60**	**Optional**	Internal
43	Manufacturing Computer Numerical Control Machining Processes*	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Optional units group D – learners complete 0 - 1 unit			
8	Further Engineering Mathematics	**60**	**Optional**	Internal
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
10	Computer Aided Design in Engineering	**60**	**Optional**	Internal
11	Engineering Maintenance and Condition Monitoring Techniques	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems	**60**	**Optional**	Internal
14	Electrical Installation of Hardware and Cables	**60**	**Optional**	Internal
15	Electrical Machines	**60**	**Optional**	Internal
16	Three Phase Electrical Systems	**60**	**Optional**	Internal
18	Electrical Power Distribution and Transmission	**60**	**Optional**	Internal
20	Analogue Electronic Circuits	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal
22	Electronic Printed Circuit Board Design and Manufacture	**60**	**Optional**	Internal
24	Maintenance of Mechanical Systems	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
27	Static Mechanical Principles in Practice	**60**	**Optional**	Internal
30	Mechanical Measurement and Inspection Technology	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal

* Learners can take only two units.

Qualification structure

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering

Mandatory units

There are eight mandatory units, three external and five internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least seven optional units. Learners must take a minimum of six units from group C. Learners take one further unit from group C or group D. Only two units from group C can be a * unit (either unit 10, 13, 22, 30 or 36).

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
39	Modern Manufacturing Systems	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 6 - 7 units			
10	Computer Aided Design in Engineering*	**60**	**Optional**	Internal
13	Welding Technology*	**60**	**Optional**	Internal
22	Electronic Printed Circuit Board Design and Manufacture*	**60**	**Optional**	Internal
30	Mechanical Measurement and Inspection Technology*	**60**	**Optional**	Internal
36	Programmable Logic Controllers*	**60**	**Optional**	Internal
40	Computer Aided Manufacturing and Planning	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
42	Manufacturing Primary Forming Processes	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
43	Manufacturing Computer Numerical Control Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal
46	Manufacturing Joining, Finishing and Assembly Processes	**60**	**Optional**	Internal
47	Composites Manufacture and Repair Processes	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal
	Optional units group D – learners complete 0 - 1 unit			
8	Further Engineering Mathematics	**60**	**Optional**	Internal
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
11	Engineering Maintenance and Condition Monitoring Techniques	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems	**60**	**Optional**	Internal
14	Electrical Installation of Hardware and Cables	**60**	**Optional**	Internal
16	Three Phase Electrical Systems	**60**	**Optional**	Internal
19	Electronic Devices and Circuits	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal
24	Maintenance of Mechanical Systems	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
26	Mechanical Behaviour of Non-metallic Materials	**60**	**Optional**	Internal
27	Static Mechanical Principles in Practice	**60**	**Optional**	Internal
28	Dynamic Mechanical Principles in Practice	**60**	**Optional**	Internal
29	Principles and Applications of Fluid Mechanics	**60**	**Optional**	Internal
34	Computer Systems Support and Performance	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal

* Learners can take only two units.

Qualification structure

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering

Mandatory units

There are eight mandatory units, three external and five internal. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units in group A. Learners must complete all mandatory internal units in group B.

Optional units

Learners must complete at least seven optional units. Learners must take a minimum of six units from group C. Learners take one further unit from group C or group D. Only two units from group C can be a * unit (either unit 10, 11, 12, 19, 25 or 36).

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
	Mandatory units group A – learners complete and achieve all units			
1	Engineering Principles	**120**	**Mandatory**	External
2	Delivery of Engineering Processes Safely as a Team	**60**	**Mandatory**	Internal
3	Engineering Product Design and Manufacture	**120**	**Mandatory and Synoptic**	External
4	Applied Commercial and Quality Principles in Engineering	**60**	**Mandatory**	Internal
6	Microcontroller Systems for Engineers	**120**	**Mandatory**	External
	Mandatory units group B – learners complete all units			
5	A Specialist Engineering Project	**60**	**Mandatory**	Internal
7	Calculus to Solve Engineering Problems	**60**	**Mandatory**	Internal
48	Aircraft Flight Principles and Practice	**60**	**Mandatory**	Internal
	Optional units group C – learners complete 6 - 7 units			
10	Computer Aided Design in Engineering*	**60**	**Optional**	Internal
11	Engineering Maintenance and Condition Monitoring Techniques*	**60**	**Optional**	Internal
12	Pneumatic and Hydraulic Systems*	**60**	**Optional**	Internal
19	Electronic Devices and Circuits*	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials*	**60**	**Optional**	Internal
36	Programmable Logic Controllers*	**60**	**Optional**	Internal
49	Aircraft Workshop Methods and Practice	**60**	**Optional**	Internal
50	Aircraft Gas Turbine Engines	**60**	**Optional**	Internal
51	Aircraft Propulsion Systems	**60**	**Optional**	Internal
52	Airframe Construction and Repair	**60**	**Optional**	Internal
53	Airframe Mechanical Systems	**60**	**Optional**	Internal

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering				
Unit number	**Unit title**	**GLH**	**Type**	**How assessed**
54	Aircraft Electrical and Instrument Systems	**60**	**Optional**	Internal
55	Aircraft First Line Maintenance Operations	**60**	**Optional**	Internal
	Optional units group D – learners complete 0 - 1 unit			
8	Further Engineering Mathematics	**60**	**Optional**	Internal
9	Work Experience in the Engineering Sector	**60**	**Optional**	Internal
13	Welding Technology	**60**	**Optional**	Internal
15	Electrical Machines	**60**	**Optional**	Internal
16	Three Phase Electrical Systems	**60**	**Optional**	Internal
21	Electronic Measurement and Testing of Circuits	**60**	**Optional**	Internal
26	Mechanical Behaviour of Non-metallic Materials	**60**	**Optional**	Internal
28	Dynamic Mechanical Principles in Practice	**60**	**Optional**	Internal
29	Principles and Applications of Fluid Mechanics	**60**	**Optional**	Internal
31	Thermodynamic Principles and Practice	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
43	Manufacturing Computer Numerical Control Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal
47	Composites Manufacture and Repair Processes	**60**	**Optional**	Internal
56	Industrial Robotics	**60**	**Optional**	Internal

* Learners can take only two units.

External assessment

This is a summary of the type and availability of external assessment, which is of units making up 33% of the total qualification GLH. See *Section 5* and the units and sample assessment materials for more information.

Unit	Type	Availability
Unit 1: Engineering Principles	• Written exam set and marked by Pearson. • Two hours. • 80 marks.	**Jan and May/June** **First assessment May/June 2017**
Unit 3: Engineering Product Design and Manufacture	• A task set and marked by Pearson and completed under supervised conditions. • Prior to the supervised assessment, learners will be provided with a case study in order to carry out research in no more than 3 hours in a one week period timetabled by Pearson. • The supervised assessment period is 8 hours and can be arranged over a two-week period timetabled by Pearson. Once the assessment has started it must be completed by the learner within five days. • Written submission. • 60 marks.	**December/January and May/June** **First assessment May/June 2017**
Unit 6: Microcontroller Systems for Engineers	• A task set and marked by Pearson and completed under supervised conditions. • The supervised assessment period is 12 hours and can be arranged over a two-week period timetabled by Pearson. Once the assessment has started the learner must complete within five days. • The task must be completed using a computer. • 80 marks.	**Jan and May/June** **First assessment May/June 2018**

Synoptic assessment

The mandatory synoptic assessment requires learners to apply learning from across the qualification to the completion of a defined vocational task. Within the assessment for *Unit 3: Engineering Product Design and Manufacture*, learners complete product design and manufacturing tasks which draw together underpinning engineering science principles and skills such as engineering drawing and health and safety. Learners complete the task using using knowledge and understanding from their studies of the sector and apply both transferable and specialist knowledge and skills.

In delivering the unit you need to encourage learners to draw on their broader learning so they will be prepared for the assessment.

Employer involvement in assessment and delivery

You need to ensure that learners on this qualification have a significant level of employer involvement in programme delivery or assessment. See *Section 4* for more information.

3 Units

Understanding your units

The units in this specification set out our expectations of assessment in a way that helps you to prepare your learners for assessment. The units help you to undertake assessment and quality assurance effectively.

Each unit in the specification is set out in a similar way. There are two types of unit format:

- internal units
- external units.

This section explains how the units work. It is important that all teachers, assessors, internal verifiers and other staff responsible for the programme review this section.

Internal units

Section	Explanation
Unit number	The number is in a sequence in the sector. Numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that we always use and it appears on certificates.
Level	All units are at Level 3 on the national framework.
Unit type	This shows if the unit is internal or external only. See structure information in *Section 2* for full details.
GLH	Units may have a GLH value of 120, 90 or 60 GLH. This indicates the numbers of hours of teaching, directed activity and assessment expected. It also shows the weighting of the unit in the final qualification grade.
Unit in brief	A brief formal statement on the content of the unit that is helpful in understanding its role in the qualification. You can use this in summary documents, brochures etc.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, how learning is structured, and how learning might be applied when progressing to employment or higher education.
Learning aims	These help to define the scope, style and depth of learning of the unit. You can see where learners should be learning standard requirements ('understand') or where they should be actively researching ('investigate'). You can find out more about the verbs we use in learning aims in *Appendix 2*.
Summary of unit	This new section helps teachers to see at a glance the main content areas against the learning aims and the structure of the assessment. The content areas and structure of assessment are required. The forms of evidence given are suitable to fulfil the requirements.
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 content for the unit or learning aim(s) has been covered.

Section	Explanation
Assessment criteria	Each learning aim has Pass and Merit criteria. Each assignment has at least one Distinction criterion. A full glossary of terms used is given in *Appendix 2*. All assessors need to understand our expectations of the terms used. Distinction criteria represent outstanding performance in the unit. Some criteria require learners to draw together learning from across the learning aims.
Essential information for assignments	This shows the maximum number of assignments that may be used for the unit to allow for effective summative assessment, and how the assessment criteria should be used to assess performance.
Further information for teachers and assessors	The section gives you information to support the implementation of assessment. It is important that this is used carefully alongside the assessment criteria.
Resource requirements	Any specific resources that you need to be able to teach and assess are listed in this section. For information on support resources see *Section 10*.
Essential information for assessment decisions	This information gives guidance for each learning aim or assignment of the expectations for Pass, Merit and Distinction standard. This section contains examples and essential clarification.
Links to other units	This section shows you the main relationship among units. This section can help you to structure your programme and make best use of materials and resources.
Employer involvement	This section gives you information on the units that can be used to give learners involvement with employers. It will help you to identify the kind of involvement that is likely to be successful.

External units

Section	Explanation
Unit number	The number is in a sequence in the sector. Numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that we always use and it appears on certificates.
Level	All units are at Level 3 on the national framework.
Unit type	This shows if the unit is internal or external only. See structure information in *Section 2* for full details.
GLH	Units may have a GLH value of 120, 90 or 60 GLH. This indicates the numbers of hours of teaching, directed activity and assessment expected. It also shows the weighting of the unit in the final qualification grade.
Unit in brief	A brief formal statement on the content of the unit.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, how learning is structured, and how learning might be applied when progressing to employment or higher education.
Summary of assessment	This sets out the type of external assessment used and the way in which it is used to assess achievement.
Assessment outcomes	These show the hierarchy of knowledge, understanding, skills and behaviours that are assessed. Includes information on how this hierarchy relates to command terms in sample assessment materials (SAMs).
Essential content	For external units all the content is obligatory, the depth of content is indicated in the assessment outcomes and sample assessment materials (SAMs). The content will be sampled through the external assessment over time, using the variety of questions or tasks shown.
Grade descriptors	We use grading descriptors when making judgements on grade boundaries. You can use them to understand what we expect to see from learners at particular grades.
Key terms typically used in assessment	These definitions will help you analyse requirements and prepare learners for assessment.
Resources	Any specific resources that you need to be able to teach and assess are listed in this section. For information on support resources see *Section 10*.
Links to other units	This section shows the main relationship among units. This section can help you to structure your programme and make best use of materials and resources.
Employer involvement	This section gives you information on the units that can be used to give learners involvement with employers. It will help you to identify the kind of involvement that is likely to be successful.

Index of units

This section contains all the units developed for this qualification. Please refer to *pages 9–12* to check which units are available in all qualifications in the engineering sector.

Unit 1: Engineering Principles

Level: **3**

Unit type: **External**

Guided learning hours: **120**

Unit in brief

Learners apply mathematical and physical science principles to solve electrical-, electronic- and mechanical-based engineering problems.

Unit introduction

Modern life depends on engineers to develop, support and control the products and systems that are all around us. For example, cars, heart rate monitors and manufacturing and transport systems. To make a contribution as an engineer you must be able to draw on an important range of principles developed by early engineering scientists, such as Newton, Young, Faraday and Ohm. There is an increasing demand for 'multi-skilled' engineers who can apply principles from several engineering disciplines to develop solutions.

This unit will develop your mathematical and physical scientific knowledge and understanding to enable you to solve problems set in an engineering context. You will explore and apply the algebraic and trigonometric mathematical methods required to solve engineering problems. The mechanical problems you will encounter cover static, dynamic and fluid systems. The electrical and electronic problems you will encounter cover static and direct current (DC) electricity, DC circuit theory and networks, magnetism, and single-phase alternating current theory. You may apply these engineering principles to solve problems involving more than one of these topic areas.

This unit is externally assessed. It sits at the heart of the qualification and gives you a foundation to support you in any engineering technician role, an engineering apprenticeship or in higher education.

Summary of assessment

The unit will be assessed through one paper of 80 marks lasting two hours that will be set and marked by Pearson.

Learners will be assessed through a number of short- and long-answer problem-solving questions. Learners will need to explore and relate to the engineering contexts and data presented. Assessment will focus on learners' ability to solve problems that require individual and combined application of mathematical techniques, and electrical, electronic and mechanical principles to solve engineering problems.

The assessment availability is twice a year in January and May/June. The first assessment availability is May/June 2017.

Sample assessment materials will be available to help centres prepare learners for assessment.

Assessment outcomes

AO1 Recall basic engineering principles and mathematical methods and formulae

Command words: calculate, describe, explain, identify, name

Marks: ranges from 1 to 5 marks

AO2 Perform mathematical procedures to solve engineering problems

Command words: calculate, convert, find, solve

Marks: ranges from 1 to 10 marks

AO3 Demonstrate an understanding of electrical, electronic and mechanical principles to solve engineering problems

Command words: find, calculate, describe, draw, explain

Marks: ranges from 1 to 5 marks

AO4 Analyse information and systems to solve engineering problems

Command words: calculate, draw

Marks: ranges from 1 to 5 marks

AO5 Integrate and apply electrical, electronic and mechanical principles to develop an engineering solution

Command words: calculate, draw, explain

Marks: ranges from 1 to 10 marks

Essential content

The essential content is set out under content areas. Learners must cover all specified content before the assessment.

A Algebraic and trigonometric mathematical methods

- Application of appropriate units

A1 Algebraic methods

- Solve, transpose and simplify equations.
- 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).
- Application to problems involving exponential growth and decay.
- Linear equations and straight line graphs:
  - linear equations of the form $y = mx + c$
  - straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line)
  - pair of simultaneous linear equations in two unknowns.
- Factorisation and quadratics:
  - multiply expressions in brackets by a number, symbol or by another expression in a bracket
  - extraction of a common factor $ax + ay$, $a(x + 2) + b(x + 2)$
  - grouping $ax - ay + bx - by$
  - quadratic expressions $a^2 + 2ab + b^2$
  - roots of an equation, including quadratic equations with real roots by factorisation, and by the use of formula.

A2 Trigonometric methods

- Circular measure:
  - radian
  - conversion of degree measure to radian measure and vice versa
  - angular rotations (multiple number (n) of 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
  - application of vectors:
    - calculation of the phasor sum of two alternating currents
    - diagrammatic representation of vectors
    - resolution of forces/velocities.

- Mensuration:
  - standard formulae to solve surface areas and volumes of regular solids
    - 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 $CSA = \pi rl$

B Static engineering systems

- Application of appropriate units

B1 Static engineering systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems, involving:

- Non-concurrent coplanar forces:
  - representation of forces using space and free body diagrams
  - moments
  - resolution of forces in perpendicular directions $F_x = F\cos\theta$, $F_y = F\sin\theta$
  - vector addition of forces – resultant, equilibrant and line of action
  - conditions for static equilibrium $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$
- Simply supported beams:
  - concentrated loads
  - uniformly distributed loads (UDL).
- Reactions:
  - support reactions
  - pin reaction forces
  - roller reaction forces.

B2 Loaded components

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- direct stress and strain: direct stress $\sigma = \frac{F}{A}$, direct strain $\varepsilon = \frac{\Delta L}{L}$
- shear stress and strain: shear stress $\tau = \frac{F}{A}$, shear strain $\gamma = \frac{a}{b}$
- tensile and shear strength
- elastic constants: Young's Modulus (modulus of elasticity)

  $E = \frac{\sigma}{\varepsilon}$; Modulus of rigidity $G = \frac{\tau}{\gamma}$

C Dynamic engineering systems

- Application of appropriate units

C1 Dynamic engineering systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- kinetic parameters and principles:
  - displacement (s)
  - velocity – initial velocity (u), final velocity (v)
  - acceleration (a)
  - equations for linear motion with uniform acceleration
    $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$
- dynamic parameters and principles:
  - force
  - inertia
  - torque (T)
  - mechanical work $W = Fs$, mechanical power (average and instantaneous)
  - mechanical efficiency
  - energy: gravitational potential energy $PE = mgh$, kinetic energy $KE = \frac{1}{2}mv^2$
  - Newton's Laws of Motion
  - principles of conservation of momentum
  - principles of conservation of energy.
- angular parameters:
  - angular velocity (ω)
  - centripetal acceleration $a = \omega^2 r = \frac{v^2}{r}$
  - uniform circular motion power $P = T\omega$
  - rotational kinetic energy $KE = \frac{1}{2}I\omega^2$
- lifting machines, including inclined planes, scissor jacks, pulleys:
  - velocity ratio
  - mechanical advantage
  - effort and load motion
  - friction effects.

D Fluid engineering systems

- Application of appropriate units

D1 Fluid systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- submerged surfaces in fluid systems:
  - hydrostatic pressure and 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
  - determination of density using floatation methods
  - relative density

- fluid flow in a gradually tapering pipe:
  - flow rate (volumetric and mass)
  - flow velocities (input and output)
  - input and output pipe diameters
  - incompressible fluid flow (continuity of volumetric flow $A_1v_1 = A_2v_2$ and mass flow $\rho A_1v_1 = \rho A_2v_2$)

E Static and direct current electricity and circuits

- Application of appropriate units

E1 Static and direct current electricity

Recall, perform procedures, demonstrate an understanding of and analyse information and systems, in the context of electrical circuits (networks) and devices, including:

- conductance
- conventional current flow
- charge/electron flow $I = \frac{q}{t}$
- voltage
- Coulomb's law $F = \frac{q_1q_2}{4\pi\varepsilon_o r^2}$
- factors affecting resistance, including conductor length, cross sectional area, resistivity, and temperature coefficient of resistance $R = \frac{\rho l}{A}$, $\frac{\Delta R}{R_0} = \alpha\Delta T$
- resistors, including function, fixed, variable, values
- electric field strength, including uniform electric fields $E = \frac{F}{q}$, $E = \frac{v}{d}$
- factors affecting capacitance, including plate spacing, plate area, permittivity $C = \frac{\varepsilon A}{d}$
- capacitors – typical capacitance values and construction, including plates, dielectric materials and strength, flux density, permittivity.

E2 Direct current circuit theory

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- Ohm's law $I = \frac{V}{R}$
- Power $P = IV$, $P = I^2R$, $P = \frac{V^2}{R}$
- Efficiency (η)= $\frac{P_{out}}{P_{in}}$
- Kirchhoff voltage and current laws $V = V_1 + V_2 + V_3$ or $\Sigma PD = \Sigma IR$, $I = I_1 + I_2 + I_3$
- Charge, voltage, capacitance and energy stored in capacitors

  $Q = CV$, $W = \frac{1}{2}CV^2$
- RC transients (capacitor/resistor), charge and discharge, including exponential growth and decay of voltage and current, and time constant $\tau = RC$
- Diodes, including forward and reverse bias characteristics:
  - forward mode applications, including rectification, clamping, circuit/component protection
  - reverse mode applications, including zener diode for voltage regulation

E3 Direct current networks

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- DC power sources, including cells, batteries, stabilised power supply, photovoltaic cell/array and internal resistance
- at least five resistors in series and parallel combinations

  $R_T = R_1 + R_2 + R_3$

  $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
- DC circuits containing resistors and two power sources
- DC power source with at least two capacitors connected (series, parallel, combination).

F Magnetism and electromagnetic induction

- Application of appropriate units

F1 Magnetism

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- magnetic field:
  - flux density $B = \dfrac{\phi}{A}$
  - magnetomotive force (mmf) and field strength (H), $F_m = NI$, $H = \dfrac{NI}{l}$
  - permeability $\dfrac{B}{H} = \mu_0 \mu_r$
  - B/H curves and loops
  - ferromagnetic materials
  - reluctance $S = \dfrac{F_m}{\phi}$
  - magnetic screening
  - hysteresis
- electromagnetic induction and applications:
  - induced electromotive force (emf)
  - relationship between induced emf, magnetic field strength, number of conductor turns and rate of change of flux
  - relationship between number of turns, magnetic length, permeability, and inductance
  - eddy currents
  - principle of operation of electric motors and generators including efficiency
  - self inductance, including inductance of a coil, energy stored in an inductor, induced emf

    $$L = \frac{N\phi}{I},\ W = \frac{1}{2}LI^2,\ E = Blv,\ E = -N\frac{d\phi}{dt} = -L\frac{dl}{dt}$$
  - mutual inductance (principals of transformer operation – step up/down, primary and secondary current and voltage ratios, including efficiency.)

    $$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$
  - application of Faraday's and Lenz's laws.

G Single-phase alternating current

- Application of appropriate units

G1 Single-phase alternating current theory

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- waveform characteristics:
  - sinusoidal and non-sinusoidal waveforms
  - amplitude, time period, frequency
  - instantaneous values:
    - peak/peak-to-peak
    - root mean square (RMS):

      RMS voltage = $\frac{\text{peak voltage}}{\sqrt{2}}$
    - average values:

      average value = $\frac{2}{\pi}$ × maximum value
    - form factor:

      form factor = $\frac{\text{RMS value}}{\text{average value}}$
- AC principles:
  - determination of values using phasor and trigonometric representation of alternating quantities
  - graphical and phasor addition of two sinusoidal voltages
  - reactance and impedance of pure R, L and C components

    $X_C = \frac{1}{2\pi fC}$, $X_L = 2\pi fL$
  - total impedance of an inductor in series with a resistance $z = \sqrt{X_L{}^2 + R^2}$
  - total impedance of a capacitor in series with a resistance $z = \sqrt{X_C{}^2 + R^2}$
  - rectification, including half wave, full wave.

Grade descriptors

To achieve a grade a learner is expected to demonstrate these attributes across the essential content of the unit. The principle of best fit will apply in awarding grades.

Level 3 Pass

Learners are able to use and apply basic electrical, electronic, mechanical and mathematical principles to solve simple and familiar engineering and mathematical problems directly. They can provide responses showing understanding and analysis of basic and familiar engineering problems. They can interpret and analyse diagrams, graphical information and systems, using their knowledge and understanding to solve basic and familiar problems. They can select and implement appropriate basic procedures to provide solutions for given mathematical and engineering situations. They often use appropriate engineering and mathematical terminology and units.

Level 3 Distinction

Learners are able to use and apply advanced electrical, electronic, mechanical and mathematical principles to solve complex and unfamiliar engineering and mathematical problems directly, indirectly and synoptically. They can provide balanced responses showing developed understanding and evaluation of complex familiar and unfamiliar engineering problems. They can interpret and evaluate diagrams, graphical information and systems, using their knowledge and understanding to solve complex familiar and unfamiliar problems. They can select and implement appropriate advanced procedures to provide justified and optimised solutions for given engineering and mathematical situations. They use appropriate and technically accurate engineering and mathematical terminology consistently. Learners can propose solutions to problems, drawing on their knowledge and understanding of electrical, electronic, mechanical and mathematical principles.

Key terms typically used in assessment

The following table shows the key terms that will be used consistently by Pearson in our assessments to ensure students are rewarded for demonstrating the necessary skills.

Please note: the list below will not necessarily be used in every paper/session and is provided for guidance only.

Command or term	Definition
Calculate	Learners judge the number or amount of something by using the information they already have, and add, subtract, multiply, or divide numbers. For example, 'Calculate the reaction forces…'
Convert	Learners will change the form of a measurement to different units without a change of size or amount. For example, 'Convert degrees into radians…'
Draw	Learners make a graphic representation of data by hand (as in a diagram). For example, 'Draw a diagram to represent…'
Describe	Learners give a clear, objective account in their own words showing recall, and in some cases application, of the relevant features and information about a subject. For example, 'Describe mechanical advantage…'

Command or term	Definition
Explain	Learners make something clear or easy to understand by describing or giving information about it. For example, 'Explain one factor affecting…'
Find	Learners discover the facts or truth about something. For example, 'Find the coordinates where…'
Identify	Provide or select an answer from a number of alternatives. For example, 'Identify the unit of measure for the energy loss and identify the definition of…'
Label	Learners affix a label to; mark with a label. For example, 'Label the diagram to show…'
Name	Give the correct term for something.
Solve	Learners find the answer or explanation to a problem. For example, 'Solve the equation to…'
State	Learners declare definitely or specifically. For example, 'State all three conditions for…'

Links to other units

This unit would relate to the teaching of the following and other units:

- Unit 2: Delivery of Engineering Processes Safety as a Team.
- Unit 3: Engineering Product Design and Manufacture
- Unit 4: Applied Commercial and Quality Principles in Engineering.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 2: Delivery of Engineering Processes Safely as a Team

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore how processes are undertaken by teams to create engineered products or to deliver engineering services safely.

Unit introduction

The use of engineering processes is integral to the manufacture of engineered products and the delivery of engineering services. Thousands of engineering processes are used in the manufacture and service of a complex product, such as an aeroplane. To ensure that these engineering processes can be planned and carried out safely and effectively, engineers must be able to work together to get the job done. It is for this reason that so many engineering companies focus time and effort on understanding engineering processes and developing teamwork.

In this unit, you will examine common engineering processes, including health and safety legislation, regulations that apply to these processes and how individual and team performance can be affected by human factors. You will learn the principles of another important process, engineering drawing, and develop two-dimensional (2D) computer-aided drawing skills while producing orthographic projections and circuit diagrams. Finally, you will work as a team member and team leader to apply a range of practical engineering processes to manufacture a batch of an engineered product or to safely deliver a batch of an engineering service. To complete the assessment task within this unit, you will need to draw on your learning from across your programme.

It is important that engineers understand how engineering processes are used to safely transform ideas and materials into products and services, and how critical it is to be able to work as a valuable member of an effective team or as a team leader. This unit will enable you to apply the knowledge and understanding you gained in *Unit 1: Engineering Principles*. The unit will help to prepare you for an engineering apprenticeship, a higher education engineering degree or a technician-level role in a wide range of specialist engineering areas.

Learning aims

In this unit you will:

A Examine common engineering processes to create products or deliver services safely and effectively as a team

B Develop two-dimensional computer-aided drawings that can be used in engineering processes

C Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine common engineering processes to create products or deliver services safely and effectively as a team	**A1** Common engineering processes **A2** Health and safety requirements **A3** Human factors affecting the performance of engineering processes	A report, prepared as an individual, detailing engineering processes and the impact that human factors can have on their performance, using a case study based on a given engineered product/ products or a given engineering service/services.
B Develop two-dimensional computer-aided drawings that can be used in engineering processes	**B1** Principles of engineering drawing **B2** 2D computer-aided drawing	Practical activities to be undertaken as an individual to produce 2D computer-aided drawings. The drawings should include an orthographic projection and an electric circuit diagram. The evidence will include the drawings, observation records/witness statements and annotated screenshots.
C Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team	**C1** Principles of effective teams **C2** Team set-up and organisation **C3** Health and safety risk assessment **C4** Preparation activities for batch manufacture or batch service delivery **C5** Delivery of manufacturing or service engineering processes	Complete practical engineering processes as a leader and as a member of a team. The evidence will include records of team meetings (minutes), activity logs, a risk assessment, set-up planning notes, quality control charts/annotated drawings, modified production plans, annotated photographs of the processes and observation records/witness statements.

Content

Learning aim A: Examine common engineering processes to create products or deliver services safely and effectively as a team

A1 Common engineering processes

- Transforming ideas and materials into products or services, including:
  - preparation processes undertaken before manufacture or service delivery – use of information sources and the creation of technical specifications, engineering drawings, work plans and quality control documentation with due regard to the scale of production (one-off, small batch, large batch, mass or continuous)
  - standards relevant to the specialist area of study – guidelines/rules to ensure conformity in processes or outputs, e.g. BS 8888, reference charts (limits and fits, tapping drills, bend allowances), procedure specifications.
- A product and a service are closely aligned concepts, define:
  - a product as a tangible and discernible item, e.g. a car
  - a service as an intangible benefit, either in its own right or as a significant element of a tangible product, e.g. a car service.
- Common processes used to create engineered products, including:
  - fitting, e.g. at a bench using manual tools (drilling, cutting, filing)
  - machining, e.g. turning, milling, grinding
  - fabrication, e.g. welding, sheet metal work (bending, stamping, punching)
  - electrical, e.g. installation of looms, use of connectors/cables
  - forming, e.g. casting, forging, moulding.
- Common processes used in engineering services, including:
  - disassembly, e.g. use of general tools and special tools to strip or remove
  - inspection, e.g. checking for faults/correct operation, testing
  - systems servicing, e.g. capture of fluid, depressurisation
  - installation/replacement, e.g. rigging, assembly, refitting.

A2 Health and safety requirements

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

- Current Health and Safety at Work legislation – duties of employers, employees, the Health and Safety Executive (HSE) and others, general prohibitions
- Current Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) – duties of employers, the self-employed and people in control of work premises (the Responsible Person) to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences
- Current Personal Protective Equipment (PPE) at Work Regulations – appropriateness if risk cannot be controlled in any other way, types of PPE, assessing suitable PPE given the hazard, supply, instructions/training, correct use, maintenance and storage
- Current Control of Substances Hazardous to Health Regulations (COSHH) – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Current Manual Handling Operations Regulations (MHOR) – avoiding the need for manual handling, types of hazard, assessing risk of injury when manual handling is required, controlling and reducing the risk of injury, training in the use of techniques/mechanical aids.

A3 Human factors affecting the performance of engineering processes

- Understanding that human factors affect the productivity of processes, including conformance to quality standards, reliability and the safety of individuals.
- Understanding that human factors affect the performance of individuals and teams, including:
  - professionalism – adherence to codes of conduct, acting with due care, skill and diligence by recognising appropriate behaviours and possible limitations, preventing avoidable dangers/adverse impact on the environment, enhancing operational competence
  - ethical principles – rigour, honesty, integrity, respect, responsibility
  - behaviours – values, attitude, persuasion, coercion, rapport, authority
  - limitations – stress, time pressure, fatigue, memory, capability, motivation, knowledge, experience, health, inhibitors, e.g. alcohol and drugs.

Learning aim B: Develop two-dimensional computer-aided drawings that can be used in engineering processes

B1 Principles of engineering drawing

- Attributes of orthographic projections, including:
  - geometry – shape of the component represented as different views, how the component is viewed from various angles, visibility of component features
  - dimensions – size of the component in defined units
  - tolerances – allowable variations for defined dimensions
  - material – what the component is to be made from
  - surface texture – surface quality required, e.g. roughness, flatness
  - scale – relative to actual dimensions.
- Drawing conventions or other relevant international equivalents, including:
  - standards including BS 8888 and BS 60617 or other relevant international equivalents
  - title block/layout – drawing number(s), projection symbols, scale, units, general tolerances, name of author, date, border, parts referencing
  - views – elevation, plan, end, section, hatching style, auxiliary
  - line types – centre, construction, outline, hidden, leader, dimension
  - common features, e.g. screw threads, springs, splines, repeated items, holes, chamfers, radii
  - circuit diagram symbols and components, e.g. cell/battery, switch, resistor, diode, capacitor, transistor, integrated circuit, light-emitting diode (LED), motor, buzzer
  - lettering – titles, notes, annotation
  - abbreviations – A/F, CHAM, DIA, R, PCD, M.

B2 2D computer-aided drawing

Using a computer-aided design (CAD) system to produce engineering drawings and circuit diagrams, including:

- coordinates – absolute, relative, polar
- drawing template – border, title block with all necessary information
- layers – names, line types, colours, visibility
- commands – line, circle, arc, polygon, chamfer, fillet, grid, snap, copy, rotate, erase, stretch, trim, scale, dimensioning, text, pan, zoom-in, zoom-out, insertion and editing commands to produce and erase circuit components and connections
- cross-hatching – simple and complex areas, predefined hatch patterns, application to cross-sectioning.

Learning aim C: Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team

C1 Principles of effective teams

- Good communication – verbal, written (e.g. electronic documents and data, activity logs, meeting minutes), effective listening, respect for others' opinions, negotiation, assertiveness and non-verbal actions, e.g. smiling.
- Planning – thinking ahead, organisation, consideration of alternatives.
- Motivation – shared goals, collaboration, reaching agreements, adapting behaviour, fairness and consideration, opportunities to take responsibility, constructive feedback.
- Working with others – team player, flexibility/adaptability, social skills, supporting others.
- Working environment – conducive to successful outcomes, safe, supportive, challenging, opportunities to show initiative and leadership.

C2 Team set-up and organisation

- A team is defined as containing three or more individual members who have a shared common objective to complete.
- Strengths and limitations of team members – perceived competencies and constructive peer feedback.
- Allocation of responsibilities – roles, activities.
- Timescales – planning the activities.
- Objectives – team targets.

C3 Health and safety risk assessment

Risk assessment in an engineering workshop and for specific engineering processes, following guidance from the HSE (or other relevant international equivalents), including:

- identification of hazards – bad housekeeping, poor lighting, lack of grip/uneven surfaces/heights, lifting and handling operations, hand tools, machines, substances, heat/flammability
- assessing risk by determining how hazards can cause injury – contact, being struck, lifting and handling injury, fall, slip, trip, trap, exposure
- choosing and using appropriate control measures and precautions to reduce risk – good work area design, substitution, safe means of access and egress, safe system of work (permits to work), periodic inspection, testing and maintenance, physical barriers (guarding), PPE, supervision and training, good housekeeping, cleaning regime
- recording all findings – standard HSE (five steps) pro forma
- reviewing the risk assessment after new equipment/work activities have been undertaken, at regular intervals.

C4 Preparation activities for batch manufacture or batch service delivery

- A batch is defined as a quantity of three or more of a product or service delivered together.
- Understanding the requirements of production plans, specifications, engineering drawings and other technical documentation, including:
  - operations – sequence of production
  - health and safety factors – product or service based
  - processes – disassembly, mechanical, electrical, assembly, testing
  - materials, parts and components – to be disassembled, worked on, processed, joined, assembled and checked
  - equipment – marking out, hand tools, machinery, measuring
  - quality checks – critical production control points, how quality will be checked and inspected.

C5 Delivery of manufacturing or service engineering processes

- For engineered products or engineering services.
- Examples of engineered products, e.g. screwdriver, toolmakers' clamp, fabricated box/enclosure, outside calipers, ball joint splitter, clamp stand, assembling looms.
- Selecting, setting up and using engineering equipment to manufacture engineered products, including:
  - marking out processes, e.g. using a scriber, rule/tape, punch, square, vernier height gauge, marking out medium
  - manual processes, e.g. using shears, punch, guillotine, bender, saw, tap, die, file
  - machining processes, e.g. using a drill, lathe, milling machine
  - assembly processes, e.g. using adhesive, mechanical fasteners, cables/connectors
  - quantity production, e.g. using form tools, template, jig, mould, fixture, stops
  - measuring processes, e.g. using a micrometer, vernier calipers, comparators.
- Examples of engineering services, e.g. dismantling/assembly of alternators, including replacing worn parts and testing, removing and replacing fluid plumbing and checking for leaks, stripping out a variety of hardware and reinstalling/testing, assembly of pipework, including the connection of valves and operational checks, assembly and testing of electrical switch panels.
- Selecting, setting up and using engineering equipment to deliver engineering services, including:
  - disassembly/removal/strip processes, e.g. using a screwdriver, wrench, spanner, sockets, pliers/grips, keys
  - manual processes, e.g. using snips, cutters, knives, punch, saw, file, hammer
  - assembly processes, e.g. using a soldering iron, mechanical fasteners, cables/connectors, crimping tools, pneumatic tools, clamps
  - inspection/testing processes, e.g. using a multimeter, flow meter, torque meter, pressure sensor/gauge.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine common engineering processes to create products or deliver services safely and effectively as a team		**A.D1** Evaluate, using high-quality written language, the effectiveness of using different engineering processes to manufacture a product or to deliver a service and how human factors, as an individual and as a team, affect the performance of engineering processes.
A.P1 Explain how three engineering processes are used safely when manufacturing a given product or when delivering a given service. **A.P2** Explain how human factors, as an individual or as a team, affect the performance of engineering processes.	**A.M1** Analyse why three engineering processes are used to manufacture a product or to deliver a service and how human factors, as an individual and as a team, affect the performance of engineering processes.	
Learning aim B: Develop two-dimensional computer-aided drawings that can be used in engineering processes		**B.D2** Refine, using layers, an accurate orthographic projection of a component containing at least three different common feature types and a circuit diagram containing at least six different component types to an international standard.
B.P3 Create an orthographic projection of a given component containing at least three different feature types. **B.P4** Create a diagram of a given electronic circuit containing at least six different component types.	**B.M2** Produce, using layers, an accurate orthographic projection of a component containing at least three different feature types and a circuit diagram containing at least six different component types that mostly meet an international standard.	
Learning aim C: Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team		**C.D3** Consistently manage own contributions effectively using feedback from peers, as a team member and as a team leader, to set up, organise and manufacture a product or deliver a service safely, demonstrating forward thinking, adaptability or initiative.
C.P5 Manage own contributions to set up and organise a team in order to manufacture a product or deliver a service. **C.P6** Produce, as an individual team member, a risk assessment of at least one engineering process. **C.P7** Set up, as an individual team member, at least one process safely by interpreting technical documentation. **C.P8** Manage own contributions safely, as a team member and as a team leader, to manufacture a batch of an engineered product or to deliver a batch of an engineering service.	**C.M3** Manage own contributions safely and effectively using feedback from peers, as a team member and as a team leader, to manufacture a product or to deliver a service.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.P7, C.P8, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of technical documentation (such as engineering drawings, production plans, specifications, health and safety regulations), components and circuits
- suitable CAD workstations and output devices, e.g. printers and plotters, and 2D CAD software that is capable of professional 2D drawings and their output, e.g. AutoCAD 2D, AutoCAD Lt, TurboCAD Deluxe, DraftSight
- standard engineering workshop equipment and resources (as specified in the learning aims and unit content section), so learners can carry out common engineering processes to manufacture an engineered product batch or deliver an engineering service as a member of a team.

Essential information for assessment decisions

Learning aim A

The processes to be considered for learning aim A do not have to be the same as those used for learning aim C.

For distinction standard, learners will produce evidence that evaluates the relative merits of using different common engineering processes to manufacture a given product or deliver a given service, by comparing and contrasting the advantages and limitations of the chosen processes and of using other possible processes. Learners will provide detailed and justified reasons as to which processes are most effective, by referring to the specific requirements of the given product or service, for example by considering why a product is cast rather than machined, or whether to test or disassemble at a given interval.

Learners will also produce evidence that shows they can evaluate the impact that a range of human factors, as an individual and as a team, can have on the performance of engineering processes, for example, how coercion by someone in authority could lead to an individual or team introducing unnecessary hazards and risks into the engineering processes.

Overall, the evidence will be easy to read by a third party, who may or may not be an engineer, and will be easily understood. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will produce evidence that shows they can give detailed reasons as to why three common engineering processes have been chosen to manufacture a given product or to deliver a given service. The analysis will be consistent across all the processes and will include a contextual commentary. For example, for each process it will refer to scale of manufacture, the achievement of accuracy in comparison to a standard, and specific health and safety requirements.

Learners will also produce contextual evidence that shows they can analyse how human factors, as an individual and as a team, can impact on the performance of the three common engineering processes, for example by anticipating and preventing common errors, avoidable dangers or adverse impacts on the environment.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will produce evidence that shows they understand how three common engineering processes are used to manufacture a product or deliver a service. The evidence will be factually accurate and will include clear references to health and safety legislation and regulations, for example how drilling, turning and milling are used to produce a given product/products, or how to dismantle and replace worn parts and test an item using safe working practices and personal protective equipment, including why and how to report a dangerous occurrence during a process.

Learners will also produce evidence that shows they recognise the impact that human factors, either as an individual or as a team, can have on the three common engineering processes, for example the productivity of the processes being affected by an individual's attitude or capability, or safety being affected by fatigue.

Overall, the explanations may be basic in parts and may have some inaccuracies relating to engineering terminology.

Learning aim B

The orthographic drawings must be created on a 2D CAD package and not on a 3D CAD package. The component and electrical circuit to be drawn for learning aim B do not have to be used for learning aims A or C. The drawing should be created from an actual engineered component that must contain at least three different types of common feature. Learners will create the drawings using the knowledge and understanding gained in *Unit 1: Engineering Principles*. For example, taking measures from and performing calculations using the physical component, which could include geometry/vectors, basic arithmetic, trigonometry, and surface area and volume.

For distinction standard, learners will show in their evidence that they used a full range of CAD commands when generating the drawings and prepared and used additional layers as required for the drawing template, dimensioning and annotation.

Overall, all details in the 2D CAD orthographic projection and the electrical circuit diagram must be produced to typically represent the standards found in BS 8888 and BS 60617 (or other relevant international equivalents), with no omissions or errors evident.

For merit standard, learners will show in their evidence that they used a layer for a drawing template with a full title block, border and appropriate text.

Overall, all details in the 2D CAD orthographic projection and the electrical circuit diagram must be produced to typically represent the standards found in BS 8888 and BS 60617 (or other relevant international equivalents), although there may be some minor errors evident, such as the lack of a visible gap between some features of the component and extension lines, or some text that is incorrectly orientated.

For pass standard, learners will produce elevations that are technically correct but there may be some errors, such as a repeated dimension or inaccurate annotation.

Overall, all details in the 2D CAD orthographic projection drawing and the electric circuit diagram must be suitable for a competent third party to manufacture the component or the electric circuit from the drawings.

Learning aim C

Learners will work as a team to deliver an engineering service or to manufacture a product. They will use the knowledge and understanding gained in *Unit 1: Engineering Principles* to undertake and manage a practical service or manufacturing task. During assessment, a team should manufacture a batch of an engineered product or deliver a batch of an engineering service, not both. The choice is likely to be dependent on the sector context and/or the resources available. All planning and manufacturing or service activities should take no more than 15 hours in total. A team should consist of three or four learners and it is expected that the role of team leader will be undertaken by all team members (in rotation) after the initial planning activities. The number of items in a batch, and the number of processes in a product or service, should be between three and six.

Teams should be given a range of technical documentation (such as engineering drawings, production plans and specifications) prior to the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. Materials can be prepared and engineering equipment can be laid out prior to team activities, but each learner must set up and undertake at least one engineering process.

For distinction standard, learners will consistently demonstrate at least one of the following traits during the planning and manufacturing or service activities: forward thinking, adaptability or initiative. For example, learners may respond to opportunities as they arise by convincing the team to adopt a more efficient approach to the manufacturing or service activities, or a different approach if a lack of equipment or resources demands it, or they may adapt to circumstances quickly by providing feedback to team members or by coaching others who are struggling with an activity or process. Learners may also prove their capability to adapt a process and/or machines to manufacture quantities of a product, for example by setting stops or by using simple techniques to process components at the same time. Similar approaches could be used in the delivery of a batch of an engineering service.

Learners will show their ability to objectively review team targets at suitable points and reach agreements with other team members as to an appropriate way forward given current progress.

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 demonstrate an active role in making decisions concerning the allocation of roles and responsibilities, time planning and setting team targets, for example by explicitly taking into account the preferences and perceived strengths of team members.

Learners will produce a risk assessment, which will be laid out on an appropriate industry-standard template and will include detailed attention to all five steps, for example clear identification of all significant hazards, who might be harmed and how, current precautions in place, further control measures needed and a suitable time period until review.

Learners will interpret technical documentation to set up safely and effectively at least one engineering process, for example, so that others in the team could also carry out the process with minimal explanation required.

During the delivery of manufacturing or service processes, learners will show that they can work effectively as a team member and as a team leader to make effective progress towards team targets. For example, they will modify their approach based on feedback from peers and will generate a progress log to allow team members to quickly review progress.

Overall, the evidence will be clear, but some parts of it may be presented in an inconsistent fashion, making it more difficult for a third party to understand.

For pass standard, learners will manage their contribution to making decisions concerning the allocation of roles and responsibilities, time planning and setting team targets. These activities will be completed as a minimum to set up and organise the team to manufacture a batch of an engineered product or to deliver a batch of an engineered service.

It will be essential to ensure that each team member has clear responsibilities and that everyone makes a contribution to the end result during the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. All individual team members must be clear about who is responsible and accountable for each aspect of the work, and team targets should be set and reviewed. To facilitate this, each team must carry out a series of meetings both prior to and during the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. Each member of the team must produce their own evidence against the assessment criteria, as evidence cannot be shared.

Learners will produce their own risk assessment to show how health and safety is managed in the engineering workplace, for at least one engineering process to be used when manufacturing the engineered product or when delivering the engineering service. The risk assessment should consider the most significant hazards with details of suitable control measures and be laid out on an appropriate industry-standard template. It will be appropriate, but may lack detail. For example, it may focus on the more obvious hazards and control measures, including those already in place.

Learners will also interpret technical documentation, including a production plan and an engineering drawing given to them, to set up safely at least one engineering process, for example, so that they can carry out the process in a consistent manner.

During the delivery of manufacturing or service processes, learners will show that they can act independently as a team member and as a team leader to make progress towards team targets, although learners may demonstrate some reluctance to adapt to changing circumstances. The products or services delivered by the team do not have to be accurate and do not need to be tested for functionality, but teams must keep quality records. For example, the dimensions of a hole would be checked for conformance against the technical documentation and notes would be made on the outcome of the quality check. Also, teams do not need to rework any non-conforming product or service outcomes.

Overall, the evidence will be logically structured but may be imprecise and basic in some parts, meaning that only a third party with technical knowledge can understand aspects of it.

Links to other units

In the Certificate (180 GLH) qualification this unit should be completed towards the end of the programme. In order to complete the synoptic assessment task in this unit, learners should select and apply relevant knowledge and skills from other areas of the mandatory content. Learners should build on their knowledge of engineering approaches and their applications from *Unit 1: Engineering Principles*.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 3: Engineering Product Design and Manufacture

Level: **3**

Unit type: **External**

Guided learning hours: **120**

Unit in brief

Learners will explore engineering product design and manufacturing processes and will complete activities that consider function, sustainability, materials, form and other factors.

Unit introduction

Engineering products are part of our daily lives, from aircraft to the smallest electronic circuits found in medical devices. Engineering products are designed as a result of the identification of a need or opportunity, and then engineers using creative skills and technical knowledge to devise and deliver a new design or improvements to an existing design. For example, advances in the development of fuels led to the first internal combustion engine, and engineers have been improving its design ever since.

In this unit, you will examine what triggers changes in the design of engineering products and the typical challenges that engineers face, such as designing out safety risks. You will learn how material properties and manufacturing processes impact on the design of an engineering product. Finally, you will use an iterative process to develop a design for an engineering product by interpreting a brief, producing initial ideas and then communicating and justifying your suggested solution. You will draw on and apply knowledge and understanding from *Unit 1: Engineering Principles* and *Unit 2: Delivery of Engineering Processes Safely as a Team*, for example by using calculations to demonstrate a reduction in mass, by sketching using orthographic projection drawing methods or by justifying an engineering process as its use reduces the carbon footprint of a product. To complete the assessment task within this unit, you will need to draw on your learning from across your programme.

It is important that engineers use creative and technical knowledge, understanding and skills to transform ideas into viable products, and that they understand the critical importance of this activity in ensuring that products are both safe and effective. This unit will help prepare you for an engineering apprenticeship, engineering courses in higher education or for technician-level roles in a variety of engineering sectors.

Summary of assessment

This unit is assessed by a set task of 60 marks provided by Pearson and completed under supervised conditions. Part A is given to learners one week before Part B is scheduled. Learners are advised to spend no more than 3 hours on Part A. Learners will be given a case study and produce independent research, no design work should take place at this time, the perimeters of the design are contained in part B.

The supervised assessment period is eight hours and can be arranged over a number of sessions within a two-week assessment period timetabled by Pearson, once the assessment has started the learner must complete within five days. During the supervised assessment period, learners will complete a task that will require them to follow a standard development process of interpreting a brief, scoping initial design ideas, preparing a design proposal and evaluating their proposal.

The assessment availability is December/January and May/June each year. The first assessment availability is May/June 2017.

Sample assessment materials will be available to help centres prepare learners for assessment.

Assessment outcomes

AO1 Demonstrate knowledge and understanding of engineering products and design

AO2 Apply knowledge and understanding of engineering methodologies, processes, features and procedures to iterative design

AO3 Analyse data and information and make connections between engineering concepts, processes, features, procedures, materials, standards and regulatory requirements

AO4 Evaluate engineering product design ideas, manufacturing processes and other design choices

AO5 Be able to develop and communicate reasoned design solutions with appropriate justification

Essential content

The essential content is set out under content areas. Learners must cover all specified content before the assessment.

A Design triggers, challenges, constraints and opportunities, and materials and processes

A1 Design triggers

The triggers that stimulate engineering design activity, including:

- market pull/technology push (product and process)
- demand
- profitability
- innovation
- market research
- product/process performance issues
- sustainability (carbon footprint)
- designing out risk.

A2 Design challenges

Commercial-, regulatory- or public policy-based trends that challenge current technology or design, including:

- reduction of energy wasted during design of an engineered product
- reduction of energy wasted during operation of an engineered product
- reduction of physical dimensions
- reduction of product mass
- increase in component efficiency
- energy recovery features
- reduced product life cycle costs
- integration of different power sources for vehicles
- reduced use of resources in high-value manufacturing
- sustainability issues throughout the product lifecycle (raw materials, manufacture, packaging and distribution, use and reuse, end of life)
- designing out risk (for individual employees and customers).

A3 Equipment level and system level constraints and opportunities

Factors that place limitations and offer opportunities at equipment level on the design of engineering products, including:

- reasons for selecting different solutions for equipment interfaces (mechanical, electrical, hydraulic, software)
- systems integration compromises (cooling, location for optimum equipment performance, bonding, centre of gravity, electrical and electronic compatibility)
- equipment product design specification (PDS) (shortcomings absorbed at system level, electromagnetic compatibility (EMC), mass, cooling)
- cost effective manufacture (capital outlay, use of tooling, set up cost).

A4 Material properties

Properties, modes of failure, protection and lubrication of engineering materials and components that impact upon their selection when designing an engineering product, including:

- mechanical properties
- physical properties
- thermal properties
- electrical and magnetic properties

- behaviour of advanced materials (bio materials, smart alloys, nanoengineered materials)
- modes of failure
- surface treatments and coating
- lubrication (purposes, regimes).

A5 Mechanical power transmission

Characteristics of an engineering system that makes use of forces and movement that impacts on mechanical power transmission component selection when designing an engineering product, including:

- linkages (types, mechanical advantage, examples from nature)
- mechanical motion (linear, rotary, reciprocating, oscillating)
- power sources (mechanical, electrical, energy from nature)
- control of power transmission (sensors, actuators, servomotors).

A6 Manufacturing processes

Characteristics and effects of manufacturing processes that impact on the selection of engineering materials and components when designing an engineering product, including:

- processes for metals (additive, moulding, machining, forming, casting, powder metallurgy, joining, assembly)
- processes for polymers (additive, casting, moulding, extrusion, thermoforming)
- processes for ceramics (additive, casting, forming)
- processes for composites (layup, moulding, automated tow placement)
- effects of processing (recrystallisation, grain structure, alloying elements, material combinations, process parameters)
- scales of manufacture (one-off, small batch, large batch, mass, continuous).

B Interpreting a brief into operational requirements and analysing existing products

B1 Design for a customer

Meeting customer needs during engineering design activity, including:

- types of customer (internal, external)
- product and service requirements (performance specifications, compliance to operating standards, manufacturing quantities, reliability/product support, product life cycle, usability, anthropometrics)
- product design specification/criteria (cost, quantity, maintenance, finish, materials, weight, aesthetics, product life cycle, sustainability, carbon footprint, reliability, safety, testing, ergonomics, usability, competition, market, manufacturing facility, manufacturing constraints, manufacturing processes)
- commercial protection (patents, registration, copyright, trademarks).

B2 Regulatory constraints and opportunities

Regulatory factors that place limitations and opportunities on the design of engineering products, including:

- legislation, standards, codes of practice, national and international certification requirements
- environmental constraints (sustainability, carbon footprint, product life cycle)
- health and safety, security (product and process).

B3 Market analysis

Engineering goals in terms of marketing when designing an engineering product, including:

- unique selling point (USP)
- benefits of the design
- obsolescence.

B4 Performance analysis

Engineering goals in terms of performance when designing an engineering product, including:

- product form
- product functionality
- technical considerations
- choice of materials and components
- environmental sustainability (impact, carbon footprint)
- interactions with other areas/components
- likelihood of failure or wear.

B5 Manufacturing analysis

Engineering goals in terms of manufacturing when designing an engineering product, including:

- processes for manufacturing/assembly
- manufacturing requirements
- quality indicators
- environmental sustainability (impact, carbon footprint)
- design for manufacture.

C Using an iterative process to design ideas and develop a modified product proposal

C1 Design proposals

Initial and developed propositions to improve an engineering product, including:

- technical design criteria
- idea generation (context, creativity, range)
- initial design ideas (fitness for purpose, refinements, recognition of constraints)
- developed design idea (aesthetics, ergonomics, sizes, mechanical and electronic principles, material requirements, manufacturing processes, assembly arrangements, cost estimations, factor of safety, selection procedures for bought out components)
- use of information sources.

C2 Communicating designs

Communication of an initial and a developed proposition to improve an engineering product, including:

- freehand sketching and diagrams (2D and 3D, illustrations, technical)
- graphical techniques (charts, keys, shading, animation, symbols, conventions)
- written skills (annotation, technical language, interpreting results)
- documentation (detail and assembly orthographic projections, specifications, parts list, materials list, production plan, circuit/block diagrams, flowchart, design log).

C3 Iterative development process

Using an iterative process to improve an engineering product, including:

- refining a task or process (analysing, adapting, enhancing)
- cyclic process (logical non-linear approach, focus on product design specification/criteria).

D Technical justification and validation of the design solution

D1 Statistical methods

Statistical techniques as applied to engineering problems, including:

- statistical measurement (discrete/continuous, mean, median, mode, variance)
- data handling:
  - graphical representation (bar chart, pie chart, frequency table, histogram, cumulative frequency diagram or graph)
  - frequency distributions (normal, skewed, standard deviation).

D2 Validating designs

Rationalise choices made when generating a developed proposition to improve an engineering product, including:

- objective referencing against product design specification/criteria
- objective referencing against weighted matrix
- indirect benefits and opportunities
- balancing benefits and opportunities with constraints (cost-benefit analysis, environmental benefits, health and safety risks, product life cycle considerations)
- design for manufacturing
- further modifications (technology-led adaptations).

Grade descriptors

To achieve a grade a learner is expected to demonstrate these attributes across the essential content of the unit. The principle of best fit will apply in awarding grades.

Level 3 Pass

Learners demonstrate knowledge and understanding of iterative design methodologies, processes, features and procedures and their application to engineering products. They can interpret a design brief to generate ideas, and will deploy skills and selected techniques to develop modified products in context. Learners demonstrate research and analytical skills in order to create a product design specification to meet the requirements of a brief. They make recommendations and proposals relevant to familiar and unfamiliar situations, with consideration of design sustainability and safety issues. Learners will make evaluative judgements in relation to their design proposal and be able to provide technical justifications in the validation of their design solution.

Level 3 Distinction

Learners demonstrate thorough knowledge and understanding of iterative design methodologies, processes, features and procedures and can apply this understanding to engineering products in context. They can interpret a design brief to generate complex design ideas, and will deploy a range of skills and selected techniques to develop modified products in context and with justification. They demonstrate comprehensive research and analysis skills in order to generate a product design specification that fully and effectively meets the requirements of the brief. They present justified recommendations and proposals relevant to familiar and unfamiliar situations, with consideration of design sustainability and safety issues. Learners are able to select appropriate techniques and processes to design ideas and will justify applications in arriving at creative, feasible and optimised solutions. Learners will make robust, evaluative judgements in relation to their design proposal and be able to provide detailed technical justifications in the validation of their design solution.

Key terms typically used in assessment

The following table shows the key terms that will be used consistently by Pearson in our assessments to ensure students are rewarded for demonstrating the necessary skills.

Please note: the list below will not necessarily be used in every paper/session and is provided for guidance only.

Command or term	Definition
Client brief	Outlines the client's expectations and requirements for the product.
Design	A drawing and/or specification to communicate the form, function and/or operational workings of a product prior to it being made or maintained.
Manufacture	To make a product for commercial gain.
Project log	A document to record the progress made, key activities and decisions taken during the development of a project.

Links to other units

The assessment for this unit should draw on knowledge, understanding and skills developed from:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safety as a Team
- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 5: A Specialist Engineering Project
- Unit 6: Microcontroller Systems for Engineers
- Unit 7: Calculus to Solve Engineering Problems
- Unit 32: Computer System Principles and Practice
- Unit 39: Modern Manufacturing Systems
- Unit 48: Aircraft Flight Principles and Practice.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 4: Applied Commercial and Quality Principles in Engineering

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore commercial engineering, for example key business activities, cost control, quality systems and value management, which is used by engineering organisations to create value.

Unit introduction

Engineering organisations use a wide range of systems and methods to ensure that they are competitive. For example, organisations can develop a competitive advantage by increasing the quality of their products, innovating with new product designs or reducing the cost of their operations. Well-known brands that have successfully produced a competitive advantage in this way include Dyson, Rolls-Royce and Škoda.

In this unit, you will explore how key business activities and trade considerations influence engineering organisations and are used to create a competitive advantage. You will understand why organisations need to control costs and how they make decisions, applying an activity-based costing methodology. You will also understand what is meant by quality and why it means different things to different people; you will investigate quality systems, including quality assurance and control. Finally, you will explore value management as a process to create value in an organisation.

The quality systems and value management principles and processes provide a foundation for business process improvement techniques, such as Lean and Six Sigma, which many engineering organisations follow to ensure continuous improvement. It has not been possible to include these methodologies as part of this unit; however, should you encounter them in the workplace then this unit provides a basis for understanding and applying them.

As an engineer, it is important that you understand some of the commercial and competitive considerations which ensure that engineering organisations thrive. You will need to apply these principles to technical engineering projects to ensure that they add value to the organisation and are profitable. This unit will help to prepare you for an engineering apprenticeship, higher education and technician-level engineering roles.

Learning aims

In this unit you will:

A Examine business functions and trade considerations that help engineering organisations thrive

B Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable

C Explore how engineering organisations use quality systems and value management to create value.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine business functions and trade considerations that help engineering organisations thrive	**A1** Business functions and key activities **A2** Trade considerations **A3** Competitive advantage	A written report that evaluates how key business activities and trade considerations influence a local engineering organisation and can create competitive advantage.
B Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable	**B1** Reasons for cost control and types of costs **B2** Activity-based costing method	A research and problem-solving project to explore the costs associated with engineering activities and the completion of an activity-based cost model for a product or service.
C Explore how engineering organisations use quality systems and value management to create value	**C1** Quality systems **C2** The principles and processes of value management	A research activity to explore quality systems and value management processes. In addition, an applied value analysis exercise to determine if further value can be created from an engineering product or service.

Content

Learning aim A: Examine business functions and trade considerations that help engineering organisations thrive

A1 Business functions and key activities

Functions within an engineering organisation, including human resources (HR), finance, sales, marketing, operations, research and development, and purchasing.

Key activities of business functions, to include:

- manufacturing of products and delivering services, e.g. forming, fabrication, removal of material, addition of material, assembly processes, quality control
- supply chain management, e.g. outsourcing decisions, supplier appraisal
- marketing and sales, e.g. brand awareness, market research, sales, customer feedback
- customer relations, e.g. meeting expectations, being proactive
- resource management, e.g. sources of funding, resource allocation, stock control
- staff recruitment, e.g. internal and external recruitment, apprenticeships
- staff management, e.g. appraisals, support and training (continuing professional development)
- financial, e.g. financial statements (profit and loss, break-even).

A2 Trade considerations

Tendering and contracting, or other relevant international equivalents, including:

- terms, both expressed and implied, e.g. breach of contract, force majeure
- warranties and conditions, e.g. indemnities, guarantees, insurance
- consequences of non-performance, e.g. rejection of goods/services, financial penalty clauses
- documentation, e.g. drawings, estimates, quotations, specifications.

Definition and purpose of intellectual property rights, including patents, registered designs and trademarks.

A3 Competitive advantage

Competitive advantage is the term used to describe what an organisation does that allows it to outperform competitors. It can be created by all functions and/or any combination of activity and trade consideration:

- by innovating
- using new technology
- protecting intellectual property
- managing costs.

Learning aim B: Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable

B1 Reasons for cost control and types of costs

- Reasons for cost control:
  - identifying hidden costs and managing all costs
  - informed decision making, e.g. investment, withdrawal, make or buy
  - improving competitiveness.
- Types of costs, including:
  - direct costs, e.g. raw materials, work in progress (WIP), direct labour costs
  - indirect costs, e.g. energy, insurance, wages, consumables
  - variable costs, e.g. raw materials, consumables
  - semi-variable costs, e.g. overtime costs, commission, maintenance
  - fixed costs, e.g. overheads, rent, machinery costs, depreciation, insurance
  - general/administration costs, e.g. human resources (HR), finance and information technology.

B2 Activity-based costing method

Stages of implementing activity-based costing:

- identifying activities, including the processes and activities required to produce an output
- assigning resource costs to activities, including direct costs, indirect costs and general/administration costs
- identifying outputs, including products, services or customers
- assigning activity costs to outputs, including using activity drivers to assign costs to outputs (cost objects)
- activity cost pools, including material handling, set-up costs, and procurement
- application of activity-based costing to determine profitability.

Learning aim C: Explore how engineering organisations use quality systems and value management to create value

C1 Quality systems

- Quality standards and accreditation include international quality standards that can be applied for voluntarily by engineering organisations, allowing them to show that they have quality management systems in place. Quality standards associated with engineering activities include:
  - the International Organization for Standardization (ISO) 9000 series, a quality assurance system for the manufacturing and service industries, including:
    - ISO 9000 – knowledge of the 20 requirements for a quality management system
    - ISO 9001 – a planning tool for quality, and to support continual improvement
  - the ISO 14000 series, an environmental management system, including:
    - ISO 14001 –a method of reducing waste
    - ISO 14006 – to improve product quality in an environmentally positive way
    - ISO 14040 series – for life-cycle assessments.
- Quality assurance:
  - definition –planned activities to ensure that the quality requirements of a product or service are met
  - quality assurance as a company-wide philosophy
  - total quality management (TQM) – PDCA cycle (plan, do, check, act).
- Purposes of implementing a quality system, including:
  - benchmarking against other organisations
  - ensuring consistency of processes
  - ensuring conformity of the product or service to a standard
  - reducing unnecessary waste, e.g. inventory, over processing and over production
  - improving the effectiveness of the engineering organisation
  - gaining a competitive advantage
  - achieving customer satisfaction
  - ensuring that a product or service is fit for purpose.
- Quality control:
  - definition – the testing and monitoring of activities that are used to check the quality of a product or service outcome
  - inspection, sampling and testing
  - condition monitoring, e.g. vibration or thermal analysis
  - planned maintenance
  - applying a 'right first time' philosophy.

C2 The principles and processes of value management

- Principles of value management:
  - definitions of cost, value, value added and non-value added activities
  - concepts of function, process and product
  - reasons for poor value, e.g. lack of innovation, poor communication.
- Phases in the process of carrying out a value analysis exercise on a product or service:
  - information phase, e.g. identification of key issues, identification of added and non-value added processes, and cost overviews
  - analysis phase, e.g. functional analysis, which existing processing methods are used, identifying features or parts which are unnecessary
  - creative phase, e.g. generating alternatives for better value solutions, problem-solving tools and methods, developing a least-cost solution
  - evaluation phase, e.g. assessing and prioritising ideas
  - development and reporting phase, e.g. refining ideas and developing action plans.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine business functions and trade considerations that help engineering organisations thrive		**A.D1** Evaluate, using language that is technically correct and of a high standard, how key business activities and trade considerations combine to influence an engineering organisation, which can create a competitive advantage.
A.P1 Explain how key business activities influence an engineering organisation. **A.P2** Explain how trade considerations influence an engineering organisation.	**A.M1** Analyse how key business activities and trade considerations influence an engineering organisation, which can create a competitive advantage.	
Learning aim B: Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable		**B.D2** Produce an accurate and refined activity-based costing model, during the process, for a product or service to determine the major cost areas that could impact on profitability, explaining the reasons for cost controls.
B.P3 Explain why an engineering organisation controls costs. **B.P4** Produce an activity-based cost model for an engineering product or service.	**B.M2** Produce accurately an activity-based cost model for an engineering product or service, explaining the reasons for cost controls.	
Learning aim C: Explore how engineering organisations use quality systems and value management to create value		**C.D3** Evaluate the outcome of a value management exercise for a given engineering activity and make recommendations which include the use of quality systems to implement efficiencies in the engineering activity.
C.P5 Explain the purposes of different quality management systems and value management used by engineering organisations. **C.P6** Complete a value analysis exercise on a given engineering process.	**C.M3** Analyse the purpose of different quality management systems and value management used by engineering organisations. **C.M4** Complete accurately a value analysis exercise on a given engineering process.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- case studies outlining the operations of engineering organisations
- financial statements for engineering activities
- products or services to analyse, including details of the processes used to achieve the outcomes.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and thorough evaluation of how key business activities and trading considerations combine to influence an organisation. The evaluation will explore, for example, the joint decision of finance, purchasing and operations functions within the organisation to outsource an activity or service, the consideration of whether the organisation has the resources to undertake the activity in-house, and, if suitable suppliers are available, whether they would be able to meet the expectations of the organisation, and agree suitable trading terms. Learners will evaluate whether the use of outsourcing would give the organisation a competitive advantage, for example by lowering costs.

Overall, the evaluation will use correct technical terms, be easy to read and be logically structured. It will be written in a way that is easy to understand for a third party who may or may not be an engineer.

For merit standard, learners will provide a thorough analysis of business activities and trading considerations, using examples to demonstrate that a range of factors impact on the organisation. For example, learners will explain how decisions regarding staff recruitment made by the HR function will impact on financial cash flow. Also, learners will explain the purpose of intellectual rights and how the protection of such rights can be used by engineering organisations to develop a competitive advantage, for example by protecting a brand name through the use of trademarks.

Overall, the analysis will be logically structured and use correct technical terms.

For pass standard, learners will explain how key business activities influence an engineering organisation. For example, learners will explain that the finance function produces a range of financial statements, such as profit and loss reports, to determine the financial viability of the organisation.

Learners will also explain how tendering, contracting and other trade related considerations influence a business organisation. For example, learners will identify and explain the main terms used in contracts or the types of documents used for contracts and tenders, and how these are used by the organisation. For intellectual rights, learners will explain how each of the intellectual rights is used, and how this could benefit the organisation.

Overall, the evidence will be logically structured, and make appropriate use of technical terms. Some explanations may have minor technical inaccuracies, such as using the term 'warranties' when 'guarantees' is more appropriate.

Learning aim B

For distinction standard, learners will provide an accurate activity-based cost model for a given engineering product or service that is refined during the process, to include all of the activities required to produce the final output. Learners will record all costs, assigning them to the correct cost type, and use the model to identify any hidden costs, for example maintenance of equipment or staff training.

Learners' evidence will explain why costs are controlled and will evaluate how the cost model can be used to improve the profitability of an engineering product or service. The evidence will explain how costs are categorised, and give specific examples from an engineering activity for each cost category. For example, raw materials can be apportioned directly to an engineering activity; however, these costs are also variable since they are dependent on the amount of product being manufactured.

The cost model will be used to identify cost areas that have the greatest impact on the profitability of the product or service. For example, learners may identify that the biggest cost area is energy consumption but that there is scope to reduce it.

Overall, the cost model will be clearly presented, thorough and accurate. There will be no arithmetic and/or follow-through errors and all costs will be identified and assigned appropriately. The evidence will contain the correct technical terms, be easy to read and be logically structured.

For merit standard, learners will produce an accurate activity-based cost model for a given engineering product or service. The model will include all of the engineering activities that contribute to the output and will assign the majority of these correctly to appropriate cost types. Learners will explain the reasons for producing an activity-based cost model, for example as part of an investment decision-making process to evaluate how costs could be reduced.

Overall, the activity-based cost model and evidence will be clearly presented, and use correct technical terminology throughout. The model may contain some minor arithmetic and/or follow-through errors.

For pass standard, learners will explain why it is important for an engineering organisation to analyse and control costs. For example, learners will explain that cost control information can be used for decision-making purposes, including make or buy decisions for a new engineering-based product or service.

An activity-based cost model will be produced for a given product or service. The model may contain some errors, such as assigning a couple of costs inappropriately and/or omitting some activities that contribute to the output.

Overall, learners must be able to demonstrate the correct use of method when applying activity-based costing and use the correct units. The cost model and evidence should be logically structured, although basic in parts, and it may contain minor arithmetic and/or follow-through errors.

Learning aim C

For distinction standard, learners will use evidence to evaluate the outcomes of a value analysis exercise and consider the results alongside the use of quality management systems. They will identify and explain, using evidence, how efficiencies can be made for a given engineering product or service. Learners will evaluate how quality management tools, such as the ISO 9000 and ISO 14000 groups of international standards can improve a given engineering activity. For example, learners may include how the problem will be defined and the data collected during the planning stage, a solution will be developed during the implementation stage, comparisons to the original process will be considered during the checking stage, and recommendations should be made in the acting stage. Learners will use the findings of this activity, in conjunction with the outcomes of a value analysis activity, to evaluate methods of implementing efficiencies for an engineering activity. They will identify where there is scope to improve quality or where meeting aspects of the ISO 9000/14000 standards will bring an improvement to the product or service.

Learners will complete a value analysis exercise for the same product or service and present their results covering the appropriate phases of the process. An example would be a simple engineered product where the cost of the product is the amount paid to manufacture it, its value is how much it is worth, value added activities include machining and processing, and non-value added activities such as transportation or inspection and testing are also included. Learners will include a functional analysis of the processes involved in producing the outcome, for example considering if different materials which offer better value could be used, with the results being used to generate alternatives which would offer better value solutions. They will use their analysis to identify where waste, such as excessive manufacturing techniques, occurs during the activity, and identify improvements that could be made to the process to improve efficiency and develop a lower-cost alternative solution.

Finally, learners will evaluate their findings from the quality management activity and the value analysis task to identify which areas can increase the profitability and efficiency of the process being investigated. They will suggest methods to improve the activity, and prioritise those aspects that will offer the greatest benefit to the organisation.

Overall, the evidence will be logically structured and clearly presented. The evaluation will be written using accurate technical language.

For merit standard, learners will analyse the quality management and value analysis tools that an engineering organisation uses to improve efficiency and gain a competitive advantage. For example, learners will analyse the potential benefits of implementing a quality system for an activity and how this would relate to the quality assurance and control checks that are already applied to the process. Learners will evaluate what may be achieved by gaining ISO 9001 accreditation and continue to analyse the reasons why value management methods, such as value analysis, are applied to the same engineering activities.

Learners will complete an accurate value analysis exercise for a given engineered product or service. The major value added and non-value added activities will be identified, with cost assumptions for each being made. Learners will produce ideas to improve the value of the processes, for example by suggesting the use of standardised components or removing some non-value added features of the product or service.

Overall, the value analysis and associated report will be clearly presented and use correct technical language throughout. The value analysis will be accurate, but may omit some minor aspects of the engineering activity.

For pass standard, learners will explain how an engineering organisation can use quality and value management systems to create a competitive advantage. For example, learners will explain that quality assurance and quality control are used to improve the outcomes of the product or service, and will give the organisation a competitive advantage, as the product or service being provided will then have greater value. Learners will make reference to relevant ISO standards, such as the ISO 9000 group, which offer engineering organisations the potential to improve quality. Further, they will explain that improving the efficiency of the activity will also improve the competitiveness of the organisation by increasing the value of the outcome compared to the initial cost.

Learners will complete a value analysis exercise for a given engineered product or service. Most of the key stages of the process will be identified, with costs associated to each activity. There may be some errors, and some non-value added activities may be missed, but overall the analysis will result in the identification of opportunities for a better value solution.

Links to other units

This mandatory unit is linked to many of the other units in the qualification and in particular to mandatory *Unit 5: A Specialist Engineering Project*.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with commercial and quality systems expertise
- contribution of ideas to unit assignment/project materials.

Unit 5: A Specialist Engineering Project

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners apply project-management principles to undertake a 30-hour individual project and will produce a product, system or process relevant to their specialist area of study.

Unit introduction

Project management, and understanding the project life cycle, is a fundamental part of all engineering disciplines, from aerospace and computing – which may involve the development of new products and services – to the manufacturing sector, which may involve refurbishing or installing equipment. The output from a project is varied and could be a product/service, system or process that is relevant to your specialist area of study.

There are many approaches to project management, and in this unit you will understand and apply one project-management approach over the life cycle of a project to solve an engineering-based problem on a given theme or idea. This will involve you researching an engineering-based problem and using your creative skills to generate a range of solutions to the problem. You will produce a feasibility study to select the most appropriate solution given the known constraints. Over the life cycle of the project you will make use of project-management processes, such as monitoring progress and managing risks, to design and develop a solution that is fit for audience and purpose. You will demonstrate high-standard behaviours during the development of your solution and will present your solution in a portfolio of evidence. In this unit, you will draw on your learning from across your programme to complete assessment tasks.

The purpose of the specialist engineering project is for you to consolidate and build on the knowledge and skills gained throughout your BTEC National programme of study. The completion of this unit will help you to progress to employment as an engineering technician, or to an apprenticeship or higher education.

Learning aims

In this unit you will:

A Investigate an engineering project in a relevant specialist area

B Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry

C Undertake the solution for a specialist engineering project and present the solution as undertaken in industry.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate an engineering project in a relevant specialist area	**A1** Project life cycle **A2** Project idea generation and solution development **A3** Feasibility study of solutions	Research evidence, investigating an initial idea and possible solutions, scoping out alternative technical solutions and completing a feasibility study report of the possible solutions.
B Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry	**B1** Planning and monitoring project-management processes **B2** Risk and issue project-management processes **B3** Technical specification **B4** Design documentation	Evidence of applying project-management processes, such as planning during the design of a solution. Also, the development of a technical specification that may include design documentation, such as orthographic projections of the chosen solution.
C Undertake the solution for a specialist engineering project and present the solution as undertaken in industry	**C1** Undertake and test the solution to the problem **C2** Demonstrate relevant behaviours **C3** Present a solution to the problem	Evidence of applying project-management processes, such as project monitoring, and applying relevant behaviours during the development and testing of a solution. A portfolio of evidence generated while completing the specialist project, reviewing the processes and reflecting on own performance.

Content

Learning aim A: Investigate an engineering project in a relevant specialist area

A1 Project life cycle

An approach to a project life cycle is to split a project into the following four stages:

- initiation, to include identifying a problem, research and clarification of a problem, establishing key design features of possible solutions and constraints, idea generation and a feasibility study
- planning and design, to include resource and time planning for the chosen solution and creating a design based on the customer's requirements
- implementation, to include undertaking project processes to develop the solution while controlling the project by monitoring it against the plans and managing risks and issues
- evaluation, to include reviewing the outcome of the project, e.g. whether the customer requirements were met, whether the project was delivered on time and to budget, and how the project was delivered to the given theme or specification.

A2 Project idea generation and solution development

Identification of a suitable problem, perhaps based on a theme, and creation of alternative solutions, including:

- researching a given project theme or initial idea and identifying problems to be solved using tools, e.g. the internet, journals, databases, libraries, publicly available company information
- creativity tools to solve problems, e.g. rewording problems, challenging assumptions, thinking in reverse, mind mapping, drawing a diagram, group discussion, brainstorming and Edward De Bono's Six Thinking Hats®
- a specification that scopes out alternative technical solutions, using outline information to define what possible, as yet undesigned, products, systems or processes are intended to contain and do. The specification could include:
  - graphic solutions, e.g. sketches, diagrams, photographs and storyboards
  - an outline of the required processes, e.g. machine tools, systems, assemblies, high-level flow chart
  - an outline of costings, e.g. spreadsheet, material cost, budgets
  - initial technical information, e.g. approximate mass, approximate volume, suggested materials, outline performance parameters.

A3 Feasibility study of solutions

- Criteria to determine the feasibility of different solutions to a problem, including the potential:
  - size and complexity of the problem to be solved
  - size of the benefit and performance improvement, e.g. how well a solution solves a problem
  - cost and time required to develop each solution, available time, available budget
  - expertise required to develop a solution
  - risks in developing a solution, e.g. unknowns, unproven technology, equipment, time and cost
  - sustainability, e.g. environmental impact of mass production, waste material, choice of materials, recycling
  - legal constraints, e.g. the current data protection legislation, Health and Safety at Work legislation or other relevant international equivalents.
- Selection of the proposed solution:
  - objective testing
  - design analysis, e.g. iterative steps, feasibility assessment.

Learning aim B: Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry

B1 Planning and monitoring project-management processes

Tools to plan and monitor a project:

- resource plan, to include the internet, humans, peers, books and equipment
- time plan, to include a Gantt chart and critical path analysis to set priorities for different activities
- project contingency, e.g. an amount of time or additional budget that is included in the plan to manage unforeseen events
- project constraints, including time, budget, scope, sustainability, ethics and legality
- scheduled and frequent monitoring and management of the project, including:
  - logbook of problems and solutions, technical support, progress, discussions, group activities and development iterations
  - progress against the plan, project milestones, modifications
  - teacher monitoring, peer reviews.

B2 Risk and issue project-management processes

- The purpose of risk and issue management:
  - avoiding 'crisis management'
  - improving the probability of success and increasing competitive advantage.
- A risk is an event that adversely impacts on the project processes or outcome, and an issue is a future event which could adversely or positively impact project processes or outcome.
- Risk and issue measures, including:
  - risk and issue severity = low, medium, high and extreme
  - probability of occurrence = unlikely, likely and very likely
  - expected project impact = minor, moderate and major
- The risk or issue severity = probability of the occurrence × expected impact on the project, e.g. on the customer's requirements, delivery to time and to budget.
- The resultant risk and issue 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
	Expected impact on the project			

- Risks and issues should be assessed throughout the delivery of the project and medium, high and extreme severity risks and issues should be managed.
- Management of risks and issues (mitigation), including:
  - prevention (to eliminate the threat of a risk occurring)
  - reduction (to reduce the likelihood of a risk occurring or to reduce the impact of a risk or issue)
  - acceptance (to do nothing about a risk or issue) or transference (to transfer the risk to a third party).
- Allowing contingency in the plans provides some flexibility in the event that risks and issues occur.

B3 Technical specification

Technical specification for the chosen product, system or process being developed, e.g. function and features, interfaces (physical, software, human and electrical/electronic), materials, tolerances, standards, security, environmental considerations and sustainability, operational conditions, process capability, reliability, capacity (current and future), maintenance and performance.

B4 Design information

Tools to design a solution to the problem:

- engineering drawings, computer-aided design (CAD), e.g. 3D, 2D and diagrams
- simulations, e.g. pneumatic circuits, hydraulic circuits, electrical/electronic circuits and software models
- physical modelling, e.g. 3D rapid prototyping (also known as 3D printing or additive manufacturing), mock-ups in wood, cardboard and modelling material
- processes or computer program, e.g. detailed flow chart(s), planning, operation sheets
- documents, e.g. tables, formulas, pseudocode, outline of key algorithms, description and record of ergonomic analysis
- safety and sustainability considerations, including:
  - regulations, e.g. health and safety legislation relevant to the specialist engineering sector
  - demand and costs, e.g. possible demand, material costs, manufacturing costs
  - culture, e.g. beliefs, laws, customs.

Test plans to relevant British Standard (BS) or International Standard (IS) where appropriate, e.g. destructive and non-destructive test inspection methods and data (normal, extreme and erroneous).

Learning aim C: Undertake the solution for a specialist engineering project and present the solution as undertaken in industry

C1 Undertake and test the solution to the problem

Undertake and test the final solution against the technical specification, including:

- the use of project-management processes during the development of a solution, to include status reporting and management of risks and issues
- the safe use of resources, e.g. machines, workshops, tools and consumables
- troubleshooting methods to resolve problems, e.g. expected behaviour, half-split, cause and effect, 5 Whys
- fitness for purpose, e.g. quality, usability, functionality, performance, compliance to customer requirements (see technical specification)
- testing methods, e.g. destructive, non-destructive, inspection, measurement
- fitness for audience, e.g. end-user customer testing.

C2 Demonstration of relevant behaviours

Relevant behaviours include:

- time planning and management to complete all the different activities within an appropriate timeframe and in an appropriate order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and verbally
- commercial and customer awareness to ensure the product, process or system is fit for purpose and meets the brief
- observable emotions linked to successes and issues during the project development, including personal successes and issues as well as attitudes and behaviour
- individual support required to complete the project, e.g. practical support, academic support, external support.

C3 Present a solution to the problem

Collation of a project portfolio, including:

- thematic title and/or initial idea
- research and clarification of the problem
- possible solutions and constraints
- initial specification of alternative technical solutions
- feasibility study
- technical specification
- project-management documents, including plans and a risk and issues log
- logbook of events, e.g. diary, outline sketches, notes, records
- design documents, e.g. sketches, engineering drawings, simulation and flow charts
- artefacts for a product, service or process, e.g. prototype product, computer program, pneumatic or hydraulic circuit, electronic circuit, experiment process demonstration
- test documentation, e.g. results, video, customer feedback and photographs
- peer reviews and tutor monitoring
- conclusions on the success of the solution against the project theme and initial idea.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate an engineering project in a relevant specialist area		**A.D1** Evaluate, using language that is technically correct and of a high standard, at least three realistic solutions to an engineering problem on a given theme and justify a preferred solution.
A.P1 Research an engineering problem based on a given theme and scope out at least three alternative solutions. **A.P2** Outline at least three alternative solutions to an engineering problem and select a preferred solution.	**A.M1** Assess consistently at least three solutions to an engineering problem on a given theme and recommend a preferred solution.	
Learning aim B: Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry		**B.D2** Optimise the project-management processes and design solution while allowing for reasonable contingency and considering constraints.
B.P3 Implement project-management processes, including planning, monitoring and risk and issue management. **B.P4** Produce the technical specification for a solution to an engineering problem. **B.P5** Produce design documentation to detail the solution, including a test plan and taking account of sustainability.	**B.M2** Implement project-management processes, including detailed planning and monitoring and proactive risk and issue management. **B.M3** Design a coherent solution, considering alternative approaches.	
Learning aim C: Undertake the solution for a specialist engineering project and present the solution as undertaken in industry		**C.D3** Optimise the project-management processes to develop a solution that is fit for audience and purpose while anticipating and resolving risks and issues, demonstrating behaviours to a professional standard.
C.P6 Produce a solution safely using project-management processes while recording progress. **C.P7** Perform relevant behaviours effectively while developing a solution safely.	**C.M4** Perform effective project-management processes while justifying refinements and demonstrating effective behaviours consistently, to develop a solution that is fit for audience and purpose.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.M2, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

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 in the other units in the qualification. Learners may also require access to workshops, laboratories and specialist software and databases.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce research evidence containing a series of at least three possible solutions to the given theme or initial idea. The research evidence and alternative solutions to an engineering problem will be realistic, accurate and concise. For example, a project to design and manufacture a scale model (1 : 43) body shell of a Formula 1® racing car will involve researching computer-aided design (CAD)/computer-aided manufacturing (CAM) processes, as well as manufacturing the model using a vacuum-forming process. Also, the CAD/CAM processes will be appropriate to the task, and problems relating to its integration with the moulding processes will be considered and resolved. Learners will provide an outline specification of the solution to include sketches, required processes, outline costs and technical information.

The feasibility study will be fully supported by research applied consistently across each solution. A range of criteria will allow good justification for the preferred solution to be presented. For example, the outline sketches and specification of the model body shell will be assessed against the availability and suitability, in terms of size and capability, of the computer numerical control (CNC) machines and vacuum-forming machine at the centre. Also, costs will be calculated and compared to the budget allocated by the centre.

Overall, the evidence, including the research and feasibility study, 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 have a high standard of written language. Consideration will also be given to the number of possible design iterations required while developing the solution.

For merit standard, learners will produce research evidence covering at least three possible solutions to an engineering problem. All solutions will be investigated consistently (to a similar breadth and depth) but one solution may not be realistic. A high-level specification scoping out alternative technical solutions to the problem will also be given.

The feasibility study will assess each of the alternative solutions in turn. The study will be supported by research evidence of consistent breadth and depth across the three solutions. Sufficient criteria will be used in the assessment to make an informed rationale for the preferred solution. For example, for the manufacturing cost (including materials and tooling) the model body shell will be estimated and compared against the budget. Also, the appropriateness of the centre's resources, including CAD systems, CNC machines and a vacuum-forming machine, will be assessed against their suitability to manufacture the model body shell, for example in terms of size.

Overall, the evidence will be logically structured, technically accurate and easy to understand. However, learners may not appreciate the number of design iterations required to scope out three different solutions.

For pass standard, learners will produce research evidence covering at least three possible solutions to an engineering problem. The research will be patchy in some areas and it may not support all the solutions given. At least one solution may not be realistic. For example, the CAD and CAM process may not be totally appropriate for the model body shell of a Formula 1 racing car as it does not consider the working envelope of the CNC machine. A high-level specification scoping out alternative technical solutions to the problem will be produced.

The feasibility study will assess each of the alternative solutions in turn. The study will be supported by the research although the depth of evidence will be inconsistent across the three solutions and the study will not cover enough criteria to make an informed decision on which solution to develop. A preferred solution will be selected. For example, for the model body shell the learner will have taken into consideration the suitability of the human resources and materials and the capability of some machines but will not have estimated the costs.

Overall, the evidence will be logically structured, although basic in parts, and may contain minor technical inaccuracies relating to engineering terminology such as stating 'lines of code within the CNC program' instead of 'blocks within the CNC program'.

Learning aim B

For distinction standard, learners will produce an optimised project time and resource plan, outlining the critical path and suitable milestones and breaking down the activities in an appropriate way given the constraints, allowing a reasonable contingency. Most time and resource estimates will be reasonable and consideration will be given to optimising the plan so that it can be implemented in an efficient and effective way.

Throughout the project, progress will be monitored and risks and issues managed by anticipating some problems before they become issues and categorising risks and issues appropriately.

The technical specification will detail the customer's operational requirements that link together to create a functioning and coherent solution given the known constraints. For example, the model body shell of a Formula 1 racing car will be vacuum formed, and details of appropriate mould materials, typically aluminium or wood, and working tolerances, such as draft angles, will be provided to an international standard.

The design evidence, which may be included in the technical specification, will provide details of the proposed solution and appropriate tools will be used given the nature of the product, system or process. The design evidence will consider sustainability and contain appropriate detail. The solution will be optimised by iteration, within given constraints, by considering the merits of alternative approaches to achieving the chosen solution. For example, the CNC program for manufacturing a mould for a model body shell will be optimised by manual coding to improve the post-processed program which may be inefficient, if for example it is too long as canned cycles were not used. An outline test plan with parameters that demonstrate a fully functioning product, system and process will be given.

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, learners will produce a detailed project time and resource plan, outlining the critical path and suitable milestones and breaking down the activities in an appropriate way. Most time and resource estimates will be reasonable. For example, the estimated start and finish times to produce CAD drawings and use CNC and vacuum-forming machines to manufacture a model body shell will be realistic. Project-monitoring documentation will also be prepared.

Risk and issue management processes will be set up and major risks and issues will be recorded and proactively managed with effective mitigation to prevent some major risks becoming issues.

The technical specification will detail the customer's operational requirements that link together to create a functioning and coherent solution. For example, to manufacture a model body shell to a scale of 1 : 43 will be necessary to meet the customer's requirements.

The design evidence, which may be included in the technical specification, will provide details of the proposed solution, and appropriate tools will be used given the nature of the product, system or process. The design evidence will consider sustainability and contain appropriate detail while considering the merits of alternative approaches to achieving the chosen solution. For example, one alternative approach in a CNC program used to manufacture a mould for a model body shell would be to use canned cycles.

An outline test plan with parameters that demonstrate a fully functioning product, system and process will be given. For example, the inspection and proving methodology for the CNC program used to manufacture a mould for a model body shell will be given, including dry runs, simulations, mechanical inspection methods and documentation for the mould and final product, complete with relevant tolerances.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will produce evidence containing a project time and resource plan outlining the critical path. The plan will be sufficiently detailed to track the project, although some tasks may be omitted and the time and resource estimates for several tasks may be extreme, making them unrealistic. For example, the time estimated to produce the CAD drawings for the model body shell of a Formula 1 racing car may be specified as a couple of hours when a realistic estimate would be two days to complete and edit the drawings. Project-monitoring documentation will also be prepared.

Risk and issue management processes will be set up and major risks and issues will be recorded, although actions taken to prevent risks becoming issues are unlikely to be implemented and/or the mitigating actions will not be successful.

The technical specification will outline operational customer requirements that may not link together to create a functioning and coherent solution. For example, the manufacture of a model body shell may include the tooling required for the CNC machine but not other processes.

The design evidence, which may be included in the technical specification, will provide details of the proposed solution and appropriate tools will be used given the nature of the product, system or process. The design evidence may lack appropriate detail to implement the solution and some consideration for sustainability will be made. For example, the material used for proving the CNC program to manufacture a model body shell may be wax as it can be recycled easily.

An outline test plan with parameters that demonstrate a limited understanding of a functioning product, system and process will be given. For example, no inspection methodology will be specified for the CNC program used to manufacture a mould of the model body shell, such as undertaking dry runs and simulations. However, consideration of the final product with relevant tolerances will be given.

Overall, the design will be logically structured and will be generally fit for purpose given the constraints. However, it may be basic in parts, it may contain minor inaccuracies such as rounding errors or inconsistent units and some engineering terminology may be inaccurate. For example, learners may have used the term 'absolute' when 'relative' was intended within a CNC program.

Learning aim C

For distinction standard, learners will produce evidence showing how the project solution was developed effectively and efficiently using project-management processes to produce a product/service, system or process. The implementation of tasks will be structured and carried out in an appropriate order. There will also be evidence of refinements being made to the solution during the process to optimise it. For example, during the moulding process for a model body shell of a Formula 1 racing car, bubbles may form within the skin of the polymer creating an undesirable finish. The solution to the issue would be to dry the polymer thoroughly prior to moulding the body shell.

Appropriate tests will be completed on the product, system and process and against the test plan. For example, final measurements will be taken on the model body shell. If some of the measurements are marginally above learners' permitted tolerance they may decide that the product is fit for purpose and audience or they may rework the mould.

Relevant behaviours will be applied to a professional standard throughout the process. For example, learners will anticipate risks before they arise, taking appropriate action to resolve risks and issues in a structured way and acting appropriately at all times in the workshop.

Overall, the final solution will be presented in a concise portfolio of evidence that is logically structured, and conclusions will demonstrate that the solution is fit for audience and purpose. Any minor inaccuracies, such as rounding errors or follow-through errors, will occur infrequently if at all. Units and engineering terminology will be accurate and used appropriately throughout. For example, all drawings for the model body shell will be dimensioned in millimetres, with tight and reasonable tolerances. If errors are identified then learners will identify the source of the error, for example a programming mistake, and take corrective action.

For merit standard, learners will produce evidence detailing the project-management processes, including monitoring progress and risk and issue management that were used effectively during the development of the product, process or system. The implementation of tasks will be structured and carried out in an appropriate order. Any changes made to the solution during the process will also be justified and risks and issues managed. For example, if the final model body shell contained webs (unplanned folds in the plastic) then learners will identify the issue of inappropriate moulding temperatures or the mould being too tall in relation to the base and justify a solution to the issue.

Appropriate tests will be completed on the product, system and process and against the test plan. These will demonstrate that the final solution is fit for audience (the end users) and purpose (functionality and technical specification). For example, the output of a scale-model body shell of a Formula 1 racing car will be dimensionally accurate as demonstrated by the inspection evidence that may cover the final product and the mould.

Relevant behaviours will be effectively applied throughout the process. For example, learners will take the initiative to resolve issues as they occur, tracking the project and undertaking the project in a structured way.

Overall, the final solution will be presented in a portfolio of evidence that is logically structured, and conclusions will demonstrate that the solution is fit for audience and purpose. It will include justification of any improvements to the processes and behaviours that could be applied next time. However, the evidence may contain minor inaccuracies, such as rounding errors or a limited number of follow-through errors. Units and engineering terminology will be accurate and used appropriately.

For pass standard, learners will produce evidence detailing the project-management processes, including monitoring progress, and risk and issue management processes used during the development of a product, process or system. For example, a product could be to produce a model body shell of a Formula 1 racing car. However, the implementation of tasks will be unstructured and may not be carried out in an appropriate order. This will result in some inefficiency and there will be limited evidence of refinements being made to the solution during the process. For example, if the design of the model body shell did not take into account the size of the vacuum-forming machine, the CNC-machined mould would not then fit within the working envelope of the machine, resulting in some rework to the mould.

Using the test plan, appropriate tests will be completed on the product, system or process. However, the final solution may not be fully fit for audience (the end users) and purpose (functionality and technical specification). For example, the manufactured model body shell may not conform to specification due to minor engineering drawing errors that have been compounded by further minor tolerance errors while machining the mould.

Relevant behaviours will be applied during the process. For example, learners will take responsibility to undertake processes safely and to submit work on time.

Overall, the final solution will be presented in a portfolio of evidence that is logically structured and the conclusion will demonstrate that the solution is generally fit for purpose given the constraints. However, it may be basic in parts, it may contain minor inaccuracies, such as rounding errors or inconsistent units, and the engineering terminology will be limited and may be inaccurate. For example, learners may not be able to differentiate between different milling cutters, referring to ‘end mills’ when they should be ‘slot drills’.

Links to other units

This mandatory unit can be linked to all other units in the qualification.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in a range of specialist areas
- contribution of ideas to unit assignment, for individual learner projects and project materials.

Unit 6: Microcontroller Systems for Engineers

Level: **3**

Unit type: **External**

Guided learning hours: **120**

Unit in brief

Learners explore how programmable devices and electronic components are developed systematically to form physical systems controlled by computer code.

Unit introduction

Programmable devices are already used in numerous systems and products, such as car engine control, wearable and health technology products, environmental control and process control systems. A popular programmable device is a microcontroller, it contains all the internal components of a computer on a single chip and it runs a stored computer program to achieve the intended purpose. The advantages of microcontrollers are that they are cheap, small, have low power consumption, are readily available and can be programmed to control products and systems, making them economical for developing products and systems. Microcontrollers and their programs form an important part of the rapidly growing 'Internet of Things' (IoT), a network of billions of interconnected physical objects, which is bringing the next information revolution with it.

In this unit, you will investigate how microcontrollers are applied to solve engineering problems and learn how to program or code them. You will explore the hardware used to create a physical microcontroller system or product and consider the interfacing between the microcontroller and the input/output devices. You will develop an understanding of the constructs (instructions or commands) used to program a microcontroller and how to represent both hardware and logical instructions in diagrammatic format. You will design and develop a prototype microcontroller system to solve a problem.

As technology trends evolve there is an increasing demand for more complex, connected systems that interact seamlessly together, providing enhanced features and benefits for customers. It is important for all types of engineer to understand how physical systems are developed. This will involve gaining knowledge, understanding and practical skills that are transferable to many other programmable devices, such as programmable logic controllers (PLC) and/or computers, such as the Raspberry Pi™, as well as developing computer programs and apps. This unit will help prepare you for an engineering apprenticeship, engineering courses in higher education or for technician-level roles in a variety of engineering sectors.

Summary of assessment

This unit is assessed by a set task of 80 marks provided by Pearson and completed under supervised conditions. Learners will have 12 hours in which to complete the task and this can be arranged over a number of sessions over a two-week period timetabled by Pearson, once the assessment has started the learner must complete within five days.

During the supervised assessment period, learners will be assessed by a practical task where they will develop a prototype microcontroller system to solve a problem. Learners must complete this task using a computer.

Each year a different task will be set by Pearson which will involve learners following a standard development process of: analysing the brief, system design and program planning, system assembly and coding, system testing and recording the system in operation. All external assessment tasks can be solved using a range of components given in the unit content.

The assessment availability is twice a year in January and May/June. The first assessment availability is May/June 2018.

Sample assessment materials will be available to help centres prepare learners for assessment.

Assessment outcomes

AO1 Demonstrate knowledge and understanding of computer coding principles, electronic hardware components and the development process

AO2 Apply knowledge and understanding of computer coding principles, electronic hardware components and of the development process to design and create a physical computer system to meet a client brief

AO3 Analyse test results and evaluate evidence to optimise the performance of a physical computer system throughout the development process

AO4 Be able to develop a physical computer system to meet a client brief with appropriate justification

Essential content

The essential content is set out under content areas. Learners must cover all specified content before the assessment.

A Investigate typical microcontroller system hardware

A1 Control hardware

- Control hardware specifications and requirements for a selected microcontroller development system:
  - input and output capabilities – number, type (analogue/digital), ports
  - hardware specification – bus width, processor speed
  - memory – random-access memory (RAM), read-only memory (ROM)
  - hardware features – interrupts, stack, pulse-width modulation (PWM)
  - required peripherals
  - cost and accessibility
  - ease of use
  - software and programming language
  - operating voltages and power requirements.
  - The only acceptable microcontroller hardware and programming languages:

Hardware device family	Software Integrated Development Environment (IDE)	Programming language
Arduino™ Genuino™	Arduino IDE or Flowcode	Arduino C or Flowchart
PIC®	MPLAB® IDE (MPLAB C) or Flowcode	C or Flowchart
PICAXE®	Picaxe Editor	Basic or Flowchart
GENIE®	GENIE Studio or Circuit Wizard	Basic or Flowchart
ARM® Cortex, STM32™	Arm® Mbed™	C or C++

A2 Input devices

Characteristics, operation and application considerations of a range of common input devices.

- User input:
  - digital – switches and buttons
  - analogue – control potentiometer.
- Temperature:
  - thermistor
  - temperature sensors
  - environmental sensor – temperature and humidity.
- Light:
  - light-dependent resistor (LDR)
  - infrared – phototransistor, photodiode or infrared receiver.
- Movement/orientation: tilt switch.
- Presence: reed switch, inductive and capacitive proximity sensors, passive infra-red (PIR), micro-switch and ultrasonic.
- Input interfacing requirements:
  - signal conditioning
  - analogue-to-digital (ADC) conversion
  - modular sensor boards
  - PWM
  - serial communications
  - input interfacing requirements – Inter-Integrated Circuit (I^2C).

A3 Output devices

Characteristics, operation and application considerations of a range of common output devices.

- Optoelectronic:
  - light-emitting diode (LED) – indicator and infrared
  - 7-segment display
  - liquid crystal display (LCD) or organic LED display.
- Electromechanical:
  - relay
  - direct current motor
  - servo.
- Audio:
  - buzzer or siren
  - speaker or piezo transducer.
- Output interfacing requirements:
  - power requirements and drivers:
    - transistor output stage
    - relay
  - PWM
  - serial communications
  - I^2C device interfacing.

A4 Selecting hardware devices and system design

Select and justify the selection of appropriate input, output and control hardware devices for microcontroller system. Selection criteria and justifications should cover:

- inputs:
  - parameter to be measured
  - required accuracy and range
  - usability of user controls – aesthetics, control and ergonomics
  - cost and availability
  - interfacing requirements
- output:
  - required output/effect
  - electrical, mechanical and dimensional specification
  - usability of indication and display devices – aesthetics and visibility or audibility
  - cost and availability
  - interfacing and power control requirements.

Generation of a system design based on the input, output and control hardware shown by schematic and/or connection diagrams to BS 8888 and BS 3939 or other relevant international equivalent.

A5 Assembling and operating a microcontroller system

- Assemble and operate a microcontroller system. Assembly methods will vary according to the equipment and development platform:
  - making up input/outputs circuitry using a breadboard
  - connecting input/output modules
  - identifying appropriate devices on a pre-assembled prototyping board.
- Safe and appropriate use of typical electronic tools and test electronic equipment:
  - power supplies and power sources
  - small hand tools – wire cutters, wire strippers, pillars, screwdrivers
  - electrostatic discharge (ESD) precautions and component handling.

B Programming Techniques and Coding

B1 Programming techniques

Programming techniques and constructs may vary depending on centre software choice but should include the following (or applicable equivalent of).

- Use of a programming development environment:
  - software operation
  - connecting to microcontroller hardware
  - creating and managing program files
  - syntax/error checking
  - simulation (where applicable)
  - compiling, downloading and live testing
  - monitoring/debugging
  - safe use of computer and display screen equipment (DSE).
- Coding practices:
  - device set-up and program initiation
    - introductory comments
    - chip set-up
    - pin modes
    - libraries
    - declarations
  - efficient/effective code authoring
    - code syntax
    - in-line commenting
    - code organisation and structure.

B2 Coding constructs

Programming constructs may vary depending on centre software choice but should include the following (or applicable equivalent of).

- Input/output:
  - digital – bit and port level read/write
  - analogue read/write, resolution, calibration
  - tone and sound generation
  - pulse and PWM
  - communication, including serial and I^2C.
- Program flow and control:
  - calling libraries
  - subroutines and functions – naming, declaring, call, return
  - control structure sequence selection iteration – if, else, switch, case, for, do, while, until and end
  - delays and timing
  - interrupts.
- Logic and arithmetic:
  - variables – data types (Boolean, character, byte, integer, word, float, long, double, string), declaration, conversion and manipulation.
  - arrays (1D)
  - comparative operators – equal, not equal, less than, more than, less than or equal, more than or equal
  - Boolean operators – AND, OR, NOT
  - logic using input condition – digital and analogue
  - arithmetic operations – adding, subtracting, multiplication, division, increment, decrement, random.

B3 Structured program design

Represent a program using a recognised convention, including:

- pseudo code
- flowchart (to BS 4058 or other relevant international equivalent)
- decision table.

B3 Number systems

- Bits, bytes.
- Parallel and serial.
- Binary to decimal conversion (and vice-versa).

C System development cycle

C1 Development processes

Stages of the development process.

- Analysis of the brief:
  - analysis of the customer requirements and any other information provided
  - production of a technical specification
  - creation of a test plan.
- System design and program planning:
  - selection and justification of input/output devices and control hardware
  - design of input/output circuitry
  - design of the program structure – flow chart (to BS 4058 or other relevant international equivalent), truth tables, calculations, sketches, pseudo code.
- System assembly and coding:
  - assembly and connection of physical components
  - program authoring
  - developmental testing and refining.
- System testing and operation:
  - operation of the finished system
  - carry out test plan and recording results
  - description of the system operation linking system behaviour to hardware and software function
  - analysis of test data and evaluation of the completed system.

C2 Documentation

A portfolio of evidence produced throughout the development process.

- Technical specification with operational requirements.
- Test plan.
- Details and justifications of input/output devices and hardware selected.
- System connection diagrams/schematics.
- Initial design of the program structure.
- Annotated copies of all code.
- Audio-visual recording of operation with commentary.
- Test data and analysis.
- Structured project log.

Grade descriptors

To achieve a grade a learner is expected to demonstrate these attributes across the essential content of the unit. The principle of best fit will apply in awarding grades.

Level 3 Pass

Learners demonstrate knowledge and understanding of coding principles and hardware components and are able to apply them in familiar and unfamiliar contexts. They can analyse client briefs in order to interpret operational requirements and can produce plans to test the operation of their proposed system. Learners can develop and deliver a structured system that demonstrates an understanding of the relationship between the program and hardware. They are able to test the functionality of the system, and make judgements on the conformity of what has been developed against the brief. Learners follow their development process and are able to provide technical justifications to support their solution.

Level 3 Distinction

Learners demonstrate thorough knowledge and understanding of coding principles and hardware components and are able to apply them in familiar and unfamiliar contexts. They can analyse client briefs in order to interpret operational requirements and can produce plans to comprehensively test the operation of their proposed system, under a variety of conditions. Learners can develop and deliver an optimised system with consideration of enhanced user experience that demonstrates thorough understanding of the relationship between the program and hardware. They test the full functionality of the system in a structured way, including unexpected events, and make critical judgements on the conformity of what has been developed against the brief. Learners follow their structured development process and are able to provide technical justifications to support their solution.

Key terms typically used in assessment

The following table shows the key terms that will be used consistently by Pearson in our assessments to ensure students are rewarded for demonstrating the necessary skills.

Please note: the list below will not necessarily be used in every paper/session and is provided for guidance only.

Command or term	Definition
Client brief	Outlines the client's expectations and requirements for the system.
Integrated Development Environment (IDE)	A specialist piece of software in which computer programs are created. It contains a number of tools to help the programmer code.
Microcontroller	Contains all the internal components of a computer, for example processor and memory, on a single integrated circuit chip.
Project log	A document to record the progress made, key activities and decisions taken during the development of a project.
Test plan	A document that provides a structured approach for testing hardware and software. It describes the purpose of the tests, any input test data, actual test results and comments/justification.

Links to other units

This mandatory unit is linked to many of the other units in the qualification and in particular:

- Unit 17: Power and Energy Electronics
- Unit 19: Electronic Devices and Circuits
- Unit 21: Analogue Electronic Circuits
- Unit 22: Electronic Measurement and Testing of Circuits
- Unit 23: Digital and Analogue Electronic Systems
- Unit 32: Computer System Principles and Practice
- Unit 33: Computer Systems Security
- Unit 34: Computer Systems Support and Performance
- Unit 35: Computer Programming
- Unit 36: Programmable Logic Controllers
- Unit 37: Computer Networks
- Unit 38: Website Production to Control Devices.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 7: Calculus to Solve Engineering Problems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners use differential (rates of change) and integral (summing) calculus to solve engineering problems and develop a mathematical model of a local and relevant system.

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, you will investigate how to apply differential and integral calculus methods to solve engineering problems. You will learn about the rules and procedures of calculus mathematics to obtain solutions to a variety of engineering problems. You will solve a complex problem from your 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 your study of other topics in the BTEC Nationals engineering programme, for example in mechanical principles and electrical systems.

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

Learning aims

In this unit you will:

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

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

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

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how differential calculus can be used to solve engineering problems	**A1** Functions, rate of change, gradient **A2** Methods of differentiation **A3** Numerical value of a derivative **A4** Second derivative and turning points	A report containing the results of learners' analysis and calculation, carried out under controlled conditions.
B Examine how integral calculus can be used to solve engineering problems	**B1** Integration as the reverse/inverse of differentiation **B2** Integration as a summating tool **B3** Numerical integration	A report containing the results of learners' analysis and calculation, carried out under controlled conditions.
C Investigate the application of calculus to solve a defined specialist engineering problem	**C1** Thinking methods **C2** Mathematical modelling of engineering problems **C3** Problem specification and proposed solution **C4** Solution implementation	A report containing the results of learners' analysis, planning and calculation, carried out under controlled conditions.

Content

Learning aim A: Examine how differential calculus can be used to solve engineering problems

A1 Functions, rate of change, gradient

- Function notation, e.g. $y = \mathrm{f}(x)$, $s = \mathrm{f}(t)$, $Q = \mathrm{f}(t)$
- 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. $I = \dfrac{z+3}{5-4z}$
  - 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.

A2 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 $\left(\dfrac{\mathrm{d}y}{\mathrm{d}x}\right)$ or representing the derivative of a function.
- Engineering notation for the derivative, e.g. $\left(\dfrac{\mathrm{d}s}{\mathrm{d}t}\right)$, $\left(\dfrac{\mathrm{d}Q}{\mathrm{d}t}\right)$
- Independent variable and the coding method 'with respect to' (w.r.t.).
- Differentiation by standard results ($y = ax^n$, where $\dfrac{\mathrm{d}y}{\mathrm{d}x} = nax^{(n-1)}$)
- 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: $\dfrac{\mathrm{d}y}{\mathrm{d}x} = v\dfrac{\mathrm{d}u}{\mathrm{d}x} + u\dfrac{\mathrm{d}v}{\mathrm{d}x}$, $\dfrac{\mathrm{d}y}{\mathrm{d}x} = \dfrac{\left(v\dfrac{\mathrm{d}u}{\mathrm{d}x} - u\dfrac{\mathrm{d}v}{\mathrm{d}x}\right)}{v^2}$
- Function of a function (chain rule) method.
- Substitution method.

A3 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.

A4 Second derivative and turning points

- Leibniz notation for the second derivative $\left(\frac{d^2y}{dx^2}\right)$
- 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.

Learning aim B: Examine how integral calculus can be used to solve engineering problems

B1 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.

B2 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.

B3 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.

Learning aim C: Investigate the application of calculus to solve a defined specialist engineering problem

C1 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.

C2 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.

C3 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.

C4 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine how differential calculus can be used to solve engineering problems		**A.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.
A.P1 Find the first and second derivatives for each type of given routine function. **A.P2** Find, graphically and analytically, at least two gradients for each type of given routine function. **A.P3** Find the turning points for given routine polynomial and trigonometric functions.	**A.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.	
Learning aim B: Examine how integral calculus can be used to solve engineering problems		**B.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.
B.P4 Find the indefinite integral for each type of given routine function. **B.P5** Find the numerical value of the definite integral for each type of given routine function. **B.P6** Find, using numerical integration and integral calculus, the area under curves for each type of given routine definitive function.	**B.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.	
Learning aim C: Investigate the application of calculus to solve a defined specialist engineering problem		**C.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.
C.P7 Define a given engineering problem and present a proposal to solve it. **C.P8** Solve, using calculus methods and a mathematical model, a given engineering problem.	**C.M3** Analyse an engineering problem, explaining the reasons for each element of the proposed solution. **C.M4** Solve accurately, using calculus methods and a mathematical model, a given engineering problem.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.P5, B.P6, B.M2, B.D2)

Learning aim: C (C.P7, C.P8, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to maths support websites, spreadsheet software, e.g. www.mathcentre.ac.uk/students/topics

Essential information for assessment decisions

Learning aim A

For distinction standard, 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 with a 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 will be 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 merit standard, 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. A limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For pass standard, 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 functions. Some functions will be sufficiently complex to enable learners to select and apply the correct method (product, quotient, function of a function and substitution) when producing first and second derivatives.

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

Overall, learners must be able to demonstrate the correct use of a method when differentiating functions and use the correct units. Minor arithmetic and scaling errors are acceptable. There will also 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).

Learning aim B

For distinction standard, learners will demonstrate mastery in the application of integral calculus methods to solve 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 will use correct 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 merit standard, 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 have been 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. A limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For pass standard, learners will apply the correct skills and methods when integrating at least eight given routine mathematical functions. Learners will correctly manipulate at least two routine functions for each of the different function types (polynomial, trigonometric, reciprocal and exponential). At least one of each type will be an indefinite integral and one of each type will be a definitive integral. In total, at least eight different routine functions will be solved, and some will be sufficiently complex to enable the learner to select and apply the correct method (substitution and by parts) when producing indefinite and definite integrals.

Numerical integration will be completed on the four definitive integrals and they can be manipulated using a spreadsheet, provided that formulae are visible (printed out). There will also be evidence of simple checks being undertaken to determine if numerical answers are 'reasonable'` reasonable'.

Overall, learners must be able to demonstrate the correct use of method and units when integrating functions analytically and by a numerical method. Minor arithmetic and scaling errors are acceptable.

Learning aim C

For distinction standard, learners will demonstrate mastery in the application of calculus methods to solve 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 a 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 by using a logical approach to the solution and/or efficient use of a spreadsheet for numerical analysis.

For merit standard, 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 by using a substitution method to integrate terms rather than by expansion.

For pass standard, 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 of a moving vehicle would be expected to determine the maximum accelerating force and work done to get the vehicle up to a given velocity.

Overall, the report should be logically structured and contain a 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, although 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 the correct use of units, but there may be errors in their application.

Links to other units

This mandatory unit is linked to many of the other units in the qualification, in particular mandatory *Unit 1: Engineering Principles*, as well as a number of optional units including:

- Unit 15: Electrical Machines
- Unit 17: Power and Energy Electronics
- Unit 21: Analogue Electronic Circuits
- Unit 27: Static Mechanical Principles in Practice
- Unit 28: Dynamic Mechanical Principles in Practice
- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 31: Thermodynamic Principles and Practice
- Unit 48: Aircraft Flight Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- technical workshops involving staff from local organisations with expertise in applying calculus to solve engineering problems
- contribution of ideas to unit assignment/project materials.

Unit 8: Further Engineering Mathematics

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners use algebraic and statistical methods to carry out mathematical modelling and analysis to solve engineering problems.

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 you will use algebraic techniques to solve engineering problems involving sequences, series, complex numbers and matrices; these topics support other units in the BTEC programme such as *Unit 16: Three Phase Electrical Systems*, *Unit 27: Static Mechanical Principles in Practice* and *Unit 28: Dynamic Mechanical Principles in Practice*. 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 the BTEC National engineering qualifications. 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 aims

In this unit you will:

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

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

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

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

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how sequences and series can be used to solve engineering problems	**A1** Arithmetic and geometric progressions **A2** Binomial expansion **A3** Power series	An informal report containing the results of learners' analysis and calculation, carried out under controlled conditions.
B Examine how matrices and determinants can be used to solve engineering problems	**B1** Matrices **B2** Determinants	An informal report containing the results of learners' analysis and calculation, carried out under controlled conditions.
C Examine how complex numbers can be used to solve engineering problems	**C1** Complex numbers	
D Investigate how statistical and probability techniques can be used to solve engineering problems	**D1** Statistical techniques **D2** Probability distributions **D3** Statistical investigation	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 using a spreadsheet.

Content

Learning aim A: Examine how sequences and series can be used to solve engineering problems

A1 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 $a + b + c + d \dots$
  - 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):

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

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

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

    - 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.

A2 Binomial expansion

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

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

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

  - binomial theorem when n is not a positive integer:

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \dots + x^n \quad \text{for } -1 < x < 1 \text{ only (an infinite series)}$$

- 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.

A3 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 $f(x) = f(a)+f'(a)(x-a)+\frac{f^2(a)}{2!}(x-a)^2+\ldots+\frac{f^{(n)}(a)}{n!}(x-a)^n$
- 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.

Learning aim B: Examine how matrices and determinants can be used to solve engineering problems

B1 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.

B2 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).

Learning aim C: Examine how complex numbers can be used to solve engineering problems

C1 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 $y^* = a \mp jb$

Learning aim D: Investigate how statistical and probability techniques can be used to solve engineering problems

D1 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 $y = mx +$ 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.

D2 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.

D3 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 criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine how sequences and series can be used to solve engineering problems</td><td rowspan="2">A.D1 Evaluate, using technically correct language and a logical structure, engineering problems using non-routine sequence and series operations, while solving all the given problems accurately using routine and non-routine operations.</td></tr>
<tr><td>A.P1 Solve given problems using routine arithmetic and geometric progression operations.
A.P2 Solve given problems using routine power series operations.</td><td>A.M1 Solve given problems accurately using routine and non-routine arithmetic and geometric progression operations.
A.M2 Solve given problems accurately using routine and non-routine power series operations.</td></tr>
<tr><td colspan="2">Learning aim B: Examine how matrices and determinants can be used to solve engineering problems</td><td rowspan="4">BC.D2 Evaluate, using technically correct language and a logical structure, engineering problems using non-routine matrices, determinant and complex operations, while solving all the given problems accurately using routine and non-routine operations.</td></tr>
<tr><td>B.P3 Solve given problems using routine matrices and determinant operations.</td><td>B.M3 Solve given problems accurately using routine and non-routine matrices and determinant operations.</td></tr>
<tr><td colspan="2">Learning aim C: Examine how complex numbers can be used to solve engineering problems</td></tr>
<tr><td>C.P4 Solve given problems using routine complex number operations.</td><td>C.M4 Solve given problems accurately using routine and non-routine complex number operations.</td></tr>
<tr><td colspan="2">Learning aim D: Investigate how statistical and probability techniques can be used to solve engineering problems</td><td rowspan="2">D.D3 Evaluate the correct synthesis and application of statistics and probability to solve engineering problems involving accurate routine and non-routine operations</td></tr>
<tr><td>D.P5 Solve an engineering problem using routine central tendency, dispersion and probability distribution operations.
D.P6 Solve an engineering problem using routine linear regression operations.</td><td>D.M5 Solve an engineering problem accurately using routine and non-routine central tendency, dispersion and probability distribution operations, providing an explanation of the process.
D.M6 Solve engineering problems accurately using routine and non-routine regression operations, providing an explanation of the process.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aims: B and C (B.P3, C.P4, B.M3, C.M4, BC.D2)

Learning aim: D (D.P5, D.P6, D.M5, D.M6, D.D3)

Further information for teachers and assessors

Resource requirements

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 a Casio FX-85GT.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving sequences and series. Where appropriate to 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 a specified numerical precision, as determined by the assessor, through the use of appropriate significant figures.

For merit standard, 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 using appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units should be used, with a limited number of minor errors or omissions in non-routine operations.

For pass standard, learners must be able to 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 is used correctly in subsequent calculation of the series, affecting the final value. Learners will demonstrate an appreciation of the need for 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'.

Learning aims B and C

For distinction standard, 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 to 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 a specified numerical accuracy, as determined by the assessor, through the use of appropriate significant figures.

For merit standard, 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 using appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units should be used, with a limited number of minor errors or omissions in non-routine operations.

For pass standard, learners must be able to 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 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'.

Learning aim D

For distinction standard, 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 datasets 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 a specified numerical precision, as determined by the assessor or that is 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.

For merit standard, 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) required 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, an accurately produced annotated scatter graph (with a chart title and axis titles, including units and gridlines), and calculation of a line of regression and correlation coefficient for a linear relationship and a 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 a 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.

For pass standard, 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 problems to solve. 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) required 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 which 'carry-through', for example, the value of the mean of a set of sampled dimensional data from a machining operation may be incorrect but the value is 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 the need for 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'.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 15: Electrical Machines
- Unit 17: Power and Energy Electronics
- Unit 20: Analogue Electronic Circuits
- Unit 27: Static Mechanical Principles and Practice
- Unit 28: Dynamic Mechanical Principles and Practice
- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 31: Thermodynamic Principles and Practice
- Unit 48: Aircraft Flight Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- technical workshops involving staff from local organisations with expertise in applying relevant mathematical techniques to solve engineering problems
- contribution of ideas to unit assignment/project materials.

Unit 9: Work Experience in the Engineering Sector

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the benefits of work experience. They carry out and reflect on a period of work experience, and plan for their personal and professional development.

Unit introduction

If you are thinking about a career in engineering, you should do some work experience to make you aware of the kinds of tasks and activities you may be required to do. It will help you reflect on and develop your attributes and skills required for work in the sector and will also help to extend your knowledge and understanding of the roles and responsibilities of engineering professionals.

In this unit, you will learn about the benefits of work experience in engineering. You will examine how work experience can help you to develop personal and professional skills such as communication and teamwork and help you to understand more about the expectations of different professional roles. You will develop a plan to support your learning in placement and you will monitor your progress through a reflective journal. This is a very practical unit, which will support your work experience placement in engineering and provide a foundation for you to develop, apply and reflect on knowledge and skills in a realistic situation.

A work experience placement will help you prepare for further study in a variety of higher education programmes. It is an important factor in progression to higher education, and is a component of many degree courses accredited by the Engineering Council.

Learning aims

In this unit you will:

A Examine the benefits of work experience in engineering for own learning and development

B Develop a work experience plan to support own learning and development

C Carry out work experience tasks to meet set objectives

D Reflect on how work experience influences own personal and professional development.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine the benefits of work experience in engineering for own learning and development</td><td>A1 Developing skills and attributes
A2 Clarifying expectations for employment in engineering
A3 Exploring career options</td><td rowspan="2">A report evaluating the benefits of work experience in the engineering sector and the importance of preparing for placement. The report must include a plan to meet personal and professional goals.</td></tr>
<tr><td>B Develop a work experience plan to support own learning and development</td><td>B1 Preparation for work experience
B2 Setting goals and learning objectives</td></tr>
<tr><td>C Carry out work experience tasks to meet set objectives</td><td>C1 Work experience tasks
C2 Work shadowing and observation</td><td rowspan="2">Observation of learners on work placements in the engineering sector carrying out tasks and activities and interacting with customers and staff, evidenced by observation report signed by assessor.
Reflective log evaluating own development on work placement.</td></tr>
<tr><td>D Reflect on how work experience influences own personal and professional development</td><td>D1 Reviewing personal and professional development
D2 Using feedback and action planning</td></tr>
</table>

Content

Learning aim A: Examine the benefits of work experience in engineering for own learning and development

A1 Developing skills and attributes

- Reflecting on own skills and attributes and areas for development.
- Developing professionalism.
- Communication and interpersonal skills.
- Organisational skills, e.g. time management, prioritising tasks.
- Technical skills and their application in the workplace.
- Ability to link theory with practice.
- Teamwork skills.
- Confidence and personal responsibility.

A2 Clarifying expectations for employment in engineering

- Understanding the rights and responsibilities of engineers.
- Respecting diversity, equality and dignity in the workplace.
- Respecting confidentiality.
- Understanding health, safety and security regulations.
- Preparation for employment in the sector.

A3 Exploring career options

- Working in different engineering sectors, e.g. aerospace, manufacturing, electrical/electronic.
- Sources of information about careers and career pathways in engineering.
- Professional engineering bodies and types of membership, e.g. Engineering Technician (Eng Tech), Incorporated Engineer (IEng).
- Using work experience to inform career choices, confirm ideas or consider alternative options.

Learning aim B: Develop a work experience plan to support own learning and development

B1 Preparation for work experience

- Expectations for learners on work experience, e.g. dress, behaviour.
- Responsibilities and limitations for learners on work experience, e.g. restrictions due to experience or training requirements to carry out tasks.
- Researching specific work experience placements, e.g. organisation, job roles.
- Role of placement supervisors/mentors.

B2 Setting goals and learning objectives

- Reflecting on current knowledge and skills.
- Identifying own strengths and areas for development.
- Identifying established standards and values required for engineering professionals, e.g. entry requirements for membership of professional bodies such as the Institution of Mechanical Engineers (IMechE), Institution of Engineering and Technology (IET).
- Identifying SMART (specific, measurable, achievable, realistic and time-related) targets for own work experience.
- Setting personal development goals, e.g. developing communication skills, confidence.
- Setting professional development goals, e.g. developing competence, technical ability.

Learning aim C: Carry out work experience tasks to meet set objectives

C1 Work experience tasks

- Assisting and participating in engineering tasks, e.g. preparing the workplace to carry out given tasks.
- Assisting and participating in non-engineering tasks, e.g. attending meetings, general office tasks.
- Participating as part of a team.
- Understanding the importance of supervision of work activities.
- Using work experience reflective journals to link theory with practice, reflecting on how work experience placement influences own professional development.

C2 Work shadowing and observation

- Work shadowing different professionals to appreciate the range of engineering functions.
- Observing specific procedures to gain new knowledge and skills.
- Working relationships and agreed ways of working in engineering, developing trust, mutual respect, mindfulness, open communication and welcoming diversity.
- Reflecting on work practice and procedures used within the setting.

Learning aim D: Reflect on how work experience influences own personal and professional development

D1 Reviewing personal and professional development

- Understanding that reflective practice is an ongoing activity.
- Theories and frameworks for reflective practice.
- Reviewing work experience reflective journal.
- Evaluating own performance.
- Reflecting on personal and professional development.

D2 Using feedback and action planning

- The importance of continuing professional development (CPD).
- Identifying areas of positive and constructive feedback.
- Highlighting areas for improvement.
- Creating an action plan for personal and professional development.
- Identifying career goals.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the benefits of work experience in engineering for own learning and development		
A.P1 Explain how work experience can support the development of own professional skills and personal attributes for work in engineering. **A.P2** Discuss ways in which work experience can inform own career choices and help prepare for employment in engineering.	**A.M1** Analyse how work experience can provide support in gaining a realistic understanding of the engineering sector.	**AB.D1** Justify the benefits of preparation in supporting own understanding of the expectations of work experience.
Learning aim B: Develop a work experience plan to support own learning and development		
B.P3 Explain own responsibilities and limitations on work experience in engineering. **B.P4** Explain how to meet own specific personal and professional development goals while on work placement.	**B.M2** Assess the importance of own work experience plan to support own learning and development.	
Learning aim C: Carry out work experience tasks to meet set objectives		
C.P5 Demonstrate work-related skills to meet set objectives for work experience tasks. **C.P6** Discuss ways in which work shadowing and observation can support development of own skills while on work placement.	**C.M3** Demonstrate work-related skills with confidence and proficiency to meet objectives in different situations.	**C.D2** Demonstrate work-related skills proficiently, taking the initiative to carry out activities according to own responsibilities and setting's procedures, selecting appropriate skills and techniques for different situations. **D.D3** Justify how planning for and reflecting on skills developed during own work experience placement have informed future plans for personal and professional development.
Learning aim D: Reflect on how work experience influences own personal and professional development		
D.P7 Review own strengths and areas for development in response to feedback on work experience placement. **D.P8** Produce a personal development plan which identifies improvements to personal and professional skills for the future.	**D.M4** Assess how self-reflection can contribute to personal and professional development in a work experience placement.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, A.P2, B.P3, B.P4, A.M1, B.M2, AB.D1)

Learning aims: C and D (C.P5, C.P6, D.P7, D.P8, C.M3, D.M4, C.D2, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to a ten working-day equivalent work experience placement in an engineering setting.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will reach valid judgements about the benefits of preparation for work experience placements. Learners must use research to justify the validity of proposals about the expectations of work experience and articulate their views concisely to justify conclusions. They must draw on and show knowledge to make suitable justifications and recommendations for their planned placement.

For merit standard, learners will make reasoned analytical judgements involving comparison and discussion. Learners must use research to extend their understanding about the expectations of work experience placements. They must select and apply knowledge to demonstrate the relevance and purpose of their work experience plan to support their learning and development.

For pass standard, learners will recall key knowledge to demonstrate their understanding of how work experience can provide preparation for employment in engineering. Learners must use research with relevance to given situations to explain their responsibilities and limitations in a work experience placement. They must select and organise information using appropriate knowledge and concepts to produce a plan to meet their specific personal and professional development goals while on work placement.

Learning aims C and D

For distinction standard, learners will make valid judgements about the risks and limitations of techniques and processes used in relation to desired outcomes and own skills development. They must select appropriate skills and techniques in relation to the work situation and desired outcomes and show that they have developed their skills to achieve increased quality of outcomes while on placement. For example, they must communicate professionally using appropriate methods for their audience to achieve desired outcomes.

Learners must show initiative while acting within expected constraints and assess their contribution to at least three different work-related tasks and three work shadowing tasks or observations. Learners must justify any decisions taken related to their work situation. They must manage themselves successfully to prioritise activities and monitor their own progress.

They must engage actively with others and on their own initiative to gain feedback and to create opportunities for personal improvement. They must evaluate the basis for taking decisions in their work experience placement and respond effectively to feedback. They must draw together their learning and experiences gained across the learning aims, demonstrating valid insights into their own planning and performance in order to plan their future personal and professional development.

For merit standard, learners will act within given work-related contexts to show required attributes and select and deploy appropriate techniques, processes and skills with increased confidence and proficiency to meet set objectives in three different work experience situations. Learners will modify techniques and processes to suit different situations and to deal with contingencies. For example, they must select and use appropriate communication methods to suit particular audiences, such as interacting with different staff or contributing to a team meeting. They will reflect on knowledge and skills gained through three work shadowing experiences or observations. They must manage their time to prioritise activities and progress towards required outcomes.

Learners will use knowledge, skills and understanding to select and justify solutions in relation to how work experience tasks support their personal and professional development. They must monitor their achievement against their work experience plan to ensure the relevance of targets and must reflect actively on evidence of their own performance using feedback from others.

For pass standard, learners will carry out tasks and activities fully, correctly and safely to achieve required outcomes. Learners must select appropriate techniques, processes or skills in well-defined situations, and review the success of these techniques, processes and skills in relation to three work experience tasks and three work shadowing experiences or observations. They must identify the responsibilities of staff within the placement and relate this knowledge to occupational roles and organisational structures. They must communicate in a variety of ways, using appropriate English, vocational language and graphical methods, responding to communication from others. They must manage their time effectively to undertake work activities and manage outcomes.

Learners will apply knowledge, skills and understanding to explore solutions to realistic and vocational tasks in relation to the ways in which work shadowing and observation can support personal and professional development.

Learners must maintain structured records of their work experience which show how they have planned opportunities to develop their skills and gain feedback on their performance from others.

Links to other units

This unit links knowledge and skills from learners' entire programme of study, but it would be advisable if the following units were taught prior to the work placement:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacture.

It may be taught alongside:

- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 5: A Specialist Engineering Project.

Employer involvement

This unit would benefit from employer involvement in the form of opportunities for observation during the work experience and assessment of any project work.

Learners must have access to a ten working-day equivalent work experience placement in an engineering setting.

Unit 10: Computer Aided Design in Engineering

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners develop two-dimensional (2D) detailed drawings and three-dimensional (3D) models using a computer-aided design (CAD) system.

Unit introduction

Computer-aided design (CAD) spans most areas of engineering, as well as aspects of other disciplines such as construction and media. Engineering is a multi-disciplinary vocational subject that uses CAD as part of other processes to develop (design and manufacture), improve and maintain cutting edge products and systems. For example, Formula 1® racing teams test all their cars on bespoke CAD packages to analyse performance and stresses, and make modifications to the cars as a result.

In this unit you will use CAD software and hardware to produce 2D and 3D drawings. You will acquire the skills to produce models of products, editing and modifying these, and exploring materials and their properties. You will output a portfolio of drawings, for example orthogonal, 3D shaded or solid model, and detail view drawings, to an international standard.

As an engineer it is important to be able to interpret and produce engineering drawings that help individuals and organisations to communicate ideas, design and manufacture products and improve product performance. Studying this unit will help you to progress to employment as a draftsperson and gain other technician level roles in engineering. It also prepares you for an engineering-based apprenticeship, and for higher education.

Learning aims

In this unit you will:

A Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes

B Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes

C Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes	**A1** 3D parametric modelling **A2** Develop 3D components **A3** Develop a 3D model **A4** Output of drawings from a model	A practical drawing activity to produce a 3D model of a product and determine the material properties of components. A portfolio of drawings should include: orthogonal, 3D shaded or solid model, parts list/bill of material and a detail view.
B Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes	**B1** 2D drawing commands **B2** Development of 2D engineering drawings **B3** Output of 2D drawings	A practical drawing activity to produce 2D drawings for an assembled product. A portfolio of drawings should include: orthogonal, an assembly drawing, parts list/bill of material and a sectional view.
C Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes	**C1** 3D modelling commands **C2** Develop 3D components **C3** Development of a 3D model **C4** Output of product drawings	A practical drawing activity to produce a rendered 3D model of a thin walled and fabricated product. A portfolio of drawings should include: orthogonal, 3D shaded or solid model, parts list/bill of material, a detail view, rendered output and flat patterns.

Content

Learning aim A: Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes

A1 3D parametric modelling

- Configure the parametric modeller, including origin, units, snap and grid, correct format, project files, selection of file types and planes, e.g. XY, XZ and YZ.
- Sketching commands, including line, arc, centre line, construction line, circle, fillet, and dimension.
- Display commands, including pan, zoom, and orbit.
- Editing commands, including erase, extend, trim, and rotate.
- Construction commands, including:
  - 3D primitives, e.g. cube, cylinder
  - 3D creation, e.g. extrude, revolve
  - 3D modify, e.g. hole, move face, chamfer
  - 3D Boolean, e.g. intersect, addition, subtraction
  - 3D assembly, e.g. place, constrain
  - 3D analysis, e.g. stress, mass.

A2 Develop 3D components

- Creation of 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D model, including rotate about an axis, revolve, extrude, and Boolean manipulation.
- 3D features, including:
  - threads, male and female
  - holes, including plain, drilled
  - threads, countersunk, counterbore, fillet, chamfer, rectangular or circular copy.
- Combination of solid objects, including Boolean operations.
- 2D sketching on 3D faces.
- Modification of the 3D model, including addition of features to existing geometry, e.g. cut-outs, projected geometry and new holes and extrusions.
- Application of materials to include:
  - mass based on common engineering materials, e.g. aluminium and carbon steel
  - surface area of the whole or part of a component
  - volume of the whole or part of a component
  - density mass per unit volume of material
  - principal moments, moments of inertia of a body about its principal axis.

A3 Develop a 3D model

- Placement of 3D components, including degrees of freedom, XYZ translational freedom and XYZ rotational freedom.
- Assembly constraints and the relationships between components, including mate constraint and angle constraint assembly relationships, insert constraint and tangent constraint assembly relationships.
- Modification to 3D components due to assembly constraints.
- Consideration of assembly, including storyboarding, component relationship.

A4 Output of drawings from a model

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- 2D paper space, including drawing template, scale, size, title block, editing
- creation of component drawings, including an orthogonal base view and projected views, 3D solid model/surface model, appropriate scale, detail views, dimensioning, and centre lines
- creation of an assembly drawing, including parts list or bill of materials (BOM).

Learning aim B: Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes

B1 2D drawing commands

- Configuration of a 2D CAD system, including format units, snap and automatic snaps, grid, precision, angular, drawing limits, layers, user coordinate system, world coordinate system, and file systems.
- Use of drawing commands, including line, arc, circle, polyline, absolute, relative, and polar.
- Use of display commands, including pan, zoom.
- Use of modify commands, including erase, trim, mirror, move, array, copy, undo and stretch.

B2 Development of 2D engineering drawings

- Drawing commands, including line types, centre line, dashed, text, offset, hatching and editing of hatching.
- Use of layers, including manipulation, creation, switching on/off, frozen and locked.
- Use of blocks/symbols, including creation of blocks/symbols, symbols library, insertion of blocks.
- Use of modify commands, including mirror, pan, scale, chamfer, and fillet.
- Use of dimensioning, including dimension styles, dimensions, and editing of dimensions.

B3 Output of 2D drawings

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- set up of output parameters, including paper size, units, plot area, scale, orientation, paper space, model space, model and layout drawing, and template
- creation of component drawings, including orthogonal views, appropriate scale, sectional view, dimensioning, and centre lines
- creation of an assembly drawing, including general arrangement, parts list or bill of materials (BOM).

Learning aim C: Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes

C1 3D modelling commands

- Configuration of the parametric modeller, including origin, units, snap and grid, correct format, project files, selection of file types, and planes, e.g. XY, XZ and YZ.
- Creation of 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D model, including rotate about an axis, revolve, extrude, and Boolean manipulation.
- Sheet metal parameters, including folding rule, bending rule, corner reliefs.
- Use of sketching commands, including line, arc, centre line, construction line, circle, fillet, and dimension.
- Use of construction sheet metal commands, including face, material thickness, bends, flange, holes, slots, 3D modify, e.g. hole, move, face, chamfer.
- Use of construction thin walled commands, including 3D creation, imprint/shell, Boolean manipulation, sweep, loft, shell, work planes, emboss, 3D modify, e.g. hole, move, face, chamfer.

- Use of display commands, including pan, zoom, and orbit.
- Use of editing commands, including erase, extend, trim, and rotate.

C2 Develop 3D components

- Create 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D component and sheet metal fabrication, including folding, bending, slots, revolve, extrude, and Boolean manipulation.
- 3D features of the components, including:
  - threads – male and female
  - holes – plain, drilled, threads, countersunk, fillet, chamfer
  - combination of solid objects, including Boolean operations.
- 3D features of the thin walled components, including shell/imprint, loft, fillet, chamfer, array (rectangular or circular), and combination of solid objects, including Boolean operations.

C3 Development of a 3D model

- Placing 3D components, including degrees of freedom, XYZ translational freedom and XYZ rotational freedom.
- Assembly constraints and the relationships between components, including mate constraint and angle constraint assembly relationships, insert constraint and tangent constraint assembly relationships.
- Modification to 3D components due to assembly constraints.
- Consideration of assembly, including storyboarding, component relationship.
- Use of rendering, including render, shadows, reflections, lights, materials, textures, ray tracing.

C4 Output of product drawings

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- 2D paper space, including drawing template, scale, size, title block, editing
- creation of component drawings, including an orthogonal base view and projected views, 3D solid model/surface model, appropriate scale, detail views, rendered models, dimensioning, flat patterns, and centre lines.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes</td><td rowspan="2">A.D1 Refine models and drawings to an international standard of an accurate and correctly orientated 3D assembled product that is fit for purpose, applying appropriate materials to all components and create a drawing template.</td></tr>
<tr><td>A.P1 Create models and drawings of at least five 3D components from an assembled product, and apply a material to two or more components.
A.P2 Create a model and drawings of an assembled product containing at least five components with two or more components well orientated.</td><td>A.M1 Produce accurate models and drawings that mainly meet an international standard of an assembled 3D product containing at least seven well orientated components and apply a material to all components.</td></tr>
<tr><td colspan="2">Learning aim B: Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes</td><td rowspan="2">B.D2 Refine, using accurate layers from a master layer, drawings to an international standard of an accurate and correctly orientated 2D assembled product that is fit for purpose.</td></tr>
<tr><td>B.P3 Create, using layers, drawings of at least six 2D components from an assembled product.
B.P4 Create a 2D assembly drawing containing at least six components, with at least two components well orientated.</td><td>B.M2 Produce, using accurate layers, drawings that mainly meet an international standard of an assembled product containing at least ten accurate and well orientated components.</td></tr>
<tr><td colspan="2">Learning aim C: Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes</td><td rowspan="2">C.D3 Refine drawings to an international standard of two accurate and correctly orientated 3D models with realistic rendering that are both fit for purpose.</td></tr>
<tr><td>C.P5 Create partially rendered models and drawings of at least two 3D components from a thin walled assembled product.
C.P6 Create partially rendered models and drawings of at least four 3D components from a fabricated assembled product.</td><td>C.M3 Produce an accurate model and drawings, that mainly meet an international standard of at least two well orientated and fully rendered 3D components from a thin walled assembled product.
C.M4 Produce an accurate model and drawings, that mainly meet an international standard of at least four well orientated and fully rendered 3D components from a fabricated assembled product.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- suitable CAD workstations and output devices, e.g. printers and plotters
- 2D CAD software that is capable of professional 2D drawings and their output, e.g. AutoCAD 2D, AutoCAD LT, TurboCAD Deluxe, and DraftSight
- 3D modelling software that is capable of professional solid 3D models and fabricated models, creates assemblies and outputs 2D drawings, e.g. AutoCAD 3D, AutoCAD Inventor, SolidWorks, and SolidEdge.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will show consistently accurate components with a material applied correctly to every component, for example, an engine/cylinder block material could be made from either aluminium or cast iron. The components should be assembled into a model, for example a model Formula 1® racing car or a model aircraft landing gear, with all the components orientated correctly.

A drawing template should be created and used so that a professional portfolio of drawings can be output. The evidence should include orthogonal drawings, a 3D shaded/solid model, and a detail view. Overall, the drawings should be to an international standard, such as BS 8888, and the model should fully meet its purpose, for example to display accurate visualisation to a potential customer, and be clear for a third party to understand.

For merit standard, learners will accurately draw at least seven components, for example they should be the correct size and compatible when assembled. At least five of the components should be correctly orientated when assembled, for example an incorrectly orientated component could be orientated correctly from one angle but not another. A material should be applied to all components.

A drawing template from the standard library should be used to output a portfolio of drawings that should generally be to an international standard, such as BS 8888. Specifically, orthogonal drawings may contain at most a couple of missing dimensions and/or a couple of dimensions may be inappropriately positioned or inconsistent, and a detail view that may have minor errors, for example an incorrect scale applied, or incorrectly labelled. The 3D shaded/solid model should contain no inaccuracies in the drawing layout and title block and an accurate parts list/bill of materials should be given.

Overall, the evidence should provide an appropriate 3D model that generally meets its purpose.

For pass standard, learners will draw at least five components but they may not all be fully accurate, for example an incompatibility in a male and female thread, or incorrect depth of thread could be used, causing a bolt not to seat correctly. Components such as pins, washers and basic fasteners do not contribute towards the component count. The components should be assembled into a model with at least two components orientated correctly and a material will be applied to at least one component.

A drawing template from the standard library should be used to output a portfolio of drawings. Specifically, orthogonal drawings, which may contain some missing dimensions and/or some dimensions may be inappropriately positioned or inconsistent, and a 3D shaded/solid model may have some minor errors within the drawing layout and/or title block.

Overall, the evidence should demonstrate a 3D model that partially meets its purpose.

Learning aim B

For distinction standard, learners will show accurate components that form an assembly and all components should be orientated correctly. Layers should be used so that component attributes are grouped on one layer, for example, hatching is contained on a single layer and should be used to create different assemblies and/or components possessing similar attributes from the master layer. Another example would be a series of brackets with common attributes, such as a bar with a differing series of holes on a pitch circle diameter (PCD), which would be created from one master layer with the PCDs on separate layers to enable the output of several drawings.

A drawing template should be created to output professional drawings, to include a general arrangement, component drawings, and a sectional view. Overall, the portfolio of drawings should be to an international standard, such as BS 8888, and they should demonstrate a clear and accurate 2D model that fully meets its purpose, for example to manufacture the component(s), and is clear for a third party to understand.

For merit standard, learners will draw ten components, which may have minor inaccuracies, for example external dimensions are created incorrectly but they do not affect final assembly, or components may not be fully compatible. Layers should be used to create components and they should be well oriented to create the assembly.

A drawing template from the standard library should be used to output professional drawings, to include a general arrangement, component drawings, and a sectional view. These drawings should be to an appropriate international standard.

Overall, the evidence should provide an appropriate 2D model that generally meets its purpose.

For pass standard, learners will draw six components, which may have some inaccuracies, such as errors in sizes and compatibility. Components such as pins, washers and basic fasteners do not contribute towards the component count. Also, the assembly should contain at least two correctly orientated components. Layers should be utilised so that components are created using layers, with some minor errors, for example layers may have been left frozen, or only partially printed.

A drawing template from the standard library should be used to output a professional portfolio of drawings, to include a general arrangement and orthogonal drawings. The orthogonal drawings may contain some minor errors within the drawing layout, title block and dimensioning.

Overall, the evidence should demonstrate a 2D model that partially meets its purpose.

Learning aim C

For distinction standard, learners will show in their portfolios accurately modelled fabricated and thin walled components. The fabricated components together should contain a minimum of four folds, two bends and four slots. The components should be assembled into a model that contains a minimum of six components that are orientated correctly, containing a minimum of three fabricated components, plus rods, dowels and shafts may be included, for example a lever and linkage system or a scissor lifts. The thin walled components should be assembled together to create one assembly with no inaccuracies, for example a small hairdryer or a computer mouse. Both models should be rendered to show a realistic product.

A drawing template should be created to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication.

Overall, the portfolio should provide 3D models that fully meet their purpose, for example to display accurate visualisation to a potential customer, and are clear for a third party to understand.

For merit standard, learners will show accurate, fabricated and thin walled components. The fabricated components should contain a minimum of two folds, two bends and two slots, containing a minimum of two fabricated components, plus rods, dowels and shafts may be included. The components should be assembled into a model that contains a minimum of four components that are orientated correctly. The thin walled components should be assembled together to create one assembly, which may contain minor inaccuracies, for example minor misalignments, but correctly orientated. Both models should be rendered but it may not be fully realistic, for example, there may be minor errors in shadows, lighting, reflections, and views.

A drawing template from the standard library should be used to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication. Drawings may contain minor dimensioning errors or missing dimensions.

Overall, the evidence should provide an appropriate 3D model that generally meets its purpose.

For pass standard, learners will show generally accurate, fabricated and thin walled components. The fabricated components should contain a minimum of one fold, one bend and one slot. The components should be assembled into a model that contains a minimum of three components and some may be orientated incorrectly. The thin walled components should be assembled together to create one assembly, with some inaccuracies, for example inaccuracies in component orientation or alignment. Components such as split pins and washers do not contribute towards the component count. One component may be rendered, with some errors in shadows, lighting, reflections, and views.

A drawing template from the standard library should be used to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication. Drawings may contain minor dimensioning errors or some missing dimensions.

Overall, the evidence should provide an appropriate 3D model that partially meets its purpose.

Links to other units

This unit links to:

- Unit 3: Engineering Product Design and Manufacture
- Unit 5: A Specialist Engineering Project
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 43: Manufacturing Computer Numerical Control Machining Processes
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations
- contribution of ideas to unit assignment/project materials.

Unit 11: Engineering Maintenance and Condition Monitoring Techniques

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore types of engineering maintenance, their use and impact on the monitoring and maintenance of engineered plant and equipment.

Unit introduction

The maintenance and monitoring of engineered plant and equipment are key to productivity, profitability, safety and efficiency wherever such items are used. For example, in manufacturing plant breakdowns, malfunctions and unscheduled stoppages cost money and can compromise quality and performance.

In this unit, you will investigate and explore different types of maintenance and condition monitoring techniques and their applications across a variety of engineered plant and equipment. You will examine the relative costs and benefits of monitoring and maintaining engineered plant and equipment in good order. Additionally, you will analyse condition monitoring data and undertake a practical, planned maintenance procedure on an item of engineered plant or equipment.

Engineering maintenance and condition monitoring are key functions across a range of sectors, for example advanced manufacturing, aerospace, automotive, power and chemical engineering. The knowledge, skills and understanding you gain in this unit are relevant to a range of job roles, for example facilities maintenance, manufacturing planning and control, specialist machine tool design and construction, installation and commissioning. This unit also helps to prepare you for a relevant apprenticeship or entry to higher education.

Learning aims

In this unit you will:

A Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely

B Examine the use of condition monitoring techniques to detect faults and potential failures before they occur

C Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely	**A1** Types of maintenance and common maintenance techniques **A2** Maintenance cost considerations **A3** Reasons for maintenance	A report on the use of three different types of maintenance as they are applied to items of engineered plant or equipment.
B Examine the use of condition monitoring techniques to detect faults and potential failures before they occur	**B1** Condition monitoring techniques **B2** Condition monitoring equipment and data **B3** Principles of and factors contributing towards potential faults and failures	A report focusing on condition monitoring techniques and an analysis of given monitoring data to identify potential faults and failure.
C Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation	**C1** Maintenance and condition monitoring plan **C2** Health and safety requirements when undertaking maintenance activities **C3** Preparation for maintenance activities **C4** Completion of a maintenance activity	A detailed maintenance and condition monitoring plan and log, including supporting paperwork, when carrying out maintenance and condition monitoring activities safely. Observation records and witness statements of completing the routine maintenance activity.

Content

Learning aim A: Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely

A1 Types of maintenance and common maintenance techniques

Types of engineering maintenance and common techniques, including:

- reactive or breakdown maintenance – repairs and replacement undertaken once a breakdown has occurred
- planned maintenance – maintenance carried out on specific items of plant and equipment according to a fixed plan at prescribed intervals, e.g. monthly, yearly
- preventative maintenance – regular inspection, detection and correction of plant and equipment to prevent breakdown, e.g. visual inspection, checking alignment, making routine adjustments, cleaning, lubrication
- corrective maintenance – a fault is detected, reported and rectified in order to restore an item to normal working order
- total productive maintenance (TPM) – integrated means of ensuring that all plant and equipment is maintained in excellent working condition so that manufacturing processes run continuously without disruption
- predictive maintenance – doing what is required to monitor and diagnose the condition of an item of plant or equipment, e.g. condition monitoring and statistical process control and quality assurance data.

A2 Maintenance cost considerations

Costs and impact upon profitability of maintenance activities, including the cost of:

- different types of maintenance as a proportion of total expenditure
- the type of maintenance applied and the benefits that result
- direct and indirect labour
- spares and consumables held
- lost output
- equipment hire and replacement
- outside contracting
- health and safety and the environment.

A3 Reasons for maintenance

Understand the reasons for engineering maintenance, including:

- to improve plant reliability
- to improve productivity
- to reduce wastage
- to reduce costs
- to improve safety
- to improve quality
- to improve comfort and welfare
- to adhere to legal and statutory requirements, e.g. noise levels
- to adhere to manufacturer’s guidance and instructions, e.g. warranty.

Learning aim B: Examine the use of condition monitoring techniques to detect faults and potential failures before they occur

B1 Condition monitoring techniques

Measuring and monitoring a specific function, parameter or item of plant or equipment, including:

- vibration analysis, e.g. monitoring and recording the vibration of a rotating shaft in a motor
- temperature analysis, e.g. detecting changes in temperature in a critical component, such as a bearing, fuse, or relay
- flow analysis, e.g. monitoring the performance of a pump
- crack detection, e.g. identifying surface cracks in heat-treated components
- thickness analysis, e.g. monitoring the wall thickness of tubes in a continuous tube manufacturing mill
- oil analysis – the detection of contaminants in a lubricating oil, e.g. water in a turbine
- corrosion detection, e.g. monitoring the degradation of critical surfaces in an aircraft fuselage
- emissions analysis, e.g. the measurement of pollutants discharged by an internal combustion engine.

B2 Condition monitoring equipment and data

Condition monitoring equipment and data collection, including:

- manual or remote fixed and portable equipment for online and offline data
- collection, e.g. hand-held data logger able to measure and transmit a range of information, e.g. temperature, light, pressure
- equipment performance data, including self-diagnostics
- smart sensors, e.g. onboard vibration sensors built into an electric motor that monitor and distribute information continuously
- statistical process control and quality assurance data.

B3 Principles of and factors contributing towards potential faults and failures

- Causes of faults and failure, including:
  - failure rate – the predicted frequency of failure of a component or system over a period of time or number of cycles
  - failure mode – the way in which failure occurs
  - functional failure – the point at which a component or system no longer functions as required and is considered to have failed.
- Calculations concerning failure:
  - mean time to failure (MTTF) – the average period of time a component or system will operate before failing
  - mean time to repair (MTTR) – can be either the average period of time to repair a fault or the average time between successive needs to repair a component or item of equipment
  - mean time between failures (MTBF) – the average period of time between successive failures of a component or item of equipment.
- Factors that may contribute to faults and failures, including:
  - design and capability – a fault in the design features of a component or item of equipment, e.g. poor material specification
  - mode of operation – the manner and purpose for which an item of equipment is used, e.g. overloading a machine beyond its capability
  - environment – the conditions in which an item of equipment is used, e.g. temperature and humidity
  - manufacturing processes – inappropriate method(s) of manufacture.

Learning aim C: Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation

C1 Maintenance and condition monitoring plan

A typical maintenance plan for an item of engineered plant or equipment should include the following detail:

- equipment type, description, location, identification number
- type of maintenance procedure
- maintenance procedure description
- frequency of procedure
- date of next procedure
- specialist skills required, e.g. mechanical, electrical, fluid engineering
- personnel involved
- equipment status, e.g. running, shutdown, isolated
- task list
- estimated time and actual time for each task
- tools, equipment and materials required
- health and safety requirements including personal protective equipment (PPE)
- item checked, tested, handover
- task report including the identification of any further maintenance needs.

C2 Health and safety requirements when undertaking maintenance activities

- Key features of regulations, or other relevant international equivalents, including:
  - isolation and permit to work systems
  - working in confined spaces and at heights
  - Current Control of Substances Hazardous to Health (COSHH) Regulations and amendments, including lubricants, degreasing agents and other hazardous substances dependent upon the nature of the plant or equipment being maintained
  - Current Personal Protective Equipment (PPE) at Work Regulations and amendments, where hazards exist to lungs, eyes, head, feet, skin or the body
  - Current Lifting Operations and Lifting Equipment Regulations and amendments, including the safe use of appropriate lifting equipment, e.g. hoist
  - Current Manual Handling Operations Regulations (MHOR) and amendments, referring to the HSE manual handling assessment charts.
- Other safe working practices relevant to an engineering maintenance activity, including:
  - organisation rules and maintenance protocols
  - environmental issues
  - health and safety procedures
  - reporting of accidents
  - reporting of hazardous items of plant or equipment
  - emergency procedures
  - reporting and treatment of injuries.
- Risk assessment of the general working environment and specific maintenance procedure, including:
  - defining hazard by inspection of the general environment and location, e.g. remove and clean jets in a gas-powered heat treatment furnace
  - defining risk by determining how hazards may cause injury, e.g. falling objects when maintaining a crane
  - putting control measures in place to reduce risk, e.g. isolating the work area
  - Health and Safety Executive (HSE) guidance on risk assessment to include the five steps and the use of standard pro forma.

C3 Preparation for maintenance activities

Obtain available supporting documentation for an engineering maintenance procedure, e.g. manufacturer's drawings, parts list, service manual, maintenance documentation, maintenance/service history, plant register, standing instructions, permit to work, handover documents, maintenance reports, condition monitoring data.

- Select materials, spares and equipment to complete the maintenance activity:
    - hand tools, e.g. spanners, wire strippers, bearing puller
    - consumables, e.g. lubricants, electrical wire
    - replacement parts, e.g. bearings, filter.

C4 Completion of a maintenance activity

Complete a maintenance activity on an item of equipment or plant safely, including:

- disassemble, remove or strip item
- visually inspect components
- repair, replace or replenish as required
- reassemble item
- inspect and test
- complete documentation
- return item to service
- complete documentation.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely		**A.D1** Evaluate, using language that is technically correct and of a high standard, the characteristics and suitability of three different types of maintenance used for the continued operation of plant and equipment.
A.P1 Explain, using examples, the characteristics of and reasons why three different types of maintenance are used for the continued operation of plant and equipment.	**A.M1** Compare, using examples, the characteristics and suitability of three different types of maintenance used for the continued operation of plant and equipment.	
Learning aim B: Examine the use of condition monitoring techniques to detect faults and potential failures before they occur		**B.D2** Evaluate the condition monitoring practice for a piece of plant or equipment and the results from a given condition monitoring exercise on a piece of plant or equipment, recommending appropriate interventions to rectify the faults and failures.
B.P2 Explain the different condition monitoring techniques and equipment used to detect faults and potential failures. **B.P3** Interpret the results from a given condition monitoring exercise on a piece of plant or equipment, identifying the possible causes.	**B.M2** Analyse the condition monitoring techniques and equipment used to detect potential faults and failures in a piece of plant or equipment, including the contributory factors. **B.M3** Analyse the results from a given condition monitoring exercise on a piece of plant or equipment, identifying realistic causes for the faults or failures.	
Learning aim C: Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation		**C.D3** Refine, during the process, the planning and performance of a maintenance activity on an item of plant or equipment safely, accurately and efficiently, returning it to service, and identifying any future maintenance requirements and/or advice.
C.P4 Produce a plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. **C.P5** Prepare materials, equipment, and procedures to complete maintenance activity on a piece of plant or equipment. **C.P6** Complete a maintenance activity safely on a piece of plant or equipment, returning it to service.	**C.M4** Produce a detailed and accurate plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. **C.M5** Perform a maintenance activity safely and accurately on a piece of plant or equipment, returning it to service.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- items of engineered plant and equipment – these could be items of workshop equipment, modern motor vehicles or items of plant and equipment located elsewhere in the institution or made available by local companies
- hand-held condition monitoring equipment
- condition monitoring data for an item of plant or equipment
- a range of hand and power tools suitable for maintenance activities
- the provision of consumable items for maintenance tasks
- accompanying documentation for the equipment referred to above and relevant health and safety regulations, as required by the unit content
- appropriate websites such as the HSE.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a balanced evaluation of the characteristics and suitability of three different types of engineering maintenance. They will identify the items being maintained, the purpose of the maintenance, the techniques used and why the type of maintenance is appropriate. Learners will provide a conclusion regarding the suitability of each type of maintenance. For example predictive maintenance is employed on a gas turbine engine because of the safety critical nature of the product as well as the availability and increased capabilities of diagnostic tools to monitor the performance and condition of the engine that form the basis for this type of maintenance.

Overall, learners' evaluations will be easy to read and understand by a third party who may or may not be an engineer. They will be well structured and presented in a logical way using the correct, technical engineering terms and will be a high standard of written language regarding spelling and grammar. Also, charts and illustrations will be clear and easy to understand.

For merit standard, learners will produce a detailed comparison of the characteristics (types of maintenance procedure undertaken, the techniques applied, and the costs) and suitability of three different types of maintenance applied to plant or equipment. Learners will select and research the applications and will make a personal judgement on the suitability of the maintenance chosen. For example using planned maintenance for a continuous tube manufacturing mill to ensure that the plant is able to run continuously between scheduled shutdowns, whereas breakdown maintenance is acceptable for a lawn mower in a non-commercial setting, as the costs would outweigh the benefits of operating a planned maintenance system.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the characteristics and suitability of three different types of maintenance for the particular applications they have chosen, for example a domestic lawn mower, a gas turbine engine, a continuous tube manufacturing mill. The characteristics referred to will cover the type of maintenance undertaken, the techniques applied, the costs and reasons why the approach is used, for example the continuous tube manufacturing mill may be maintained using planned maintenance to ensure the reliability of the plant and the quality tube it produces. Learners will refer to an experienced and available maintenance team to complete the work, as well as the cost benefits to the organisation of maintaining continuous running of the mill greatly outweighing the wider disruption caused by breakdowns.

Overall, learners' evidence will be logically structured, although it may be basic in parts, for example they may only provide simple reasons for their use, perhaps missing out a reference to cost, and it may contain minor technical inaccuracies relating to engineering terminology, such as 'mending' faults rather than 'rectifying' faults.

Learning aim B

For distinction standard, learners will produce a balanced evaluation of condition monitoring techniques and equipment. They will analyse in detail the results from a given condition monitoring exercise, identifying the item, the parameters measured, and the techniques and equipment used. They will identify factors that may contribute to a fault or potential failure and recommend appropriate interventions to rectify the fault(s) and/or failure(s). For example, learners may refer to the data obtained from frequently monitoring the condition of a lubrication oil in a production machine, possibly identifying the presence of water, wear debris or other contaminants that might compromise the machine's reliability and performance and lead to fault(s) or potential failure(s).

Overall, learners' evidence will 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, charts, tables and illustrations will be clear and understandable.

For merit standard, learners will provide a detailed analysis of condition monitoring techniques and equipment used to detect potential faults or failures in an item of plant or equipment. For example, learners may refer to using a hand-held optical pyrometer to record temperature variations in a heat treatment furnace that may, if not addressed, compromise the mechanical properties of the components being manufactured.

Learners will interpret the results from a condition monitoring exercise, identifying some realistic causes for the faults or failures which could cover the design, mode of operation and conditions in which it is used. For example, they may identify significant variations in temperature in a heat treatment furnace possibly due to blocked gas jets.

Overall learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the different types of condition monitoring techniques and equipment, the parameters they measure and the faults and failures they can identify and predict. For example, learners may refer to motor vehicle exhaust emission test equipment to measure and record the level of gases and other pollutants.

Learners will interpret the results of data from a given condition monitoring exercise on a piece of plant or equipment, for example recording temperature measurements from a heat treatment furnace over a prescribed period of time, calculating mean time to repair. They will also identify the possible causes for the failure, although the causes may not be realistic.

Overall learners' evidence will be logically structured, although it may be basic in parts, for example a limited explanation of different types of condition monitoring equipment, perhaps misinterpreting some of the results from the exercise, and it may contain some minor technical inaccuracies, for example misspelling 'thermocouple'.

Learning aim C

For distinction standard, learners will produce logical refinements to their detailed maintenance plan and risk assessment, making refinements as they plan, prepare and complete the maintenance activity on a piece of plant or equipment.

Learners will prepare and perform the activity safely, accurately and efficiently, rectifying the fault and/or performing routine maintenance and returning the piece of plant or equipment to service, for example removing and replacing a set of bearings for a roller on an airport luggage conveyor system and returning the system back to service. Throughout the activity learners will be efficient, for example by thinking ahead to organise the tasks, preparing any consumables and other materials and completing tasks in the correct order while making any adjustments for unforeseen problems as they occur.

Also, learners' evidence, for example the task report, will identify any future maintenance requirements and/or advice. For example, when changing an oil filter, learners may observe that a bearing needs replacement and/or that the head of a casing bolt is worn so care is needed during the assembly and disassembly procedure and replacement may be advised during the next scheduled maintenance activity.

Overall, learners' evidence will be easy to read and understand by a third party who may not be an engineer. It will be well structured and presented in a logical way using the correct, technical engineering terms. Also charts, forms, plans and illustrations will be clear and understandable.

For merit standard, learners will produce a detailed and accurate plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. For example, learners will break down the maintenance procedure into logical and easy to understand steps, and all the tools required for the job will be listed.

Learners will prepare and perform the activity safely and accurately, rectifying the fault and/or performing routine maintenance and returning the piece of plant or equipment back to service. For example, accuracy means applying the correct torque to bolts and sealing bearings correctly or ensuring gas jets are thoroughly free of rust and dust before being reassembled into the furnace.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand. For example, the task report/documentation will reference quality control checks and provide details of the condition of the parts replaced so maintenance schedules can be adjusted, such as to increase the frequency of cleaning and lubricating bearings on a conveyor system.

For pass standard, learners will produce a maintenance plan and risk assessment for a maintenance activity on an item of plant or equipment. Learners' risk assessments will include consideration of all significant hazards, be laid out on in appropriate template and include suitable control measures.

They will prepare for the activity by selecting materials and equipment, following prescribed procedures and complete the activity safely by rectifying any faults and/or completing routine maintenance, returning the piece of plant or equipment back to service, for example by replacing the brushes in an electric motor. Some tasks, however, may not be completed in the most efficient order.

Overall, learners' evidence will be logically structured, although it may be basic in parts, for example the plan may lack details of estimated and actual time taken, the task report/documentation may make limited reference to quality control checks and there may be some minor technical inaccuracies, for example specifying the wrong tool to remove the gas jets in a heat treatment furnace, or a missing a spring washer from a securing bolt.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 15: Electrical Machines
- Unit 24: Maintenance of Mechanical Systems
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 50: Aircraft Gas Turbine Engines
- Unit 53: Airframe Mechanical Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in maintenance and/or condition monitoring techniques
- contribution of ideas to unit assignment/project materials.

Unit 12: Pneumatic and Hydraulic Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the safe operation of pneumatic and hydraulic systems, including simulation of circuits using software and practical system assembly and testing.

Unit introduction

Pneumatic and hydraulic systems are an important part of many modern engineering products and systems. For example, aircraft landing gear relies on hydraulics, as do the robotic machines that are used in vehicle assembly plants. Pneumatic systems are widely used in the manufacturing industry and pneumatically operated tools are commonplace in garages and engineering workshops.

You will study the safe operation and maintenance of pneumatic and hydraulic power systems by investigating industrial case studies. You will learn how to use computer-aided design (CAD) software to create circuit diagrams of pneumatic and hydraulic systems and then simulate their function before gaining practical experience of assembling and testing a physical system.

As an engineer you may need to operate, maintain and repair pneumatic and/or hydraulic systems safely. This unit helps to prepare you for an engineering apprenticeship, for higher education and for technician-level roles, such as in plant maintenance or as a hydraulic/pneumatic technician.

Learning aims

In this unit you will:

A Examine the safe operation and maintenance of pneumatic and hydraulic powered systems

B Develop pneumatic and hydraulic circuit diagrams and simulate their operation

C Explore the safe development of pneumatic or hydraulic powered systems.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the safe operation and maintenance of pneumatic and hydraulic powered systems	**A1** Hydraulic and pneumatic power supply components **A2** Hydraulic and pneumatic actuator components **A3** Hydraulic and pneumatic system control components **A4** General system safety and maintenance **A5** Common applications of industrial hydraulic and pneumatic power systems	An illustrated technical report based around two contrasting case studies that include an evaluation of pneumatic and hydraulic systems and how they are used in industry.
B Develop pneumatic and hydraulic circuit diagrams and simulate their operation	**B1** Creating hydraulic and pneumatic power circuit diagrams **B2** Simulating the operation of hydraulic and pneumatic power circuits	Hydraulic and pneumatic power circuit diagrams and annotated screenshots of circuit simulation will be supported by witness statements and/or observation records.
C Explore the safe development of pneumatic or hydraulic powered systems	**C1** Health and safety requirements for the safe operation of hydraulic and pneumatic power systems **C2** System assembly **C3** Testing and fault finding pneumatic and hydraulic powered systems	Evidence from practical tasks will be evidenced by a logbook, written notes, annotated photographs, witness statements and observation records.

Content

Learning aim A: Examine the safe operation and maintenance of pneumatic and hydraulic powered systems

A1 Hydraulic and pneumatic power supply components

- Function and operation of pneumatic power supply system components:
  - compressor types, including piston, diaphragm, rotary vane, screw, typical operating pressures, compressor delivery volume
  - storage receivers, including constructional and safety features, shape and qualitative understanding of sizing factors, e.g. air consumption, network size
  - fluid conditioning equipment, including filters, lubricators, exhaust silencers, pressure regulators, dryers, drainage points and oil separators
  - key parameters, including operating pressures, compressor delivery volume, cycle regulation.
- Function and operation of hydraulic power supply system components:
  - pump types, including fixed displacement, e.g. gear, lobe, balanced vane, piston, variable displacement, e.g. vane, piston
  - fluid storage, including gas-pressurised and spring-loaded accumulators, simple tank and pressurised reservoirs, reservoir safety features, including stack pipe, de-aeration features, filters
  - fluid conditioning equipment, including supply and return reservoir filters, component filters and heat exchangers
  - key parameters, including pump flow rates, pressure limits, reservoir capacity.

A2 Hydraulic and pneumatic actuator components

- Function, operation and practical applications of:
  - linear actuator components, including single-acting cylinders, double-acting cylinders, cylinders with cushioning
  - rotary actuator components, including piston motors, sliding vane motors and gear motors.
- Key parameters, including actuator stroke length, load resistance, speed of operation.

A3 Hydraulic and pneumatic system control components

- Control component function and operation:
  - directional control valves, including 4-or 3-way valve, closed/neutral position
  - flow control valves, including throttle valve, sequence valve
  - pressure control valves, including pressure relief valve (PRV), thermal relief valve (TRV), pressure reducing valve
  - non-return valves, including check valve
  - position sensors, including pressure switch, microswitch
  - control component actuation methods, including pressure, manual, mechanical, electrical (solenoid) and pilot pressure actuation.
- Key parameters, including operating pressure, flow rate, temperature and control component requirements.

A4 General system safety and maintenance

- Safe maintenance of pneumatic systems, including compliance with maintenance manuals and procedures for checks on:
  - filter condition, water traps, lubricator fluid level, leaks, physical damage, security of attachment of components and fittings, lubrication of moving parts and linkages and system functional tests and checks.

- Safe maintenance of hydraulic systems, including compliance with maintenance manuals and procedures for checks on:
  - fluid levels, filter condition, accumulator pre-charge pressures, fluid plumbing and component leaks, physical damage and security of attachment of components, fittings and fluid plumbing, component fouling, aerated oil, lubrication of moving parts, functional tests and checks.
- Main hazards associated with fluid power systems:
  - sudden release of pressurised fluid, including impact injuries from pressure vessel rupture, ejected components/debris, flailing hoses
  - contact with pressurised fluid, including high temperature hydraulic fluid causing burns, cuts or injection injury
  - entrapment in moving parts
  - hydraulic fluid, including contamination due to leaks, harmful effects of skin contact, long term health implications.
- Safety design features, including pressure relief valves (PRVs), emergency stops, guarding, use of abrasion resistant flexible hoses, safe shutdown procedures, fail-safe systems.

A5 Common applications of industrial hydraulic and pneumatic power systems

- Pneumatic power systems, e.g. automotive paint spray booth, workshop equipment, rail, automotive, automated manufacturing systems.
- Hydraulic power systems, e.g. agricultural machines, motor transport, aircraft systems, industrial equipment.

Learning aim B: Develop pneumatic and hydraulic circuit diagrams and simulate their operation

B1 Creating hydraulic and pneumatic power circuit diagrams

- Symbols and circuit diagrams for hydraulic and pneumatic power systems and components to BS ISO 1219-1:2012 or other relevant international equivalents.
- Use of CAD software to create pneumatic circuit diagrams to BS ISO 1219-1:2012 or other relevant international equivalents, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell, clamp an object using a two-cylinder arrangement, rotary actuator with reversing action, cylinder with deceleration air cushion.
- Use of CAD to create hydraulic circuit diagrams to BS ISO 1219-1:2012 or other relevant international equivalents, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell and regeneration, motor with variable speed and reversing action.

B2 Simulating the operation of hydraulic and pneumatic power circuits

- Simulating the behaviour of hydraulic and pneumatic power circuits during operation.
- Recording output variables, e.g. generating plots of cylinder velocity versus time.
- Changing circuit and component input parameters and component type or layout, observing changes to circuit output variables and their effect on circuit performance, e.g. changing flow control valve settings to determine the effect on cylinder velocity, improving pressure losses by reducing the complexity of circuit layout and/or component selection.

Learning aim C: Explore the safe development of pneumatic or hydraulic powered systems

C1 Health and safety requirements for the safe operation of hydraulic and pneumatic power systems

- Main regulations and Approved Codes of Practice (ACOP) or other relevant international equivalents covering pressure systems, e.g.:
  - Pressure Equipment Regulations 1999 and amendments, (deals with the design, manufacture and supply of pressure systems)
  - Pressure Systems Safety Regulations (PSSR) 2000, (deals with the safe operation of a pressure system)
  - ACOP and guidance on Regulations L122 Second Edition 2014 (provides further advice on pressure systems safe operation).

- Safe working practices, including:
  - care and handling of pressurised gases, including storage bottles and receivers, airlines and pressurised systems
  - control of hazardous substances, including hydraulic fluid and lubricants
  - personal protection when handling gases and liquids and pneumatic and hydraulic system components, including use of barrier creams and other precautions to avoid dermatitis and the inhalation of noxious fumes
  - ensure system is depressurised prior to work
  - avoid checking for system leaks using hands
  - ensure correct fluids are used for replenishment
  - keep clear of system components when carrying out functional tests and checks.

C2 System assembly

- Component assembly, including:
  - familiarisation with safe and appropriate use of fluid system power supply components, fluid compressors, motor pump combinations, supply pressure regulation and safety features, fluid storage and conditioning components
  - component use, selection, physical and functional requirements, including system service loading, pressure and flow limits, linear and rotary movement parameters, sizing, porting, component actuation and control methods
  - component mounting and safe connection systems.
- Identification, selection and assembly of fluid conductors, including:
  - qualitative understanding of conductor sizing factors, including standard tubing sizes, flow velocity, operating pressure
  - pipework materials and types, including steel, aluminium alloy, copper rigid pipes and tubing, plastic tubing, rubber, neoprene and steel reinforced flexible hoses
  - fittings, including threaded and quick release couplings and connectors, pipe elbows, flared tube fittings, clamped and sealed end fittings.

C3 Testing and fault finding hydraulic and pneumatic powered system

- Functional tests and checks in accordance with maintenance manuals:
  - checking, including correct assembly, security of attachment, fluid plumbing and leaks, physical damage, fluid levels
  - system testing, including freedom of movement, fouling, operating in the correct sense, correct sequencing, spongy operation, range and freedom of movement, cycle speeds, operating pressures.
- Fault finding, including:
  - fault finding aids, e.g. circuit diagrams, flow charts, isolation methods
  - causes of failure, including fluid quality and contamination, overloading of components, lack of maintenance, fouling
  - common modes of failure, e.g. seizing of components, leakage, slow or sluggish movement.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the safe operation and maintenance of pneumatic and hydraulic powered systems		**A.D1** Evaluate, using language that is technically correct and of a high standard, the safe operation, maintenance requirements, component selection and key parameters necessary for a hydraulic and a pneumatic system to meet service requirements, including any improvements.
A.P1 Explain the safe operation, maintenance requirements, and component selection for a hydraulic and a pneumatic powered system.	**A.M1** Analyse the safe operation, maintenance requirements, component selection, and key parameters for a hydraulic and a pneumatic powered system to meet service requirements.	
Learning aim B: Develop pneumatic and hydraulic circuit diagrams and simulate their operation		**B.D2** Optimise the performance of the pneumatic and hydraulic circuit simulations, ensuring that the requirement of the client brief is met.
B.P2 Create circuit diagrams for a hydraulic and a pneumatic circuit that each contain at least eight components. **B.P3** Simulate the operation of a pneumatic and a hydraulic circuit that each contain at least eight components.	**B.M2** Produce accurate diagrams for a hydraulic and a pneumatic circuit containing at least eight components to an international standard, to meet the client brief. **B.M3** Simulate the correct operation of a pneumatic and a hydraulic circuit determining the effect of changing component parameters to meet the system purpose.	
Learning aim C: Explore the safe development of pneumatic or hydraulic powered systems		**C.D3** Refine, during the process, the performance of a fully functioning pneumatic or hydraulic system to better meet the client brief, while explaining the importance of safe working practices.
C.P4 Explain the importance of safe working practices when assembling and testing pneumatic and hydraulic circuits. **C.P5** Assemble a hydraulic or pneumatic system containing at least eight components safely. **C.P6** Test the operation of a hydraulic or a pneumatic system safely, identifying any faults.	**C.M4** Develop a fully functioning hydraulic or pneumatic system, safely rectifying faults, while explaining the importance of safe working practices.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- specialist fluid power systems, CAD software for the creation of circuit diagrams to ISO standards and the simulation of hydraulic and pneumatic system operation, e.g. Automation Studio™
- software that allows system and component parameters to be adjusted to optimise circuit function and is capable of calculating and plotting system variables, such as cylinder velocity during the operating cycle
- hydraulic or pneumatic system test rig or mock-up that allows a range of components to be safely fixed, connected, tested and adjusted to refine the system function
- a range of health and safety regulations and guidance documents, maintenance manuals, procedures and fault finding aids, as specified in the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce detailed and comprehensive evaluations of the hydraulic and pneumatic systems, demonstrating a clear understanding of how the systems and components in the system operate and function. Key parameters will be stated and their importance explained for each of the major system components, for example piston cross-sectional area for a simple hydraulic cylinder determines the maximum force that it can apply at any given pressure.

Learners will evaluate the type of system and components selected to meet a specific industrial service requirement. For example, the evidence might suggest the selection of hydraulics for an industrial press, by virtue of the high power, high force, accuracy and repeatability required, and then a reasoned argument would be given as to why these service requirements would not be achieved to the same standard using pneumatics.

In addition, the evaluation will include suggestions for improvement to the safety and maintenance of the system, for example improving maintenance efficiency by replacing a piston accumulator with a bladder accumulator thus avoiding the need for repeated pre-charging in the event of piston seal leakage.

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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse the hydraulic and pneumatic systems in sufficient depth and demonstrate a clear understanding of how the systems and components in the system operate and function, and how the required maintenance continues to ensure that the systems remain safe and fit for purpose. Key operating parameters will be stated and their importance explained for each of the major system components.

Learners will also analyse how the system and component operating parameters influence the choice of system and the system architecture needed to meet a specific industrial service requirement. For example, by considering the constraints on the required system layout and the service loads acting on a wheel braking system, learners will decide whether the system should be pneumatically or hydraulically powered.

Overall, the analysis, such as an illustrated written report, will be logically structured, technically accurate and easy to understand.

For pass standard, learners will provide an explanation of how pneumatic and hydraulic systems and components in the system operate, including key parameters and function of the system and corresponding components. Learners will explain the maintenance requirements for each type of fluid system and its associated components to ensure its continued safe operation. The explanation will include details on the industrial applications best suited to pneumatically or hydraulically powered systems, as used in industry.

Overall, the evidence, such as an illustrated written report, will be logically structured, although basic in parts and may lack some depth and breadth of understanding. The explanations must, however, cover all essential aspects of safety when working on or maintaining pneumatic and hydraulic powered systems and their associated components.

Learning aim B

For distinction standard, learners will accurately produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components, to meet the system purpose and then optimise the performance of the circuit by iteratively adjusting operating parameters to produce circuit simulations that accurately meet all aspects of the client brief. For example, in combination with changing system pressure, learners will alter bleed valve settings in a pneumatic cylinder to vary cylinder extension speed or change the pneumatic cylinder to a different size or type.

Overall, learners will demonstrate a logical and systematic approach throughout and will present clear, accurate and well-structured circuit diagrams and simulation data. Sufficient, detailed evidence of the simulation and optimisation processes will be presented so that it could be repeated by a third party, and correct engineering terms will be used throughout.

For merit standard, learners will accurately produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components, to meet the intended purpose of the system.

Learners must systematically record the effects of changing component parameters on circuit operation and determine the values required for the system's intended purpose to be met. For example, learners will change bleed valve settings in a pneumatic cylinder to vary cylinder extension speed.

Overall, learners will demonstrate a systematic approach throughout and will present clear and accurate circuit diagrams, simulation data and will use appropriate technical terms.

For pass standard, learners will produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components.

Learners must make an accurate record of the circuit simulation, including the system and component settings. For example, after setting and recording the initial system and component parameters for a circuit controlling a pneumatic cylinder, learners will then record its displacement versus time characteristics in operation.

Overall, learners will present clear and well-structured circuit diagrams, simulation data and will use limited or inappropriate technical engineering terms.

Learning aim C

For distinction standard, learners will provide evidence of how refinements were made safely throughout the assembly, testing and fault finding of their chosen system, improving its functionality and performance to better meet the client brief. For example, evidence may show learners manually adjusting a flow control valve to obtain optimum actuator speed, eliminating kinks in feed lines, replacing blocked filters.

Learners will demonstrate consistently good technical understanding of safe system assembly, testing and fault diagnosis. For example, when assembling system components, learners will ensure that they are securely attached to the system structure, correctly coupled, tested for leaks and correct operation, and adjusted appropriately to refine the system operation before any of the component adjusters are finally locked into position.

Overall, the evidence presented will cover all aspects of the practical system development and 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 throughout.

For merit standard, learners will provide evidence showing how safe assembly, testing and fault finding was used to develop a fully functional system. For example, the evidence may show learners changing system and component parameters, testing function and rectifying faults, such as tightening leaking unions.

Learners will demonstrate safe practice and a good technical understanding of most aspects of system assembly, testing and fault diagnosis. For example, they will, by following the circuit diagrams, be able to physically assemble components safely, securely and in the correct order within the system. This will ensure that system actuators not only operate in the correct sense and range but also in the correct sequential order.

Overall, the evidence presented, for example an illustrated portfolio or report, will be easy to read and understand. It will be logically structured and will use appropriate technical engineering terms.

For pass standard, learners will provide evidence explaining how assembly, testing and fault finding of a hydraulic or a pneumatic system was carried out safely. For example, evidence may show learners setting initial system and component parameters, testing the system and identifying faults, for example leaking unions, incorrect connections. They will also explain the importance of safe working practices required when working with physical systems.

Learners will demonstrate safe practice and some technical understanding of system assembly, test and fault diagnosis. For example, after the correct assembly of system components, learners will be able to identify the correct checks and test procedures that need to be carried out to ensure correct system operation but, when physically carrying out such checks and tests, may omit minor aspects of the test procedure that would have ensured all aspects of the system operation had been covered.

Overall, the evidence presented, for example an illustrated portfolio or report, will be easy to read and understand. It will be logically structured and learners will make limited or inappropriate use of technical engineering terms.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 10: Computer Aided Design in Engineering
- Unit 11: Engineering Maintenance and Condition Monitoring Techniques
- Unit 24: Maintenance of Mechanical Systems
- Unit 29: Principles and Applications of Fluid Mechanics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in pneumatic and/or hydraulic systems
- contribution of ideas to unit assignment/project materials.

Unit 13: Welding Technology

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine the principles and technology used in common welding processes and produce welded joints in differing materials and welding positions.

Unit introduction

A diverse range of welding processes are used in the manufacturing sector and in industry, including manual, automated and mechanised processes. The selection and application of these welding processes is vital in terms of the integrity, safety and the economic viability of the finished product.

In this unit, you will examine the common welding processes used to produce high-quality, permanent metal joints. You will select the most appropriate welding processes for a specific application. You will understand and apply strict safe working practices designed to protect you and colleagues from various hazards that are inherent to the welding process, such as electric currents, combustible gas mixtures and parts rotating at high speed. You will examine the materials and their behaviour during the welding process, helping you to create 'good' welded joints. Finally, you will plan and carry out a welding task to join different materials and joints together in different welding positions safely.

As an engineer, it is important to understand the welding technology, processes and the mechanisms of planning and creating joints and components. This unit helps to prepare you for employment, for example as a welding technician, for an apprenticeship or for entry to higher education to study engineering.

Learning aims

In this unit you will:

A Examine common welding processes used to produce welded joints safely for different applications

B Examine weldable materials and their behaviours during the welding process

C Carry out practical welding skills safely to join metallic materials together.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine common welding processes used to produce welded joints safely for different applications	**A1** Welding terminology for processes and equipment **A2** Gas-shielded arc welding – shielding gases **A3** Common welding processes **A4** Welding electrotechnics	A written report examining the suitability of welding processes for at least two different applications. The report will also cover the safe working practices and equipment required.
B Examine weldable materials and their behaviours during the welding process	**B1** The properties and behaviours of materials **B2** Unalloyed steel materials **B3** Alloyed steel and non-ferrous materials **B4** Defects and irregularities in welded joints	A written report about the properties and structures of alloyed and unalloyed steel and non-ferrous materials, determining how defects are prevented and which tests are applied to detect defects.
C Carry out practical welding skills safely to join metallic materials together	**C1** Prepare for welding operations **C2** Welding parameters and settings **C3** Welding of joints safely	Preparation activities before the welding of joints, including tools, equipment and consumables. A welding procedure specification (WPS) should also be used. Carry out welding operations to produce safely welded joints in two different materials, in two different welding positions and using two selected welding processes.

Content

Learning aim A: Examine common welding processes used to produce welded joints safely for different applications

A1 Welding terminology for processes and equipment

- Types of manual welding process, e.g. manual metal arc (MMA), tungsten inert gas (TIG), metal inert gas (MIG)/metal active gas (MAG), flux-cored arc welding (FCAW).
- Automated and mechanised welding processes, e.g. orbital welding, resistance welding.
- The major differences between types of welding process, correct use of abbreviations, range of applications, advantages and disadvantages, potential problems, and potential hazards and methods of safe handling and working.

A2 Gas-shielded arc welding – shielding gases

The characteristics and operating principles:

- processes, including TIG, MIG/MAG, flux-cored welding
- shielding gas used for each process
- safe handling and storage of shielding gases
- standards for shielding gases and filler materials
- potential hazards and methods of safe handling and working.

A3 Common welding processes

Welding processes:

- TIG welding process, including arc ignition methods and their applications, common applications for each type of current, polarity and electrode type, use of and care for the equipment and accessories, standards for consumables, joint preparation and potential problems to overcome and potential hazards, and methods of safe handling and working
- MIG/MAG welding, including metal transfer modes and their applications, selection of appropriate type of current, polarity and electrode according to application, appropriate joint preparations and potential problems to be overcome, welding parameters on the weld bead and be able to outline the welding parameters for particular applications, main components of the equipment and accessories, appropriate standards for consumables and how they are to be selected, care for the equipment and accessories, potential hazards and methods of safe handling and working
- FCAW process, including common applications for each type of current, polarity and electrode, appropriate joint preparations and potential problems to be overcome, appropriate welding parameters on the weld bead and outlining welding parameters for particular applications, potential hazards and methods of safe handling and working, functions of the main components of the equipment and accessories, appropriate standards for consumables, how consumables should be selected, and care for the equipment and accessories
- MMA welding process, including principles of MMA welding, selection of the appropriate type of current, polarity and electrode according to application, applications, appropriate joint preparations and potential problems to be overcome, range of welding parameters for particular applications, hazards and methods of safe handling and working, component of the equipment and accessories, handling, control and storage of the various types of electrodes, use of appropriate standards, influence of electrode coating on droplet transfer and weld metal properties.

A4 Welding electrotechnics

- The function of welding power source components:
  - alternating current (AC) and direct current (DC) and give examples of their individual application to different welding processes
  - transformers
  - rectifiers, including bridge (half and full wave).

- Power sources for arc welding:
  - how a welding power source works (AC and DC), including the most common devices used
  - arc welding power source, including the voltage static characteristic, operation point and control of arc stability
  - open-circuit voltage, arc voltage short-circuit current, duty cycle of a power source, voltage losses, and current to cable section relationship
  - appropriate power sources for a given welding process
  - settings and switches on different power sources and their effects on the welding process.

Learning aim B: Examine weldable materials and their behaviours during the welding process

B1 The properties and behaviours of metallic materials

- Properties of metallic materials:
  - mechanical properties of metals, e.g. plasticity, elasticity, cold and hot deformation, work hardening and strain ageing
  - loading conditions on the properties of metallic materials, e.g. temperature, loading speed, environment.
- The behaviour of metallic structures under loading:
  - stress – normal stress, shear stress
  - deformation – axial strain, shear strain
  - stress-strain relationship graphically
  - stress resulting from internal forces and moments.

B2 Unalloyed steel materials

Behaviour of structural steels in fusion welding:

- temperature distribution in welds and the microstructure formed as a result for a single-pass weld versus a multi-pass weld
- effects of heat input, cooling rate and multi-pass operation on weld metal solidification
- the microstructure formed for a single-pass weld versus a multi-pass weld
- the effects of the weld protection, the type of consumables on the microstructure of the weld metal and on it properties for a single-pass weld versus a multi-pass weld
- recognise areas of the heat-affected zone (HAZ), the reasons for grain size and microstructure changes and their effects on properties for a single-pass weld versus a multi-pass weld.

B3 Alloyed steel and non-ferrous materials

- Nickel and nickel alloys:
  - nickel and nickel alloy weldability
  - applicable welding processes and types of consumable for nickel and nickel alloys.
- Aluminium and aluminium alloys:
  - aluminium and aluminium alloy weldability
  - applicable welding processes and types of consumable for aluminium and aluminium alloys.
- Titanium and other metals and alloys:
  - the welding metallurgy of specified metals, e.g. titanium, magnesium
  - the weldability of the specified metals
  - appropriate welding processes.
- Joining dissimilar materials, including the weldability aspects involved when joining dissimilar materials.

B4 Defects and irregularities in welded joints

- Cracking phenomena in welded joints:
  - metallurgical mechanisms for each of the major types of cracking
  - susceptibility to cracking and suggest appropriate precautions to avoid cracking
  - type of cracking and the reason for its occurrence from study of fractured material and its history
  - reduce or eliminate the occurrence of lamellar tearing in welded construction/fabrication.
- Fractures and different kinds of fractures:
  - recognise the differences between cracks and fractures
  - recognise the differences between ductile and brittle fractures.
- Heat treatment of base materials and welded joints:
  - recognise the necessity to perform heat treatment after welding, depending on the type and thickness of steel, the application
  - post weld heat treatment (stress relieving).
- The various types of corrosion:
  - the chemical and electrochemical phenomena involved in corrosion
  - the most common types of corrosion, including intercrystalline, transcrystalline, knife-line attack, pitting, crevice, and stress-corrosion
  - common protection methods.
- Destructive and non-destructive testing of materials and welded joints:
  - destructive testing and the limitations of the data generated
  - testing methods and the parameters to be measured, including destructive and non-destructive, e.g. tensile, bend, impact, hardness, creep, root and face bend, nick break, and x-ray
  - recognise when and why special testing should be specified.

Learning aim C: Carry out practical welding skills safely to join metallic materials together

C1 Prepare for welding operations

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

C2 Welding parameters and settings

- Manual processes, including gas pressure, flow rates, voltage, current (either AC or DC), according to electrode or filler size.
- Mechanised processes:
  - safety devices
  - welding speed
  - parameters, including electrical current and voltage, wire feed rate, filler diameter, gas shielding system
  - mechanical functions, including handling, loading, work holding, transfer.
- Weld bead and morphology in relation to the settings and parameters used, e.g. parameters affecting bead shape.
- Consumables, e.g. appropriate to process, electrode (rutile, basic, nickel alloy, cellulosic, stainless steel, other electrodes), filler wire, gases (oxygen, shielding gases), inert and active gases, and safe storage of consumables.

C3 Welding of joints safely

- Safe working practices:
  - fire prevention
  - electrical safety
  - electromagnetic (EM) and ultraviolet (UV) radiation
  - accident prevention and reporting
  - using risk assessments
  - manual handling
  - equipment maintenance
  - checking conditions, e.g. gas leaks, voltage and amperage, fuses, circuit breakers, leads
  - wearing personal protective equipment (PPE)
  - ventilation and extraction fumes
  - using ventilation and extraction
  - closing down equipment safely after use.
- Joints and components:
  - for manual processes – butt, fillet, autogenous weld (without filler wire)
  - for semi-automatic processes – two different joint configurations, two different material groups.
- Welding positions, e.g. flat (PA), horizontal vertical (PB), horizontal (PC), vertical upwards (PF), vertical downwards (PG), overhead (PE).
- Welding technique, e.g. torch angle, filler angle.
- Material:
  - forms, e.g. plate (thickness appropriate to process, up to 6 mm, section, sheet < 3 mm), other forms
  - types, e.g. carbon steel, stainless steel, aluminum.
- Welding discontinuities and faults, considering the chosen welding process and the applied parameters.
- Meet the required accuracy as specified, e.g. dimensions, tolerances, weld quality, visual checks, uniformity, alignment, correct fusion, fillet of appropriate size, porosity, slag inclusions, parent metal substantially free from arcing or chipping marks.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine common welding processes used to produce welded joints safely for different applications		**A.D1** Justify, using language that is technically correct and of a high standard, the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.
A.P1 Explain the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.	**A.M1** Analyse the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.	
Learning aim B: Examine weldable materials and their behaviours during the welding process		**B.D2** Evaluate the structure, mechanical properties and defects of alloyed and unalloyed steel and non-ferrous materials used in welding processes, including the effects of irregularities, forces and loading on the joints.
B.P2 Explain the structure and mechanical properties of alloyed and unalloyed steel and non-ferrous materials used in welding processes. **B.P3** Explain the effect of forces and loading on welded joints. **B.P4** Explain the defects and irregularities that occur in alloyed and unalloyed steel and non-ferrous materials used in welding processes.	**B.M2** Analyse the structure, mechanical properties, and defects of alloyed and unalloyed steel and non-ferrous materials used in welding processes, including the effects of irregularities, forces and loading on the joints.	
Learning aim C: Carry out practical welding skills safely to join metallic materials together		**C.D3** Refine, during the process, the planning and production of welded joints using two different materials, processes and welding positions safely accurately, efficiently and effectively.
C.P5 Produce a plan to create two welded joints, using two different welding processes safely. **C.P6** Produce welded joints using two different materials, processes and welding positions safely.	**C.M3** Produce a detailed and accurate plan to create two welded joints, using two different welding processes safely. **C.M4** Produce welded joints using two different materials, processes and welding positions, safely and accurately.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to appropriate:

- welding equipment
- welding consumables and materials
- destructive and non-destructive testing equipment
- health and safety materials and procedures.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will give a balanced justification for the choice of at least two welding process for two different welding applications given to them. For example, their evidence could cover why welders use the MIG process in preference to MMA for thin sheet steel, particularly exploring why warping (distortion) occurs and the HAZ effects on the material. The justification will also cover different types of materials, shielding gases and safety considerations. For example, learners could examine the welding of aluminium using the optimum electrode, filler rod and inert gas and compare this to the MIG process. Learners will also detail how safe working practices vary by process.

Overall, the 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. Learners' written language will be of a high standard, for example they will use correct grammar.

For merit standard, learners will analyse the choice of at least two welding processes for two different welding applications given to them. For example, welding using the MIG process is considered easier to learn and quicker to master than MMA, although a comparison of the joint quality may contradict this argument. The evidence will demonstrate how the material and joint can influence the welding process. For example, why 18/8 (chromium/nickel) stainless steel may produce a better weld than welding stainless steel with 12% chromium.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain the choice of welding process for at least two different welding applications given to them, for example the reasons why low carbon steel can be welded using most processes, but cast iron requires a specific process and special welding rods. Learners will also explain the equipment and safe working practices required.

Overall, the evidence, such as a report, will be logically structured, although basic in parts. Learners will likely include minor technical inaccuracies relating to engineering terminology, such as mentioning 'MIG' instead of 'MAG'.

Learning aim B

For distinction standard, learners will give a balanced evaluation of different welding processes with regard to the weldable materials used and their behaviours. For example, their evaluation could cover why temperature differences cause a HAZ and a change in material properties and to the materials' microstructure. In addition, certain materials require the HAZ to be removed for cosmetic reasons and others due to the material becoming hard and brittle. Learners will evaluate the defects found in weldable materials. For example, they could examine how and why a longitudinal crack has occurred along the centre of a weld. They will explore the rationale for propagating cracks and their detection using non-destructive tests, including why it is advantageous to use an x-ray method in some cases and dye penetrate in others.

Learners will also evaluate the effects of forces and loading on welded joints, such as those caused by fatigue. For example, the internal structure of the weld may be porous or contain internal tensile stresses, which cause the welded joint to fail under fatigue loads. Therefore, it is important to understand the relationship between maximum stress and the loading or cyclic loading on the weld.

Overall, the justification will be easy to read and understand by a third party, who may or may not be an engineer.

For merit standard, learners will give a balanced analysis of different welding processes with regard to weldable materials and their behaviours. For example, they could cover why it is important to remove the thin layer of aluminium oxide before welding and the effect on temperatures and the cleaning solution that gives the best and safest results. Learners will also give a rationale for welding defects. For example, some metals, such as pure aluminium, do not show any colour change due to temperature increase which makes it difficult for technicians to know when to start welding.

Learners will analyse the effects of forces and loading on welded joints. Their analysis will cover why the creation of stress points is an issue in welded joints and how the application of preheating or stress relieving can mitigate this issue.

Overall, the analysis will be logically structured, be technically accurate and easy to understand.

For pass standard, learners will give a balanced explanation of the materials and their behaviours during welding. For example, they could cover why it is important to use the correct flux so that it may improve the alloying elements across the arc. Learners will give reasons for fractures occurring and the testing methods employed. For example, hidden porosity or lack of fusion and a destructive test such as 'nick break' may be used to check for this. Non-ferrous alloys have different material properties when compared to alloyed or unalloyed steels. For example, pure aluminium is very reactive and an oxide film forms quickly. This oxide needs removing before welding, but it is highly flammable, especially when mixed with steel dust.

Learners will also explain the effects of forces and loading on welded joints. For example, the effect on loaded joints of an effective throat thickness to ensure that sufficient heat is generated to give a good bond between the parent metal and the weld metal. This would then enable the weld to carry the designed forces.

Overall, the evidence, such as a report, will be logically structured, although basic in parts. Learners will likely include minor technical inaccuracies relating to engineering terminology, such as mentioning 'stress' instead of 'strain'.

Learning aim C

For distinction standard, learners will refine during the process the WPS plan to ensure that the equipment parameters and settings produce 'good' results, and that all preparation is completed methodically and thoroughly. For example, learners could discuss and decide on the most appropriate welding settings for voltage, wire speed and gas flow rates to ensure a 'good' weld using a specific material and electrode. Learners will select appropriate materials and welding positions to successfully complete two welds safely and accurately. The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners may select a vertical up-weld, in 3 mm low-carbon steel plate, using the MMA process for one weld, while ensuring it meets the appropriate weld specification. Effectiveness and efficiency of weld production will also be demonstrated, for example:

- effectiveness will be evidenced by considering the electrode selection and welding parameters to complete the weld with compliance to all safety requirements
- efficiency will be evidenced by optimising run speed and monitoring for weld quality to ensure there are no distortion, cracks, or porosity and minimising slag.

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 procedures followed, together with accurately and correctly completed planning and checking documentation for each of the tasks completed. Learners' evidence, such as annotated photographs and observation records, will show clearly how they worked effectively, efficiently, accurately and safely during the welding processes.

For merit standard, learners will create a detailed and accurate WPS plan to ensure that the correct equipment is selected for the process and all preparation is completed. For example, learners will probably follow the vast majority of the manufacturers' recommended settings, except to use trial and error to select the most appropriate gas flow rate setting to ensure enough heat is available without burning a hole in the component. Learners will select appropriate materials and welding positions to successfully complete two welds. The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners could select a flat fillet weld, in 6 mm low-carbon steel plate, using MIG safely and accurately, ensuring it meets the appropriate weld specification.

Overall, the evidence will be logically presented, technically accurate and easy to understand. It will include the safe working practices that were applied throughout the welding tasks. Learners' evidence, such as annotated photographs and observation records, will show clearly how working accurately and safely was considered throughout the welding processes.

For pass standard, learners will create a welding plan to ensure that suitable equipment is selected for each welding process and some preparation is completed. Learners will probably follow the manufacturers' recommended settings for all parameters. Learners will select appropriate materials and welding positions to successfully complete two welds, using two different welding processes (two welds for each process). The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners could safely produce a flat butt weld, in 2 mm aluminium sheet, using the TIG process for one weld, while ensuring it meets the appropriate welding specification.

Overall, any supporting evidence may be limited, for example there may only be some evidence of preparation tasks and the inspection documentation may lack the required detail. Learners' evidence, such as annotated photographs and observation records, will show clearly how working safely was considered and applied throughout the welding tasks.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 24: Maintenance of Mechanical Systems
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and fabrication organisations with expertise of welding
- contribution of ideas to unit assignment/project materials.

Unit 14: Electrical Installation of Hardware and Cables

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners develop knowledge and skills to interpret electrical circuit diagrams and protection systems, and install lighting and power circuits safely.

Unit introduction

Although we rely on electrical appliances, many people have little understanding of how electricity arrives safely at its point of use, or appreciate the safety requirements for different applications.

This unit gives you an understanding of the circuits found in domestic and commercial installations. You will gain practical experience investigating and constructing common circuits and systems. You will learn about statutory and non-statutory regulations and their application, for example how to select cables for a specific current carrying capacity, and choose the correct type and rating of protective devices, including the design and provision of protection systems. Electrical engineering technicians install, maintain and repair electrical equipment and controls in a wide range of locations and industries.

This unit helps to prepare you for employment, for example as an electrical engineering technician, as part of an apprenticeship, or for entry to higher education to study, for example, electrical engineering.

Learning aims

In this unit you will:

A Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations

B Interpret lighting and power circuit diagrams for domestic and commercial applications

C Select materials and documentation for an electrical installation

D Develop an electrical installation that incorporates different types of circuits in compliance with current regulations.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations	**A1** Types of electrical installation **A2** Statutory and non-statutory regulations **A3** Reducing the risk of electrical shock **A4** Circuit protection methods	A report detailing the requirements of appropriate statutory and non-statutory regulations, circuit protection methods and identifying areas of increased risk.
B Interpret lighting and power circuit diagrams for domestic and commercial applications	**B1** Lighting circuits for domestic installations **B2** Power circuits for domestic installations **B3** Circuits for commercial installations	A report analysing given domestic and commercial electrical installations in terms of the suitability of components to meet the requirements of regulations and guidance relative to the application.
C Select materials and documentation for an electrical installation	**C1** Cables **C2** Connectors **C3** Wiring enclosures **C4** Sustainability	Safe construction of an electrical installation (preferably wall mounted) together with a log detailing construction, testing, calculations, circuit layout and construction plans, photographs, one or more observational witness statements and a formal assessment of the final installation, with reference to how sustainability issues have been considered.
D Develop an electrical installation that incorporates different types of circuits in compliance with current regulations	**D1** Safe working practices **D2** Safe working procedures **D3** Circuit testing	

Content

Learning aim A: Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations

A1 Types of electrical installation

Electrical installations have been classified here as either:

- domestic – as defined in Section 2.2 of Part P of Schedule 1 to the Building Regulations
- commercial, e.g. retail units, offices, industrial factories and warehouses.

A2 Statutory and non-statutory regulations

The scope, object, principles and use of relevant parts of statutory wiring, installation and site regulations or other relevant international equivalents to include:

- Institute of Engineering and Technology (IET) wiring regulations, BS 7671:2008 incorporating amendment 3:2015, and relevant guidance notes
- Building Regulations 2010 – Approved document P: Electrical safety – Dwellings
- Electrical Equipment (Safety) Regulations 1994
- and/or other relevant international equivalents.

A3 Reducing the risk of electrical shock

- Identification of the sources of the risk of electrical shock in specific situations, and their reduction through the application of the knowledge of competent persons' schemes, when and how they should be applied.
- Areas of increased risk of electrical shock, e.g. rooms containing a fixed bath or shower (zones 0–2), sauna, swimming pool and equipment outside the equipotential zone, including a shed, garage, workshop, garden, pond.
- Voltage bands and their segregation, e.g. segregation of Band I and Band II circuits.

A4 Circuit protection methods

Knowledge of the construction, operation and application of:

- low-voltage switchgear to European harmonised standard BS EN60439-3 or similar international standard, to include:
  - electrical protection
  - safe isolation from live parts
  - local or remote switching
- over-current protection devices to include:
  - fuses, e.g. cartridge
  - miniature circuit breaker (MCB)
  - residual current breaker with overload protection (RCBO)
- circuit protection methods to include:
  - earthing and bonding:
    - earthed equipotential bonding and disconnection of supply (EEBADS or EEBADOS)
    - earthed neutral system, system classification (terra-terra (TT), terra-neutral (TN), with combined (C) and separate (S) variations (TN-C, TN-S, TN-C-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 II equipment, Class III 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.

Learning aim B: Interpret of lighting and power circuit diagrams for domestic and commercial applications

B1 Lighting circuits for domestic installations

Interpretation of lighting circuit diagrams to identify components and circuit types to include:

- connections, one way, two way loop-in
- switches, one way, two way
- lamp types, e.g. halogen, light-emitting diode (LED), fluorescent, compact fluorescent
- cable properties
- types of connectors
- types of wiring enclosures
- ancillary components, including luminaires, fittings, brackets, clips.

B2 Power circuits for domestic installations

Interpretation of power circuit diagrams to identify components and circuit types to include:

- fused plug socket outlet
- ring circuit
- radial circuit
- switched fused spur
- other, e.g. cooker, immersion heater, heating control, shower, external supplies.

B3 Circuits for commercial installations

Knowledge and understanding of circuits for commercial installations to include:

- classification of commercial buildings, e.g. A1 shops and B2 general industrial
- compliance with standards
- operational conditions
- isolation and switching
- protection against shock, e.g. provision of RCDs
- lighting, e.g. fluorescent lamps, luminaires, high intensity discharge lamps, such as high-pressure sodium (HPS) lamps, high-pressure mercury (HPM) lamps.

Learning aim C: Select materials and documentation for an electrical installation

C1 Cables

- Knowledge of the construction and properties of cables to include multi and single core, and insulation materials to be used, including poly vinyl chloride (PVC), cross-linked polyethylene (XLPE), low smoke and fume (LSF), low smoke halogen free (LSHF), mineral insulated (MI), steel wire armoured (SWA).
- Selection of suitable cables for different applications, including cable type, voltage and current rating, and the use of a cable size calculator and standard tables.
- Selection of cable identification systems.

C2 Connectors

- Selection of appropriate connectors, including terminal blocks, high density module blocks, pins, ground/earth points, threaded and bayonet multi-pin couplings, plugs, rack and panel connectors, and other consumables required to complete safe construction.

C3 Wiring enclosures

- Selection of appropriate wiring enclosures to include conduit (PVC and metallic), basket and ladder systems, and ducting systems.

C4 Sustainability

Promote the practice of energy efficiency through the:

- optimisation of installation design
- selection of energy efficiency products, e.g. low-energy lighting systems
- reduction of waste
- increase in the use of recyclable materials
- elimination or reduction in use of hazardous substances.

Learning aim D: Develop an electrical installation that incorporates different types of circuits in compliance with current regulations

D1 Safe working practices

- Carry out an assessment of safe working practices to mitigate hazards that have been identified through the hazard identification process.
- Follow correct procedures to obtain permissions and carry out safe isolation before working.
- Check test instruments are appropriate, fit for purpose and in calibration.

D2 Safe working procedures

Lighting and power circuits installation in accordance with Institute of Engineering and Technology (IET) wiring regulations or other relevant international equivalent to include:

- use of tables and/or cable size calculators (including software apps) to select cable type and size
- preparation of cables and electrical connectors for termination, for example for crimping or soldering
- selection and use of circuit components to include consumer unit/circuit isolation device, light switching, e.g. 1-gang, 2-gang, 1-way, 2-way, intermediate
- power socket outlets to include ring, radial, switched fused spur connection units
- other types of power circuits requiring individual consideration, e.g. immersion heater, heated towel rail.

D3 Circuit testing

Systematic testing of circuits to verify:

- compliance with circuit diagram
- operation of switches
- circuit continuity
- polarity, insulation resistance
- operation of RCDs
- earth fault loop impedance.

Documentation to include a formal test record to confirm the safety and integrity of the installation in accordance with current IET or other relevant international equivalent wiring regulations, using appropriate forms.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations</td><td rowspan="2">A.D1 Evaluate, using language that is technically correct and of a high standard, the requirements of at least four statutory and non-statutory safety regulations used in installations, including circuit protection methods and how the risk of electrical shock is reduced.</td></tr>
<tr><td>A.P1 Explain the requirements of four statutory and non-statutory safety regulations used in installations.
A.P2 Explain how the risk of electrical shock is reduced in the two types of installation and the operation and applications of circuit protection methods.</td><td>A.M1 Analyse the requirements of at least four statutory and non-statutory safety regulations used in installations, including circuit protection methods and how the risk of electrical shock is reduced.</td></tr>
<tr><td colspan="2">Learning aim B: Interpret lighting and power circuit diagrams for domestic and commercial applications</td><td rowspan="2">B.D2 Justify the design, including compliance to safety regulations, of a domestic and a commercial electrical circuit diagram, each containing two lighting and two power circuits.</td></tr>
<tr><td>B.P3 Explain the function of the components used and compliance to safety regulations in a domestic and a commercial circuit diagram, each containing two lighting and two power circuits.</td><td>B.M2 Analyse the design, including compliance to safety regulations, of a domestic and a commercial circuit diagram, each containing two lighting and two power circuits.</td></tr>
<tr><td colspan="2">Learning aim C: Select materials and documentation for an electrical installation</td><td rowspan="4">CD.D3 Refine, during the process, the development of an accurate, effective and efficient electrical installation containing at least five circuits safely from a given design, while taking account of sustainability and safety.</td></tr>
<tr><td>C.P4 Select, using appropriate calculations, the components, consumables and documentation for an electrical installation containing at least five circuits, while taking account of sustainability and safety.</td><td>C.M3 Select effectively, using appropriate calculations, components, consumables and documentation for an electrical installation containing at least five circuits, while taking account of sustainability and safety.</td></tr>
<tr><td colspan="2">Learning aim D: Develop an electrical installation that incorporates different types of circuits in compliance with current regulations</td></tr>
<tr><td>D.P5 Construct an electrical installation containing at least five circuits safely from a given design.
D.P6 Test the electrical installation safely and repair any functional faults.</td><td>D.M4 Develop an accurate and effective electrical installation containing at least five circuits safely that function as intended.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.M2, B.D2)

Learning aims: C and D (C.P4, D.P5, D.P6, C.M3, D.M4, CD.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- suitably equipped workshops for the installation of electrical circuits, preferably with installation onto walls or, where necessary, boards, together with relevant test equipment to carry out tests to prescribed regulations
- a range of wiring diagrams, test rigs and wiring boards, electrical tools, components and cabling required for lighting and power installations
- appropriate documentation such as statutory and non-statutory regulations, e.g. BS 7671:2008 incorporating amendment no. 3:2015, IEC 60364 series, IEC 61557 (EN61557), IEC 6101 (EN6101), manufacturers' catalogues, data sheets and relevant cable, component and equipment specifications
- a software cable size calculator – this would be beneficial but is not essential.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of at least four statutory and non-statutory regulations relating to domestic and commercial electrical installations. Learners will make comparisons and consider alternatives between the domestic and commercial regulations, the operation and applications of at least three circuit protection methods and how the risk of electrical shock can be reduced. For example, in locations containing a bath or shower, all circuits in or passing through the location must be protected by the use of one or more RCDs not exceeding 30 mA; this requirement means serving or passing through the bathroom and is not limited to circuits within the zones.

Overall, the evidence will be easy to read and will be understood by a third party who may or may not be an engineer. It 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.

For merit standard, learners will analyse the safety requirements of domestic and commercial electrical installations. Learners will produce a methodical and detailed review of at least four statutory and non-statutory regulations, including how the risk of electrical shock can be reduced and the operation and applications of at least three circuit protection methods. For example, in locations containing a bath or shower, all circuits of the location must be protected by the use of RCDs. They will also cover the interrelationships between the regulations. For example, sections of the IET wiring regulations, BS 7671:2008, apply to all installations – 'Good workmanship by skilled (electrically) or instructed (electrically) persons and proper materials shall be used in the erection of the electrical installation' – while others refer to more specific detail, for example outdoor lighting installations (Section 714).

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the requirements of four statutory and non-statutory regulations relating to domestic and commercial electrical installations. For example, Part P of the Building Regulations states that the installation of a new circuit must be undertaken or reviewed and signed off by a registered electrician.

Learners' evidence will explain how the risk of electrical shock is reduced, for example by defining areas of increased risk of shock. They will also explain the operation, including construction, of at least three common circuit protection methods to include fuses, miniature circuit breakers (MCB), residual current breakers with overload protection (RCBO), residual current devices (RCD), earthing and bonding methods. The suitable applications for each device will also be given.

Overall, the evidence, such as a report, will be logically structured. It may be basic in parts, the requirements of the regulations may not be fully explained, or it may contain minor inaccuracies or omissions, for example the difference between MCBs and RCDs may not be clear.

Learning aim B

For distinction standard, learners will justify the design of a domestic and a commercial electrical installation, each of which will include at least two lighting and two power circuits. Learners' justifications will be consistent and relate the design to current statutory and non-statutory safety regulations. For example, a consumer unit should be designed, manufactured and tested to the European harmonised standard BS EN60439-3: low-voltage switchgear and control gear assemblies.

Overall, the evidence will be logically structured, be technically accurate and be easy to understand by a third party who may or may not be an engineer.

For merit standard, learners will analyse designs for one domestic and one commercial electrical installation, each containing at least two lighting and two power circuits. They will relate component choice to current statutory and non-statutory safety regulations. For example, a consumer unit should be accessible, with the devices mounted at a height no greater than 1.2 m above the floor.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the function of components in at least two lighting and two power circuits for a domestic and a commercial electrical installation. Learners may not cover the function of all the components in the installation and the function of hardware consumables, for example fixings should not be included. Learners will also make reference to relevant safety regulations that impact on the design of each installation.

Overall, the evidence, such as a report, will be logically structured. It may be basic in parts, for example descriptions may lack detail, or it may contain some minor inaccuracies or omissions, for example cable calculations may have minor numerical inaccuracies or omit units.

Learning aims C and D

For distinction standard, learners will refine, during the process, the development of an accurate, effective and efficient electrical installation containing at least five circuits from a given design, while taking account of sustainability and safety. Learners will prioritise tasks and use time efficiently. They will justify the selection of hardware and cables with regard to the principles of sustainability in terms of energy efficiency, the use of recyclable materials, reduction in waste and the elimination of hazardous materials. For example, cable runs will be designed to minimise the amount of cable used while taking into account factors such as direction (horizontal or vertical but not diagonal) and minimum bend radii and client requirements. The test and inspection evidence, such as a report, will fully document the results using forms compatible with sector guidance and industry standards. All the work will be carried out with due regard to safe working practices and procedures.

Overall, the evidence, including calculations, drawings and test reports, will be logically structured, technically accurate and easy to understand by a third party who may or may not be an engineer. The practical activity will be carried out safely, using safe working practices and procedures to a good technician standard.

For merit standard, learners will demonstrate that they have selected suitable components and consumables effectively, using appropriate calculations, for either a domestic or commercial electrical installation, that contains at least five circuits. They will take account of sustainability while selecting appropriate hardware and cables. Relevant safety information and manufacturers' data sheets will be chosen to demonstrate how safety information will be applied, for example using a technical data sheet to select a suitable 2 pole 2 module 40 A 230 V RCD with 30 mA tripping current.

Learners will develop (construct and test) an accurate installation effectively which meets the requirements of the current regulations and manufacturers' data sheets. For example, learners will plan tasks and use time well, cables will be straight, without twists, and routed appropriately given the environment. There may be some minor issues which can be easily rectified, for example a stray 'whisker' from a multicore cable escaping from a connector. Learners will complete accurate visual and numerical tests on the installation and provide inspection evidence, such as a report, documenting the results using forms compatible with sector guidance in line with industry standards. There may be some omissions or minor errors, for example the type of earthing arrangement may not be sufficient. The circuits will function as intended.

Overall, the practical activity will be carried out safely, using safe working practices and procedures, and to a good standard. The documentary evidence will be structured logically. It may be basic in parts, for example descriptions may lack detail, or it may contain minor inaccuracies or omissions, for instance the insulation resistance may be measured but not compared with acceptable values (Table 61 BS 7671).

For pass standard, learners will demonstrate that they have selected suitable components, and consumables, using calculations where necessary, for either a domestic or commercial electrical installation containing at least five circuits. Their selection will consider the issue of sustainability, for example waste reduction. Relevant safety information and manufacturers' data sheets will also be chosen in preparation for constructing the circuit.

Learners will construct the electrical installation using the given design to meet current regulations. However, there may be some issues that need to be rectified before testing, for example a cable path may be off-line or exceed the stated maximum bend angle.

Learners will test their circuits and complete test and inspection evidence, such as a report, documenting the results using forms compatible with sector guidance. There may be some omissions or minor errors in testing, for example the insulation resistance may not have been measured. Learners will also repair any functional faults in the circuits.

Overall, the practical activity will be carried out safely, using safe working practices and procedures, and to an acceptable standard. The documentary evidence will be logically structured. It may be basic in parts, for example supporting evidence may lack detail and contain minor inaccuracies in the numerical calculations, or omissions.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 15: Electrical Machines
- Unit 16: Three Phase Electrical Systems
- Unit 18: Electrical Power Distribution and Transmission.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electricians
- contribution of ideas to unit assignment/project materials.

Unit 15: Electrical Machines

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the safe operation of electrical machines such as direct current (DC) motors and their practical applications in industry.

Unit introduction

Electrical machines are an important but often unseen part of modern engineering products and systems. For example, the air-conditioning system on an aircraft contains an electric motor at its heart, while in the home, food processors and fan ovens have electric motors.

You will explore the safe operation, including construction, of the most common electrical machines, from step-up/down transformers commonly used in stabilised power supplies, through to direct current (DC) and alternating current (AC) motors. You will study single-phase machines and the more common three-phase induction machines used in industry.

As an electrical engineer you may need to safely operate, maintain and repair electrical machines. To do this well, and to design feasible solutions to engineering problems, you need to incorporate electrical machines as well as theoretical and practical skills. This unit prepares you for an electrical, electronic or mechatronic-based engineering apprenticeship, for higher education and for technician-level roles such as that of electrician and electrical fitter.

Please note that you may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, you cannot take both.

Learning aims

In this unit you will:

A Examine how to operate electrical machines safely to prevent injury or loss of life

B Explore the safe operation of direct current electrical machines as used in industry

C Explore the safe operation of alternating current electrical machines as used in industry.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine how to operate electrical machines safely to prevent injury or loss of life</td><td>A1 Health and safety requirements for the safe operation of electrical machines
A2 Risk assessment</td><td>A report exploring how key regulations and guidance notes relate to the safe operation of electrical machines.
A risk assessment and evaluation on testing electrical machines.</td></tr>
<tr><td>B Explore the safe operation of direct current electrical machines as used in industry</td><td>B1 Function and operation of electrical test meters
B2 Operation of DC motors and generators
B3 Control circuits used in DC motors
B4 Applications of DC machines</td><td rowspan="2">A portfolio of results gathered through practical experiments to safely explore the operation of electrical machines, including construction and appropriate control circuitry, and to justify the selection of the most appropriate machine for an application. Supported by a developmental logbook, images, observations records, theoretical data and calculations.</td></tr>
<tr><td>C Explore the safe operation of alternating current electrical machines as used in industry</td><td>C1 Function and operation of electrical test meters
C2 Operation of single-phase AC transformers
C3 Operation of single-phase AC machines
C4 Operation of three-phase AC induction motors
C5 Control circuits used in AC motors
C6 Applications of AC machines</td></tr>
</table>

Content

Learning aim A: Examine how to operate electrical machines safely to prevent injury or loss of life

A1 Health and safety requirements for the safe operation of electrical machines

- Key features of regulations, or other relevant international equivalents, including:
  - Electrical Equipment (Safety) Regulations 1994 and amendments, for example outlining how equipment is safe, well maintained and constructed to CE (*Communauté Européenne*) standards
  - Machinery directives, including British and International Standards (BS 7671 and 17th Edition IEE Wiring Regulations), e.g. covering the correct rating of protection devices.
- Guidance notes or other relevant international equivalents, including:
  - GS38 electrical test equipment for use by electricians, e.g. outlining safe isolation procedures and when working live is permitted
  - codes of practice for specific industries, for example Civil Aviation Authority (CAA) for aeronautical engineers and the Institution of Electrical Engineers (IEE) for electrical and electronic engineers.

A2 Risk assessment

Risk assessment of the working environment and specific requirements to operate and test DC and AC electrical machines. To include hazard identification and classification.

- Defining a hazard, including any that can cause an adverse effect, e.g. rotating machinery causes an entrapment hazard to loose clothing/hair.
- Defining risk of the severity of any hazard, normally calculated as a risk rating of likelihood multiplied by severity.
- Putting control measures in place to reduce risk, e.g. using correctly rated and shrouded cables and guarding rotating components.
- Five steps of a risk assessment as defined in the Health and Safety Executive (HSE) template.

Learning aim B: Explore the safe operation of direct current electrical machines as used in industry

B1 Function and operation of electrical test meters

- Function and operation of a volt, amp and watt meter, including:
  - how watt meters can be connected to a voltage coil across the load
  - how an amp meter can be connected in series with the load to calculate power output ($P = VI$)
- Function and operation of a swinging field dynamometer, including:
  - switching off the power to the meter when it is not in use
  - how to set torque to zero before testing.

B2 Operation of DC motors and generators

- Purpose of pole segments and field windings to create a fixed magnetic field, as determined by Fleming's right-hand rule.
- Interaction of the fixed magnetic field with an armature winding to create movement, as determined by Fleming's left hand rule and rotation due to the armature being fixed at a central pivot point.
- Connection of the field and armature windings to create three types of DC motor, series, shunt and compound, and the difference in operation between all three.
- Construction of the rotor with conductor coils embedded within a laminated iron core to increase magnetic field strength and reduce power losses due to eddy currents.

- Purpose of input voltage commutation and how the commutator component achieves this.
- Starting issue with the use of single commutator segments and how these issues are minimised.
- Current contact with the armature windings through carbon brushes and the reasons for using carbon, to include good electrical conductivity, self-lubricating material and reduced switching noise.
- Causes and consequences of overheating motors, including reduced power output.
- Methods for cooling motors to include:
  - fins on the yoke to increase surface area
  - fan on the rotor to create forced air cooling during operation.
- Measurement of speed and torque characteristics in DC motors (series, shunt and compound) to include:
  - input current and input voltage
  - power output $P_{out} = \frac{2\pi\tau N}{60}$ and motor efficiency, $\eta = \frac{P_{out}}{P_{in}}$
  - the effect of cogging torque on the motor and how it can be minimised, including using skewed poles.
- Measurement of speed and torque characteristics in DC generators:
  - terminal voltage and current
  - voltage regulation of the generator using a fixed speed and a range of output loads.

B3 Control circuits used in DC motors

- Speed control methods for DC machines to include field weakening and rheostat (variable resistor) control.
- The use of starting circuitry in DC motors to avoid large spike in current on start-up created by the absence of back electromotive force (emf). Understand the operation of a faceplate starter circuit to help overcome this problem.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips, how these devices are connected to the control circuitry.

B4 Applications of DC machines

The selection of DC motors and generators for different applications, including:

- a shunt motor is used as an electric vehicle drive motor, in a robot arm and as part of an aircraft's autopilot system
- a series motor is used as a car starter motor
- a DC generator (dynamo) is used as a power source for bicycle lights.

Learning aim C: Explore the safe operation of alternating current electrical machines as used in industry

C1 Function and operation of electrical test meters

- Function and operation of a volt, amp and watt meter, including:
  - how watt meters can be connected to a voltage coil across the load
  - how an amp meter can be connected in series with the load to calculate power output ($P = VI$)
- Function and operation of a swinging field dynamometer, including:
  - switching off the power to the meter when it is not in use
  - how to set torque to zero before testing.

C2 Operation of single-phase AC transformers

- Construction of primary and secondary windings to include the diameter of the wire and insulation methods, e.g. varnish or shellac, to avoid short circuiting.
- Principles of mutual induction, where an alternating current creates a changing magnetic field around one coil that creates a changing current in the secondary coil.

- Both coils being wound on a ferromagnetic core (soft iron) to increase the efficiency of the transformer through increasing the flux density.
- Transformer efficiency to include transformer losses, eddy currents, magnetic leakage and power losses, I^2R
- Different methods for winding the coils to help reduce leakage losses, including shell, core and toroidal types of transformer.
- Lamination of the soft iron core to reduce eddy current power losses.
- Additional secondary windings on the same primary core allowing for multiple output voltages from a single input and negligible voltage losses.
- Measurement of single-phase transformer characteristics to include:
  - input and output voltage, current and power
  - ideal transformer equation $\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
  - transformer efficiency, $\eta = \frac{P_{out}}{P_{in}}$

C3 Operation of single-phase AC machines

- Field windings in a single-phase AC motor generate a magnetic field.
- The smoothness of the machine's rotation is determined by the number of pole pairs that each create an additional magnetic field.
- The rotor has conductors embedded in a laminated iron core, which needs a permanent connection to the power supply to operate. This is achieved through the use of slip rings and carbon brushes.
- Single-phase AC motors require starting circuitry to set up a magnetic field allowing the motor to operate.
- Single-phase AC generators produce an AC waveform, where the terminal voltage is proportional to the speed of rotation.

C4 Operation of three-phase AC induction motors

- The stator in three-phase induction motors generates a rotating magnetic field.
- Synchronous speed is calculated by $n_{sync} = \frac{f \times 60}{P}$
- Wound rotors and squirrel-cage rotors use laminations in the core to reduce power losses.
- Understand how a current is induced in the rotor bars or windings and how this current produces torque in the rotor.
- For wound rotor motors the purpose of slip rings and brushes is to continuously connect the windings to the alternating power supply during operation. Benefits of wound rotor motors in using starting circuits include access to the windings so that increased resistance can be added and removed in resistance starters.
- Definition of slip speed is the difference between shaft speed and synchronous speed and also how to determine slip as a percentage of the rated speed $\frac{n_{sync} - n_m}{n_{sync}}$
- Speed control of three-phase induction motors to include variable frequency drives, inverters and pulse width modulation (PWM) systems.
- Measurement of single- and three-phase induction motor characteristics to include:
  - single-phase motor currents on start-up and the phase shift required to self-start
  - synchronous speed for an induction motor with a known number of poles
  - motor shaft speed and motor slip
  - torque versus speed for induction motors.
- Input power, current and voltage using $\sqrt{3}V_L V_l \cos\phi$ and output power using $P_{out} = \frac{2\pi\tau N}{60}$ to calculate the efficiency of the induction motor.

C5 Control circuits used in AC motors

- Types of single-phase AC motor starting circuits include capacitor start, capacitor start and run, shaded pole and split phase. Understand how each method creates two separate magnetic fields that are out of phase with each other, causing the rotor to start moving.
- Circuit diagrams and operation of starter circuits to include direct on line (DOL), star-delta and rotor resistance.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips, and how all devices are connected into the control circuitry.

C6 Applications of AC machines

The selection of AC motors, transformers and generators for different applications, including:

- a three-phase induction motor is used as a lathe drive motor and as part of an air-conditioning unit in cars and aircraft
- a step-up/down transformer is used as a laptop power supply
- a single-phase generator is used as an alternator in a car engine.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine how to operate electrical machines safely to prevent injury or loss of life</td><td rowspan="2">A.D1 Evaluate, using language that is technically correct and of a high standard, the local risk assessments against relevant regulations and guidance notes, justifying appropriate control measures for electrical machines.</td></tr>
<tr><td>A.P1 Explain how one regulation and one guidance note relate to the safe operation of electrical machines.
A.P2 Produce a risk assessment on operating a range of electrical machines safely.</td><td>A.M1 Compare the practicality of the risk assessment against local control procedures already in place to manage hazards from electrical machines.</td></tr>
<tr><td colspan="2">Learning aim B: Explore the safe operation of direct current electrical machines as used in industry</td><td rowspan="4">B.D2 Evaluate the DC electrical machines, comparing the results from safely conducted experiments and theoretical curves and calculations, and explain the conditions for optimal performance and suitable applications.
C.D3 Evaluate the operation of AC electrical machines, comparing the results from safely conducted experiments and theoretical curves and calculations, and explain the conditions for optimal performance and suitable applications.</td></tr>
<tr><td>B.P3 Conduct experiments safely to determine the characteristics of two types of DC motor and a DC generator.
B.P4 Explain, using the experimental results and theoretical data, how the two DC motors and a generator operate, including any required control circuitry, and suggest suitable applications.</td><td>B.M2 Conduct experiments accurately and efficiently to determine the characteristics of three types of DC machine.
B.M3 Analyse, using the results and theoretical data and calculations, the operation of three types of DC machine.</td></tr>
<tr><td colspan="2">Learning aim C: Explore the safe operation of alternating current electrical machines as used in industry</td></tr>
<tr><td>C.P5 Conduct experiments safely to determine the characteristics of a single-phase transformer, motor and generator and a three-phase motor.
C.P6 Explain, using the experimental results and theoretical curves, how the single-phase transformer, motor and generator and a three-phase motor operate, including any required control circuitry, and suggest suitable applications.</td><td>C.M4 Conduct experiments accurately and efficiently to determine the characteristics of four AC machines.
C.M5 Analyse, using the results and theoretical curves and calculations, the operation of four AC machines.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aims: B and C (B.P3, B.P4, C.P5, C.P6, B.M2, B.M3, C.M4, C.M5, B.D2, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- two of the three types of DC motor, series, shunt and compound – note that the shunt motor can also be used as a DC generator
- at least one single-phase AC transformer, a single-phase AC capacitor start or start and run AC motor, and a three-phase AC induction motor
- associated test meters and equipment, including voltmeters, ammeters, watt meters and a dynamometer
- feedback systems which produce a series of modular test equipment ideal for the range of experiments to be undertaken, for example the Powerframes series
- a range of health and safety regulations and guidance documents, as specified in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a professional, balanced evaluation of their risk assessment, including the identification of hazards, justification of how they have determined the risk rating and how they selected the control measures. Overall, the evaluation will use correct technical engineering terms and will be written in a way that is easy for a third party, who may or may not be an engineer, to understand.

Learners should evaluate possible alternative approaches, including those found in a locally produced risk assessment (by the school or college), that could have been used to improve efficiency or reduce impact on the operator, while meeting relevant regulations and following guidance notes. For example, learners could suggest placing physical guarding around the entire machine, but that would increase the time it takes to conduct the experiments (or to operate the machines in industry).

For merit standard, learners will produce a comparison of their risk assessment against the local control measures (produced by the school or college) already in place to eliminate and reduce the hazards. The comparison will discuss the practicalities of implementing control measures, including the principle contained in the regulation and guidance documents of being 'reasonably practicable', but not necessarily covering any additional measures highlighted in the risk assessment.

For pass standard, learners will provide evidence explaining, for example, that as part of the Electrical Equipment (Safety) Regulations 1994 and amendments, all equipment should be checked for the CE or BS Kitemark stamp and to check that it is not damaged, before undertaking any work. Learners' evidence may contain some errors in the engineering terminology used, for example stating that current runs 'across a device' rather than 'through' it, and the explanations may be basic in parts. There must be a clear demonstration of knowledge and understanding of the relevant safety documents and their use in the specific sector being studied, for example the aerospace or manufacturing pathway.

Learners will identify all significant hazards and calculate the associated risks. For example, when performing experiments on electrical machines a low likelihood of shock multiplied by high severity of injury would result in a medium risk. Risks should be documented on an agreed risk assessment pro forma. A risk assessment may not identify all the associated hazards, for example a risk assessment should cover the direct risks, such as electrical shock and entrapment in rotating parts, but it might not include manual handling of the machines.

Learning aims B and C

For distinction standard, learners will cover in their reports experiments on three DC and four AC machines. They will evaluate how the machines operate, which will include a justification of the differences between the experimental results and accurate theoretical curves and calculations. For example, differences in the results occur because of stray resistances in the test equipment because of particularly warm or cold conditions when the tests were undertaken, or due to power losses in the machines that are not accounted for in theoretical calculations.

The evaluation should also include evidence on the conditions for optimum machine performance that is backed up by the practical experimentation results and learners' observations.

Overall, the evidence will be logically structured and will use the correct technical engineering terms about the operation of electrical machines.

For merit standard, learners will safely and efficiently set up and carry out the experiments on the electrical machines, specifically on two DC motors, one DC generator, a single-phase transformer, a single-phase motor and a generator and a three-phase induction motor. Circuit diagrams will be followed precisely and learners should choose leads of suitable length to avoid entanglement or trailing leads becoming a hazard. The experimental results will be accurate, neatly tabulated, clearly labelled and graphs will be drawn to scale.

To enhance the explanation of how the machines operate, learners will get at least two other reputable sources of information, which have been correctly referenced. For example, learners will use diagrams from an online source, confirm the test validity using a recommended book, and identify the appropriate components on the tested machine.

Overall, learners will use theoretical calculations and standard data curves to accurately analyse the operation of the DC and AC electrical machines.

For pass standard, learners will select appropriate equipment, connect the equipment in an appropriate way and undertake six experiments safely. Learners will record what they are doing along with their results in a logbook.

Overall, evidence will be logically structured, but there may be some minor inaccuracies in the recording of the results, for example the DC results will tabulate the different starting torques for two different types of DC motors and the proportionality between speed and terminal voltage in a DC generator. The results for the:

- single-phase transformer will include the link between the number of turns and voltage ratio
- single-phase motor will include the phase difference between the current in the start winding and the run winding
- single-phase generator will demonstrate the proportionality between speed and frequency of the terminal voltage
- three-phase induction motor will include the synchronous speed, torque and motor shaft speed.

Learners will prepare evidence on how the machines operate. The evidence will include details on how the machines are constructed and some reference will be made to the underpinning theory and standard curves. For example, the:

- DC shunt motor operates at a relatively constant speed, the experimental results will have been compared with typical curves and an explanation will have been given for why some DC motors contain control circuitry to start
- DC generator should include an explanation of how Faraday's law applies
- single-phase transformer will cover the application of Faraday's and Lenz's laws
- single-phase motor will cover the effect of phase shift in creating a pseudo-rotating magnetic field, the reasons why starting circuitry is needed and an explanation of how the circuitry works
- single-phase generator will cover the link between speed of rotation and frequency of the AC signal and the effect of increasing the number of poles in the machine
- three-phase induction motor will cover synchronous speed and slip as well as determining the torque versus speed characteristic.

Based on the explanation of how the electrical machines operate and from the characteristics observed during experiments, learners should suggest at least two suitable applications for each type of electrical machine.

Overall, the explanations should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 16: Three Phase Electrical Systems
- Unit 17: Power and Energy Electronics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise of electrical machines
- contribution of ideas to unit assignment/project materials.

Unit 16: Three Phase Electrical Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore multiple-phase electricity, its transmission and distribution, and how to calculate and reduce costs.

Unit introduction

Three-phase electrical systems are an integral part of the national grid in the UK and equivalent systems around the world. The majority of industrial electrical applications are based on a standard three-phase supply, for example machines in mechanical workshops, the lifts used in automotive workshops and the mains supply for domestic homes are all based on a three-phase supply. As an electrical engineer you will design and maintain these systems, and in some roles select the most suitable equipment for an application. It is important, therefore, to understand their underlying principles and operation.

In this unit, you will cover the construction and operation of three-phase generators and how they supply electricity to the nation. You will take measurements on three-phase circuits and determine how to reduce costs to the customer.

This unit will help to prepare you for employment as an electrical maintenance technician in both the electrical and manufacturing sectors, and as a technician in the motor vehicle or aerospace sectors. The unit is also a good foundation for progression to higher education.

Learning aims

In this unit you will:

A Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity

B Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally

C Investigate the cost of using three-phase electrical power systems in typical industrial applications.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity	**A1** Construction and operation of synchronous generators **A2** Transmission and distribution networks **A3** Safety considerations on high voltage transmission systems	A written report examining the infrastructure of the national grid (or similar), to include generation transmission, distribution and protection.
B Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally	**B1** Connection methods for three-phase power circuits **B2** Electrical calculations for three-phase power circuits **B3** Electrical measurements for three-phase power circuits	An experimental report based on physical measurements and theoretical calculations, exploring the relationship between currents voltages and powers in three-phase power circuits.
C Investigate the cost of using three-phase electrical power systems in typical industrial applications	**C1** Supply considerations **C2** The cost of using electricity	A written report investigating the cost of using electricity, including tariff structures and power factor correction.

Content

Learning aim A: Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity

A1 Construction and operation of synchronous generators

- Stator construction comprising three windings separated by 120 degrees, giving three phases at the same amplitude in a single rotation.
- Phase sequence, effect of incorrect winding and purpose and impact of harmonisation colours (red, yellow and blue harmonised to brown, grey and black).
- Winding configuration, including distributed windings, salient pole.
- Reduction of power losses by the use of laminated core in the wound rotor.
- Effect of excitation current on power factor of the generator. Slip rings and brushes to make a continuous connection between the windings and the alternating power supply.
- Synchronous speed, calculated by $n_{sync} = \dfrac{f \times 60}{P}$
- Frequency, determined using the number of poles by $f = \dfrac{NP}{60}$
- Definition of 'poles' and 'pole pairs' and the difference between them.
- Effect of rotor excitation current on the power factor of the output, issues regarding power factor when synchronising onto the mains supply.
- Generator operating characteristics, e.g. open circuit response and v-curves.
- Methods of synchronising generators to include signal lamps and synchroscope.

A2 Transmission and distribution networks

Overview of the UK national grid, or other relevant and equivalent national infrastructure, from generator to customer, including:

- diagrammatic representations of the Grid and Supergrid, including operating voltages
- transformer connections, including star-star, star-delta, delta-star
- the role of transmission and distribution companies and responsibilities for different parts of the network
- typical construction of overhead and underground three-phase cables
- considerations required for the use of overhead lines, including tower construction and effect on the environment.

A3 Safety considerations on high-voltage transmission systems

Safety precautions when working with high-voltage electrical systems, including:

- safe isolation procedures, including warning notices, labelling and personal protective equipment (PPE)
- limitation of access and permits to work on both live and non-live systems
- earthing arrangements and regular maintenance procedures for high-voltage (HV) overhead and underground cables
- monitoring and protection equipment used on the high-voltage networks, including:
    - common protection methods, e.g. overcurrent and overvoltage detection devices
    - construction and operation of current transformers and voltage transformers for use in HV protection
    - issues with arcing in HV systems and construction of solutions, e.g. air-blast relays, arcing horns and insulators.

Learning aim B: Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally

B1 Connection methods for three-phase power circuits

- Connection methods to include:
  - four wire balanced resistive star connected loads
  - four wire unbalanced resistive star connected loads
  - four wire balanced reactive star connected loads
  - balanced three wire delta connected resistive and reactive loads
  - utilising circuit and phasor diagrams.
- Line and phase parameters and how determining their value depends upon the connection method.
- Star connection circuit to include:
  - line and phase voltage relationship: $V_{line} = \sqrt{3}V_{phase}$
  - line and phase current relationship: $I_{line} = I_{phase}$
- Delta connection circuit to include:
  - line and phase voltage relationship: $V_{line} = V_{phase}$
  - line and phase current relationship: $I_{line} = \sqrt{3}I_{phase}$
- Relationship between the configurations and the amount of power delivered, e.g. delta connection gives three times more power than star.

B2 Electrical calculations for three-phase power circuits

Calculation of the operation of three-phase power circuits to include:

- calculation of phase voltage and current when given line voltage
- determination of:
  - capacitive reactance $X_C = \dfrac{1}{2\pi fC}$
  - inductive reactance $X_L = 2\pi fL$
- calculation of phase impedance of reactive balanced loads $Z = \sqrt{R^2 + (X_L - X_C)^2}$
- determination of phase currents in unbalanced resistive loads
- calculation of neutral current in four wire balanced and unbalanced systems
- the power triangle, and relationships between true, reactive and apparent powers, including use of watts kVA and kVAr values
- determination of phase angle $\phi = \dfrac{X_L - X_C}{R}$ and power factor $\cos\phi$ of reactive systems
- calculation of phase power and total power in three-phase loads.

B3 Electrical measurements for three-phase power circuits

- Function and operation of a volt, amp, phase and watt meter, including how watt meters can be connected to a voltage coil across the load and an amp meter can be connected in series with the load to calculate power output. ($P = VI$)
- Correct working practices for taking measurements on live high-voltage apparatus, including correct use of shrouded leads and correctly rated equipment.
- Measurements of the operation of three-phase power circuits to include currents, voltages, power dissipated in one phase and the associated three-phase power.
- Blondel's theorem to reduce the number of watt meters required to measure three-phase power in balanced and unbalanced systems.

Learning aim C: Investigate the cost of using three-phase electrical power systems in typical industrial applications

C1 Supply considerations

- Availability of supply to customers, including environmental considerations for installation, and voltage levels at the substations.
- How a single phase supply is taken from a three-phase feed, and how the demand is calculated across the three phases.
- How commercial and industrial supplies differ with respect to distribution voltage levels and the balancing of phases.
- What is meant by maximum demand, how it is determined, and how companies can reduce their usage of electricity.
- Electricity meters:
  - their construction and operation (including smart meters and prepayment meters)
  - how they record usage and how this can be used to inform cost-saving exercises.

C2 The cost of using electricity

- Per unit method of calculating power, and the standard unit of electricity as kWh.
- Tariff structures, using standing charges and unit charges and how these differ between different applications.
- The effect of power factor on the cost of using machines, and how the use of power factor correction (PFC) equipment can reduce costs.
- PFC calculations, to include:
  - annual savings when using PFC (cost without correction – cost with correction)
  - cost of implementation of PFC
  - depreciation of PFC equipment.
- Equipment used to correct power factor in industry to include: individual capacitors on single machines and capacitor banks used on large supplies.
- Calculations of the cost of electricity, to include:
  - comparisons between tariffs
  - cost of implementing PFC and potential yearly savings.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity		
A.P1 Explain the construction and operation, including calculation, of a synchronous generator that is part of a national grid system. **A.P2** Describe the electrical transmission and distribution networks that form part of a national grid system. **A.P3** Explain the operation of at least three safety devices used as part of a national grid system.	**A.M1** Analyse the generation, transmission and distribution system required to supply electricity as part of a national grid system.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the safe supply of electricity by a national grid system.
Learning aim B: Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally		
B.P4 Conduct experiments safely to determine the operation of balanced and unbalanced resistive and reactive loads in star and delta connected circuits. **B.P5** Explain, using the experimental results and theoretical calculations, how balanced and unbalanced resistive and reactive loads in star and delta connected circuits operate.	**B.M2** Conduct experiments accurately to determine the operation of balanced and unbalanced resistive and reactive loads in star and delta connected circuits. **B.M3** Analyse, comparing the results and calculations, how balanced and unbalanced resistive and reactive loads in star and delta connected circuits operate.	**B.D2** Evaluate how three-phase power circuits operate, comparing the results from safely conducted experiments and theoretical calculations, suggesting improvements to the experimental procedures.
Learning aim C: Investigate the cost of using three-phase electrical power systems in typical industrial applications		
C.P6 Explain how the maximum electricity demand for a industrial/commercial customer is determined. **C.P7** Calculate the cost of electricity for two given engineering companies.	**C.M4** Compare at least two electricity tariffs and select the most cost-effective solution for two given engineering companies.	**C.D3** Justify the choice of tariff and potential cost savings possible through the use of power factor correction for a given engineering company, which forms part of a comparison of costs and tariffs for two companies.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.P5, B.M2, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a three-phase supply and resistive, capacitive and inductive load banks
- electrical tariffs for commercial usage from a range of suppliers for comparison purposes
- a range of health and safety regulations and guidance documents, as specified in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a balanced evaluation of the complete electrical journey, from synchronous generator through to the customer. Learners will fully explain the purpose and justify the presence of all safety equipment and the transmission medium used at each stage, for example justify using overhead cables rather than underground cables. They will correctly identify the points at which the responsibility for the supply changes between the different companies, for example where the generating company's responsibility ends and that of the national grid starts.

Overall, learners' 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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse elements of electrical supply from generation to the customer, for example how synchronous generators are constructed and operated, how they are synchronised onto a national grid (infinite bus bar), and the requirements to protect the supply system. Learners will discuss the need for organised maintenance across all generating companies to keep the supply constant and how the supply companies may need to work 'live' as it is not practicable to remove a generator for emergency maintenance without jeopardising the supply.

Overall, learners' evidence should be logically structured, be technically accurate and be easy to understand.

For pass standard, learners will provide evidence to explain the construction of a synchronous generator and how it is synchronised onto a national grid using lamps and/or a synchroscope. Learners will describe the layout of the supply chain, generation, transmission and distribution, and explain the construction of at least three safety devices used when working with high-voltage electricity.

Overall, learners' evidence will be logically structured. The evidence may be basic in parts, for example there may be some omissions in the descriptions of the infrastructure, such as a missing substation or incorrect voltage levels used at certain points. It may also contain minor technical inaccuracies relating to engineering terminology, such as apparent power ratings being given in watts.

Learning aim B

For distinction standard, learners will present a detailed evaluation, using the experimental results and theoretical calculations, on how the three-phase power circuits operate. Learners will justify the differences between the various configurations. They will include accurate diagrams and use these as a benchmark to judge their experimental findings against. Learners should also consider improvements to the experiments, for example the accuracy of measuring equipment and methods used (if repeated). They will also accurately discuss the implementation of Blondel's theorem and how it can make three-phase meters more efficient.

Overall, the evidence will be logically structured and use the correct technical engineering terms about the three-phase power circuits.

For merit standard, learners will safely and accurately set up and carry out the experiments on the three-phase power circuits, for example learners will select measuring equipment that has the appropriate resolution and verify that the equipment complies with safety guidance. The experimental results will be accurate, neatly tabulated, clearly labelled and graphs will be drawn to scale.

Overall, learners will use accurate experimental results and theoretical calculations to analyse how the three-phase power circuits operate. They will include logical comparisons between measured and calculated results and will give suitable conclusions about the differences between star and delta connected circuits.

For pass standard, learners will select appropriate equipment, connect the equipment in an appropriate way and undertake experiments safely. Learners will record what they are doing along with their results (voltage, current and power) in a logbook.

Overall, evidence will be logically structured, but there may be some minor inaccuracies in the recording of the results, for example tables may have units omitted or the lead/lag of the circuit may not be noted.

Learners will explain how the power circuits operate. The explanation may contain minor numerical errors in the calculations and diagrammatic errors, for example the accuracy of calculated answers may be affected by the degree of rounding up/down used; power units may be incorrect by using watts (W) rather than volt-amps (VA or VAr).

Overall, the explanations, although basic in parts, should be logically structured, covering the operation of the five circuits tested.

Learning aim C

For distinction standard, learners will produce a professional, balanced justification of the cost of given tariffs for two engineering companies, selecting one of the companies for a more detailed analysis. This analysis will have explanations and justifications of the savings and costs of implementation of power factor correction through accurate calculations for all tariffs and detailed explanations of the reasons why one tariff has been chosen.

Overall, the justification will be easy to read and understand by a third party who may or may not be an engineer. For example, it 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 produce an accurate analysis of the costs of using two different tariff structures in their two given engineering companies. They will explain all parts of the charges, including standing charge and unit charge, and all calculations will be accurate.

Overall, the comparison will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain how the maximum electricity demand is determined for a given engineering company, and to use two given tariffs to calculate the annual cost of electricity for each company.

Overall, the explanations and calculations should be logically structured and be correct, although basic in parts. They may contain minor technical inaccuracies relating to engineering terminology, for example learners stating that PFC improves the efficiency of the machine.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 15: Electrical Machines
- Unit 18: Electrical Power Distribution and Transmission.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers.
- technical workshops involving staff from local engineering organisations with expertise of three phase electrical systems
- contribution of ideas to unit assignment/project materials.

Unit 17: Power and Energy Electronics

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the sustainable use of power electronic devices by building circuits and measuring values in typical applications.

Unit introduction

Power electronics comes into play wherever there is a need to modify a form of electrical energy, for example its voltage, current or frequency. Therefore it plays a critical role in almost all aspects of our daily lives. For example, choosing a mobile phone or laptop computer for its battery life is actually a decision about power electronics.

In this unit, you will connect circuits using common power electronic devices to discover their function, and investigate their operation and construction. You will explore some typical applications practically, for example direct current (DC) motor speed and direction control and voltage conversion, including rectification (changing an alternating current (AC) to DC) and level shifting (DC to DC). Inversion (DC to AC) is covered more theoretically. You will discover the importance of power electronics to areas such as renewable energy, electricity generation and supply, transport systems and industrial processes, considering issues arising from their use.

Before taking this unit you should have completed *Unit 19: Electronic Devices and Circuits* and may also be studying *Unit 20: Analogue Electronic Circuits* and/or *Unit 21: Electronic Measurement and Testing of Circuits*.

A wide range of industries, including aerospace, automotive, industrial control and factory automation, requires engineers with knowledge and skills to work with complex systems incorporating power electronics. This unit helps to prepare you for employment, for example as an electrical/electronic technician, for an apprenticeship or for entry to higher education to study electrical and electronic engineering.

Learning aims

In this unit you will:

A Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy

B Explore applications of common power electronic devices that are used to modify a form of electrical energy

C Investigate sustainable applications of power electronics.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy	**A1** Construction and operation of different types of power electronic device **A2** Characteristics of power electronic devices in switching circuits	A logbook collating practical experiment reports exploring the operation of common power electronic devices in relation to device construction.
B Explore applications of common power electronic devices that are used to modify a form of electrical energy	**B1** DC motor control circuits **B2** Voltage conversion circuits	A logbook collating practical experiment reports exploring applications of power electronic devices.
C Investigate sustainable applications of power electronics	**C1** Applications of power electronics **C2** Sustainability issues relating to power electronics **C3** Regulations relating to power electronics	A written report investigating power electronic applications in each of the four sectors, exploring one of them in greater depth.

Content

Learning aim A: Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy

A1 Construction and operation of different types of power electronic device

Construction and operation of different types of power electronic device in switching circuits, to include:

- PN junction diode:
  - circuit symbol and physical material construction
  - voltage-current characteristics in respect to semiconductor theory
- bipolar junction transistor (BJT):
  - circuit symbol and physical material construction of NPN and PNP BJT
  - BJT configurations to include common base, common emitter, common collector
  - switching characteristics in terms of semiconductor theory
- metal oxide semiconductor transistor (MOSFET):
  - circuit symbol and physical material construction of N-channel and P-channel FETs in enhancement and depletion mode connection
  - enhancement and depletion mode switching in terms of semiconductor theory
- insulated gate bipolar transistor (IGBT):
  - circuit symbol and physical material construction of IGBT
- semiconductor controlled rectifier (SCR) or thyristor:
  - circuit symbol and physical material construction of thyristor, two transistor analogy
- triac:
  - circuit symbol and physical material construction of triac, two thyristor analogy.

A2 Characteristics of power electronic devices in switching circuits

- PN junction diode:
  - comparison of real and ideal voltage-current characteristics
  - power diodes, high forward current capability (kA) and reverse blocking voltage (kV).
- BJT:
  - transistor as a switch, including operating regions, cut-off and saturation, use of flywheel diode when switching inductive loads
  - Darlington transistor pair, NPN and PNP configurations, Darlington transistor integrated circuits (ICs).
- MOSFET:
  - N-channel enhancement mode MOSFET as a switch, operating regions, cut-off and saturation, use of flywheel diode when switching inductive loads, comparison with BJT.
- IGBT:
  - comparison between IGBT, BJT and MOSFET in switching circuits with regard to typical parameters such as voltage, current, mode of operation, cost.
- SCR or thyristor:
  - switching thyristor in DC and AC circuits
  - conditions for switching thyristor on/off.
- Triac:
  - triac switching and phase control, use of diac to even triggering and reduce harmonics.

Learning aim B: Explore applications of common power electronic devices that are used to modify a form of electrical energy

B1 DC motor control circuits

- Speed control using pulse-width modulation (PWM), e.g. generating a PWM output using a 555 timer to control the switching of:
  - a BJT in common emitter connection
  - an N-channel enhancement mode MOSFET in common source connection
  - an N-channel P-channel MOSFET complementary pair.
- Speed and direction control using a MOSFET H-bridge.

B2 Voltage conversion circuits

- Rectifier (AC to DC):
  - comparison of uncontrolled and controlled half-wave rectification of a single-phase AC supply using a PN junction diode and a thyristor
  - fixed voltage regulated full-wave rectification of a single-phase AC supply using PN junction diodes.
- Converter (DC to DC):
  - comparison of fixed voltage regulators and switching regulators in DC to DC conversion, e.g. step down (buck), step up (boost).
- Inverter:
  - topology of a single-phase voltage signal inverter using switch elements
  - single-phase voltage signal inverter using thyristors as the switch elements, e.g. McMurray-Bedford half-wave inverter.

Learning aim C: Investigate sustainable applications of power electronics

C1 Applications of power electronics

- Knowledge and understanding of the drivers for developments in power electronics such as:
  - international targets for a low-carbon economy, e.g. UK government target is to reduce carbon dioxide (CO_2) emissions by at least 80 per cent by 2050 from the 1990 levels
  - the potential for power electronics to contribute to CO_2 reduction targets, e.g. industrial electric motor drives account for an estimated 43–46 per cent of all global electricity consumption, giving rise to about 6040 mega tonnes of CO_2 emissions.
- Knowledge and understanding of the potential for power electronics to contribute to developments in:
  - electricity generation and supply, including:
    - sustainable generation of electrical energy
    - reduction in energy consumption, e.g. by the development of a 'smart grid'
  - renewable energy sources:
    - developments in devices and controls systems to convert energy from solar, wind, wave and other sources
  - transportation, including:
    - automotive applications to reduce energy consumption, e.g. battery technology, hybrid and all-electric vehicles, integrated mechanical, electronic, computer, software and control engineering, energy recovery from braking and downhill operation, driverless vehicles
    - aerospace applications to reduce energy consumption, e.g. replacement of all hydraulic and pneumatic power and controls with electrical alternatives enabled by power electronics, unmanned aerial vehicles (UAV) or drones
  - industrial process applications to reduce energy consumption:
    - developments in industrial drives – systems that include motors, motor control, sequencing and communications functions to optimise the operation of not only the motor but also the machine or process in which it operates, either autonomously or as part of a larger factory automation scheme.

C2 Sustainability issues relating to power electronics

- Sustainability issues, including:
  - sustainable development as an approach to development that looks to balance different, often competing, needs against an awareness of the environmental, social and economic limitations we face as a society
  - ethics:
    - standards governing what is acceptable behaviour in the practice of engineering – acting honourably, truthfully, responsibly and lawfully
    - duty to protect the safety of the general public
  - six professional engineering principles to help achieve sustainable and ethical development:
    - contribute to building a sustainable society, present and future
    - apply professional and responsible judgement and take a leadership role
    - do more than just comply with legislation and codes
    - use resources efficiently and effectively
    - seek multiple views to solve sustainability challenges
    - manage risk to minimise adverse impact to people or the environment.

C3 Regulations relating to power electronics

Knowledge and understanding of the need for regulations in safe, sustainable and ethical applications of power electronics, with particular regard to:

- Electromagnetic Compatibility (EMC) Directive 2004/108/EC
- Electrical Equipment (Safety) Regulations 1994 (SI 1994 No 3260), implementing Council Directive 2006/95/EC.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy		**A.D1** Evaluate, using language that is technically correct and of a high standard, the operation and switching behaviour of each type of power electronic device, comparing semiconductor theory and the results from safely conducted experiments.
A.P1 Build a circuit for each type of power electronic device safely and determine the operating characteristics of each. **A.P2** Explain, using semiconductor theory and test results, the correct operation of each type of power electronic device.	**A.M1** Build a circuit for each type of power electronic device safely and determine accurate operating characteristics of each. **A.M2** Analyse, using semiconductor theory and test results, the correct operation of each type of power electronic device.	
Learning aim B: Explore applications of common power electronic devices that are used to modify a form of electrical energy		**B.D2** Evaluate the operation of DC motor speed and direction control and voltage conversion circuits employing a range of power electronic devices safely, using test results and theory.
B.P3 Build, using BJT and MOSFET devices, a DC motor speed control circuit safely and determine the operating characteristics of each. **B.P4** Explain, using test results and theory, the correct operation of DC motor speed control circuits. **B.P5** Build a controlled and uncontrolled AC–DC rectifier and a DC–DC converter safely and determine the operating characteristics of each. **B.P6** Explain, using test results and theory, the operation of voltage converters, including controlled and uncontrolled AC–DC, DC–DC and DC–AC.	**B.M3** Build, using BJT and MOSFET devices, a DC motor speed control circuit safely and determine accurate operating characteristics of each. **B.M4** Analyse, using test results and theory, the correct operation of DC motor speed control circuits. **B.M5** Build a controlled and uncontrolled AC–DC rectifier and a DC–DC converter safely and accurately determine the operating characteristics of each. **B.M6** Analyse, using test results and theory, the operation of voltage converters, including controlled and uncontrolled AC–DC, DC–DC and DC–AC.	
Learning aim C: Investigate sustainable applications of power electronics		**C.D3** Evaluate how power electronic devices can be used in two different applications to improve sustainability.
C.P7 Explain how power electronic devices can be used in two different applications to improve sustainability.	**C.M7** Analyse how power electronic devices can be used in two different applications to improve sustainability.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.P6, B.M3, B.M4, B.M5, B.M6, B.D2)

Learning aim: C (C.P7, C.M7, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- an electronics laboratory fitted with a range of electronic test and measurement equipment, including low voltage bench supplies (DC and AC), digital multimeters, function generators and dual trace oscilloscopes, tachometers (or similar) to measure motor speed
- electronic circuit prototyping equipment such as breadboard or plugboards
- basic components and appropriate specialised discrete and integrated circuit power electronic devices, together with relevant catalogues, application notes and data sheets.

A rapid prototyping development system such as LJ Create Advanced Electronic Platform and study modules is useful but centres may develop their own kits to build test circuits for motor control and voltage conversion. Centres may already have suitable test circuits from previous requirements.

Software to support schematic capture and SPICE circuit simulation is not essential but is useful in determining expected circuit behaviour.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will explore the operation of sufficient physical circuits for each power electronics device to cover the unit content. They will also take accurate measurements from the circuits.

Learners will apply semiconductor theory, use diagrams and explanations to accurately illustrate what materials are used, the physical construction and how they are reflected in the component circuit symbol. For example, the evaluation of an NPN BJT will include an explanation of doping silicon to give N-type and P-type material, with diagrams to show a typical monolithic structure and how it relates to the circuit symbol. Learners will evaluate how conduction takes place and is controlled. They will also identify other materials which may be used for power electronic devices, such as silicon carbide (SiC) and gallium nitride (GaN).

Learners will compare the semiconductor theory and the results from safely conducted experiments, using data such as circuit schematics, waveform sketches, manufacturers' data sheets, observations and measurements. For example, they will compare the collector voltage of a BJT for different base-emitter voltages with expected values from theory.

Overall the evidence, such as a logbook (which may be in any appropriate form) and 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 will use correct technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling. Measurements will be given to a realistic degree of accuracy, with consistent use of correct units.

For merit standard, learners will build and take measurements of each circuit containing at least one power electronics device. The results will demonstrate accurate characteristics of the device during operation. For example, learners may note the base-emitter voltage required to switch on an NPN BJT, or the conditions to switch off an SCR. The circuits must cover most of the unit content.

Learners' evidence of how the devices operate will include the application of simple semiconductor theory to analyse the materials used and the physical construction of power electronic devices and how they relate to the component circuit symbol. For example, the response for an NPN BJT may not define N-type and P-type and the description of conduction processes may lack detail.

Learners will compare the measurements taken from each physical circuit with theoretical predictions. For example, the analysis of a BJT may include measurements of a circuit containing an NPN transistor in common emitter mode switching a resistive load, and a circuit using a Darlington pair (either discrete devices or an integrated circuit). The comparison of results from practical testing and theory will extend beyond observation to include actual values. For example, it would not be sufficient to say the transistor switches on a lamp if the base emitter is high, as an appropriate value is expected.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will build at least one circuit for each type of power electronics device safely, recording the measurements taken from each physical circuit during operation. For example, learners will connect circuits to investigate the conditions needed to switch each device on and off.

Learners' evidence will explain how the device operates. It will include the application of semiconductor theory to identify the materials used and describe the physical construction of power electronic devices and how they relate to the component circuit symbols. For example, the response for an NPN BJT may simply state 'silicon' as the material and for the description use diagrams to relate the circuit symbol for a simple 'sandwich' of N-P-N material.

Evidence will also cover the operating characteristics of each device, for example the investigation of a BJT may include measurements of a circuit containing an NPN transistor in common emitter mode switching a resistive load. The comparison of results from practical testing and theory will be in the form of simple conclusions. For example, it would be sufficient to say the transistor switches on if the base emitter is high without stating a precise value.

Overall, the evidence, such as a logbook and a report, will be logically structured. The evidence may be basic in parts, for example making general statements about the switching behaviour rather than stating accurate values, and may contain technical inaccuracies or omissions, such as not comparing advantages and disadvantages of IGBT, BJT and MOSFET devices.

Learning aim B

For distinction standard, learners will present a balanced evaluation of the operation of power electronic devices in DC motor control and voltage conversion circuits using test results and theory. They will practically explore speed and direction control of a DC motor using bipolar junction transistors and MOSFETs in circuits using more than one active device.

Learners will evaluate the operation of voltage conversion circuits, comparing the measurements taken from each physical circuit with theoretical behaviour, for example, using voltage waveforms from oscilloscope traces of a thyristor rectifier circuit to demonstrate how the output voltage is controlled by the firing angle. Learners will investigate voltage conversion (DC to DC) by comparing the use of fixed voltage regulators and a switching regulator circuit (either buck or boost).They will research a single-phase half-wave voltage inverter (DC to AC), for example a McMurray-Bedford half-wave inverter, and evaluate its function, outlining the principles of how it operates.

Overall, learners' evidence, such as a logbook and report, will be easy to read and understand by a third party who may or may not be an engineer. It will include data such as circuit schematics and waveform sketches, as well as accurate measurements and explanations. It 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 a good level of graphical communication.

For merit standard, learners will build DC motor control and voltage conversion circuits, using power electronics devices safely, for example explaining why a flyback diode is included in the circuit to prevent voltage spikes across the inductive load. The measurements taken from each physical circuit will demonstrate accurate use of the measuring instrumentation, for example oscilloscope amplifier settings stated with waveforms.

Learners will analyse the operation of speed control in a DC motor using single devices and combinations, for example an NPN BJT in common emitter connection, a Darlington connection, and equivalent circuits using N-channel MOSFETs in depletion mode. The comparison of results from practical testing and theory will extend beyond qualitative explanation. For example, learners would need to give values to support a statement that increasing the duty cycle increases the speed.

Learners will analyse the operation of voltage conversion circuits. For example, they will compare the voltage output waveforms of rectifier circuits using PN junction diodes and thyristors and relate them to the measured DC output. Learners will investigate voltage conversion (DC to DC) by measuring the output of a fixed voltage regulator for different input voltages. They will compare the measurements taken from each physical circuit and analyse the results, for example the voltage level of a thyristor voltage rectifier can be varied by changing the firing angle, and give an estimate of the expected value, such as at a firing angle of 45°. They will explain the function of a single-phase half-wave voltage inverter (DC to AC), without detailing the way it operates.

Overall, the evidence will be logically structured, technically accurate and easy to understand. Evidence will include data such as circuit schematics and waveform sketches, as well as measurements and explanations.

For pass standard, learners will build DC motor control and voltage conversion circuits safely, using power electronics devices, for example including a flyback diode in the circuit to prevent voltage spikes across the inductive load without justifying its inclusion. They will record measurements taken from each physical circuit during operation and use the observations to explain the operation of speed control in a DC motor. They will compare the results for bipolar junction transistors and MOSFETs in circuits using single devices, for example, an NPN BJT in common emitter connection and an equivalent circuit using an N-channel MOSFET in depletion mode. The comparison of results from practical testing and theory may consist of qualitative statements only, for example stating that increasing the duty cycle increases the speed.

Learners will explain the operation of voltage conversion circuits, using measurements taken from each physical circuit and theory to draw some qualitative conclusions, for example, the output voltage level of a thyristor voltage rectifier can be varied by changing the firing angle without indicating actual values. The function of a voltage inverter will be described.

Overall, learners' evidence, including results, will be logically structured and will include data such as circuit schematics and waveform sketches, as well as measurements and descriptions, though there may be some omissions or unnecessary inclusions. The evidence may be basic in parts, for example descriptions may lack detail and contain minor technical inaccuracies relating to engineering terminology, such as not differentiating between amplitude, peak to peak or root-mean-squared (RMS) voltage in the rectifier circuits.

Learning aim C

For distinction standard, learners will evaluate in their evidence the potential applications for power electronics in two topics from renewable energy, electricity generation, transport and industrial processes. The evidence should include diagrams, charts and tables of data. Each section will clearly identify the purpose of the application, giving specific detail of the required technology, reviewing the current ability to implement it. Learners will comment knowledgeably on potential issues related to sustainability as a result of implementing the application. For example, concerns raised by the proposed construction of a 'solar farm' on a brown field site should contain comment on environmental impact, ethics and relevant regulations.

Overall, the evidence will be well structured, factually accurate, easy to read and will be understood by a third party who may or may not be an engineer.

For merit standard, learners will analyse in their evidence two potential applications of power electronics. The evidence will explain the purpose of each application and give some detail of the required technology. For example, learners may identify that a photovoltaic (PV) system requires an inverter without specifying parameters such as voltage and current limit. Learners will identify potential issues related to environmental impact and ethics as a result of implementing the application, though there may be little or no inclusion of regulations. For example, the arguments related to concerns raised by the proposed construction of a 'solar farm' on a brown field site may concentrate more on environmental than ethical considerations.

Overall, the evidence will be logically structured, technically accurate and easy to understand. The evidence may lack specific detail or include some irrelevant information.

For pass standard, learners will explain in their evidence how power electronic devices can be used sustainably in two different applications. The evidence should be approximately 500 words in length for each application and be supported by appropriate diagrams. The evidence will identify the purpose of each application but may lack detail. For example, the need for an inverter in the PV system may not be identified. The evidence may include some irrelevant information or there may be omissions. For example, the arguments about concerns raised by the proposed construction of a 'solar farm' on a brown field site may focus on a single issue.

Overall, the evidence may be basic in parts, for example making general statements about potential applications rather than precise ones, and may contain minor technical inaccuracies or omissions, for example not considering the impact of the application on the safety of the general public.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 3: Engineering Product Design and Manufacture
- Unit 5: A Specialist Engineering Project
- Unit 15: Electrical Machines
- Unit 19: Electronic Devices and Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 23: Digital and Analogue Electronic 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 electrical and electronic systems
- contribution of ideas to unit assignment/project materials.

Unit 18: Electrical Power Distribution and Transmission

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the principles and the design of the transmission and distribution infrastructure that supplies electricity to organisations and domestic households.

Unit introduction

The electricity supply is a fundamental part of everyday life that is often taken for granted. For example, people rarely pay much attention to the electricity pylons running across the country that provide much of the power we use every day for domestic devices and industrial processes.

In this unit, you will explore the operation and construction of nuclear and fossil fuel power stations, which are still the most common methods for generating electricity. You will identify where the responsibility passes from the power to the transmission companies, and the methods they use to transfer high-voltage electricity over long distances safely. Finally you will investigate the methods used to reduce the electrical voltage and distribute it safely to customers.

As an electrical engineer you may work for one of the large electricity distribution network operators or transmission companies where you could be involved in the design or maintenance of a national grid, or similar infrastructure. This unit prepares you for an electrical power-based engineering apprenticeship, for higher education and for a technician-level role in an electrical power company.

Learning aims

In this unit you will:

A Investigate the operation of thermal and nuclear reactor power generation that supplies electricity to the national grid

B Examine the design of a typical transmission network used to supply electricity

C Design a distribution system to meet customer requirements for a new electrical installation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the operation of thermal and nuclear reactor power generation that supplies electricity to the national grid	**A1** Thermal power generation **A2** Nuclear power generation **A3** Comparisons between the two generating methods	A report detailing the operation and construction of nuclear and thermal power stations and the perceived benefits and drawbacks of each.
B Examine the design of a typical transmission network used to supply electricity	**B1** Transmission networks **B2** Transmission network design features **B3** Design of overhead power transmission	An analysis of a given transmission network, which details the relevant sections and why certain decisions have been made.
C Design a distribution system to meet customer requirements for a new electrical installation	**C1** Network design **C2** Power distribution **C3** Distribution substations	The design of a distribution network for a given customer requirement that justifies all choices made and costs incurred.

Content

Learning aim A: Investigate the operation of thermal and nuclear reactor power generation that supplies electricity to the national grid

A1 Thermal power generation

- Types of fossil fuel: coal, gas and oil.
- Generation process in the plant to convert fuel to electricity:
  - fuel burns to boil water into superheated steam typically high pressure water 175 bar at very high temperatures for efficiency 540–570 °C
  - steam used to turn a turbine, which in turn spins the synchronous generator at the correct speed to produce the desired frequency supply
  - steam then passes through condensers and as it cools it turns back into water for reuse.
- Boiler construction and design to help ensure safe operation, e.g. water feed control measures to maintain pressure, pressure overload detection and release measures, and to prevent inherent hazards in them, e.g. thermal insulation of water pipes and segregation between the different temperature sections.
- Construction of the steam-driven turbines.
- Thermal efficiency, including thermodynamic principles to include heat transfer, latent heat and qualitative explanation of the Rankine cycle.
- Generated voltage values and frequency, requirements for interconnection onto the national grid and methods used to interconnect different generating sources, e.g. two generators operating within a single power station.

A2 Nuclear power generation

- Awareness of the history of nuclear energy generation in the UK or other international jurisdiction generating nuclear power and the developments that have been introduced.
- Sources of radioactive material for the fuel pellets, typically enriched uranium, most common areas it is mined and how it is treated.
- Design and operating principles of one type of nuclear power station e.g. pressurised water reactor (PWR), boiling water reactor (BWR) or advanced gas cooled reactors (AGR).
- The nuclear reactor process, e.g. enriched uranium fuel is bombarded by neutrons, which causes the atoms to split, releasing more neutrons. Control rods absorb some of the neutrons to control the process.
- Reactor cooling is required to ensure safe, continuous operation. The cooling normally takes place in stages as the primary coolant takes on short-term radioactivity e.g. primary coolant, very pure treated water carries heat from the core. Secondary coolant, also very pure treated water passes through the turbine. Cooling water (tertiary) is used to cool the condenser.
- Safety systems, e.g. control rods to absorb excess neutrons, control room procedures (for example, at Hinckley Point one person per reactor and one extra person in overall control), exposure timers on employees working 'reactor side' of the site.
- Legislation from the Office for Nuclear Regulation (ONR) governing nuclear energy, including maximum exposure to workers and civilians living close to the plant.

A3 Comparisons between the two generating methods

- Efficiency of thermal and nuclear reactors.
- Environmental issues to include carbon emissions and EU CCS Directive on Geological Storage of Carbon Dioxide (Directive 2009/31/EC), regarding carbon capture and storage and the Office for Nuclear Regulation rules regarding nuclear waste treatment and storage.
- Positive and negative aspects of both methods of producing energy, including public perceptions of dangers.

Learning aim B: Examine the design of a typical transmission network used to supply electricity

B1 Transmission networks

- Responsibilities of transmission companies, including managing output, security and maintaining voltage and frequency.
- Methods used for balancing supply with customer demand.
- Purpose and responsibilities of grid control centres.

B2 Transmission network design features

Regulatory requirements of network design, including:

- requirements for easements and wayleaves
- environmental factors, e.g. nature reserves, which may result in a network being overhead or underground, and the subsequent permissions needed.

B3 Design of overhead power transmission

- Types of transmission tower:
  - intermediate, angle, section and terminal tower configurations and the advantages and disadvantages of each design
  - methods of stringing and terminating cables, to include tensioning and sag profiles, and the advantages and disadvantages of each design
  - conductor ice loading and galloping, cause and effect of them and methods of reducing or removing
  - safety features, including single pole tripping and reclosing, directional overcurrent relay protection and correct use of barriers and signage to avoid trespass and theft of cable.
- Typical conductors used in overhead power lines, their sizes and why each type of conductor is used:
  - aluminium conductor composite core (ACCC)
  - aluminium conductor steel reinforced (ACSR)
  - all aluminium alloy conductor (AAAC).
- Voltage range bundle configurations, for instance 275 kV and 400 kV in the UK or other relevant international equivalents.
- Purpose and construction of overhead ground wire.

Learning aim C: Design a distribution system to meet customer requirements for a new electrical installation

C1 Network design

- Circuit types, ring and radial single and twin circuits.
- High-voltage (HV) network design:
  - voltage range typically 6.6 kV and above in the UK or other relevant international equivalents
  - purpose and methods, e.g. single end fed, double end fed and closed ring network of interconnecting HV circuits
  - circuit layout from primary to secondary substations, including how different operators may have their own standard symbols
  - principles of HV protection, including types of circuit breakers at customers and substations.
- Low-voltage (LV) network design:
  - voltage range typically 400 V–6.6 kV three phase in the UK or other relevant international equivalents
  - purpose and methods of interconnecting LV circuits, e.g. single end fed, double end fed and closed ring network
  - circuit layout from secondary substations to customer, including how different operators may have their own standard symbols
  - principles of LV protection, types of circuit breakers at customers and substations.

C2 Power distribution

- Responsibilities and roles of the distribution network operator (DNO) in maintaining supply to the customer.
- Environmental concerns regarding routing of cables, choice between overhead and underground.
- Resource planning processes and design principles to include regulatory requirements and responsibilities for planning, for example easements and wayleaves.
- Methods of burying underground cables and their differing purposes:
  - surface trough – a duct is run in a shallow trench in the ground and not filled, typically used only for short runs between transformers in a substation
  - direct buried allowing for greater current carrying capability but can be used only where the chances of disturbance are unlikely – this is the most common method of burying cable
  - tunnel – a strong duct is run with the cables inside it, allows for more protection from ingress and damage due to movement but costs more to install due to increased complexity.
- Properties and characteristics of the typical conductors, to include impedance per metre, cost per metre and ease of installation/jointing:
  - fluid-filled
  - cross-linked polyethylene (XLPE)
  - gas-insulated lines (GIL).
- Cost of underground cables compared with overhead lines and regulatory requirements that impact on choices between the two methods.
- Causes of cable faults and methods of location, including open circuit fault location using loop testers and possible supervisory control and data acquisition (SCADA) methods of identification.
- Methods of jointing underground cables, prevention of moisture ingress, including:
  - HV joint types to include straight, transitional and pot end
  - LV joint types to include straight, transitional and pot end.

C3 Distribution substations

- Substation design principles, to include:
  - primary and secondary substations and their purposes in the network, e.g. primary substation forming the 'load centre' for the development
  - star/delta transformer connections
  - differences between rural and urban installations, and the effect on design of substations, e.g. the overhead nature of rural distribution needs alternative hardware and protection methods.
- Substation protection principles:
  - equipment and methods of protection, including earth fault protection, barriers and signage to prevent electric shock
  - principles of substation fusing systems, including types and characteristics.
- Substation earthing principles, to include:
  - purpose and function of earthing
  - neutral point earthing
  - bonding and earthing of metalwork
  - earth resistance measurements and effects of depleted earthing.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the operation of thermal and nuclear reactor power generation that supplies electricity to the national grid		**A.D1** Evaluate, using language that is technically correct and of a high standard, thermal and nuclear power stations, including environmental concerns and public perceptions of each.
A.P1 Explain the operation of a thermal energy power station. **A.P2** Explain the operation of one type of nuclear power station.	**A.M1** Compare the operation of a thermal and one type of nuclear power station.	
Learning aim B: Examine the design of a typical transmission network used to supply electricity		**B.D2** Evaluate the design, including safety features, towers and cables, of a transmission network, suggesting possible design improvements.
B.P3 Explain the safety features of a transmission network using both overhead and underground cables. **B.P4** Describe the construction of the electricity towers and cables used in the design of a given transmission network.	**B.M2** Justify the safety features given in the design of a transmission network. **B.M3** Justify the choice of towers and cables used in the design of a given transmission network, making reference to the manufacturer's data sheets.	
Learning aim C: Design a distribution system to meet customer requirements for a new electrical installation		**C.D3** Refine, during the process, the design for a distribution system that fully meets the client's brief, justifying the choices made.
C.P5 Explain the client's requirements for a primary and secondary substation on a distribution network. **C.P6** Produce a design for a distribution system based on a client brief, describing the construction of the substations.	**C.M4** Analyse the client's requirements for the substations, considering the relative merits of building new or using existing capacity. **C.M5** Produce a detailed design for a distribution system, while documenting alternative solutions.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- wiring diagrams of typical transmission networks and design specifications for distribution networks (if actual diagrams are unavailable)
- simulation software – useful but not essential, e.g. PowerWorld Simulator software provided free with *Power System Analysis and Design*, Glover, Sarma and Overbye, Thomson Learning USA, ISBN 10: 0-495-29596-5
- technical articles and information about cables and conductors, available from the Electrical Engineering Portal (www.electrical-engineering-portal.com).

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a balanced evaluation of electrical power generated by a type of thermal energy power station and a type of nuclear energy power station, including the efficiency and safety records and the environmental concerns and public perceptions of each. For example, learners will analyse objectively the after-effects of historical accidents at different power stations.

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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will produce evidence identifying key similarities and differences between the two generation methods. Learners' statements should be supported by fact and give a balanced analysis of both thermal energy and nuclear energy power stations. Where the two methods are different, learners should discuss relative merits of both stations and justify any qualitative statements, for example the electrical efficiency is compared in terms of megawatt per ton of fuel and then offset against the disposal of waste products.

Overall, the evidence should be logically structured, technically accurate and be easy to understand.

For pass standard, learners will produce evidence identifying and explaining the operation, including construction, of a type of thermal energy power station (coal, oil or gas fired) and a type of nuclear energy power station (pressurised water, boiling water or gas cooled reactor). Learners will explain the key features of both and how the fuel is used to turn the turbines, for example coal is burned to superheat steam, which is forced through the turbine blades spinning at 3000 revolutions per minute (rpm).

Overall, the evidence will be logically structured. It may be basic in parts or contain minor inaccuracies or omissions, for example learners may omit that seawater also acts as a coolant for the nuclear reactor.

Learning aim B

For distinction standard, learners will produce a balanced evaluation of a given design for a HV transmission network. Learners will analyse all choices of conductors and routes taken as well as the types of tower selected for the network. Learners will suggest alternative methods that could be used for achieving the same transmission network and give possible reasons why some ideas were discarded, for example alternative routes to avoid environmental concerns such as protected or green belt land or topographical features.

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 justify the safety features used in the design of a transmission network, for example comparing how the time saved using automatic restart systems outweighs the complexity of the process against typical earth fault protection. Learners will justify the choice of the conductors and cables used in the design of a specific transmission network, for example cost savings using ASCR against ACCC conductors. They will include the routes used and suggest possible reasons for their choice, for example to avoid a conservation area.

Overall, the evidence should be logically structured, be technically accurate and be easy to understand.

For pass standard, learners will identify and explain the key safety features in the given design for a transmission network carrying high-voltage electricity, for example short circuit protection to protect from electric shock and the correct signage and barriers to avoid trespass. Learners will describe the construction features of the towers and at least two different overhead and two underground cables used in the proposed design of a given transmission network. Learners must include a description of the jointing methods.

Overall, the evidence will be logically structured. It may be basic in parts, for example descriptions may lack detail, as long as a complete transmission network has been covered.

Learning aim C

For distinction standard, learners will refine an accurate design for an electrical distribution system that meets the requirements of the client's brief, and justify the design decisions, for example a star transformer connection is used because domestic housing will require a phase and neutral which is not present on a delta system.

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 example, diagrams will use the correct symbols throughout and be of a high standard.

For merit standard, learners will produce a well-constructed distribution design that meets the client's requirements. They will discuss the relative merits of building new substations against using existing supplies, and will justify their choice, for example cost implications of new substations against sharing the load between existing infrastructure. Learners will also justify their choices of route and cable for the distribution network, for example to minimise disruption of roadways, and explain the requirement for easements and wayleaves, if necessary.

Overall, the evidence should be logically structured, be technically accurate and be easy to understand.

For pass standard, learners will produce an effective design of a distribution network that meets the client's requirements. The design will describe the construction requirements for the substations, and design decisions will be documented, for example routing diagrams and simulation data – if used – are present.

Overall, the evidence will be logical and correct. It may be basic in parts, for example explanations of substations may lack detail, as long as a complete network has been designed.

Links to other units

This unit links to:

- Unit 15: Electrical Machines
- Unit 16: Three Phase Electrical Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations involved with electrical power transmission and distribution
- contribution of ideas to unit assignment/project materials.

Unit 19: Electronic Devices and Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the operation of electronic devices and their uses in circuits through simulation and practical exercises to build and test physical analogue and digital circuits.

Unit introduction

Electronic analogue and digital devices and circuits are at the heart of familiar household products and high-speed complex operations in industrial applications. For example, they are fundamental to the operation of television remote controllers and to the control of processes in nuclear power stations.

In this unit, you will cover the simulation, construction, testing and evaluation of analogue electronic circuits based on diodes and transistors and combinational and sequential logic digital circuits. As part of the unit you will use software to simulate circuits and use typical bench instruments to test them, since electronic circuit designers make frequent use of software to simulate design ideas before building prototype circuits. Finally, you will reflect on the skills and understanding you have acquired during the unit and the behaviours you have applied.

A wide range of industries, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation, employs electronic engineers. This unit helps to prepare you for employment, for example as an electrical/electronic technician, for an apprenticeship and for entry to higher education.

Learning aims

In this unit you will:

A Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits

B Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits

C Review the development of analogue and digital electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits	**A1** Safe electronic working practices **A2** Diode devices and diode-based circuits **A3** Transistor devices and transistor-based circuits **A4** Operational amplifier circuits **A5** Schematic capture and simulation of analogue circuits **A6** Testing physical analogue circuits	A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.
B Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits	**B1** Logic gates and Boolean algebra **B2** Combinational logic circuits **B3** Sequential logic circuits **B4** Schematic capture and simulation of digital circuits **B5** Testing physical digital circuits	A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.
C Review the development of analogue and digital electronic circuits and reflect on own performance	**C1** Lessons learned from exploring electronic devices and circuits **C2** Personal performance while exploring electronic devices and circuits	The evidence will focus on the skills and knowledge gained when exploring analogue and digital electronic devices and their common applications, reflecting on the ways in which theoretical, simulated and measured values compare. The portfolio of evidence generated while exploring electronic devices and circuits, reflecting on own performance.

Content

Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits

A1 Safe electronic working practices

- Know how to react in an emergency, including:
  - isolate power and/or heat supplies
  - notify the responsible person
  - follow instructions from the responsible person, including raise the alarm, notify first aider, evacuate the area.
- Safe working practices: awareness and compliance with hazard identification, risk assessments and standard operating procedures associated with electronic-based tasks to include:
  - construction of electronic circuits
  - measurement and testing of electronic circuits.

A2 Diode devices and diode-based circuits

- Types of diode to include signal diodes, rectifier diodes, Zener diodes and light-emitting diodes (LED).
- Operation of diodes to include:
  - semiconductors: materials, intrinsic, extrinsic, doping, p-type, n-type
  - type: PN-junction
  - characteristics, e.g. forward and reverse bias.
- Construction of diode-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
  - rectification: half wave, full wave
  - voltage stabilisation
  - voltage regulation.

A3 Transistor devices and transistor-based circuits

- Types of transistor to include:
  - bipolar junction transistors (BJT): NPN, PNP
  - field effect transistors (FET): N channel, P channel.
- Operation of transistors to include:
  - transistor connections: common base, common emitter, common collector
  - transistor action, including no collector current (cut off), some collector current (in the active region) and collector current above the emitter current (in saturation)
  - biasing – operating point of the transistor device.
- Construction of transistor-based physical circuits safely, using e.g. bread board or strip board, for different applications including:
  - switching including function of components, comparator, digital (set point)
  - single stage amplifier, including current and voltage gains, phase inversion, bandwidth.

A4 Operational amplifier circuits

- Construction of operational amplifier-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
  - voltage comparator
  - inverting and non-inverting amplifier: negative feedback, gain.
- Characteristics of operation of operational amplifiers to include resonant frequency, cut-off frequency, gain, bandwidth, gain-bandwidth product, dependence on component values.

A5 Schematic capture and simulation of analogue circuits

- Schematic capture of analogue circuits to include electrical circuit drawing standards BS 8888, BS 3939 or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation extraction of data/measurements, e.g. voltage, current, power, input and output signals, gain, frequency analysis, e.g. Bode plot.

A6 Testing physical analogue circuits

- The safe use of physical test equipment to include multimeters, function generators, oscilloscopes and more complex equipment, e.g. Bode plotters if available.
- Calculations using measured values to include:
  - transistor current gain $h_{\mathrm{fe}} = \beta = \dfrac{I_b}{I_c}$
  - circuit voltage gain (transistor amplifier, non-inverting and inverting op-amp circuits) $A_V = \dfrac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$
- Cut-off frequency for op-amp filters $f_C = \dfrac{1}{2\pi RC}$

Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits

B1 Logic gates and Boolean algebra

- Types of logic gate: AND, OR, NOT, NAND, NOR, XOR.
- Gate symbols, British Standard (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI) or other relevant international equivalents.
- Truth tables for standard logic gates.
- Types of logic family:
  - transistor-transistor logic (TTL)
  - complementary metal oxide semiconductor (CMOS).
- Characteristics of logic families: supply voltage, input and output operating voltages, input and output impedance, propagation delay, power.

B2 Combinational logic circuits

Rules of Boolean algebra, including:

- Boolean expressions e.g. sum of products $(A \bullet B) + (C \bullet \overline{D})$
- truth tables for Boolean expressions
- minimisation of combinational logic circuits containing at least three inputs and five gates:
  - Karnaugh maps for minimisation circuits with at least three inputs
  - De Morgan’s theorem.

Construction of physical combinational logic circuits safely, using e.g. bread board or strip board.

B3 Sequential logic circuits

- Bi-stable devices (flip-flops), including R-S, D type including clocked D type and JK including master-slave JK.
- Types of sequential logic circuit, including:
  - three-stage asynchronous counter
  - three-stage synchronous counter
  - three-stage shift register.
- Construction of physical sequential logic circuits safely using, e.g. bread board or strip board and R-S, D-type and/or JK bi-stable devices.
- Practical integrated circuits using flip flops, e.g. binary counter, shift register.

B4 Schematic capture and simulation of digital circuits

- Schematic capture of digital circuits to include electrical circuit drawing standards BS 8888, BS 3939, or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation, e.g. logic probe, logic pulser, logic ‘analyzer’.
- Extraction of data/measurements, e.g. input and output logic states.

B5 Testing physical digital circuits

- The safe use of physical test equipment to include multimeters, logic probes and more complex equipment, e.g. logic ‘analyzers’.
- Calculations using Boolean algebraic and truth tables.

Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance

C1 Lessons learned from exploring electronic devices and circuits

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- electronic skills, e.g. schematic capture, simulation, construction methods, use of measurement and test equipment and techniques and semiconductor theory
- general engineering skills, e.g. mathematics, interpreting drawings and using information technology software packages.

C2 Personal performance while exploring electronic devices and circuits

Understand relevant behaviours for exploring the construction, operation and application of electronic devices in analogue and digital circuits, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- awareness of the ways in which the skills, knowledge and techniques developed in this unit can be used in further study.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits		
A.P1 Simulate, using captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.P2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one. **A.P3** Explain, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**A.M1** Simulate, using accurately captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.M2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one accurately. **A.M3** Analyse, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the operation of at least one diode, transistor and operational amplifier circuit, comparing the results from safely and accurately conducted simulations and tests.
Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits		
B.P4 Simulate, using captured schematics, the correct operation of at least one combinational logic circuit and two sequential logic circuits. **B.P5** Build at least one combinational logic circuit and two sequential logic circuits safely and test the characteristics of each one. **B.P6** Explain, using the simulation and test results, the operation of at least three logic circuits.	**B.M4** Simulate, using accurately captured schematics, the correct operation of at least one combinational logic circuit minimising the gates and at least two sequential logic circuits. **B.M5** Build at least one combinational logic circuit minimising the gates and at least two sequential logic circuits and test the characteristics of each one accurately. **B.M6** Analyse, using the simulation and test results, the operation of at least three logic circuits.	**B.D2** Evaluate the operation of at least one combinational logic circuit minimising the gates and two sequential logic circuits, comparing the results from safely and accurately conducted simulations and tests.
Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance		
C.P7 Explain how health and safety, electronic and general engineering skills were effectively applied during the development of the circuits. **C.P8** Explain how relevant behaviours were effectively applied during the development of the circuits.	**C.M7** Recommend improvements to the development of the electronic circuits and to the relevant behaviours applied.	**C.D3** Demonstrate consistently good technical understanding and analysis of the electronic circuits, including the application of relevant behaviours and general engineering skills to a professional standard.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.M3, A.D1)

Learning aim: B (B.P4, B.P5, B.P6, B.M4, B.M5, B.M6, B.D2)

Learning aim: C (C.P7, C.P8, C.M7, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- electronic laboratory and bench top test equipment, including signal generators, low-voltage DC power supplies, dual trace oscilloscopes and digital multimeters. Spectrum analyser/Bode plotter would be advantageous, but is not essential
- physical components for selection and construction using appropriate prototyping approaches such as protoboard (bread board)
- equipment that can support the verification of digital circuit operation to include at the minimum logic probes and ideally access to logic 'analyzer'
- industry-standard SPICE software. A virtual Bode plotter and logic 'analyzer' may be an acceptable alternative to use of real instruments.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the different types of analogue electronic circuit that they have captured, simulated, constructed and tested. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively. They will include evidence such as circuit schematics and waveform sketches, as well as accurate calculations, from their simulation and testing of physical circuits. For example, the voltage gain of a non-inverting amplifier will be calculated from component values, with estimated upper and lower expected values due to component tolerance.

Learners will compare their results from the simulation and safe construction and testing of physical circuits. The characteristic of device and circuit performance will be more complex than simple output to input ratios in amplifier circuits, for example voltage gain of the amplifier at different frequencies from oscilloscope traces, simulated waveforms and circuit calculations. Small variations may be noted between the results from different sources and attributed to factors such as the simulation using ideal components, but still giving results within acceptable levels considering the preferred values used.

The impact on circuit performance of modifying one criterion will also be evaluated. For example, learners will support their evaluation of changes in bandwidth as a result of increasing or decreasing gain by referring to gain-bandwidth product and its importance in op-amp circuit applications.

Overall the evidence, such as practical and simulation reports, 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, with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will capture a circuit schematic accurately and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely and accurately, such as instrument controls set to allow the amplitude and frequency of waveforms to be measured accurately, for example time base set to give just over two cycles, and voltage gain to use as much of the vertical scale as possible.

Learners will analyse the operation of the analogue circuits using the simulation and test results from physical circuits, including calculations where appropriate. For example, they will calculate the gain of a non-inverting operational amplifier from measurements and component values at a number of frequencies, but may not make specific reference to the gain-bandwidth product.

Overall, the evidence should be logically structured, technically accurate and easy to understand. For example, schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled, and virtual instruments connected correctly with controls set to realistic values.

For pass standard, learners will capture a circuit schematic and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. These circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely. For example, they will construct an inverting operational amplifier and measure input and output voltages to calculate the circuit gain.

Using the simulation and test results from physical circuits, learners will explain the operation of at least one diode-based, transistor-based and operational amplifier-based circuit. For example, an explanation and evidence for the dependence of gain of an inverting operational amplifier on component values at a given frequency would be indicative of pass level achievement. Learners will include calculations where appropriate to do so, for example the voltage gain of the amplifier from amplitude measurements of input and output sinusoidal voltages.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example calculating gain and attenuation as ratios rather than in decibel (dB), and may contain minor technical inaccuracies relating to engineering terminology, such as not differentiating between peak and root-mean squared (RMS) voltages, or inconsistent use of units.

Learning aim B

For distinction standard, learners will present a balanced evaluation of combinational and sequential logic circuits that they have captured, simulated, constructed and tested accurately.

They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates needed using one type of gate, for example NAND. They will verify that the minimised circuit functions as required.

Learners will produce a schematic diagram for two different sequential circuits that use D type and/or JK flip-flops and standard logic gates for a stated application. One of the sequential circuits should use a proprietary integrated circuit to carry out the sequential function.

Learners will verify that the circuits function as required, comparing and contrasting simulation and building and testing them accurately.

Overall the evidence, such as practical and simulation reports, 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, learners will capture circuit schematics accurately and simulate the correct operation of at least one combinational and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates using a combination of gate types.

Learners will produce a schematic diagram for two different sequential circuits using D type and/or JK flip-flops and standard logic gates, for example a minimum 3-bit asynchronous counter and a minimum 3-bit shift register. They will verify that the minimised circuits function as required using schematic capture and simulation.

Learners will construct and test the circuits and measure and record the operation of the circuits safely and accurately. For example, they will take suitable precautions when handling integrated circuits and use appropriate instruments such as a logic probe rather than a multimeter.

Overall, the evidence will be logically structured, technically accurate and easy to understand. For example, the schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled and virtual instruments connected correctly.

For pass standard, learners will capture circuit schematics and simulate the correct operation of at least one combinational logic and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format. They will verify that the circuit functions as required using schematic capture and building and testing the circuit.

Learners will produce schematic diagrams for two different sequential circuits, for example a 3-bit asynchronous counter and a 3-bit shift counter using D type and/or JK flip-flops. They will verify that the circuits function as required using schematic capture and simulation software.

Learners will construct and test the circuits and record the operation of the circuits safely.

Using the simulation and test results from physical circuits, learners will explain the operation of the circuits, for example an explanation and evidence for the operation of a shift register.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example not explaining why a shift register shifts in a given direction, and may contain minor technical inaccuracies such as not differentiating between D type and JK flip-flops.

Learning aim C

For distinction standard, learners will demonstrate, during the first two assignments, relevant behaviours and general engineering skills to a professional standard. For example, they will plan all activities in advance and they will meet all deadlines.

Their evidence will show consistently good technical understanding of the analogue and digital electronic circuits during the simulation and construction and testing processes. They will use accurate technical engineering terms and grammar and will clearly differentiate facts from opinion.

The lessons learned evidence, for example a report, will present a good technical understanding of analogue and digital electronic circuits. Overall the evidence will include a balanced view about the actions taken, electronic circuit development (circuit simulation and construction and testing processes), including health and safety compliance, and technical engineering terms used correctly and consistently. 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 provide in their evidence, such as a logbook, and especially the lessons learned report, examples of where improvements could be made to the:

- development (simulation, construction and testing) of analogue and digital electronic circuits, for example how an understanding of triggering flip-flops can help in deciding whether a shift register will shift left or right
- application of relevant behaviours, for example how listening to instructions has resulted in an activity running smoothly or a circuit operating as intended.

Overall, the suggested improvements should be reasonable and practical. Learners will give professional explanations and use engineering terminology accurately. Some parts of the evidence may have more emphasis than others, making the evidence more difficult for a third party to understand.

For pass standard, learners will give evidence, such as a lessons learned report, that is around 500 words in total and that covers the management of health and safety, analogue and digital electronic skills and general engineering skills, as well as a reflection of personal performance. The evidence will be basic in its approach, with some use of technical language, but it may not be consistent and there may be some errors throughout. The evidence will explain:

- actions taken to manage health and safety in the workplace, for example which personal protective equipment was used and whether any unforeseen issues occurred
- electronic engineering skills, such as identifying components and their characteristics, circuit theory and the skills required to construct and test circuits
- how general engineering skills were used, such as the use of IT to simulate circuits, CAD to capture schematics and interpreting drawings
- the behaviours used, such as time management and planning to ensure the activity was completed within the appropriate time.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 17: Power and Energy Electronics
- Unit 20: Analogue Electronic Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics and engineering organisations involved with electronic devices and circuits.
- contribution of ideas to unit assignment/project materials.

Unit 20: Analogue Electronic Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore single function analogue electronic circuits by simulation, building circuits, measuring values and theoretical calculation.

Unit introduction

The increasing number of digital devices we use daily might make you wonder whether analogue circuits are becoming obsolete. However, as the real world is analogue and not digital, the continued relevance of analogue electronics is ensured. For example, a few years ago a mobile phone had one important analogue sensor, a microphone, whereas today's mobile phones feature cameras, accelerometers, touchscreen sensors, proximity sensors and more.

You will cover the safe design, construction and testing of analogue electronic circuits using discrete (resistors, capacitors, inductors, diodes, transistors) and integrated circuit components. Electronic circuit designers make frequent use of software to simulate design ideas before building prototype circuits and you will use software to simulate circuits and typical bench instruments to test them. You will reflect on the skills and understanding gained while building, modifying and testing analogue circuits and the behaviours you have applied.

A wide range of industries employs analogue electronic engineers, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation. This unit will help to prepare you for employment, for example as an electrical/electronic technician, for an apprenticeship or for entry to higher education.

Learning aims

In this unit you will:

A Investigate through research and simulation the operation of single function analogue electronic circuits

B Explore the operation of single function analogue electronic circuits safely that form the building blocks of commercial circuits

C Modify a single function analogue electronic circuit to meet given parameters as widely undertaken in industry

D Review the development of analogue electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate through research and simulation the operation of single function analogue electronic circuits	**A1** Applications and characteristics of single function analogue circuits **A2** Simulation of single function analogue electronic circuits	A developmental log supported by observational witness statements. The log should contain circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits.
B Explore the operation of single function analogue electronic circuits safely that form the building blocks of commercial circuits	**B1** Construction of single function analogue electronic circuits **B2** Testing single function analogue electronic circuits **B3** Calculations for analogue circuits	
C Modify a single function analogue electronic circuit to meet given parameters as widely undertaken in industry	**C1** Component selection **C2** Simulation of a modified analogue electronic circuit **C3** Construction and testing of a modified analogue electronic circuit	A developmental log detailing the design, construction and testing of prototype circuits. Evidence should include calculations, component selection, schematic capture, simulation, circuit layout and construction plans, one or more observational witness statements and a formal assessment of the final permanently constructed circuit.
D Review the development of analogue electronic circuits and reflect on own performance	**D1** Lessons learned from exploring analogue electronic circuits **D2** Personal performance while exploring analogue electronic circuits	The evidence will focus on what went well and what did not go so well when exploring analogue electronic circuits, reviewing the processes and reflecting on own performance. A portfolio of learners' evidence generated while exploring analogue electronic circuits and reviewing the processes and reflecting on own performance.

Content

Learning aim A: Investigate through research and simulation the operation of single function analogue electronic circuits

A1 Applications and characteristics of single function analogue circuits

- Power supply:
  - applications – bridge rectifier, smoothing, regulation (discrete component and fixed voltage integrated circuit)
  - characteristics – direct current (DC) and root mean square (RMS) voltage, peak, peak-to-peak and ripple voltage.
- Passive filters:
  - applications – low pass, high pass and band pass, frequency selection, e.g. in audio and communication systems
  - characteristics – attenuation, noise and decibel.
- Transistor amplifiers:
  - applications – classes (A, B, AB and C), bipolar and field effect transistors, audio and communications systems
  - characteristics – gain, bandwidth, dependence on component values.
- Operational amplifiers:
  - applications – comparator, buffer (to interface analogue transducers), inverting amplifier, non-inverting amplifier, negative feedback
  - characteristics – gain, bandwidth, gain-bandwidth product, dependence on component values.
- Oscillators:
  - applications – LC (inductive coil and capacitor), crystal, integrated circuit oscillator/timer, sine wave and square wave
  - characteristics – positive feedback and necessary conditions for oscillation.
- Communications applications:
  - applications – transmission and reception of radio communications, amplitude modulated (AM), frequency modulated (FM)
  - characteristics – waveforms at key test points.

A2 Simulation of single function analogue electronic circuits

Schematic capture of single function analogue circuits to include:

- electrical circuit drawing standards BS 8888, BS 3939 or other relevant international equivalents
- simulation methods and the use of virtual instrumentation
- extraction of data/measurements, e.g. voltage, current, power, input and output signals, gain, frequency analysis, e.g. bode plot.

Learning aim B: Explore the operation of single function analogue electronic circuits safely that form the building blocks of commercial circuits

B1 Construction of single function analogue electronic circuits

- Circuit assembly methods:
  - interpretation of circuit diagrams
  - identification, handling and preparation of components, including:
    - passive components, e.g. resistors, capacitors, inductors and transformers
    - active components, e.g. transistors, diodes and integrated circuits
    - mechanical components, e.g. connectors, sockets and switches
  - component polarity and placement
  - prototyping methods, e.g. breadboard, stripboard, printed circuit board (PCB), plug board systems
  - hand soldering techniques.

- Quality control checks, e.g. component selection, placement and polarity, quality of construction.
- Safe working practices: awareness of and compliance with hazard identification, risk assessments and standard operating procedures associated with electronic-based tasks.

B2 Testing single function analogue electronic circuits

Appropriate test equipment to carry out functional testing to determine circuit inputs and outputs, to include:

- correct connection of test equipment to include digital multimeter, dual trace oscilloscope and function generator
- accurate measurement of key parameters, e.g. supply voltage, current, input and output signals
- comparison of measured parameters with those obtained from simulation and the client brief, e.g. frequency, gain.

B3 Calculations for analogue circuits

Typical component and parameter values determined from theory, simulation and measurement.

Types of equation to verify circuit operation and performance of circuits, including:

- power supply:
  - RMS voltage from theory and simulation waveform $V_{\text{RMS}} = \frac{V_{pk}}{\sqrt{2}}$
  - ripple voltage from measurement and simulation waveforms
- passive filters (single stage):
  - reactance and impedance, $X_C = \frac{1}{2\pi fC}$, $X_L = 2\pi fL$, $Z = \sqrt{R^2 + X_C^2}$
  - attenuation, low pass $A_v = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{X_C}{Z}$, high pass $A_v = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{R}{Z}$
  - phase shift, low/high pass, $\phi = \tan^{-1}\left(2\pi fRC\right)$
  - cut-off frequency $f_c = \frac{1}{2\pi RC}$
  - centre frequency, band pass $f = \sqrt{f_L \times f_H}$
- transistor amplifiers:
  - calculations on biasing of common emitter amplifier, e.g.:
    - current gain, $h_{\text{FE}} = \frac{I_C}{I_E}$
    - internal emitter resistance $r_e = \frac{25\text{ mV}}{I_E}$
    - voltage gain, common emitter $A_V \approx -\frac{R_L}{R_e}$
  - voltage gain from simulation and measurement $A_v = \frac{v_{\text{out}}}{v_{\text{in}}}$
  - voltage gain from simulation and measurement $A_v = 20\log\left(\frac{v_{\text{out}}}{v_{\text{in}}}\right)dB$

- operational amplifiers:
  - comparator
  - potential divider voltage $V_{ref} = \frac{R_2}{R_T} V_S$
  - output v_{out} when $v_{in} > v_{ref}$, (v_{ref} at inverting input)
  - inverting amplifier $A_v = -\frac{R_f}{R_{in}}$
  - non-inverting amplifier $A_v = \frac{R_{in} + R_f}{R_{in}}$
  - gain-bandwidth product $GBW = A_v \times BW$
- oscillators:
  - using measurements and simulation $f = \frac{1}{T}$
  - LC (inductive coil and capacitor) – resonant frequency $f_r = \frac{1}{2\pi\sqrt{LC}}$
  - integrated circuit oscillator/timer, e.g.:
    - 555 timer as monostable $T = 1.1 \times R_1C_1$
    - 555 timer as astable:

    $T = t_1 + t_2 = 0.693(R_1 + 2R_2)C$

    $f = \frac{1}{(R_1 + 2R_2)C}$

    duty cycle $d = \frac{T_{on}}{T_{on} + T_{off}} = \frac{(R_1 + R_2)}{(R_1 + 2R_2)}$
- communications applications:
  - qualitative analysis of waveforms.

Learning aim C: Modify a single function analogue electronic circuit to meet given parameters as widely undertaken in industry

C1 Component selection

Identify component values to meet a given client brief:

- selection of preferred values of components based on ideal calculated values
- calculations of expected circuit outputs using preferred value components.

C2 Simulation of a modified analogue electronic circuit

Methods to verify modifications made to an analogue circuit, to include:

- schematic capture of the modified circuit
- simulation of the modified circuit operation
- modification of component values to meet the given criteria
- determination of expected circuit operation
- circuit performance improvements, e.g. using trimmers to 'fine-tune' the frequency of an oscillator, or gain of an inverting amplifier.

C3 Construction and testing of a modified analogue electronic circuit

- Circuit assembly using one-off permanent construction methods, e.g.:
  - breadboard
  - stripboard
  - PCB.
- Circuit testing, to include:
  - use of circuit diagrams, e.g. to identify test points
  - interpretation and recording of measurements, e.g. voltage, frequency, noise, gain
  - use of test equipment, e.g. oscilloscope, signal generator, digital multimeter, frequency meter/spectrum analyser, virtual (computer-based) instruments, data capture
  - safe working practices, with emphasis on the safe use of soldering equipment, e.g. burn hazards and the potential need for fume extraction.

Learning aim D: Review the development of analogue electronic circuits and reflect on own performance

D1 Lessons learned from exploring analogue electronic circuits

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- analogue electronic circuit development skills, e.g. schematic capture, simulation, quality control methods and construction methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while exploring analogue electronic circuits

Understand relevant behaviours for modifying an analogue electronic circuit, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- commercial and customer awareness to ensure the analogue circuits are fit for purpose and meet the brief.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate through research and simulation the operation of single function analogue electronic circuits		**AB.D1** Evaluate, using language that is technically correct and of a high standard, the operation of at least two circuits from each type of analogue circuit, comparing the theoretical calculations and results from safely conducted experiments and simulations.
A.P1 Capture the circuit schematic and simulate the correct operation of at least one circuit from each type of single function analogue circuit.	**A.M1** Capture the circuit schematic and simulate accurately at least one circuit from each type of analogue circuit.	
Learning aim B: Explore the operation of single function analogue electronic circuits safely that form the building blocks of commercial circuits		
B.P2 Build one circuit from each type of single function analogue circuit safely and determine the characteristics of each. **B.P3** Explain, using theoretical calculations and test results, the correct operation of one circuit from each type of single function analogue circuit and suggest suitable applications.	**B.M2** Build at least one circuit from each type of analogue circuit and test the characteristics accurately. **B.M3** Analyse, using theoretical calculations and test results, the correct operation of at least one circuit from each type of analogue circuit.	
Learning aim C: Modify a single function analogue electronic circuit to meet given parameters as widely undertaken in industry		**C.D2** Refine, during the process, the operation of a modified single function circuit to improve its performance.
C.P4 Design a modified single function analogue circuit, using calculations of component values and simulation methods. **C.P5** Build and test safely a permanently constructed modified single function circuit.	**C.M4** Develop accurately a modified single function circuit that operates as intended, while documenting alternative solutions.	
Learning aim D: Review the development of analogue electronic circuits and reflect on own performance		**D.D3** Demonstrate consistently good technical understanding and analysis of analogue circuit development, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Explain how health and safety, design, build and general engineering skills were effectively applied during the development of the analogue circuit. **D.P7** Explain how relevant behaviours were effectively applied during the development of an analogue circuit.	**D.M5** Recommend improvements to the development of the analogue circuit and to the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, B.P2, B.P3, A.M1, B.M2, B.M3, AB.D1)

Learning aim: C (C.P4, C.P5, C.M4, C.D2)

Learning aim: D (D.P6, D.P7, D.M5, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- an electronics laboratory fitted with a range of electronic test and measurement equipment, including low-voltage bench supplies, digital multimeters, function generators and dual trace oscilloscopes (it would be an advantage if learners also had access to more advanced instrumentation, such as frequency counters and a spectrum analyser)
- electronic circuit prototyping equipment such as breadboard, stripboard, one-off PCB manufacture
- basic components and appropriate specialised integrated circuits together with relevant catalogues, application notes and data sheets
- software to support schematic capture and SPICE circuit simulation, for example MultiSIm (National Instruments). Other software packages are available for educational users, for example Livewire (New Wave Concepts). Free Spice simulators can be downloaded from the internet, but there is no guarantee of their quality
- rapid development system, such as LJ Create Advanced Electronic Platform and Study Modules.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will present a balanced evaluation of the six different types of single function analogue electronic circuit and compare the operation of at least two circuits of each type. Learners will include data such as circuit schematics and waveform sketches, as well as accurate calculations, for example oscillator frequency from component values, with estimated upper and lower expected values due to component tolerance.

Learners will explore at least two circuits for each of the six different types, comparing the measurements taken from each physical circuit with values obtained from the simulation and theoretical calculations, for example oscillator frequency from oscilloscope traces, simulated waveforms and circuit calculations. Small variations in oscillator frequency may be noted and attributed to the simulation using ideal components, but still be within acceptable levels considering the preferred values used.

Overall, the evidence, such as a logbook and 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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will simulate the circuits accurately, for example selecting appropriate test points and instrumentation and interpreting values from measurements correctly.

Learners will build and test at least one circuit for each circuit type accurately and it is expected that two circuits for two or more types of analogue circuit will be built. Learners will select components correctly, for example using colour coding to verify that component values match the design values. They will connect components in the correct orientation as indicated by the circuit diagram and in the manufacturers' data sheets.

The comparison of results from practical testing and simulation will extend beyond simple statements to an indication of the relevance, or potential cause, of variation, for example it would not be sufficient to say the simulated cut-off frequency was 1200 Hz and the measured 1150 Hz without further comment, such as 'this is within the expected experimental error with the instruments used' or 'the use of 5% tolerance resistors means that this is as close as I can get to the specified value'.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will simulate the operation of one circuit from each of the six types and build each one, taking measurements of each circuit's operation. Learners will demonstrate that they can use electronic measuring equipment safely and use the physical test and simulation results to explain the operation of each circuit.

Overall, the evidence, such as a logbook and a report, will be logically structured. Evidence may be basic in parts, for example calculating gain and attenuation as ratios rather than in decibel (dB), and may contain minor technical inaccuracies relating to engineering terminology, such as not differentiating between amplitude, peak to peak or RMS voltage.

Learning aim C

For distinction standard, learners will provide evidence, including a development logbook, of justifications for design decisions and of refinement throughout the process to improve the performance of the circuit, for example including variable passive components or combinations of components to trim the frequency of an oscillator or the gain of an inverting amplifier.

The final circuit design will be permanently constructed and refined throughout the process. The soldering will be of an excellent quality, with no defects. The circuit will be tested to demonstrate that it meets the client brief and operates as intended.

For merit standard, learners will produce schematic diagrams that are drawn accurately and efficiently, with components labelled appropriately, and are neat, readable and with good organisation in line with standards. Learners will give evidence of alternative design solutions. For example, a low pass filter with a given cut-off frequency can be designed using many combinations of passive components to generate the product term RC.

Learners will construct and assemble the circuits to a high standard safely and accurately, for example selecting components and placing them accurately with correct orientation. Their soldering will be of a good quality (little or no bridged, incomplete, dry, excessively soldered or overheated joints) and the leads neatly trimmed. Learners will compare the circuit function with the client brief to demonstrate that it operates as intended.

For pass standard, learners will design a modified single function analogue circuit for a given client brief by calculating appropriate component values and generating an accurate circuit diagram. They will simulate the circuit behaviour and measure parameters to verify the design, for example the input and output voltages of an amplifier to calculate gain.

Learners will select components with values set in accordance with the circuit diagram. The components will be connected correctly in a permanently constructed circuit and tested for functionality. Learners will take appropriate safety precautions, such as using the correct personal protective equipment. The circuit should function but may not fully meet the given client brief. For example, a 555 timer stable circuit may oscillate, but at a frequency outside the expected tolerance.

Learning aim D

For distinction standard, learners will demonstrate, during assignments 1 and 2, relevant behaviours and general engineering skills to a professional standard. For example, they will plan all activities in advance and demonstrate commercial awareness, either by building a final modified analogue electronic circuit that fully meets the client brief or by acknowledging how the circuit does not operate as intended. In addition, all deadlines will have been met.

As part of the refinement process the 'lessons learned report' will give a technical understanding of the analogue electronic circuit design and safe construction process, including technical engineering terms and accurate grammar, and will clearly differentiate facts from opinion.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. Learners will include a balanced view about the actions taken, including health and safety compliance, and the circuit design, construction and testing process.

For merit standard, learners will give detailed examples in their notes or logbook, and especially in the 'lessons learned report', of where improvements could be made to the:

- development (simulation, construction, theoretical calculations and testing) of analogue electronic circuits. For example, how time spent refining the circuit operation at the simulation stage of the process can result in a speedier and more accurate realisation of the final circuit
- application of relevant behaviours, for example how listening to instructions has resulted in an activity running smoothly or a circuit operating as intended.

Overall, the suggested improvements should be reasonable and practical and explanations will be professional, using accurate engineering terminology. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will produce evidence that includes a 'lessons learned report' of between 500 and 1000 words in length. Evidence will cover the management of health and safety, the application of analogue circuit development and general engineering skills, and a reflection on personal performance. Evidence will be basic in its approach, with some, but not consistent, use of technical language, and there may be some errors throughout. The evidence will explain what:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- electronic/electrical engineering skills were used, such as identifying components and their characteristics, electronic circuit theory and using schematic diagrams
- electronic circuit design and construction skills were used, such as component selection and the skills required to manufacture and assemble an electronic circuit efficiently and accurately
- general engineering skills were used, such as the use of IT, CAD and interpreting drawings
- behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 3: Engineering Product Design and Manufacture
- Unit 5: A Specialist Engineering Project
- Unit 10: Computer Aided Design in Engineering
- Unit 19: Electronic Devices and Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics and engineering organisations with expertise in analogue electronics
- contribution of ideas to unit assignment/project materials.

Unit 21: Electronic Measurement and Testing of Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the operation of common electronic test and measurement devices and measure and test analogue and digital circuits to diagnose faults.

Unit introduction

The majority of industrial and domestic processes are controlled by electronic circuitry, so it is important for engineers in a range of sectors to be proficient with fault finding and testing techniques, even though they may not be an expert in electronics.

In this unit, you will explore the operational features, including the construction of a range of devices used in the testing of analogue and digital electronic circuits, using discrete and integrated circuit components. You will also explore fault finding techniques and prepare a test plan for diagnosing faults. You will go on to measure and test operational circuits to diagnose the location and nature of faults.

The standard fault finding techniques introduced as part of this unit can be applied to a wide range of industries, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation. This unit will help to prepare you for employment, for example as an electrical/electronic technician, an apprenticeship or for entry to higher education.

Learning aims

In this unit you will:

A Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits

B Examine fault finding techniques and test plans used when measuring and testing electronic circuits

C Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely

D Review the measurement and testing of electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits	**A1** Operational features of measurement devices **A2** Operational features of test devices	A written report exploring the operational features of typical measurement and testing devices. Learners will explore the measurement and test devices in the laboratory and through research.
B Explore fault finding techniques and test plans used when measuring and testing electronic circuits	**B1** Fault finding techniques **B2** Preparation for testing and test plans	A test plan to analyse each electronic circuit, detailing the fault finding techniques to be used and preparation tasks to be undertaken. It will also explain the rationale behind the application of different techniques. A logbook and fault finding record for the circuits, detailing tests undertaken, symptoms and final identification of the faulty components in analogue and digital circuits. One or more observational witness statements.
C Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely	**C1** Safe working practice **C2** Practical fault finding on analogue and digital circuits	
D Review the measurement and testing of electronic circuits and reflect on own performance	**D1** Lessons learned from measuring and testing electronic circuits **D2** Personal performance while measuring and testing electronic circuits	Evidence will focus on what went well and what did not go so well when testing and measuring electronic circuits, reviewing the processes and reflecting on own performance. A portfolio of evidence generated while measuring and testing electronic circuits and reviewing the processes and reflecting on own performance.

Content

Learning aim A: Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits

A1 Operational features of typical measurement devices

- Operational features of multiple range meters (multimeters), to include:
  - input impedance and output impedance for different parameters being measured
  - reading of analogue and digital displays
  - parallax issues with analogue meters
  - correct selection of terminals depending on the characteristics being measured
  - comparisons between analogue and digital meters
  - comparisons between autoranging and manual selection meters.
- Operation of dual beam oscilloscope for accurate measurement of alternating current (AC) waveform, to include:
  - operation of the cathode ray gun
  - how the beam is deflected
  - how to read a graticule.
- Explanation of oscilloscope features, to include:
  - time base
  - amplitude
  - waveform selector
  - trigger selection (internal, external triggering)
  - inbuilt calibration facilities.
- Operation of spectrum analyser, to include:
  - continuous or swept frequency analysis
  - input bandwidth control
  - reading of the cathode ray tube (CRT) output.
- Operation of digital test devices, to include:
  - logic probe and 'logic analyser' for measurement of the output states on digital electronic circuits
  - the points at which logic states change in both complementary metal oxide semiconductor (CMOS) and transistor-transistor logic (TTL) circuits
  - the response the probe gives when in-between the two states.

A2 Operational features of electronic test devices

Operational features of standard test devices, to include:

- stabilised direct current (DC) power supply
- alternating signal generator
- digital pulse generators
- binary word generator.

Learning aim B: Explore fault finding techniques and test plans used when measuring and testing electronic circuits

B1 Fault finding techniques

Applications and process for different fault finding techniques, to include:

- visual examination:
  - generally the first test carried out
  - look for signs of burnt or damaged components or broken connections
  - check values of components against circuit diagrams to identify any errors

- input-to-output and output-to-input technique:
  - efficiently used when the expected output of the electronic system (also referred to as a circuit) is known or can be predicted
  - works forwards from the input until a fault is found or backwards from the output until predicted values are obtained
- half-split technique:
  - used to minimise the number of tests to improve efficiency
  - involves measuring at the mid-point
  - if the signal at the mid-point is faulty then the next step is to test at the midpoint between the input and this first test point
  - repeat the process until there is no fault – the fault then lies between the last two test points
  - if the signal at the mid-point is not faulty then the second test is at the mid-point of the first test point to the output
- symptom-to-cause technique:
  - efficiently used when fault data is systematically recorded
  - uses historical test data to relate symptoms to potential faults
- circuit substitution technique:
  - efficiently used when visual inspection or other analysis indicates that a particular component or circuit is faulty
  - replaces suspect components or circuits with functionally operational ones
  - system is then retested
- top-down technique:
  - efficiently used in complex electronic systems
  - involves testing the complete system, then each subsystem is tested and finally each component in the faulty subsystem (operational subsystems will have been ruled out) will be tested until the fault has been identified.

B2 Preparation for testing and test plans

- Test plan, to include:
  - Fault finding aids, e.g. relevant diagrams (block schematic, circuit wiring diagrams), component and circuit tolerances, functional charts, troubleshooting charts, component data sheets, operation and maintenance manuals, software-based records and data
  - identification of key test nodes and expected signal conditions for analogue and digital circuits
  - production of a test schedule.
- Fault reporting methods, including standardised fault finding report forms that identify the:
  - symptoms of the fault
  - details of test devices used for traceability, e.g. serial numbers
  - checks undertaken
  - proposed solution to the problem.

Learning aim C: Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely

C1 Safe working practice

Safe working practice, to include:

- observation of safety rules
- responsible behaviour at all times in a workshop environment
- identification of risk assessments and controls for the tasks to be carried out
- safe use of devices for their designed purpose
- protection of others and self.

C2 Practical fault finding on analogue and digital circuits

Measurement of signal conditions at key test points for non-faulted analogue and digital circuits to compare with nominal values.

Application of fault finding plans for analogue and digital circuits to:

- identify fault symptoms using appropriate test devices
- select and apply a suitable fault finding technique
- identify faults.

Learning aim D: Review the measurement and testing of electronic circuits and reflect on own performance

D1 Lessons learned from measuring and testing electronic circuits

Scope of the lessons learned to cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- electronic circuit measurement and testing skills, e.g. selection and correct use of electronic test devices
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while measuring and testing electronic circuits

Understand relevant behaviours for measuring and testing electronic circuits, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving and perseverance, e.g. logical approach taken to identify the faults.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits		**A.D1** Evaluate, using language that is technically correct and of a high standard, the operational features of at least six different analogue and digital circuit measurement and test devices, identifying how to ensure accurate results.
A.P1 Explain the operational features of at least six analogue and digital circuit measurement and test devices.	**A.M1** Compare the operational features of at least six different analogue and digital circuit measurement and test devices.	
Learning aim B: Explore fault finding techniques and test plans used when measuring and testing electronic circuits		
B.P2 Explain two suitable techniques for testing faults in given analogue and digital circuits. **B.P3** Produce a logical fault finding test plan for two analogue circuits and two digital circuits, each with less than four stages.	**B.M2** Produce an effective fault finding test plan for two analogue circuits and two digital circuits, each with less than four stages, comparing testing techniques.	**BC.D2** Optimise a fault finding test plan and carry out the identification of faults correctly and safely for two analogue circuits and two digital circuits, each with less than four stages, justifying the effectiveness of the test processes and any further improvements to be made.
Learning aim C: Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely		
C.P4 Identify faults correctly and safely in at least one analogue circuit. **C.P5** Identify faults correctly and safely in at least one combinational and/or one sequential logic circuit, each with less than four stages.	**C.M3** Identify faults correctly and effectively in two analogue circuits safely, while recording the results accurately. **C.M4** Identify faults correctly, safely and effectively in one combinational and one sequential logic circuit, each with less than four stages, while recording the results accurately.	
Learning aim D: Review the measurement and testing of electronic circuits and reflect on own performance		**D.D3** Demonstrate consistently good technical understanding and analysis of the measurement and testing of circuits, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Explain how health and safety, measurement, testing and general engineering skills were effectively applied when fault finding circuits. **D.P7** Explain how relevant behaviours were applied effectively during the measurement and testing of circuits.	**D.M5** Recommend improvements to the measurement and testing of circuits and to the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, C.M3, C.M4, BC.D2)

Learning aim: D (D.P6, D.P7, D.M5, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- an electronic laboratory and bench top test devices, including signal generators, low voltage direct current (DC) power supplies, dual trace oscilloscopes, analogue and digital multimeters, logic probes and logic pulsers
- pre-built analogue and digital circuits with switched faults, for example fixed voltage regulated DC power supply, two-stage class A amplifier with test points accessible, single stage active filter, position controller (servo), a combinational logic circuit such as a 4-bit adder or decision-making circuit, a sequential logic circuit such as a traffic light circuit or ripple counter
- standardised fault finding record sheets, including devices under test, initial symptoms, test devices used (including serial numbers or other identification for traceability), tests carried out, observations and conclusions, identification of root cause
- spectrum analyser/Bode plotter (advantageous)
- electronic computer-aided design (ECAD) facilities, such as MultiSIM, to allow learners to simulate the operation of the rarer test devices (advantageous).

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the operational features of common measurement and test devices used in industry. They will cover the operational features of at least four measurement devices, including digital and analogue multimeters, a dual beam oscilloscope and a logic probe, and two test devices, for example a stabilised power supply, and a signal generator identifying applications for each. They will discuss the relative merits of digital and moving coil meters in testing electronic circuits, including accuracy and ease of reading displays/scales.

Learners' evidence will identify inherent problems with accuracy for the different types of device and suggest ways to improve confidence in measurements, for example appropriate calibration.

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 merit standard, learners will compare the use of analogue and digital test devices in producing accurate measurements when testing analogue and digital electronic circuits. For example, they may note the effect of input or output impedance on measurements, or the effect of analogue to digital conversion in digital multimeters. They will compare the ease of reading digital test devices with analogue meters against their accuracy.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the operation of at least three analogue and one digital measurement devices and two testing devices used to identify faults in analogue and digital electronic circuits. They will support their explanations with annotated diagrams to illustrate the correct connection of each of the chosen devices when measuring and testing.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example explanations may omit some detail, such as how to adjust an oscilloscope to display an alternating waveform.

Learning aims B and C

For distinction standard, learners will optimise their fault finding test plans using at least two fault finding techniques. They will justify their choice of technique, making comparisons between the available options as part of the test plan and provide details of preparatory tasks. They will explain how the results will be consistent and accurate, for example identifying the serial numbers of measurement and test equipment and making comparisons using the same equipment for traceability.

Learners will use a range of documentation to produce an efficient fault finding plan, including safe working practice, to identify the cause of a single fault in each circuit. For example, the plan may be in the form of a flow chart and will include accurately validated signal values and waveforms at key test points on unfaulted circuits for comparison purposes. Learners will use their plan to find each fault in at least two complex analogue electronic circuits and two digital logic circuits (one combinational, and one sequential).

Learners will systematically document the steps taken in logical sequence, the devices used and the detailed observations made, reaching insightful conclusions using standardised documentation. The conclusions reached at each stage will lead logically to the next measurement in the sequence, for example a permanently low voltage level on the base of a transistor leading to checking for a short circuit between base and emitter, or a permanently low logic level (stuck-at zero) on a logic gate leading to the search for a short circuit to signal ground.

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 merit standard, learners will use relevant documentation to produce an effective fault finding plan, incorporating safe working practice, to identify the cause of each fault. However, the plan may not necessarily be the most efficient, for example learners may follow an end-to-end approach, measuring accurately and making logical deductions to find the fault, but a half-split method could reach the same outcome in fewer steps. Learners will also compare the advantages and disadvantages of at least two different fault finding techniques for a given circuit.

Learners will find the root cause of the faults in at least two analogue and two digital circuits. They will complete tests effectively, for example in a logical sequence, comparing measured values with those from unfaulted circuits. There may be some deviation from the initial plan as a result of the measurements taken. The conclusions learners reach will reflect the observations made and lead logically to the next test, although this may not be the most obvious alternative and could lead to additional steps being taken.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain at least two techniques for testing faults in analogue electronic circuits and complex digital electronic circuits, for example half-split andoutput-to-input techniques. The circuits will be sufficiently complex to allow learners to use a range of fault finding techniques, for example a two-stage class A amplifier, a regulated full-wave rectifier or a modulo-7 asynchronous counter using J-K flip-flops.

Learners will focus on the fault finding techniques rather than in-depth understanding of how each component works in the circuit. They will use given documentation to produce a logical test plan for an electronic circuit that incorporates safe working practice and includes preparatory tasks. The fault finding plan may not be the most efficient, for example using an input-to-output technique on a complex circuit. The plan should be logical although it may omit key detail, for example not stating if the expected signal value measured at a test point in an unfaulted analogue circuit is RMS or peak, making it difficult to select an analogue/digital multimeter or an oscilloscope as the most appropriate measurement device, but not preventing learners from finding the fault in a circuit with a single fault.

Learners will find the root cause of at least one analogue and one digital fault, carrying out fault finding procedures on each circuit, although they may deviate from the plan. Conclusions may not be drawn or, if they are, may lack detail or be misinterpreted. The next step in the testing sequence may not relate to the conclusions drawn from the first step, for example measurement of a permanently low voltage level on the base of a transistor being followed by measuring the voltage across an unconnected resistor.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example observations may lack detail such as whether a signal is sinusoidal and units may be inconsistent. Some outcomes may be inconclusive, or a reading may be misinterpreted resulting in the root cause of a particular fault not being identified correctly.

Learning aim D

For distinction standard, learners will demonstrate relevant behaviours and general engineering skills to a professional standard, for example they will plan all activities in advance and meet all the deadlines.

Their evidence will show consistently good technical understanding of measurement and testing as well as the fault finding processes. They will include accurate technical engineering terms and grammar, and will clearly differentiate facts from opinion.

Overall, the evidence will include a balanced view about the actions taken, electronic circuit fault finding (including measurement, testing, calculations and using devices), including health and safety compliance, and technical engineering terms will have been used correctly and consistently. 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 give examples, such as their lessons learned report, of where improvements could be made to:

- the fault finding process (including measurement, testing, calculations and using devices) for analogue and digital electronic circuits, for example how a database of previous fault finding results allows the fault symptoms to identify a potential cause
- application of relevant behaviours, for example using deductive reasoning to move from a test result to the next test.

Overall, the suggested improvements will be reasonable and practical, explanations will be professional and engineering terminology will be used accurately. Some parts of the evidence may have more emphasis than others, making the evidence more difficult for a third party to understand.

For pass standard, learners will provide evidence, such as a lessons learned report, around 500 words in total, that covers the management of health and safety, analogue and digital measurement, testing skills, general engineering skills and a reflection on personal performance. The evidence will be basic in its approach with some use of technical language, but this may not be consistent and there may be some errors throughout. The evidence will explain:

- the actions taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- electronic measurement and testing skills, such as consistently selecting and connecting correctly appropriate measurement and testing devices
- how general engineering skills were used, such as reading measurement and test devices accurately and interpreting schematic drawing
- behaviours used, such as problem solving and perseverance to identify the faults.

Links to other units

This unit links to:

- Unit 16: Three Phase Electrical Systems
- Unit 19: Electronic Devices and Circuits
- Unit 20: Analogue Electronic Circuits
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics organisations
- contribution of ideas to unit assignment/project materials.

Unit 22: Electronic Printed Circuit Board Design and Manufacture

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore and develop the design and manufacture of electronic printed circuit boards (PCBs). This unit does not cover the design of circuits.

Unit introduction

Electronic products are everywhere, from toasters to computer tablets, and at the heart of these devices are ever more complex electronic circuits. To make these products function as intended (reliably and safely), the circuits need to be connected effectively; and this is the job of a PCB. As well as making all of the required electrical connections that join the components together, a PCB must also physically support the components. PCBs might also comprise some user controls or a display, and can be designed to help protect the circuit from excess heat or interference.

In this unit, you will understand and explore the industrial processes involved in designing and manufacturing sustainable PCBs. You will gain an understanding of the different types of PCB and the design considerations for an electronic product or system. You will experiment with software tools to design and simulate the PCB, before safely producing a PCB that you will then examine to assess its functionality and build quality. Finally, you will reflect on the skills and understanding you have acquired while designing and manufacturing a PCB, and the behaviours applied.

It is the role of electronic design engineers to examine and analyse the diverse product and system requirements and then to develop effective, efficient and sustainable solutions, ensuring optimal performance. This unit will help to prepare you for employment and apprenticeships in electronic and electrical engineering and, in particular, electronic product design and manufacture. You may also be interested in this unit if you want to progress to higher education to study engineering.

Learning aims

In this unit you will:

A Examine the design and manufacture of printed circuit boards that are widely used in industry

B Explore how computer software is used for schematic capture and simulation of an electronic circuit

C Develop safely a printed circuit board to solve an engineering problem

D Review the development of the printed circuit board and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the design and manufacture of printed circuit boards that are widely used in industry	**A1** PCB types, technologies and applications **A2** Characteristics of printed circuit boards **A3** Heat gain and thermal management **A4** Manufacturing processes **A5** Quality control methods **A6** Sustainability and environmental considerations	A written report or formal presentation detailing the PCB technology, characteristics and thermal management techniques employed in electronic products, including a description of the relevant manufacturing processes and quality control methods.
B Explore how computer software is used for schematic capture and simulation of an electronic circuit	**B1** Schematic capture **B2** Circuit simulation	Evidence of computer-based activities capturing and simulating direct current (DC) and alternating current (AC) circuits, or a complex circuit containing DC and AC elements; witness statements accompanied by annotated screenshots, printouts and data generated.
C Develop safely a printed circuit board to solve an engineering problem	**C1** PCB design **C2** Health and safety requirements when manufacturing a PCB **C3** Risk assessment **C4** Manufacture of a single-sided PCB	A reflective developmental log detailing the design, manufacture and testing process undertaken. This should be accompanied by one or more observational witness statements, photographic evidence, a formal assessment of the final circuit board and relevant behaviours applied. The portfolio of evidence learners' generate while developing a printed circuit board and reviewing the processes and reflecting on own performance
D Review the development of the printed circuit board and reflect on own performance	**D1** Lessons learned from developing a PCB **D2** Personal performance while developing a PCB	

Content

Learning aim A: Examine the design and manufacture of printed circuit boards that are widely used in industry

A1 PCB types, technologies and applications

- Types of PCB and their technology: through hole (THC), surface mount (SMT), mixed-technology boards, single and multiple layer/sided boards, rigid, flexible and membrane PCBs and chip-on-board (COB).
- Typical PCB applications, e.g. multimedia devices, computing, household electrical items/white goods, industrial processes, aerospace, and medical, influence the choice of manufacturing technology and characteristics of the PCB.

A2 Characteristics of PCBs

- Characteristics of the different PCB technologies, including physical size and component density, composition and materials used, ease of mass manufacture, component availability and cost, design complexity, connectivity and interconnection, radio frequency immunity, mechanical characteristics, ease of rework and power handling capability.
- Justification of the technology used for different applications based on design requirements and circuit board characteristics.

A3 Heat gain and thermal management

- Causes of heat generation, e.g. resistance, internal resistance, semiconductor junction.
- Consequences of excess heat gain and thermal cycling, e.g. component failure, reduced product life span, changes to components' electrical characteristics, de-soldering, material property changes, physical stresses, safety, usability issues.
- Thermal management methods:
  - heat dissipation methods, including heat sinks, fins/cavities, heat pipe, air and liquid cooling, Peltier plate, case/enclosure design, and thermal interface efficiency (component mounting and thermal compound)
  - heat efficient PCB design, e.g. component placement (geographic and relative to other components), component density, heat dissipation via board/copper, consideration of enclosure fixtures/features
  - thermal rating conventions and typical values for simple heat dissipation devices.

A4 Manufacturing processes

PCB mass manufacturing processes:

- artwork production (photo/laser)
- drilling (manual/automated)
- chemical processes: exposure, developing, electroplating and etching
- component placement: manual insertion and automated pick and place
- soldering techniques: hand, selective, wave and reflow
- solder mask over bare copper (SMOBC)
- silkscreen
- punching, routing, scoring
- Institute for Printed Circuits (IPC) standards or other relevant international equivalents.

A5 Quality control methods

- Quality control methods used in the batch and mass manufacture of PCBs including: visual inspection techniques (manual/assisted), automated optical inspection (AOI), x-ray, automated test equipment (ATE), electrical testing, flying probe and test fixtures/'bed of nails', functional testing, standards conformity testing, e.g. electromagnetic compatibility (EMC).

- Quality control methods for the one-off and small batch manufacture of PCBs, including:
  - pre-assembly inspection methods, e.g. incomplete or bridged tracks and pads, hole completeness and hole alignment, and finish quality assessment
  - post-assembly inspection methods, e.g. component placement and polarity, quality of soldering and functional testing – test procedures and plans, basic input and output testing, test points and criteria.

A6 Sustainability and environmental considerations

Sustainability and environmental considerations of different PCB technologies, including:

- manufacturing processes:
  - waste particulate, e.g. copper, gold and epoxy/fibreglass
  - liquid effluents, e.g. acids, copper, caustics, fluorides
  - air pollutants, e.g. acid gases, formaldehyde
- leaded and lead-free solder
- materials used in manufacture
- energy usage in manufacture and product operation
- product life cycle/expectancy
- Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC (updated 2009 and 2012) or other relevant international equivalents
- hazardous product waste materials, e.g. lead, cadmium, mercury.

Learning aim B: Explore how computer software is used for schematic capture and simulation of an electronic circuit

B1 Schematic capture

Capturing a schematic circuit in a software package, including:

- selection of correct components, device models and values
- drawing of circuit network connections
- electrical circuit drawing standards BS 8888, BS 3939, or other relevant international equivalents, e.g. organisation, component identification, connections and crossovers.

B2 Circuit simulation

Software simulation of AC and DC circuit(s) prior to physical manufacture:

- Simulation Program with Integrated Circuit Emphasis (SPICE)
- onscreen simulation
- confirmation of desired operation
- extraction of data/measurements, e.g. voltage, current, power (DC analysis)
- input and output signals AC analysis.

Learning aim C: Develop safely a printed circuit board to solve an engineering problem

C1 PCB design

Design of a single-sided PCB, to include:

- schematic capture and simulation
- PCB routing/design:
  - component packages and physical layouts
  - component placement, orientation and organisation
  - layers, tracks, pads, vias
  - track width and isolation gap requirements
  - manual and automated routing
  - mechanical fixtures, mounting points and off-board connections
  - production aids, e.g. silkscreen, component numbering, test points
  - generation of manufacturing information, e.g. PCB artwork, CAD/CAM data, bill of materials (BOM), technical specification and simulation/analysis data.

C2 Health and safety requirements when manufacturing a PCB

Key features of regulations, or other relevant international equivalents, including:

- hazardous materials: storage, handling and disposal of processing chemicals, Control of Substances Hazardous to Health (COSHH) Regulations 2002 and amendments
- Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments
- Personal Protective Equipment (PPE) at Work Regulations 1992 and amendments, e.g. safety goggles, gloves, apron, fume extraction/displacement.

C3 Risk assessment

Risk assessment and work area preparation and manufacturing planning, to include hazard identification and classification:

- defining a hazard by inspection of the work environment and consideration of specific PCB design and manufacturing processes:
  - electrical, e.g. electric shock, equipment inspection, and PAT testing
  - electrostatic, e.g. grounding, storage and packaging
  - fire safety, e.g. flammable chemicals, and safe working when soldering
- defining a risk by determining how hazards may cause injury, e.g. some chemicals will cause burns
- putting control measures in place to reduce risk, e.g. using rubber gloves when handling some chemicals
- Health and Safety Executive (HSE) guidance on risk assessment, to include the five steps to risk assessment and the use of standard risk assessment pro forma.

C4 Manufacture of a single-sided PCB

- Manufacture of a single-sided PCB to include:
  - manufacturing processes for the substrate, e.g. board preparation, UV exposure, photoresist development, etching, tinning and drilling
  - visual pre-assembly quality control checks, e.g. quality of copper layer reproduction, hole completeness and hole alignment.
- Circuit assembly methods:
  - safe working practices
  - appropriate identification, handling and preparation of components, including:
    - passive components, e.g. resistors, capacitors, inductors and transformers
    - active components, e.g. transistors, diodes and integrated circuits
    - mechanical components, e.g. connectors, sockets and mountings
  - component polarity and placement
  - hand soldering techniques
  - wire preparation, e.g. stripping, tinning, trimming
  - connection of off-board components
  - post-assembly quality control checks, e.g. component placement and polarity, quality of soldering and functional testing.

Learning aim D: Review the development of the printed circuit board and reflect on own performance

D1 Lessons learned from developing a PCB

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- PCB design and manufacturing skills, e.g. schematic capture, PCB artwork generation, quality control methods and hand soldering methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while developing a PCB

Understand that relevant behaviours cover:

- time planning and management to complete all the different activities in an appropriate time and in an appropriate order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- commercial and customer awareness to ensure the design and manufacture of the PCB is fit for purpose and meets the client brief.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the design and manufacture of printed circuit boards that are widely used in industry</td><td rowspan="2">A.D1 Evaluate, using vocational and high-quality written language, the design and manufacture of at least two different printed circuit boards contained in products and consider how they are likely to evolve.</td></tr>
<tr><td>A.P1 Explain the technology used in and characteristics of at least two different PCBs contained in products.
A.P2 Explain the causes and consequences of heat gain and thermal management methods used in at least two different PCBs contained in products.
A.P3 Explain the manufacturing processes and quality control methods used in at least two different PCBs contained in products.</td><td>A.M1 Analyse the design and the manufacture of at least two different PCBs contained in products.</td></tr>
<tr><td colspan="2">Learning aim B: Explore how computer software is used for schematic capture and simulation of an electronic circuit</td><td rowspan="2">B.D2 Capture, following industry conventions, a DC and AC circuit(s) schematic and use simulation data to create a technical specification for the circuit(s)</td></tr>
<tr><td>B.P4 Capture a DC and AC circuit(s) schematic and simulate the correct operation of the DC circuit.</td><td>B.M2 Capture accurately and efficiently a DC and AC circuit(s) schematic and simulate the correct operation including the generation of representative circuit(s) data.</td></tr>
<tr><td colspan="2">Learning aim C: Develop safely a printed circuit board to solve an engineering problem</td><td rowspan="4">CD.D3 Refine, during the process, the development of a PCB safely to improve its performance, whilst applying relevant behaviours and general engineering skills to a professional standard.</td></tr>
<tr><td>C.P5 Design a PCB and generate documentation for manufacture.
C.P6 Manufacture safely a PCB and identify any issues with the quality and functionality.</td><td>C.M3 Design and manufacture accurately and efficiently a PCB that functions as intended, while documenting alternative solutions.</td></tr>
<tr><td colspan="2">Learning aim D: Review the development of the printed circuit board and reflect on own performance</td></tr>
<tr><td>D.P7 Explain how health and safety, design and manufacturing and general engineering skills were applied effectively during the manufacture of the PCB.
D.P8 Explain how relevant behaviours were applied effectively during the design and manufacture of a PCB.</td><td>D.M4 Recommend improvements to the design and manufacture of the PCB and to the relevant behaviours applied.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.M2, B.D2)

Learning aims: C and D (C.P5, C.P6, D.P7, D.P8, C.M3, D.M4, CD.D3)

Further information for teachers and assessors

For this unit, learners must have access to:

- electronics design, simulation and PCB creation software, for example Circuit Wizard, Multisim, Eagle, Tina, DesignSpark, Proteus circuit board manufacturing equipment and consumables (depending on centre manufacturing method), for example photosensitive board, photo transfer paper, PCB shear, UV exposure unit, developer (chemical, tray, tongs), etching unit, etch resist stripper, immerse tin solution, mini drills and bits
- electronic components suitable for practice activities and project circuits
- commercial electronic circuit assembly kits, these are widely available and could support teaching and learning activities, for example Rapid Electronics, RK Education, Velleman
- circuit assembly tools, equipment and consumables, for example soldering irons, extractors, sides cutters, pliers, solder, de-solder tools, IC lead setting tools
- electronics reference materials, for example catalogues, data sheets and web-based resources
- small hand assembly tools, for example files, sandpaper, drill, glue gun, junior hacksaw
- a range of electronic products and/or circuit boards that employ various manufacturing techniques and circuit technologies
- a range of health and safety regulations, as stated in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of the design of at least two PCBs contained in different products. For example, learners could cover the complexity of the circuit, power requirements and physical factors, such as product size. They will also cover environmental conditions and manufacturing considerations, such as production quantity, manufacturing cost, and quality. Learners will suggest how the products might evolve for particular applications that require changes to the PCB technology/characteristics or due to advances in technology. Learners will refer to consumer trends and market forces and how they might influence the evolution of the electronic products and the impact of these on the electronics required.

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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse each board against the other in terms of the technology, characteristics, thermal management, manufacturing processes and quality control methods. They will also analyse why the PCB technology has been used for the intended product application. This might include the requirements of the circuit itself in order to achieve the product functionality.

Overall, the evidence will be logically structured, technically accurate and be easy to understand.

For pass standard, learners will give fully illustrated responses and, as a minimum, provide a sound overview of the technology used, and the physical construction and associated hardware characteristics of the printed circuit. For example, the explanation will cover the size, materials used, component attachment methods and connections, and case mounting.

Learners will explain the causes and consequences of heat gain, and how the effects can be mitigated by thermal management methods.

The individual manufacturing steps from raw substrate board to final assembly and testing will be included. Learners will detail the process effectively and the required hardware and consumables needed, but do not need to cover detailed chemical reactions.

Overall, the evidence will be logically structured, although it may be basic in parts and contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will draw the circuit to a high standard following industry best practice. This will include a neat, well-organised and readable layout with sequential component labels. Components will be fully specified and connected accurately with efficient wiring. The positioning of power lines will be appropriate and labelling will have been used to identify the purpose of terminals or controls.

Data will have been collated and well presented as a formal document, together with circuit schematics to generate a technical specification for the circuit. This will include a table of electrical values at key points in the circuit and/or at key stages in circuit operation. The AC circuit or AC element of a complex DC and AC circuit will include characteristic waveforms.

For merit standard, learners will enter both DC and AC circuits or the complex DC and AC circuit accurately, with all components appropriately selected with accurate values and models specified. The schematic will be efficient, meaning that the components are neat and readable with good organisation, component labelling and layout. The circuit(s) will simulate as intended to confirm the operation and there will be evidence of collecting electronic data from the circuit(s). This might include voltage, current or power readings for the DC circuit or DC element of a complex DC and AC circuit and input/output traces for the AC circuit or DC element of a complex DC and AC circuit.

For pass standard, learners will capture and connect correctly a range of (at least five and up to c. 15) passive and active components in a DC and an AC circuit or in a complex DC and AC circuit. The layout of components and connections in the circuit(s) may not be logical and well organised. There may be minor discrepancies in component values or device model selections that may affect the operation of the circuit(s). As a minimum, when simulated, the DC circuit or DC element of a complex DC and AC circuit will function as intended.

Learning aims C and D

For distinction standard, learners will include justifications for design decisions, records of identification of errors/defects and remedial action taken, and iterations of the circuit board to detail refinements that would improve its performance. For example:

- consideration of the intended application, such as the positioning of fixed components and points for mounting
- a name and other reference text will be included (if applicable)
- the soldering will be of an excellent quality, with no defects
- component density and grouping optimised.

Throughout the activity, learners will demonstrate relevant behaviours and general engineering skills to a professional standard. For example, all assignments will be completed on time, the practical activities will be planned out in advance and the finished PCB will fully meet the requirements of the client brief, hence demonstrating commercial awareness.

The lessons learned report will present a good technical understanding of PCB design and safe manufacturing processes. Overall, the evidence will include a balanced view about the actions taken, and PCB design and manufacture, including health and safety compliance and technical engineering terms, which will have been used correctly. 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 be accurate and efficient in their PCB design with neat routing of tracks and minimal use of space, and alternative design ideas will have been given. The schematic diagram will be drawn accurately and efficiently, with components aligned, numbered consecutively, labelled appropriately, neat, readable and oriented with connectors at board edges. Few or no links will be required and an appropriate track width, pad size and isolation gap (depending on application) will have been used.

Construction and assembly will be to a high standard, with the board cut to size and holes drilled accurately. Learners will have manufactured the PCB safely and well, with no bridged/broken tracks and clean, sharp traces. The soldering will be of a good quality (little or no bridged, incomplete, dry, excessively soldered or overheated joints) and the leads neatly trimmed. The circuit will function correctly as intended.

Additionally, learners will explain what improvements could be made throughout the processes and to the behaviours applied. There will be a detailed explanation of these improvements and the reasoning for them will be well considered.

For pass standard, learners will include in their circuit a range of passive and active components (around five to 15 components). All components will be selected correctly with values and device models set accordingly. PCB artwork will be generated with all nets routed successfully. Manufacturing documents such as bill of materials and construction reference materials will be produced.

A risk assessment will be written and learners will demonstrate safe working practices while manufacturing, assembling and testing a PCB. The board will contain all the necessary components and the components will have correct position and polarity. The soldering will be adequate, but there may be some dry, excessively soldered or overheated, untidy or uneven joints in places. The board will be complete but may have partial or incorrect functionality.

Learners will present a lessons learned report, of between 500 and 1000 words, covering the management of health and safety, the application of design and manufacturing, general engineering skills and a reflection of personal performance. The evidence will explain what:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- electronic/electrical engineering skills were used, such as identifying components and their characteristics, and electronic circuit theory and using schematic diagrams
- electronic circuit design and manufacture skills were used, such as how accurate and efficient the PCB design was and the skills required to manufacture the PCB
- how general engineering skills were used, such as the use of IT, computer-aided design (CAD) and interpreting drawings
- behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

Overall, the evidence will be well structured and technical language will have been used where appropriate, although there may be some inaccuracies with terms used. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 5: A Specialist Engineering Project
- Unit 10: Computer Aided Design in Engineering
- Unit 19: Electronic Devices and Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in PCB design and manufacture
- contribution of ideas to unit assignment/project materials.

Unit 23: Digital and Analogue Electronic Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate fault finding in analogue, digital and mixed electronic systems that use signal conversion. Other electronics units must be completed prior to this unit.

Unit introduction

Many consumer and industrial products employ a large variety of sophisticated electronic systems that cover a wide range of applications, from fly-by-wire aircraft and self-parking vehicles to smart phones, high definition television and leisure equipment.

In this unit, you will analyse electronic systems by breaking them down into simpler functional blocks, which are connected in block diagrams to show how the individual functions combine and how signals flow through them. The focus is on what the system does rather than how it does it, which you should have already covered in other electronic units. As a minimum, *Unit 19: Electronic Devices and Circuits* and *Unit 20: Analogue Electronic Circuits* should be delivered before starting this unit. As an engineer, you will be called on to maintain and repair electronic systems and, in some roles, to design or select the most suitable system for an application. This unit will help you to develop a systematic approach to gathering data from working systems, which can be applied to the diagnosis of faults in electronic systems.

A wide range of industries require technicians to design, maintain and troubleshoot complex equipment that contains electronic systems. This unit will to prepare you for employment, for example as an electrical/electronic or multi-skilled engineering technician in production, maintenance or field-service roles, as an apprentice or for entry to higher education.

Learning aims

In this unit you will:

A Examine the principles of analogue and digital electronic systems as applied in industry

B Explore the characteristics of analogue, digital and mixed electronic systems, and the role of signal conversion in control applications

C Carry out fault finding safely on complex electronic systems as applied in industry.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the principles of analogue and digital electronic systems as applied in industry	**A1** Characteristics of analogue and digital signals **A2** Block diagrams and hierarchical design **A3** Open- and closed-loop control systems	A written report exploring the characteristics of analogue and digital signals, system blocks, block diagrams, open-loop and closed-loop control systems, with supporting calculations.
B Explore the characteristics of analogue, digital and mixed electronic systems, and the role of signal conversion in control applications	**B1** Testing electronic systems safely **B2** Analogue systems **B3** Digital systems **B4** Analogue to digital conversion (ADC) **B5** Digital to analogue conversion (DAC)	A logbook summarising practical experiments and reports exploring the sub-systems that make up complex analogue and digital systems, the measurement of signal flow through them, and the use of signal converters in mixed electronic systems.
C Carry out fault finding safely on complex electronic systems as applied in industry	**C1** Fault finding techniques **C2** Fault finding in analogue, digital and mixed systems	A logbook recording fault finding in analogue, digital and mixed electronic systems with a single fault. The evidence should include block diagrams, fault finding plans identifying techniques and selection of instrumentation, test points, test reports, results and conclusions. The evidence should also contain observation records/witness statements.

Content

Learning aim A: Examine the principles of analogue and digital electronic systems as applied in industry

A1 Characteristics of analogue and digital signals

Analogue signals:

- definition of analogue signals
- periodic waveforms, sinusoidal, square wave, triangular, amplitude, time period, frequency. $f = \frac{1}{T}$, root mean square (RMS) value of sinusoidal signal as $\frac{V_{pk}}{\sqrt{2}}$
- signal conditioning, filtering, amplification, level shifting, gain and offset.

Digital signals:

- definition of digital signals
- ideal and practical, typical voltage and current values, transistor-transistor logic (TTL), complementary metal oxide (CMOS), rise time, fall time
- fan-in, fan-out
- signal conditioning: TTL to semiconductor CMOS, CMOS to TTL, Schmitt trigger to 'square' edges.

A2 Block diagrams and hierarchical design

Block diagrams:

- sub-system blocks as input(s), process/function, output(s), e.g. amplifiers, filters, comparators, converters, transducers/sensors, actuators
- transfer function given by $\text{TF} = \frac{\text{output signal}}{\text{input signal}}$
- complex systems broken down into combinations of simpler sub-system blocks, e.g. a radio receiver can be considered as detector, tuning circuit, demodulator, amplifier, audio output
- basic gates and truth-tables: AND, OR, NOT, NAND, NOR
- flip-flops: schematic diagrams and operation of S-R, D-type, Master-slave, J-K flip-flops
- hierarchical design, e.g. 4-bit adder made from 4 full-adder units each being combinations of half adder units made from discrete gates, 4-bit shift register using a mixture of discrete gates and flip-flops.

A3 Open- and closed-loop control systems

Control systems:

- open-loop control systems, e.g. a simple heating system with no thermostat:
  - block diagram
  - derivation of system transfer function as product of individual transfer functions, open-loop transfer function (OLTF), $OLTF = A \times B \times \ldots$
  - calculations using the OLTF
- closed-loop control systems, e.g. speed controller:
- block diagram:
  - derivation of the closed-loop transfer function (CLTF), with open loop transfer function (OLTF) A and feedback factor B $CLTF = \frac{A}{1 + AB}$
  - approximation using $CLTF \approx \frac{1}{B}$ for large values of A
  - calculations using the CLTF.

Learning aim B: Explore the characteristics of analogue, digital and mixed electronic systems, and the role of signal conversion in control applications

B1 Testing electronic systems safely

Appropriate test equipment to carry out functional testing to determine circuit inputs and outputs, to include:

- correct connection of test equipment, to include digital multimeter, dual trace oscilloscope, function generator, logic probe, frequency meter
- accurate measurement of key parameters, e.g. supply voltage, current, input and output signals, logic levels
- comparison of measured parameters with those obtained from simulation and the client brief, e.g. frequency, gain, logic gate function
- circuit testing, to include:
  - use of circuit diagrams, e.g. to identify test points
  - interpretation and recording of measurements, e.g. voltage, frequency, logic level
  - use of test equipment, e.g. oscilloscope, signal generator, digital multimeter, frequency meter, virtual (computer-based) instruments, data capture
  - safe working practices, e.g. only work 'live' on low voltage systems (< 30 V).

B2 Analogue systems

Block diagram schematic analysis of a range of complex analogue electronic systems, to include:

- fixed voltage regulated direct current (DC) power supply
- signal detection and amplification system, e.g. amplitude modulated (am) radio using a diode detector, filter and pre-amplifier, power amplifier and speaker
- closed-loop motor speed controller, e.g. using tachogenerator or slotted disc as the feedback element, operational amplifier as a comparator, power amplifier
- position controller e.g. servo.

B3 Digital systems

Block diagram schematic analysis of a range of complex digital electronic systems, to include:

- a combinational logic system, e.g. a 4-bit adder
- a sequential logic system, e.g. traffic light system
- a mixed system, e.g. car alarm.

B4 Analogue to digital conversion (ADC)

- Parameters:
  - analogue voltage input range of a single-ended (unipolar) as the maximum and minimum voltage limit of the input stage compared to signal ground.
  - number of bits, n
  - resolution as resolution = $\frac{\text{range}}{2^n}\ V\ /\ bit$
  - quantisation error as $QE = \pm\frac{1}{2}lsb$
  - linearity
  - sampling rate as given by the Nyquist-Shannon sampling theorem
  - aliasing as a consequence of an under-sampling rate
  - acquisition time as the time for the sample and hold mechanism to capture the input voltage.
- Construction and operation:
  - ramp and counter (stair-step ramp or counter ADC)
  - dual slope, e.g. digital multimeter
  - successive approximation (trial and fit method)
  - flash ADC
  - commercial (integrated circuit) ADCs.

B5 Digital to analogue conversion (DAC)

- Parameters:
  - acquisition time – the interval between the release of the hold state (imposed by the input sample-and-hold) and the instant at which the voltage on the sampling capacitor settles to within 1 LSB of a new input value
  - reference voltage V_{ref} – the reference voltage sets the DAC's maximum output voltage (if the output signal is not amplified by an additional output stage)
  - resolution: V_{ref} – also defines the voltage step by which the output changes in response to a 1 least significant bit (LSB) transition at the input $V_{LSB} = \frac{V_{ref}}{2^n}$
  - settling time – the interval between a command to update (change) its output value and the instant it reaches its final value, within a specified percentage, i.e. the time taken for the output voltage to reach expected value $\pm V_{LSB}$. It is essential that the time required for voltage on the sampling capacitor to settle to within 1 LSB be less than the converter's acquisition time
  - linearity – if an ADC were ideal, each output step would be exactly the same size; when supplied with equally increasing increments of supply voltage, the output would ramp up in equal increments. Differential non-linearity (DNL) is the degree to which each output step (or code width) varies from the ideal step. Integral non-linearity (INL) measures the deviation of the entire transfer function from the ideal function
  - offset error – often called 'zero-scale' error. It is a measure of the digital value obtained when converting zero analogue input
  - monotonicity – an ADC is monotonic if the digital output code always increases as the ADC analogue input increases. A converter is guaranteed monotonic if the DNL error is no greater than ±1 LSB.
- Construction and operation:
  - weighted resistor summing operational amplifier
  - R-2R ladder
  - successive approximation
  - tracking
  - flash DAC.

Learning aim C: Carry out fault finding safely on complex electronic systems as applied in industry

C1 Fault finding techniques

Characteristics and applications of a range of fault finding techniques:

- input-to-output/output-to-input
- half-split method
- symptom to cause
- unit substitution
- visual examination
- top-down approach
- module and component isolation
- use of fault finding aids, e.g. functional charts, diagrams, troubleshooting charts, component data sheets, operation and maintenance manuals, software-based records and data
- fault/repair reporting methods, including standardised fault finding report forms.

C2 Fault diagnosis in analogue, digital and mixed electronic systems

- Safe working practices, to include:
  - observation of safety rules
  - responsible behaviour at all times in a workshop environment
  - identification of risk assessments and controls for the tasks to be carried out
  - safe use of equipment for the purpose for which it is intended
  - protection of others and self.
- Applying a fault location plan:
  - plan, e.g. obtain relevant diagrams (block schematic, circuit wiring diagrams, manufacturer's data), 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. for an operational amplifier, determine the expected output voltage level given the input signal voltage and the values of the input and feedback resistors, determine the expected logic level of the output for logic gates given the input level conditions
  - identify fault symptoms
  - select and apply a suitable fault finding technique
  - identify faults and suggest an appropriate repair.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the principles of analogue and digital electronic systems as applied in industry		
A.P1 Explain, using examples, the characteristics of analogue and digital signals. **A.P2** Draw a block diagram of a complex analogue and a complex digital electronic system. **A.P3** Explain the operation of open- and closed-loop systems in a complex analogue and a complex digital system using block diagrams and calculate the output of each given input.	**A.M1** Analyse signals and their flow in the two systems calculating the outputs for open- and closed-loop systems.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the characteristics of the two systems in open- and closed-loop systems, calculating the expected outputs.
Learning aim B: Explore the characteristics of analogue, digital and mixed electronic systems and the role of signal conversion in control applications		
B.P4 Measure signals safely in an analogue, a digital, and a mixed electronic system that includes signal conversion. **B.P5** Explain, using theoretical calculations and test results, the structure and operation of an analogue, a digital, and a mixed electronic system incorporating signal conversion.	**B.M2** Measure signals accurately at selected test points, in the three systems incorporating signal conversion. **B.M3** Analyse, using theoretical calculations and test results, the structure and operation of the three systems that includes signal conversion.	**B.D2** Evaluate the structure and operation of an analogue, a digital and a mixed electronic system incorporating signal conversion in open- and closed-loop control systems, using safely obtained test results and theoretical calculations.
Learning aim C: Carry out fault finding safely on complex electronic systems as applied in industry		
C.P6 Produce a fault finding plan for an analogue, a digital and a mixed electronic system that includes signal conversion and safe working practice. **C.P7** Test each of the three systems safely, correctly diagnosing a single fault in at least the analogue or the digital system.	**C.M4** Produce a detailed fault finding plan for the three systems that includes signal conversion. **C.M5** Test each of the three systems, correctly diagnosing a single fault in at least the mixed system and the analogue or the digital system.	**C.D3** Diagnose correctly a single fault in each of the three systems, using fault finding plans, documentation, skills and working safely.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.P5, B.M2, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- electronic laboratory and bench top test equipment, including function generators, low voltage DC power supplies, dual trace oscilloscopes, digital multimeters, logic probes, logic analyser (a spectrum analyser/Bode plotter would be advantageous)
- pre-constructed systems using open-loop and closed-loop control, for example speed control using a variable resistor (Scalextric car/electric train), temperature controlled fan using a thermistor as the feedback element
- pre-built analogue and digital circuits with switched faults, for example fixed voltage regulated DC power supply, amplitude modulated (am) radio with test points accessible, closed-loop motor speed controller, position controller (servo), a combinational logic system such as a 4-bit adder, a sequential logic system such as a traffic light system
- a control system incorporating analogue to digital and/or digital to analogue conversion. This could be a system used in another unit, for example *Unit 6: Microcontrollers Systems for Engineers* or *Unit 36: Programmable Logic Controllers*. The fault should be one that gives straightforward symptoms, for example a 'stuck at' logic level on a digit
- standardised fault finding record sheets, including equipment under test, initial symptoms, test equipment used (including serial numbers or other identification for traceability), tests carried out, observations and conclusions, identification of root cause.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the characteristics of analogue and digital signals, including the limitations of real signals compared to their theoretical values, for example the effect of noise, acceptable and nominal values.

Learners will define open- and closed-loop systems, derive and use the open loop and closed loop transfer functions (OLTF and CLTF) from given block diagrams, determining signals at key points, for example outputs of circuit blocks. They will relate circuit schematic and block diagrams for a complex analogue and a complex digital system, identifying signals and signal paths at selected key points.

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 structured logically and use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will define analogue and digital signals in terms of time variance and acceptable values in a complex analogue and a complex digital system. They will use block diagrams to explain the operation of open- and closed-loop systems and use OLTF and CLTF to calculate system output accurately for an input for each. Learners will relate circuit schematic and block diagrams for the circuits and system, identifying signals and signal paths accurately at key test points.

Overall, the evidence should be structured logically, technically accurate and easy to understand.

For pass standard, learners will define analogue and digital signals. This may be restricted to ideal values. Learners will draw block diagrams of open- and closed-loop systems, explaining their operation in simple terms, and use OLTF and CLTF to calculate system output for a given input for each. There may be some minor numerical errors, and units may be inconsistent. Learners will relate circuit schematic and block diagrams for an analogue and a digital system, identifying signals and signal paths at key test points.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example definitions may relate to ideal values only, and contain minor inaccuracies such as rounding errors or inconsistent units.

Learning aim B

For distinction standard, learners will include in their evaluations schematic and block diagrams of an analogue, a digital and a mixed electronics system, incorporating data conversion (ADC and DAC). Learners will identify signals at key test points and signal paths. They will select further points at which to measure values to gain a comprehensive set of measurements to define a working system. Learners will explain the operation of the function blocks in each system using technical language, recording measurements systematically and accurately in a number of formats, for example sketches, tables, photographs.

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. It will give learners a resource on which to base fault finding strategies for the systems being explored.

For merit standard, learners will analyse a complex analogue and a complex digital system, using schematic and block diagrams to identify signals and signal paths, and measure them logically and accurately at key test points. They will investigate practically a mixed analogue and digital system that uses signal conversion (ADC and DAC). Learners will explain the operation of function blocks, although there may be minor omissions or errors. For example, a waveform may be sketched or photographed, but the timescale will not be noted. Learners should record their observations should be recorded.

Overall, the evidence, for example in a logbook, will be logically structured and technically accurate. There should be sufficient technical content for learners to use the evidence as an aid to identifying normal system operation.

For pass standard, learners will examine a complex analogue and a complex digital system with the aid of schematic and block diagrams. They will measure signals at key test points and record their results and observations. They will also investigate practically a mixed analogue and digital electronic system that uses signal conversion (ADC and DAC). Learners will explain the operation of function blocks, although there may be some omissions or misconceptions in the evidence presented. For example, the action of a tachogenerator as a speed feedback element may be identified and described using non-technical language.

Overall, the evidence, such as a logbook, will be logically structured, include technical data for each system and be easy to understand.

Learning aim C

For distinction standard, learners will use a range of documentation to produce an efficient fault finding plan, which includes safe working practice, to identify the cause of each fault, for example in the form of a flow chart. They will use their plan to find the fault in a complex analogue, a complex digital and a complex mixed electronic system that includes signal conversion.

Learners will systematically document the steps taken in logical sequence, equipment used, detailed observations made, and the perceptive conclusions reached using standardised documentation. The conclusions reached at each stage should lead logically to the next measurement in the sequence. For example, identifying a permanently low logic level (stuck at zero) leading to the search for a short circuit to signal ground.

Overall, the evidence, for example a logbook, 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, learners will use relevant documentation to produce a fault finding plan, which incorporates safe working practice, to identify the cause of each fault, although each of these may not necessarily be the most efficient. For example, learners may select an end-to-end approach where a half-split would be more efficient.

Learners will find the root cause of the fault in at least the complex analogue or digital system and in a mixed electronic system that include signal conversion. They will carry out tests in a logical sequence and there may be some deviation from the initial plan. The conclusions reached should reflect the observations made and lead logically to the next test.

Overall, the evidence, for example a logbook, should be logically structured, technically accurate and easy to understand.

For pass standard, learners will use given documentation to produce a fault finding plan, which incorporates safe working practice, to help identify a single fault in a complex analogue, a digital and a mixed electronic system that include signal conversion. The plans should be logical, for example showing the expected values at key test points. There may, however, be some omissions or misconceptions, such as not taking into account the range of acceptable values in a digital system. Learners will find the root cause of at least one fault, carrying out fault finding procedures on each system, although these may deviate from the plan. Conclusions may not be drawn and may lack detail. For example, they may not necessarily lead to the next step in the sequence (such as stating that the voltage is too low, rather than giving a specific value).

Overall, the evidence, for example a logbook, will be logically structured. Evidence may be basic in parts, for example observations may lack detail such as signal values and units, and some outcomes may be inconclusive, for example the root cause of a fault may not be correctly identified or a reading may be misinterpreted.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 19: Electronic Devices and Circuits
- Unit 20: Analogue Electronic Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 32: Computer System Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics organisations or engineering organisations with expertise of digital and analogue systems
- contribution of ideas to unit assignment/project materials.

Unit 24: Maintenance of Mechanical Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore the processes and components associated with the maintenance of mechanical systems and undertake maintenance tasks on a mechanical system.

Unit introduction

Mechanical systems are at the heart of many of the machines that we use to carry out work on our behalf, from cars to the escalators that move us between floors in shopping centres. Mechanical systems harness power, for example from an electrical motor, and involve the movement to complete a task. Power transmission is responsible for the movement of energy from a power source to a location where it performs useful work.

In this unit, you will explore the maintenance of different mechanical systems, including the use of lubricants and lubrication systems and the application of seals, bearings and fastenings. You will explore the function of power transmission and mechanical systems in general. Finally, you will complete routine maintenance on a mechanical system safely.

As an engineer you may need to undertake work on mechanical systems competently and efficiently if they are to continue to work properly. This unit will help to prepare you for an engineering apprenticeship, an engineering degree in higher education or for technician-level roles in a variety of engineering specialist areas.

Learning aims

In this unit you will:

A Examine the characteristics of lubricants and their application in mechanical systems

B Investigate the characteristics and applications of common consumable components used in mechanical systems

C Investigate the operation and application of power transmission components used in mechanical systems

D Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of lubricants and their application in mechanical systems	**A1** Lubricant characteristics **A2** Lubrication of mechanical systems	A report about the characteristics of lubricants and their application in two mechanical systems.
B Investigate the characteristics and applications of common consumable components used in mechanical systems	**B1** Mechanical seal characteristics and common applications **B2** Bearings characteristics and common applications **B3** Fastener characteristics and common applications	A report about the characteristics, maintenance considerations and applications of common consumables and the operation and maintenance considerations of power transmission components used in mechanical systems.
C Investigate the operation and application of power transmission components used in mechanical systems	**C1** Gear train function and operation in power transmission systems **C2** Typical function and operation of other power transmission components	
D Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system	**D1** Safe working practices when undertaking routine maintenance **D2** Routine maintenance tasks on mechanical systems	Practical activity to complete maintenance tasks safely. Evidence will include a record of the procedures followed, observations records and correctly completed documentation, with witness signatures against each completed task.

Content

Learning aim A: Examine the characteristics of lubricants and their application in mechanical systems

A1 Lubricant characteristics

- Function of lubricants – to keep moving parts separate, transfer heat, reduce friction, remove contaminants and debris, transmit power, protect against wear and corrosion and seal for gases.
- Definition of viscosity – a fluid's resistance to flow at a given temperature and the internal friction of a moving fluid.
- Fluid lubricant types:
  - mineral oils derived from petroleum
  - biolubricants – vegetable oil, e.g. corn, castor and animal oils
  - synthetic lubricants – polyalphaolefins (PAO), polyglycols (PAG), esters, silicones
  - semi-fluid lubricants, e.g. greases.
- Solid lubricant types, e.g. powders, graphite, polytetrafluoroethylene (PTFE), molybdenum disulfide.
- Additives can improve the performance of lubricants, e.g. extreme pressure, oxidation, corrosion inhibitors, foam inhibitors, dispersants, and anti-wear.
- Properties high boiling point, low freezing point, high viscosity index, thermal stability, hydraulic stability, corrosion prevention, high resistance to oxidation.

A2 Lubrication of mechanical systems

- Lubrication processes – gravity feed, forced feed, splash, capillary, grease packing, compressed air.
- Applications in mechanical systems – internal combustion engines, electrical motors, transmissions, machine tools, and pumps.
- Lubricant environment – extremes of temperature, light and heavy loads, low and high speeds, accessible and non-accessible.
- Maintenance considerations – choice of lubrication type, quantity required and replenishment and/or replacement at the correct intervals related to the particular requirement of the mechanical system.

Learning aim B: Investigate the characteristics and applications of common consumable components used in mechanical systems

B1 Mechanical seal characteristics and common applications

- Function of mechanical seals – to prevent contaminants from entering, to prevent lubricants from escaping, contain pressure and/or separate sections of a system.
- Types of seal, including:
  - static seals – O-rings, gaskets
  - dynamic seals – radial shaft seals, piston seal rings
  - non-contact seals – labyrinth, gap
  - bellows and membranes.
- Materials – rubber, e.g. nitrile, silicone, PTFE, tungsten carbide, carbon graphite and ceramics, e.g. aluminium oxide.
- Applications – internal combustion engines, electrical motors, transmissions, machine tools, pumps, turbines, actuators, compressors, clutches, brakes.
- Application parameters, – temperature, pressure, environment, e.g. foreign particles and corrosion, lubricant type, chemical compatibility, surface finish and nature of any moving parts.
- Maintenance considerations – choice of seal type, seating of the seal, operating environment, replacement at the correct intervals.

B2 Bearing characteristics and common applications

- Function of bearings – to assist one surface move with ease over another, which might be in a linear or a rotational movement.
- Types of bearing:
  - contact, including plain, e.g. bush, two-piece, jewel, flexure, e.g. hinge and roller, e.g. ball, spherical and tapered
  - non-contact, including fluid and magnetic
  - applications – internal combustion engines, electrical motors, transmissions, pumps, turbines, actuators, compressors, clutches
  - materials – steels, ceramic composites, bronze, sintered, nylon, PTFE
  - application parameters – low and high speed, continual and intermittent running, small and large loading, high temperature and shock loading
  - maintenance considerations – choice of bearing type, bearing wear, lubrication, vibration.

B3 Fasteners characteristics and common applications

- Characteristics of screwed fasteners, including:
  - head form – flat, hex, round and thread form, e.g. square, triangular
  - terminology – thread pitch, thread type, torque
  - tightening methods – bolts, studs, self-tapping screws
  - locking systems – locking nuts, locking inserts, locking washers, cotter pins, locking washers, wired.
- Other types of mechanical fastener – eye bolts, latches (including snap and compression), detent pins and rivets (solid and hollow).
- Applications – mechanism covering, guarding, assemblies.
- Maintenance considerations – stress concentration, galvanic corrosion and a mismatch of thermal expansion coefficients.

Learning aim C: Investigate the operation and application of power transmission components used in mechanical systems

C1 Gear train function and operation in power transmission systems

- Function – to provide a mechanical advantage through the gear ratio, changing the speed, torque and direction of a mechanical power source. Gear trains can be fixed or provide manual or automatic transmission to change the gear ratio.
- Types – spur, helical, herring bone, bevel, spiral bevel, hypoid, simple, compound, worm and wheel, combinations, epicyclic.
- Materials – carbon steels, brass, bronze, plastics.
- Maintenance considerations – lubrication type, replenishment and replacement, filter type and replacement, gear material characteristics, e.g. plastic is self-lubricating and low cost, alignment of gears, backlash, overloading, e.g. scoring or scratching of teeth and overheating, e.g. pitting and burning of teeth.

C2 Typical function and operation of other power transmission components

- Cams and cam followers:
  - function – to convert an input motion, either rotary or linear, into a reciprocating motion of the follower, e.g. uniform velocity or acceleration and deceleration
  - types of cams – plate, cylindrical and follower, e.g. knife edge and roller
  - maintenance considerations – the follower is normally allowed to wear and is replaced during maintenance.
- Linkage mechanisms:
  - function – to modify movement and to transfer power
  - types – slider crank and inversion, four-bar linkages and inversions, slotted link quick return motion, Whitworth quick return motion
  - maintenance considerations – failure of parts of the mechanism, failure of bearings, lubrication.

- Belts:
  - function – to transfer power, modify the direction of motion and to provide synchronisation
  - types – flat V-section, synchronous, tensioning devices
  - maintenance considerations – failure of belt and lubrication.
- Transmission shafts and couplings:
  - function – to transfer power and to change the direction of motion
  - types, e.g. sections – solid, hollow, flanged couplings, splined couplings, angle couplings, Hooke universal, constant velocity
  - maintenance considerations, e.g. failure of transmission, coupling and lubrication.
- Clutches:
  - function – to transfer power in a controlled way between the driver and driven parts of mechanical systems
  - types – dog, flat plate, conical, centrifugal, fluid couplings
  - maintenance considerations – wear and failure of clutch and failure of bearings in the clutch.
- Brakes:
  - function – to slow down or to stop mechanical systems
  - types, e.g. friction – internal, external contracting, disc, dynamometers, fluid electromagnetic
  - maintenance considerations – wear and failure of individual parts.
- Applications – internal combustion engines, heat engines, transmissions, machine.

Learning aim D: Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system

D1 Safe working practices when undertaking routine maintenance

Current safe working practices, or other relevant international equivalents, including:

- compliance with the current electricity at work regulations and amendments
- Current Control of substances hazardous to health (COSHH) regulations and amendments – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Current Personal protective equipment (PPE) at work regulations and amendments – 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
- Current 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 (Work at Height Regulations 2005 and amendments) and working in confined spaces, e.g. under mechanical systems.

D2 Routine maintenance tasks on mechanical systems

- Typical routine maintenance tasks, including replacing filters, changing lubricants, replacing seals, changing bearings, replacing gears, replacing linkages, replacing belts, replacing brake pads, replacing clutches and clutch plates, replacing blades.
- Sustainability considerations, including reusing consumables and components, reducing the use of materials, recovering materials when possible and recycling where possible.

- Completing routine maintenance tasks by following the correct process (using appropriate equipment, components and following procedures), including:
  - disassembly, removal and strip processes – using screwdriver, wrench, spanner, sockets, pliers/grips, keys and draining lubricants
  - manual processes – using snips, cutters, knives, punch, saw, file, hammer
  - components and consumables – lubricants, seals, bearings, fasteners, and belts
  - assembly processes – using soldering iron, mechanical fasteners, cables/connectors, crimping tools, pneumatic tools, clamps
  - inspection and testing processes – using flow meter, calipers, torque meter, pressure sensor or gauge
  - disposal of waste materials in a sustainable way, including fasteners – reusable or non-reusable, disposal of lubricants and filters, disposal of worn bearings, disposal of broken parts.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the characteristics of lubricants and their application in mechanical systems		
A.P1 Explain the characteristics of the lubricants used and the process of and maintenance considerations for lubrication in two mechanical systems.	**A.M1** Analyse the characteristics of lubricants used and the process of and maintenance considerations for lubrication in two different mechanical systems.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the characteristics of lubricants used and the process of and maintenance considerations for lubrication in two different mechanical systems, suggesting improvements to the lubrication systems.
Learning aim B: Investigate the characteristics and applications of common consumable components used in mechanical systems		
B.P2 Explain the characteristics, applications and maintenance considerations of at least three types of consumable components used in two mechanical systems.	**B.M2** Justify the characteristics, applications and maintenance considerations of at least three types of consumable components used in two mechanical systems.	**BC.D2** Evaluate the characteristics and applications of at least three types of consumable and the operation of at least three types of power transmission components in two mechanical systems, including how they each contribute to the system and their maintenance considerations.
Learning aim C: Investigate the operation and application of power transmission components used in mechanical systems		
C.P3 Explain the operation of and maintenance considerations for power transmission gears in two mechanical systems. **C.P4** Explain the operation of and maintenance considerations for two other power transmission components in two mechanical systems.	**C.M3** Analyse the operation of and maintenance considerations for power transmission gears and two other power transmission components in two mechanical systems.	
Learning aim D: Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system		
D.P5 Explain what safe working practices apply when performing two routine maintenance tasks. **D.P6** Complete two routine maintenance tasks, using the correct process, on a mechanical system safely, and sustainably while inspecting the work.	**D.M4** Complete two routine maintenance tasks, using the correct process, on a mechanical system safely, sustainably and accurately, explaining the safe working practices that apply and inspecting the work.	**D.D3** Refine, while using the correct process, two routine maintenance tasks on a mechanical system safely, sustainably, accurately and efficiently, explaining the safe working practices that apply and inspecting the work.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, C.P3, C.P4, B.M2, C.M3, BC.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of mechanical systems containing power transmission components (these could be machines in a standard workshop and might utilise any automotive facility but it is expected that these would be enhanced by further industrial examples)
- a good range of seals, bearings and fastenings
- the required equipment for health and safety, for example PPE
- a number of industrial visits and visiting speakers (arranged through industrial partners to facilitate learners being exposed to a range of suitable enhancing experiences)
- accompanying documentation for the equipment referred to above and relevant health and safety regulations.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of the lubrication maintenance requirements, the process of lubrication in the system and the characteristics of the lubricants used. They will compare the lubrication of each system and suggest improvements to the process, characteristics or maintenance requirements. For example, the improvement could suggest a different lubricant for a mechanical system or perhaps a lubrication additive for a lawnmower engine.

Overall, learners' 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, with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse the lubricant characteristics, the maintenance requirements and the process of lubrication of the systems. Their analysis will be methodical and cover the interrelationships between the characteristics, maintenance requirements and the system. In addition, learners will compare the systems, for example a comparison of the viscosity of the lubricant in a lawnmower engine and in an electric motor, suggesting a reason for the difference.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the process of lubrication as well as the function, type, additives, properties and sustainability characteristics of the lubricants used in two different mechanical systems. They will also explain the maintenance requirements for the lubrication of the system, for example the requirements to check lubrication levels periodically and replace the oil in a lawnmower engine.

Overall, learners' evidence will be logically structured although it may be basic in parts, brief and lacking in detail. Evidence may also contain technical inaccuracies or omissions, for example referring to the lubricant as 'oil' and not using the actual technical name or description.

Learning aims B and C

For distinction standard, learners will produce evidence of a thorough and consistent investigation of two mechanical systems, evaluating the use of seals, bearings, fastenings, gear trains and two other power transmission components. They will inform their evaluation through independent research based on the internet and other credible sources. Learners will present the advantages and disadvantages of components used in the task and will suggest two alternatives, providing a justification for each. For example, learners may evaluate a solid bronze bearing employed in a system before exploring alternative roller bearings, suggesting why these might be more appropriate.

Learners will evaluate how each component in the system contributes towards the overall operation and maintenance of the system, for example considering the operational requirement of the rotational support that a roller bearing would provide for a system, noting the radial and axial loading and the speed range.

Overall, learners' 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 produce evidence of a thorough investigation and independent research of two mechanical systems. They will justify the use of the seals, bearings, and fastenings used in each system, for example the use of a roller bearing rather than a ball bearing by an analysis of the radial loading before comparing the radial loading capacity of each type of bearing.

Learners will also analyse the operation of and maintenance considerations for the gear trains and two other power transmission components, for example learners may consider the gear ratio employed in both systems and the potential for wear in each, necessitating scrutiny of the bearings.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will investigate at least two mechanical systems, each of which contains power transmission components. Their explanations will cover the applications, characteristics (types, function, materials, application parameters) and maintenance considerations of at least three types of consumable component (seals, bearings and fasteners). For example, learners may investigate the load carrying capability of the bearings employed in the mechanical system and establish the load carrying capability of the bearings in terms of radial and axial loading.

Learners will explain the operation and maintenance considerations for power transmission gear trains, going on to explain the considerations for two other power transmission components, such as belts and transmission shafts. For example, they will explain the operation of the belt drive in a typical machine tool between the electrical drive motor and the gear shaft, which could include an explanation for the number of belts and the type of belt being employed.

Overall, learners' evidence will be logically structured although it may be basic in parts, for example learners may refer to belts rather than specifying the shape and/or the number of belts. Evidence may also contain technical inaccuracies or omissions, such as mixing up the driven and driver aspects of the system or simply not specifying which is driver and which is driven.

Learning aim D

For distinction standard, learners will refine, while using the correct processes, the completion of two different maintenance tasks on an appropriate mechanical system. This will be completed safely, sustainably, accurately and efficiently. Efficiency will be evident in learners who prepare well for the task, for example by gathering the correct consumables and components in advance, walking through the task prior to completing it, outlining who will complete the tasks and what is the most appropriate order (sequence) in which to do this, while keeping the workshop well organised, reasonably clean and ensuring that risks are mitigated. Their inspection checks will be completed during the tasks and appropriate records made. Once complete, the system will work as intended.

Overall, learners' evidence will be presented clearly and in a way that is understood by a third party who may or may not be an engineer. There will be a comprehensive record of the safety procedures followed, together with accurate and correct documentation for each of the maintenance tasks completed.

For merit standard, learners will complete two different maintenance tasks on an appropriate mechanical system. This will be completed using the correct processes safely and accurately, using the correct tools, equipment and following procedures. Accuracy will be evident in learners who ensure that seals and bearings are seated correctly, fastenings are tightened to the correct torque and the correct amount of lubrication is used. Their inspection checks will be completed during the tasks and appropriate records made. Once the maintenance is complete, the system will work as intended.

Overall, learners' evidence will be logically presented, technically accurate and easily understood. This will include learners' explanations of the safe working practice that will have been prepared before starting the tasks and evidence of applying the practices will also be clear.

For pass standard, learners will explain the safe working practices that apply to the two routine maintenance tasks they undertake. For example, having selected appropriate personal protective equipment, learners will isolate the mechanical system.

Learners will complete two routine maintenance tasks on a mechanical system that contains power transmission components. They will apply safe working practices and follow the correct maintenance process, for example using the correct tools, equipment, and following procedures. Learners' evidence will demonstrate that safe working practices were applied and sustainability was considered, for example lubrication and faulty components will be disposed of in the appropriate way. Learners will inspect the quality of their work as they undertake the tasks, although the system may not be operating correctly once the work is finished.

Overall, any supporting evidence may be limited, for example there may be little evidence of preparation tasks and inspection documentation may lack the required detail.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 11: Engineering Maintenance and Condition Monitoring Techniques
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 15: Electrical Machines
- Unit 25: Mechanical Behaviour of Metallic Materials
- Unit 28: Dynamic Mechanical Principles and Practice
- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 50: Aircraft Gas Turbine Engines
- Unit 53: Airframe Mechanical Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations involved with the maintenance of mechanical machines
- contribution of ideas to unit assignment/project materials.

Unit 25: Mechanical Behaviour of Metallic Materials

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners investigate and conduct tests on the mechanical properties of metals, consider suitable applications and explore failure modes to improve component design.

Unit introduction

Selecting the most appropriate material and processing method for an engineered product or system is critical to ensure that it is fit for purpose. The materials used in the airframe of an aeroplane, car body pressings, cast components in domestic appliances and the 'T'-shaped electricity pylons (in the UK) all require careful selection and testing of appropriate metallic materials.

In this unit, you will investigate and research the microstructures of ferrous and non-ferrous metallic materials, some of which will have been processed, for example heat treated. You will inspect the microstructures of the materials you are investigating. You will also undertake destructive and non-destructive tests on the materials and use the results of the experimentation and research to determine the mechanical properties of, and suitable applications for, the materials. Finally, you will examine the reasons why components have failed in service and consider possible design improvements that could prevent failure.

As an engineer it is important to know about and understand the capabilities of a range of metallic materials to create products and systems that are suitable for application. This unit will help to prepare you for an apprenticeship or a technician-level role in industry. It will also help to prepare you for a range of higher education courses, such as a Higher National Diploma (HND) or a degree in any engineering discipline.

Learning aims

In this unit you will:

A Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties

B Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements

C Explore the in-service failure of metallic components and consider improvements to their design.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties	**A1** Types of ferrous metals and alloys **A2** Types of non-ferrous metals and alloys **A3** Mechanical properties of metallic materials **A4** Grain structure of metallic materials **A5** Effects of processing on the mechanical properties of metallic materials **A6** Microstructure investigation of metallic materials	A report containing investigative research and library images of the microstructures of metallic materials, some of which will have been processed.
B Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements	**B1** In-service requirements of metallic materials **B2** Destructive test procedures **B3** Non-destructive test procedures	A portfolio of results gathered from tests on samples of given metallic materials and an investigation of the materials, supported by a logbook and images. Observation records are essential.
C Explore the in-service failure of metallic components and consider improvements to their design	**C1** Ductile and brittle fracture **C2** Creep failure **C3** Fatigue failure **C4** Corrosion mechanisms **C5** Design considerations to help prevent component failure	A report containing investigative research into the failure mode of given engineered products or components and possible design solutions. Observation records are essential.

Content

Learning aim A: Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties

A1 Types of ferrous metals and alloys

- Plain carbon steel: low, medium, high carbon.
- Alloy steels: constructional, tool, stainless, heat-resistant.
- Cast iron: grey, white, malleable.
- Wrought iron.
- Identification methods, e.g. BS, EN, DIN and ISO coding, MIL-Spec, American UNS.

A2 Types of non-ferrous metals and alloys

- Types: aluminium, copper, gold, lead, magnesium, silver, tin, titanium, zinc.
- Alloys: aluminium (wrought and cast), copper (brass and bronze), magnesium and titanium.
- Shape memory alloys (SMA), e.g. nickel-titanium, copper-aluminium-nickel.
- Identification methods, e.g. ISO, SAE, MIL-Spec, American UNS, EN 485.

A3 Mechanical properties of metallic materials

- Elastic and plastic behaviour of a metal when subjected to stress.
- Strength: yield, proof, tensile, compressive, shear.
- Specific strength: strength per unit density.
- Surface hardness.
- Fracture toughness.
- Plasticity: ductility, malleability.
- Elastic modulus: Young's (E), shear (G).
- Specific stiffness, resistance to bending: elastic modulus per unit density.
- Fatigue limit.

A4 Grain structure of metallic materials

- Atomic lattice packing: body-centred cubic (BCC), face-centred cubic (FCC), close-packed hexagonal (CPH).
- Features of grain structure: formation, growth, boundary, size.
- Crystal defects: point, line/dislocation, planar.
- Slip planes: elastic and plastic deformation, surface slip bands.
- Metallurgical phase: single substance in an alloy system, e.g. pure metal, solid solution, uniform liquid.
- Alloys: eutectics, interstitial and substitutional solid solutions, intermetallic compounds.
- Iron/carbon thermal equilibrium diagram: ferrite, pearlite, cementite, austenite.
- Aluminium/copper thermal equilibrium diagram: solubility curve for the aluminium-rich end of the diagram, unsaturated and saturated solid solutions of copper in aluminium.
- Effect of grain structure, lattice packing and alloying on a parent metal's mechanical properties, e.g. ductility, brittleness, hardness, tensile and compressive strength.

A5 Effects of processing on the mechanical properties of metallic materials

- A non-processed material is one that has not undergone any subsequent processing from the point of being made as a raw material, e.g. bar stock or billet.
- Recrystallisation: grain growth, structure.
- Hot working: forging, pressing, rolling, extrusion.
- Cold working, e.g. rolling, drawing, pressing, deep drawing, coining, embossing, impact extrusion, spinning, stretch forming.
- Heat treatment of steels through hardening, case hardening, annealing, normalising.
- Heat treatment of aluminium alloys: solution treatment, precipitation hardening, over-ageing.

- Heat treatment of titanium alloys: precipitation hardening.
- Alloying elements in steel, e.g. chromium, manganese, molybdenum, nickel, tungsten, vanadium.
- Alloying elements in aluminium, e.g. copper, silicon, magnesium, manganese, titanium, chromium, lithium.
- Alloying elements in titanium: aluminium, vanadium.

A6 Microstructure investigation of metallic materials

- Macro-investigation and micro-investigation of metals and alloys, including identification of grain structures and boundaries, phases within grains and segregation of impurities at grain boundaries.
- If available, surface examination equipment, including a hand magnifier, optical microscope and a digital imaging system.
- Reference sources, including micrographs.

Learning aim B: Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements

B1 In-service requirements of metallic materials

- High strength requirement, e.g. vehicle suspension components, pressure vessel.
- High strength to weight ratio, e.g. aircraft undercarriage components, high-performance motor vehicles.
- High resistance to impact loading, e.g. impact tool bits.
- Hardness, e.g. drill bit.
- Toughness, resistance to fracture under impact loads, e.g. car body.
- Ductility, e.g. drawn wire.

B2 Destructive test procedures

- Tensile strength testing:
  - British Standard (BS EN ISO 6892-1:2009) or other relevant international equivalents, selection and preparation of test specimens, tensile test machine, extensometer, data recording, pull to destruction, force–extension graph, examination of fractured surface
  - analysis of results: elastic limit/limit of proportionality, yield point, tensile strength, Young’s modulus, percentage elongation and reduction in cross-sectional area.
- Hardness testing:
  - hardness standards relevant to test being performed, including British Standards BS EN ISO 6506-1:1999, BS EN ISO 6508-1:2015 or other relevant international equivalents
  - surface preparation, e.g. cleaning using light abrasion and removal of surface film
  - use of equipment to determine hardness, e.g. Brinell hardness number, Vickers pyramid number (HV), Rockwell (A, B, C) value, Shore scleroscope hardness index.
- Impact testing:
  - British Standard BS EN ISO 148-3:2008 or other relevant international equivalents, selection and preparation of test specimens
  - test specimens: selection, notch preparation
  - use of equipment to measure impact values, e.g. Izod test, Charpy test, Hounsfield balanced impact machine
  - visual inspection of the fractured surface to estimate the crystalline area percentage
  - test reporting, e.g. presentation of results and comparison with reference values taken from accredited data sources.

B3 Non-destructive test procedures

- Surface and sub-surface defect detection, e.g. visual inspection, dye penetrant, magnetic particle, ultrasonic, radiographic, eddy current.
- Test reporting and presentation of results.

Learning aim C: Explore the in-service failure of metallic components and consider improvements to their design

C1 Ductile and brittle fracture

- Effects of gradual and impact loading and grain size.
- Surface appearance: crystalline, torn, cup and cone configuration.

C2 Creep failure

- Primary, secondary, tertiary creep.
- The effect on creep rate of temperature, grain size, applied stress.
- Strain–time graphs and limiting creep stress.

C3 Fatigue failure

- Crack propagation and growth.
- Internal stress concentrations: granular defects, porosity.
- External stress concentration: surface defects, sharp changes of section.
- Stress variation: reversal due to cyclic loading, random loading, vibration.
- Stress and endurance (S/N) curves: fatigue and endurance limits for ferrous and non-ferrous alloys.
- Final, catastrophic failure: reduction in load carrying area, tensile strength exceeded.
- Characteristic appearance of fracture surface: smooth burnished area (crack growth), crystalline area (final tear), ripple-like marks showing crack progression.

C4 Corrosion mechanisms

- Chemical fundamentals, e.g. the corrosion cell, rust reactions, dry corrosion, galvanic action, active and passive materials, electro-chemical series for metals.
- Types of corrosion and their recognition and cause, e.g. hydrogen embrittlement, surface, crevice, exfoliation, inter-granular, bimetallic, pitting, fretting, stress.

C5 Design considerations to help prevent component failure

- Knowledge of the component's operating environment, e.g. static loading, dynamic loading, cyclic stressing, temperatures, wet or dry conditions.
- Correct choice of material based on mechanical properties, consequences of sudden failure, corrosion resistance.
- Design features, e.g. reducing the impact of stress raisers, e.g. sharp corners, sudden changes in cross-sectional areas, poor surface finish.
- Higher quality material, e.g. free from inclusions or porosity.
- Surface treatment and finishes, e.g. painting, polymer coating, plating.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties		**A.D1** Evaluate, using an accredited data source, the microstructures of non-processed and processed metallic materials to correctly identify the material, including how the processing history, impurities and grain boundaries affect the mechanical properties of the materials.
A.P1 Explain how the microstructures of non-processed metallic materials affects the mechanical properties of the materials. **A.P2** Explain how the microstructures of processed metallic materials affects the mechanical properties of the materials.	**A.M1** Analyse, using an accredited data source, the microstructures of non-processed and processed metallic materials to correctly identify the material, including how the processing history affects the mechanical properties of the materials.	
Learning aim B: Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements		**B.D2** Evaluate, using the results from safely conducted tests and an accredited data source, how the mechanical properties of processed and non-processed metallic materials affect their behaviour and suitability for different realistic applications, justifying the validity of the test methods used.
B.P3 Conduct destructive tests safely on different non-processed and processed metallic samples. **B.P4** Conduct one type of non-destructive test safely on one non-processed and one processed metallic sample. **B.P5** Explain, using the test results, how the mechanical properties of metallic materials affect their behaviour and suggest an application.	**B.M2** Conduct destructive and non-destructive tests accurately on different non-processed and processed metallic samples. **B.M3** Analyse, using the test results and an accredited data source, how the mechanical properties of metallic materials affect their behaviour and suggest a realistic application.	
Learning aim C: Explore the in-service failure of metallic components and consider improvements to their design		**C.D3** Evaluate, using language that is technically correct and of a high standard, the results from safely conducted and accurate checks and tests to establish how components failed in service, recommending a design solution from a range of alternatives.
C.P6 Conduct a visual inspection check and at least one test safely on components that have failed in service. **C.P7** Explain, using the results, how each component failed and how each component's design could be improved.	**C.M4** Conduct a visual inspection check and at least one test safely and accurately on components that have failed in service. **C.M5** Analyse, using the results, how each component failed and justify how each component's design could be improved.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.M2, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- access to data sources, e.g. MatWeb, an online materials information resource, www.matweb.com
- hardware equipment, including:
  - tensile test, hardness and impact testing equipment (essential)
  - non-destructive test equipment
  - creep and fatigue test equipment – preferred, but it can be replicated using simulation software.

Centres may want to provide learners with prepared metallic material samples of known composition and processing history. If physical material samples are inspected then learners will need access to hand magnifiers and a metallurgical microscope.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will investigate the microstructures of at least six unlabelled images of materials, which will comprise a mix of ferrous, non-ferrous and processed metallic materials. Learners' evaluation will involve comparing the material microstructure in each image with examples from an accredited data source and will include the impact that impurities and grain boundaries have on the mechanical properties. For example, for an image of steel learners may have identified impurities at grain boundaries, phases such as pearlite and cementite, equiaxed grains or elongated grains for a material that has been cold worked. Learners' observations will also be linked to the mechanical properties of the material, for example the elongated grain structure of wrought iron and the distribution of impurities, making for a laminated structure that improves the impact resistance. For each examined material learners' evidence will contain an equilibrium diagram marked up with phases, for example eutectic.

Overall the evidence, such as a logbook and report, 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 images of material grain structure with those from an accredited data source, to correctly identify the six or more materials. The images will comprise a mix of ferrous, non-ferrous and processed metallic materials. Learners will analyse how the microstructures affect the mechanical properties of the materials. For example, they may analyse the differences between materials with fine and coarse grains.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will investigate the microstructures of at least six unlabelled images of metallic materials. If available, learners may instead inspect prepared material samples, using a suitable hand magnifier and metallurgical microscope. The images will be of ferrous and non-ferrous metallic materials and at least three will have been processed, for example one heat treated, one alloy and one mechanically worked. Learners will use the images to explain how the microstructures of the metallic materials affect their mechanical properties. For example, fine-grained castings generally have higher toughness and strength properties than those with coarse grains.

Overall, the evidence will be logically structured, although it may be basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will safely set up and correctly use mechanical tensile, impact and hardness test equipment and gather accurate results when completing destructive tests independently. They will test at least six prepared samples comprising unlabelled ferrous and non-ferrous materials, some of which will have been processed, for example work hardened. Learners will justify why they have selected the correct test for the mechanical property that they are measuring. For example, if they are testing a thin piece of metal it would invalidate the results to use a hardness test that has a high-impact force, because it will distort the metal and the indentation measurements will not be a true indication of surface hardness.

Learners will also complete at least two non-destructive tests safely and accurately on metallic material samples.

Learners will use a combination of the mechanical test results and accredited data sources to evaluate their results. The evaluation for the:

- tensile tests will include plot load–extension plot (stress–strain graphs) and provide key data, for example yield strength, tensile strength, Young’s modulus, percentage elongation and reduction in area
- tensile and impact tests will include the condition of the fracture surface in terms of how crystalline it is
- hardness tests will make comparisons between measured hardness values and what is expected for the material
- non-destructive tests will include a report on the surface or internal condition of the given metallic materials.

Learners will present suitable realistic applications of where the tested materials might be used in service, for example appreciating that while high-strength alloy steel might be good for the passenger shell of a car, lower-strength, more malleable steel would be a better option for the front and rear crumple zones. Learners will also determine that there is often a trade-off between tensile strength, hardness and impact strength of materials.

Overall the evidence, such as a logbook and report, will have been 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 complete accurate and safe mechanical tests using at least six pre-prepared given and unlabelled samples. Limited help may be given in setting up the equipment and learners will independently gather and process their test results, for example finding the yield and tensile strengths and seeing how they compare with published values.

Learners’ analysis will compare the results of destructive testing with accredited data sources and identify the materials that were tested. For example, learners will be able to determine, from the density, colour and surface finish of two samples, that the type of material they are testing is a form of steel. The mechanical tests and data from the accredited source will allow learners to determine what types of steel they are testing and whether these have been processed.

Learners will also complete at least two non-destructive tests safely and accurately on metallic material samples and will draw conclusions from the results, for example a dye penetrant test that reveals surface cracks, with the learner explaining why the cracks have occurred.

Overall, the evidence should be logically structured, technically accurate and easy to understand. Learners’ evidence will include a realistic application for each material sample, for example stainless steel can be used for a high-temperature pressure vessel.

For pass standard, learners will complete mechanical tensile tests (to destruction), impact tests and hardness tests using pre-prepared given ferrous and non-ferrous metal samples, some of which will be processed. In total learners will test at least six samples. For each sample they will carry out a mechanical test and record their results. Throughout the delivery of the tests they will demonstrate safe working practices, for example by completing a risk assessment and checking with the assessor before conducting an impact test. Although help may be given to set up the equipment, learners will gather their test results independently.

Learners' evidence will explain, using the test results, how the mechanical properties of different metallic materials affect their behaviour. For example, a material with good impact resistance (determined, for example, from an Izod test) is better able to withstand shock loading.

Learners will also complete at least one non-destructive test safely and explain the results, for example identifying that there is porosity in a casting by completing an ultrasonic test.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the results and an application for each metallic material sample. The evidence may be basic in parts and may contain minor technical inaccuracies relating to engineering terminology.

Learning aim C

For distinction standard, learners will explore a range of given components that have failed in service after having been in use for significant periods of time. At least two components will have failed due to a mechanical fault and at least one other due to corrosion. Learners will undertake a visual inspection check of the corrosion and complete at least one mechanical test safely. The type of mechanical test(s) undertaken will depend on the components selected. It is expected that most learners will complete a hardness test, although some may also or instead complete a creep test.

Having investigated the various failure modes, learners will evaluate how to eliminate or mitigate the problem by thinking how to redesign the component, for example by specifying a larger fillet radius where there is a change of cross-section and by using a material that has a better operating performance at high temperature and stress levels, such as a titanium alloy.

Overall the evidence, such as a logbook and report, will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer. This means that learners must clearly demonstrate a good understanding of mechanical design principles when evaluating the failure modes of the selected components and suggesting improvements.

For merit standard, learners will examine at least three components that have collectively suffered creep and fatigue failure and surface degradation due to corrosion. This will involve visual inspection checks, a hardness test and/or a creep test and comparison with reference sources, for example images.

Having investigated the various failure modes, learners will justify design modifications to the components so as to eliminate or reduce the impact of the failures, for example changing the design of a product to reduce the impact of electrolytic corrosion by choosing materials that are closer together in the electromagnetic (galvanic) series.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will carry out a visual inspection check and a mechanical hardness and/or creep test on at least three sample components that have failed in service for different reasons. At least two components will have failed due to mechanical faults (fatigue and creep) and at least one other due to corrosion. Throughout the delivery of the tests they will demonstrate safe working practice, for example by completing a risk assessment and checking with the assessor before conducting a test. Although help may be given to set up some of the equipment, learners will gather their test results independently.

Using the visual inspection check and mechanical test results, learners' evidence will explain how the components failed in service. Learners will also give at least one explanation for how the design of the component could be improved, for example by increasing the size of a fillet radius on a stepped shaft.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the results. The evidence may be basic in parts.

Links to other units

This unit links to:

- Unit 3: Engineering Product Design and Manufacture
- Unit 26: Mechanical Behaviour of Non-metallic Materials
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes
- Unit 44: Fabrication Manufacturing Processes
- Unit 45: Additive Manufacturing Processes
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in metallic materials
- contribution of ideas to unit assignment/project materials.

Unit 26: Mechanical Behaviour of Non-metallic Materials

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the mechanical properties of non-metallic materials (polymers, ceramics and composites), consider their suitable applications and explore their component failure modes.

Unit introduction

Selecting the most appropriate material for an engineered product is of prime importance if it is to be fit for purpose. A design engineer must know about the range of non-metallic materials available to them and how they will behave in service.

In this unit, you will investigate the structures of common materials from three non-metallic material groups, specifically polymers, ceramics and composites. You will gain practical experience of testing the mechanical properties of these materials and an understanding of how and why they are used in a range of applications. You will also investigate how components made from these materials can fail in service, the reasons why they fail and design changes that would help prevent future problems.

As an engineer, you will need to understand non-metallic materials so that you can create and optimise the performance of products and systems you are working on. This unit will prepare you for an apprenticeship or higher level course, such as Higher National Diploma (HND), or a degree in any engineering discipline that requires an understanding of materials and their applications.

Learning aims

In this unit you will:

A Investigate how the structures of non-metallic materials influence their mechanical properties

B Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them

C Explore the in-service failure of non-metallic components and consider improvements to their design.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate how the structures of non-metallic materials influence their mechanical properties	**A1** Types of non-metallic materials **A2** Structures of non-metallic materials **A3** Mechanical properties of non-metallic materials **A4** Typical engineering applications of non-metallic materials	A report explaining the structures and mechanical properties of a range of non-metallic materials and examples of where these materials are used in an engineering and/or industrial context.
B Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them	**B1** In-service behaviour of non-metallic materials **B2** Destructive test procedures to determine mechanical properties **B3** Material defects in non-metallic materials **B4** Non-destructive tests used to identify material defects	A portfolio of results gathered from tests on samples of given materials, supported by a logbook, images and observation records.
C Explore the in-service failure of non-metallic components and consider improvements to their design	**C1** Ductile and brittle fracture **C2** Creep failure **C3** Fatigue failure **C4** Degradation processes **C5** The contribution of design to prevent component failure	A report containing investigative research into the causes of in-service failure of given engineering components and suggestions as to how these might have been avoided.

Content

Learning aim A: Investigate how the structures of non-metallic materials influence their mechanical properties

A1 Types of non-metallic materials

- Types of polymer materials, to include:
  - thermoplastic polymers, e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene
  - thermosetting polymers, e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde, epoxy resin, polyester resin
  - elastomers, e.g. thermoplastic elastomer (TPE).
- Types of ceramic materials, to include:
  - amorphous, e.g. silica glass (SiO_2)
  - crystalline, e.g. silicon carbide, alumina
  - bonded, e.g. cemented carbides.
- Types of composite materials, to include:
  - fibre reinforced:
    - fibre-reinforced polymer (FRP), composites or polymer matrix composites (PMC), which use a polymer-based resin as the matrix and fibres as the reinforcement, e.g. glass, carbon and aramid
    - metal matrix composites (MMC), which use a metal such as aluminium as the matrix, with fibres such as silicon carbide as the reinforcement
    - ceramic matrix composites (CMC), which use a ceramic as the matrix and short fibres, such as silicon carbide and boron nitride, as reinforcement.

A2 Structures of non-metallic materials

- Atomic and molecular structure:
  - elements, atoms, nucleus, electrons
  - atomic bonding mechanisms, including covalent, ionic
  - compounds, molecules, molecular weight
  - intermolecular bonding mechanisms, including hydrogen bonding, van der Waals forces.
- Structure of polymer materials, to include:
  - monomers (e.g. vinyl chloride), polymers (e.g. polystyrene), homopolymers (e.g. polyvinyl chloride (PVC)), copolymers (e.g. acrylonitrile butadiene styrene (ABS)).
  - polymer chains, including linear, branched and cross-linked
  - amorphous and semi-crystalline structures
  - glass transition temperature.
- Structure of ceramic materials, including amorphous and crystalline structures.
- Structure of composites materials, to include:
  - fibre/matrix composite structure, including fibre alignment, fibre/matrix ratio, continuous and discontinuous fibres
  - particle/matrix composite structure, including particle/matrix ratio, particle size, distribution.

A3 Mechanical properties of non-metallic materials

- Typical tensile tests (including stress–strain curves) for materials, to include thermoplastic polymer, thermoset polymer, elastomer, crystalline ceramic, fibre reinforced composite.
- Effects of temperature and humidity on the mechanical properties of polymers, including glass transition temperature.
- Strength: yield, proof, tensile, compressive, shear.
- Specific strength: strength per unit density.
- Modulus of elasticity (Young’s modulus).
- Specific stiffness, resistance to bending: elastic modulus per unit density.

- Fatigue limit.
- Fracture toughness.
- Surface hardness.

A4 Typical engineering applications of non-metallic materials

Non-metallic material groups, including polymers, ceramics and composites.

- Typical applications of polymer materials, to include:
  - polyethylene (PE), e.g. packing films, wire insulation, squeeze bottles, tubing
  - polyvinyl chloride (PVC), e.g. pipes, fittings, floor tiles
  - polypropylene (PP), e.g. ropes, containers, moulded furniture
  - polyamide (PA) or nylon, e.g. bearings, gears, ropes, electrical components
  - urea-formaldehyde (UF), e.g. electrical plugs and sockets
  - polyurethane (PU), e.g. skateboard wheels, foam seals and gaskets, automotive suspension bushes.
- Typical applications of ceramic materials, to include:
  - Automotive, e.g. valve components, water and fuel pump components, catalytic converter components and brake discs
  - electronics, e.g. capacitors, insulators, heat sinks
  - energy and environment, e.g. pump components, photovoltaics, solar thermal energy conversion, and wind and water power
  - medical technology, e.g. replacement joints, dental products
  - aerospace, e.g. engine and airframe components
  - modern industry, e.g. milling and grinding operations, cutting tips, high-speed paper manufacture, welding jigs and fixtures, extrusion dies, chemical process industries.
- Typical applications of composite materials, to include:
  - Glass-reinforced polymer (GRP), e.g. boat hulls, automotive body panels, wind turbines.
  - Carbon-fibre-reinforced polymer (CFRP), e.g. automotive and aerospace structural components
  - titanium metal matrix composites (Ti MMC), e.g. aerospace engines and airframes
  - silicon carbide reinforced CMC, e.g. high temperature aerospace applications.

Learning aim B: Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them

B1 In-service behaviour of non-metallic materials

- Desirable in-service behaviour of polymer material, e.g. low density (lightweight), good chemical and corrosion resistance, thermal and electrical insulators.
- Desirable in-service behaviour of ceramic materials, e.g. good high-temperature strength, high wear resistance and good corrosion resistance.
- Desirable in-service behaviour of composite materials, e.g. low density (lightweight), high stiffness, high tensile strength, low thermal expansion, high fatigue resistance.

B2 Destructive test procedures to determine mechanical properties

Safe working practices for destructive testing of materials, e.g. safe use of test equipment, personal protective equipment (PPE).

- Tensile strength testing:
  - selection and preparation of test specimens, tensile test machine, extensometer, data recording, pull to destruction, force–extension graph, examination of fractured surface
  - safe use of equipment to measure identified variables
  - presentation of results, to include elastic limit/limit of proportionality, yield point, tensile strength, Young’s modulus, percentage elongation and reduction in cross-sectional area
  - comparison of results with reference values taken from accredited data sources.

- Impact testing:
  - selection and preparation of test specimens, e.g. notch preparation
  - safe use of equipment to measure impact values, e.g. Izod impact test, Charpy impact test
  - visual inspection of the fractured surface to estimate the crystalline area percentage
  - comparison of results with reference values taken from accredited data sources.
- Creep testing:
  - creep is the tendency for a material to deform under a constant mechanical stress, causing the material to fail below its ultimate tensile strength
  - a simple way to investigate creep is by applying a constant force to a standard-sized sample of material, measuring its extension (e.g. by using a dial gauge) at regular time intervals and plotting the results as an extension–time graph
  - three stages of creep – primary, secondary and tertiary
  - creep mechanisms – dislocation, slip and climb, grain boundary sliding, diffusion flow
  - effect of temperature on creep.
- Fatigue testing:
  - a simple method for determining the behaviour of materials under fluctuating loads
  - a specified mean load (which may be zero) and an alternating load are applied to a specimen, and the number of cycles required to produce failure (fatigue life) is recorded.

B3 Material defects in non-metallic materials

- Polymer defects, to include microscopic, e.g. inclusions, dislocations, crystalline boundaries, amorphous interlayers and non-uniform stress distribution at points of crack initiation.
- Ceramic defects, to include microscopic, e.g. micro-cracks, internal pores, contaminants.
- Composite defects, to include porosity, inclusions, poor fibre alignment, delamination, matrix cracking.

B4 Non-destructive tests used to identify material defects

- The function, operation and effectiveness of surface and sub-surface non-destructive tests, to include visual inspection, dye penetrant, tap test, ultrasonic, and radiographic.

Learning aim C: Explore the in-service failure of non-metallic components and consider improvements to their design

C1 Ductile and brittle fracture

- Effects of gradual and impact loading.
- Fracture surface appearance: crystalline, torn, necking.

C2 Creep failure

- Primary, secondary and tertiary creep.
- The effects of temperature and applied stress on creep rate.
- Strain–time graphs and limiting creep stress.

C3 Fatigue failure

- Crack propagation and growth.
- Internal stress concentration: granular defects, porosity.
- External stress concentration: surface defects, sharp changes of section.
- Stress variation: reversal due to cyclic loading, random loading, vibration.
- Final, catastrophic failure: reduction in load carrying area, tensile strength exceeded.
- Characteristic appearance of fracture surface: smooth burnished area (crack growth), crystalline area (final tear), ripple-like marks showing crack progression.

C4 Degradation processes

- Polymers (including polymer matrix in composite materials), to include:
  - UV and thermal degradation, including scission, depolymerisation, side chain elimination and oxidation
  - chemical corrosion
  - environmental stress cracking (ESC) as a result of applied stress and a corrosive environment.
- Ceramics, to include thermal shock and sustained high temperature.
- FRP composites, to include moisture ingress and chemical contamination.

C5 The contribution of design to prevent component failure

- Component operating environment, e.g. static, dynamic and cyclic loading, service temperature, wet or dry conditions.
- Correct choice of material, based on mechanical properties, consequences of sudden failure, corrosion resistance.
- Design features, e.g. reducing the impact of stress raisers, e.g. sharp corners, sudden changes in cross-sectional areas, poor surface finish.
- Higher quality material, e.g. free from inclusions or porosity.
- Additives and surface finishes, e.g. UV inhibitors, painting.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate how the structures of non-metallic materials influence their mechanical properties		**A.D1** Evaluate, using vocational and high-quality written language, the relationship between the structures, mechanical properties and applications of at least two contrasting non-metallic materials from each group.
A.P1 Describe the structures of at least two contrasting materials from each non-metallic material group. **A.P2** Explain the relationship between the structures and mechanical properties of at least two contrasting non-metallic materials from each group, suggesting an application for each.	**A.M1** Analyse the relationship between the structures and mechanical properties of at least two contrasting non-metallic materials from each group, suggesting a realistic application for each.	
Learning aim B: Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them		**B.D2** Evaluate, using the results from safely and accurately conducted destructive tests, an accredited data source and research, the relationship between the mechanical properties, in-service behaviour and defects of at least two contrasting materials from two non-metallic material groups.
B.P3 Conduct at least one destructive test(s) safely on at least two contrasting materials from two non-metallic material groups. **B.P4** Explain, using the test results, how at least one mechanical property for each material type affects their in-service behaviour. **B.P5** Explain the operation of at least two non-destructive test methods and how the mechanical properties of two contrasting materials from two non-metallic material groups are affected by defects.	**B.M2** Conduct at least one destructive test(s), safely and accurately on at least two contrasting materials from two non-metallic material groups. **B.M3** Assess, using the test results and an accredited data source, how at least one mechanical property for each material type affects their in-service behaviour. **B.M4** Analyse the operation of at least two non-destructive test methods and how the mechanical properties of two contrasting materials from two non-metallic material groups are affected by defects.	
Learning aim C: Explore the in-service failure of non-metallic components and consider improvements to their design		**C.D3** Evaluate the results of the visual inspection of three non-metallic components and the mechanisms by which they failed, justifying a design solution that should prevent recurrent failure from a range of alternatives.
C.P6 Conduct a visual inspection to identify the mechanism by which three non-metallic components failed in service. **C.P7** Explain the mechanism by which three non-metallic components failed in service, suggesting design solutions that should prevent recurrent failure.	**C.M5** Conduct a visual inspection to accurately identify the mechanism by which three non-metallic components failed in service. **C.M6** Analyse the mechanism by which three non-metallic components failed in service, justifying detailed design solutions that should prevent recurrent failure.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.M2, B.M3, B.M4, B.D2)

Learning aim: C (C.P6, C.P7, C.M5, C.M6, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- access to data sources, e.g. www.matweb.com, CES EduPack™ (Granta Design)
- material test samples of known composition and processing history, e.g. from the Institute of Materials Minerals and Mining
- hardware equipment, including:
    - hand magnifiers, macro photography equipment
    - tensile test and impact testing equipment (essential)
    - creep and fatigue test equipment (recommended).

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate the microstructures of at least six non-metallic materials, comprising at least two contrasting examples of polymer, ceramic and composite materials. They will provide extensive information on the structures of each material, for example evaluating the nature of covalent and ionic bonding in ceramics. Learners will evaluate data from accredited sources, evaluating the impact of the structure on at least three mechanical properties for each specific material, for example the reasons why a thermoplastic such as ABS has a different tensile strength as compared to a thermosetting polymer such as urea-formaldehyde. Learners will evaluate at least one specific application for each of the non-metallic materials investigated.

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 use a high standard of written language.

For merit standard, learners will analyse, in some detail, the microstructures of at least six non-metallic materials, comprising at least two contrasting examples of polymer, ceramic and composite materials, for example by explaining how covalent and ionic bonding in ceramics affects the mechanical properties of the materials being investigated. Learners will evaluate data from accredited sources, evaluating the impact of the structure on at least three mechanical properties for each specific material, for example the property of thermoplastics such as ABS, PMMA (acrylic) and polyester to become pliable when heated due to the intermolecular forces that can be reformed on cooling, or the impact of cross-linking bonds on thermosetting plastics such as epoxy resin or melamine-formaldehyde. Learners will analyse at least one specific application for each of the non-metallic materials being investigated.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will describe the microstructures of at least six non-metallic materials, comprising at least two contrasting examples from each material group, specifically polymers, ceramics and composites. Learners will use data to relate the structure to at least three mechanical properties for each material type, for example by comparing the properties of thermoplastic and thermosetting polymers with relation to the chains of molecules. Learners will describe at least one specific application for each of the non-metallic materials investigated.

Overall, the evidence will be logically structured, although it may be basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will safely set up and correctly use at least one type of mechanical testing equipment and gather accurate results when completing tensile, impact and/or hardness destructive tests. They will test at least eight prepared samples comprising at least two contrasting types of materials from two of the material groups (polymer, ceramic and composite).

Learners will use a combination of the mechanical test results and an accredited data source to evaluate their results. The evaluation for the:

- tensile tests will include load–extension (stress–strain) graphs and provide key data, for example yield strength, tensile strength, Young’s modulus, percentage elongation and reduction in area
- tensile and impact tests will include the condition of the fracture surface
- hardness tests will make comparisons between measured hardness values and what is expected for the material.

Learners will research and assess the operation of at least two non-destructive tests used to identify defects in the structures of non-metallic materials. The evaluation will include the potential impact of structural defects on the mechanical properties of the materials being investigated, make a judgement on the effectiveness of the tests and provide the limitations of the tests, for example detecting microscopic fractures in a ceramic material and the impact that this may have on brittle fracture.

Overall, the evidence, such as a logbook and report, will have been 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 complete accurate and safe mechanical tests using at least eight samples from two of the material groups (polymer, ceramic and composite). Learners will set up the equipment and gather and process their test results accurately, for example by finding the yield and tensile strengths and seeing how they compare with published values. They will compare the results of destructive testing with an accredited data source.

Learners will research and assess the operation of at least two non-destructive tests used to identify defects in the structures of non-metallic materials, and will draw conclusions from the results, for example by describing what defects each of the tests is designed to detect and the effectiveness of the tests.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will conduct at least one appropriate mechanical test, such as a tensile (to destruction), impact and/or hardness test, using pre-prepared non-metallic material samples. In total, learners will test at least eight samples from at least two of the material groups, specifically polymer, ceramic or composite materials, and record their results. Throughout the delivery of the tests they will demonstrate safe working practices, for example by completing a risk assessment and checking with the assessor before conducting an impact test. Learners may be given help to set up the test equipment, but they will, as a minimum, independently gather their own test results.

Learners’ evidence will explain, using the test results, how at least one mechanical property for at least four materials affects the in-service behaviour of the material. For example, a material with good impact resistance (determined, for example from an Izod impact test) is better able to withstand shock loading.

Learners will explain the operation and function of at least two non-destructive tests safely and explain the results, for example ultrasonic testing is used to find voids in a composite matrix.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the test results. The evidence may be basic in parts and may contain minor technical inaccuracies relating to engineering terminology.

Learning aim C

For distinction standard, learners will visually explore a range of given components that have failed in service after having been in use for significant periods of time. At least two components will have failed due to a mechanical fault and at least one other due to degradation.

Having explored the various failure modes, learners will evaluate how to eliminate or mitigate the problem by thinking how to redesign the component. They will consider a range of alternative design solutions and justify the preferred solution, for example by specifying a larger fillet radius where there is a change of cross-section, or by using a material that has a better operating performance at high temperature and stress levels, such as a titanium alloy.

Overall, the evidence, such as a logbook and report, will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer. Learners must clearly demonstrate a good understanding of mechanical design principles when evaluating the failure modes of the selected components and suggesting improvements.

For merit standard, learners will examine at least three components that collectively have suffered mechanical failure and surface degradation. This will involve visual inspection checks and comparison with reference sources, for example by comparing the components against other sample images of failed components.

Having analysed the various failure modes, learners will justify design modifications to each of the components so as to eliminate or reduce the impact of the failures.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will carry out a visual inspection check on at least three sample components that have failed in service for different reasons. At least two components will have failed due to mechanical faults (for example fatigue and creep) and at least one other due to degradation processes.

Using the visual inspection check, learners' evidence will explain how the components failed in service. Learners will also give for each component at least one method to improve the design so that it does not fail in service, for example by increasing the size of a fillet radius on a stepped shaft.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the results. The evidence may be basic in parts.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacture
- Unit 25: Mechanical Behaviour of Metallic Materials
- Unit 45: Additive Manufacturing Processes
- Unit 47: Composites Manufacture and Repair Processes
- Unit 52: Airframe Construction and Repair
- Unit 53: Airframe Mechanical 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 non-metallic materials
- contribution of ideas to unit assignment/project materials.

Unit 27: Static Mechanical Principles in Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the effect of forces acting on structures that are in static equilibrium using theoretical principles, calculations and practical experiments.

Unit introduction

Mechanical structures and their components (sub-parts of a structure) are found in many everyday products, such as bridges, buildings, and as part of systems, such as manufacturing equipment. The design and maintenance of mechanical structures and components can be crucial to prevent injury or loss of life, and to ensure that products are usable and services are available when required. The study of the forces acting on stationary structures and their components is often referred to as 'statics'.

You will investigate the theory that underpins the design of framed structures. You will then explore, through a combination of experimentation and theory, what happens when simply supported and cantilever beams are subjected to forces generated by applied loads. Finally, you will investigate the stresses and strains generated in structural components that carry bending, shear and axial loading. Stresses produced by changes in temperature are also covered. As part of the investigation, you will look at the design of a structure or components and make improvements so that they are fit for purpose.

In our modern economy, consumers and organisations expect ever-increasing standards of safety and fitness for purpose of products, systems and other structures (e.g. buildings). Mechanical engineers will be able to work out if the loaded structure, such as a beam that forms part of a bridge, is in a safe condition. It is their job to understand and design products, systems and other structures that perform as intended. Studying this unit will help learners to progress to mechanical engineering technician job roles and also to higher education to study engineering.

Learning aims

In this unit you will:

A Examine how the forces acting in pin-jointed framed structures influence their structural integrity

B Explore safely the shear forces and bending moments in simply supported and cantilever beams

C Examine how axial, bending and shear loading affect the design of structural components.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how the forces acting in pin-jointed framed structures influence their structural integrity	**A1** Static parameters **A2** Analysis of statically determinate framed structures	A report containing graphical and mathematical modelling relating to the analysis of given pin-jointed structures.
B Explore safely the shear forces and bending moments in simply supported and cantilever beams	**B1** Beam parameters **B2** Theoretical beam analysis **B3** Experimental beam analysis	A portfolio of results gathered by experimentation when investigating given beam configurations, supported by a logbook, images, observation records and graphical and mathematical modelling (including differential calculus).
C Examine how axial, bending and shear loading affect the design of structural components	**C1** Axial loading **C2** Bending loading **C3** Shear loading **C4** Design considerations	A report containing mathematical modelling relating to the analysis of the stresses and strains in given structural components.

Content

Learning aim A: Examine how the forces acting in pin-jointed framed structures influence their structural integrity

A1 Static parameters

- Framework components: members and pins.
- Conditions for static equilibrium: $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$
- Two-dimensional framed structures: stable and unstable.
- Statically determinate structures: members (m), joints (j), determinate and indeterminate condition, $(m + 3)$ <=> $2j$ test, redundancy.
- Loading configurations: vertical force, angled force, gravitational force ($F_g = mg$)
- Fixed (pin) and rolling framework support reactions.
- Pin and rigid framework joints.
- Resolution of forces into horizontal ($F_x = F\cos\theta$) and vertical components ($F_y = F\sin\theta$)
- Primary compressive and tensile forces in structural members.
- Types of member in a framed structure: struts and ties.

A2 Analysis of statically determinate framed structures

- Graphical method, including:
  - graphical analysis method – scale and accuracy
  - space diagram – labelling joints including uppercase lettering to code members and Bow's notation including labelling with uppercase lettering, with spaces separating adjacent forces
  - funicular polygon to determine support reactions
  - reciprocal (vector) diagram – choice of starting point (a joint with no more than two unknown forces), annotation of diagram with lowercase lettering
  - sequential analysis of the framed structure – annotation of a space diagram with arrows to show the direction of forces in a member
  - tabulation of forces – member code, vector code, force including magnitude and type, type of member (strut or tie).
- Analytical method, including:
  - space diagram – labelling joints using uppercase lettering
  - determination of support reactions and choice of starting point, e.g. a joint with no more than two unknown forces
  - resolution of forces into components at first joint and determination of forces
  - sequential joint resolution, including the annotation of a space diagram with arrows to show the direction of forces in members
  - tabulation of forces – member code, forces including magnitude and type, type of member (strut or tie)
  - method of sections – selecting an appropriate cutting plane position, annotation of force directions, coding of cut members, determination and tabulation of forces.

Learning aim B: Explore safely the shear forces and bending moments in simply supported and cantilever beams

B1 Beam parameters

- Reactions, including built-in and simply supported.
- Sign conventions for shear forces, either positive or negative.
- Sign conventions for bending moments, including positive and negative, sagging and hogging.
- Simple loading, including concentrated (perpendicular to beam axis) and effective beam mass.
- Complex loading including concentrated (angled to beam axis), uniformly distributed load (UDL) and distributed beam mass.

B2 Theoretical beam analysis

- Simply supported beams with and without overhang.
- Simple cantilever beams.
- Beam support reactions, graphically by funicular polygon and analytically by taking moments.
- Shear forces, including presentation in diagrammatic form and identification of maximum values.
- Bending moments, including presentation in diagrammatic form and identification of maximum and minimum bending moments, points of contraflexure.
- Applying differential calculus (max/min theory) to the analysis of beams carrying point and uniformly distributed loads to determine the magnitude and position of the maximum bending moment.

B3 Experimental beam analysis

- Function and operation of test equipment for measuring shear forces and bending moments in loaded structures, including loading configurations, force sensing, and resolution.
- Selecting and setting up equipment, including loading configurations, dimensional parameters and force sensing.
- Effects of point loads.
- Effects of uniformly distributed loads.
- Effects of point and uniformly distributed loads on a structure.
- Measurement and recording of shear forces.
- Measurement and recording of bending moment data.
- Presentation of experimental results and comparison against theoretical analysis.

Learning aim C: Examine how axial, bending and shear loading affect the design of structural components

C1 Axial loading

- Elasticity, plasticity, Young’s modulus of elasticity, tensile strength, safe working stress, factor of safety.
- Structural components, including simple bars, complex (compound) bars with series configuration, parallel configuration and different materials.
- Effects of axial loading on structural components, including internal stress, strain, and material dimensional change.
- Effects of temperature change on fixed-end structural components, including thermal stress.

C2 Bending loading

- Neutral axis, stress distribution, second moment of area for solid and hollow rectangular sections, bending stress, Young's modulus, radius of curvature.
- Bending equation $\left(\frac{\sigma}{y}=\frac{M}{I}=\frac{E}{R}\right)$, including application to the analysis of simply supported and cantilever beams.
- Determination of bending stresses for given loading configurations and bending moment data.
- Beam efficiency, including width/depth ratio, load carrying ability, factor of safety, beam mass.

C3 Shear loading

- Single and double shear loads for bolted and riveted joints.
- Joint parameters including butt, lap, number of rivets or bolts, shear load, bolt and rivet diameters.
- Shear stress and strain in joints, shear modulus, tensile strength, factor of safety.

C4 Design considerations

- Published reference data including the mechanical and physical properties of engineering materials, second moments of area.
- Design parameters, including tensile and compressive strength, safe working stress, factor of safety.
- Design efficiency, including optimisation of physical parameters to meet load carrying and safety requirements.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how the forces acting in pin-jointed framed structures influence their structural integrity		**A.D1** Demonstrate accurately the most appropriate method for finding the forces in the central members of a pin-jointed framed structure, justifying the rationale.
A.P1 Determine graphically the support reactions and primary forces acting in the members of a pin-jointed, statically determinate framed structure. **A.P2** Calculate the support reactions and primary forces acting in the components of a pin-jointed, statically determinate framed structure.	**A.M1** Determine accurately the magnitude and nature of the primary forces acting in the components of a pin-jointed, statically determinate framed structure.	
Learning aim B: Explore safely the shear forces and bending moments in simply supported and cantilever beams		**B.D2** Evaluate the simple and complex loads acting on simply supported and cantilever beams, comparing the results from safely conducted experiments and theoretical calculations, and suggest improvements to the experimental method used.
B.P3 Conduct experiments safely to determine the shear forces and bending moments in simply supported and cantilever beams when subjected to simple loading. **B.P4** Explain, using experimental results and theoretical calculations, the shear forces and bending moments in simply supported and cantilever beams when subjected to simple loading.	**B.M2** Conduct experiments accurately to determine the shear forces and bending moments in simply supported and cantilever beams when subjected to simple and complex loading. **B.M3** Analyse, using experimental results and theoretical calculations, the shear forces and bending moments in simply supported and cantilever beams when subjected to simple and complex loading.	
Learning aim C: Examine how axial, bending and shear loading affect the design of structural components		**C.D3** Optimise the physical parameters of a structure ensuring that it is fit for purpose when subjected to axial, bending and shear loading.
C.P5 Calculate the axial stress produced in a rigidly held simple structural component when subjected to a combination of axial loading and temperature change. **C.P6** Calculate the maximum bending stress, the factor of safety in operation and the minimum radius of curvature for a simply supported beam carrying concentrated and uniformly distributed loads. **C.P7** Calculate the maximum shear stress for a single shear lap joint and a double shear butt joint for given loading.	**C.M4** Analyse accurately the axial stress produced in a rigidly held complex structural component when subjected to a combination of axial loading and temperature change. **C.M5** Develop accurately a design for a complex structure that does not fail when subjected to bending and shear loading.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- framework and beam apparatus, for example from TecQuipment
- published databases of physical and mechanical properties of metallic materials.

The practical activities should take place in a test facility with appropriate equipment, and should take account of health and safety requirements.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will select a suitable cutting plane so that the forces in a small number of internal members can be determined accurately using the 'method of sections'. The values of these forces will be compared with those found by the analysis of the framework and graphical representation (refer to the pass standard for further details). In addition to the mathematical work, learners will evaluate, in a wider context, the reasons for using the method of sections and for the given framework, and comment on the suitability of the method as compared to the analytical and graphical methods.

Overall the evaluation will be easy to read and understand by a third party who may or may not be an engineer. For example, it 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, evidence will include a graphical and mathematical analysis to a high degree of accuracy. For each member there must be correct tabulation of the force that it carries and designation of whether it is either a tie or a strut.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Figures produced by the two methods will be broadly equivalent and if there are major differences learners will go back through their work, identifying where there are errors, and complete any necessary rework.

For pass standard, the graphical analysis of a pin-jointed framework that has two support reactions (one pinned and one roller) will include a scale drawing that will have been used to generate space, and reciprocal force diagrams that are correctly annotated using the accepted conventions, for example, Bow's notation for labelling the spaces between the external forces, support reactions and structural members. There will be evidence of a check having been carried out to ensure that the framework is statically determinate.

Using the same framework, learners will also carry out a mathematical analysis using the method of joint resolution. The framework will be configured so that for each joint the forces in the members attached to it can be resolved horizontally and vertically. Learners can present a sketched space diagram for the structure which will be marked up with force direction arrows as they work sequentially through the framework.

Overall, in the graphical analysis there may be some minor scaling errors when reading off and determining the tensile or compressive force carried by each member, and in the mathematical analysis there may be minor mathematical errors. Learners will not be penalised for 'carry-through' errors.

Learning aim B

For distinction standard, learners will present a detailed evaluation of the results from safely conducted experiments and theoretical analysis, and justify the differences between them. They will have theoretical calculations and diagrams that are accurate and will use these as a benchmark against which to judge their experimental findings. They will consider aspects such as accuracy of measuring equipment, methods used and ways to improve the experimental methods if repeated. If there are major differences between experimental and theoretical results, there will be a balanced evaluation of why this happened.

Overall, the experimental reports will be logically structured and 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 selecting measuring equipment that has the appropriate resolution, and will record results methodically. The practical work will involve a combination of simple and complex loading, which will take the form of at least two point loads and one uniformly distributed load.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Theoretical calculations and the annotation of shear force and bending moment diagrams must be accurate and conform to accepted conventions, for example, a positive bending moment indicating sagging.

For pass standard, learners will conduct experimental work on a simply supported beam carrying at least three simple (point) loads and set up in two configurations – with overhang and without overhang. Learners will conduct similar experiments with a cantilever beam carrying at least two simple (point) loads.

Overall, learners' evidence will be logically structured and there may be some minor numerical and diagrammatic errors, and minor inaccuracies relating to the engineering terminology used. The explanation of each experiment will include hand-drawn, to-scale diagrams that are annotated with relevant figures, for example maximum and minimum values. Theoretical calculations will also be included, but there may be minor numerical and diagrammatic errors.

Learning aim C

For distinction standard, learners will present ideas, supported by detailed, accurate calculations, about how to optimise the design of the structure, so that for a given loading condition the best use is made of the available materials, for example, replacing a solid rectangular cross-section beam with a hollow one to reduce mass. In addition, learners will consider features such as strength to weight ratio, factors of safety, and high-strength materials. There may be some repetition of calculations; this can be done using a spreadsheet provided that formulae are visible (printed out) and the use of functions like 'goal seek' are acknowledged. Evidence will include correctly annotated sketches to support the mathematical analysis (modelling) of the structures.

Overall, 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 work with load and temperature data (as used throughout the assignment), but applied to different structural design configurations, for example, two flat plates separated with an aluminium tube spacer and held together with a steel bolt passing through the plates and spacer, and tightened with a nut. Calculations will be accurate and correctly presented using appropriate engineering notation and units.

Learners will review the stress data (refer to the pass standard for further details) and improve the accuracy of the design of the given structure, so that it is able to withstand the applied loads safely. For example, the design could include increasing the cross-sectional area of a beam or putting in more pins to withstand shear loading. Learners will demonstrate that the structure is able to withstand the applied loads by recalculating the stresses accurately.

Overall, calculations will be accurate and the evidence logically structured, with appropriate engineering terminology and units.

For pass standard, learners will present two sets of calculations. The first calculations determine the tensile or compressive stress in an axial-loaded simple component, for example a hollow support strut used in a gantry. The second calculations are to consider the effects of temperature change, if the component is assumed to have fixed ends. The analysis will have the correct interpretation of given data, correct use of formulae and presentation of logical steps to a solution.

Learners will undertake bending and shear stress calculations, and demonstrate analysis through correct interpretation of given data, correct use of formulae and presentation of logical steps to a solution. The stress analysis of riveted or pinned joints will be presented as annotated sketches and calculations.

Overall, the analysis will contain correct interpretation of the given data, correct use of formulae and be logically structured. There may be minor mathematical errors and learners will not be penalised for carry through errors.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 7: Calculus to Solve Engineering Problems
- Unit 8: Further Engineering Mathematics
- Unit 25: Mechanical Behaviour of Metallic Materials.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and construction organisations with expertise in static mechanical systems
- contribution of ideas to unit assignment/project materials.

Unit 28: Dynamic Mechanical Principles in Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners cover the principles and practical methods used to understand and explore the movement of objects and the effects of forces acting on them.

Unit introduction

A great many engineering mechanical systems are designed to transmit motion and power. These include machine tools, motor vehicles, aircraft, domestic appliances and access equipment, such as escalators and elevators. The study of motion in mechanical systems is known as kinematics and the study of the forces at work, and the power that they transmit, is known as dynamics.

In this unit, you will explore, through a combination of experimentation and theory, how applied forces or turning moments make objects move in a linear or rotational manner as the effects of inertia, frictional resistance and gravity are overcome. You will investigate the dynamics of free-standing wheeled vehicles as they move around curved tracks and you could, for example, apply this theory to an aircraft as it makes a flight manoeuvre such as a steady turn. Simple harmonic motion and the operating principles of lifting machines are other topics that you will investigate.

When a vehicle is parked, the components are at rest and subjected only to the static loads produced by the mass of the car. When the vehicle is in motion, it is operating in a dynamic environment and the additional loads generated must be taken into account when designing components. As an engineer you need to understand what happens when products are operating in a dynamic environment, for example working out if a car will slide or overturn when travelling at speed around a curve, and the power rating of the motor fitted to the winding gear of a lift (elevator). This unit will help you progress to mechanical engineering technician job roles and also to higher education to study engineering.

Learning aims

In this unit you will:

A Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems

B Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems

C Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems	**A1** Dynamics of systems undergoing acceleration **A2** Linear systems **A3** Rotational systems **A4** Complex systems	A portfolio of results gathered by experimentation when investigating linear and angular motion and by theoretical calculation, supported by images, observation records and mathematical modelling.
B Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems	**B1** System parameters **B2** Rotating systems **B3** Dynamic balancing	A report containing research on a rotating system and mathematical modelling of the system.
C Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems	**C1** Parameters of lifting machines **C2** Lifting machines **C3** Relative velocity **C4** Periodic motion	A report containing mathematical modelling of lifting machines and linkage mechanisms, as well as experimental results gathered when investigating a simple pendulum and mass–spring system.

Content

Learning aim A: Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems

A1 Dynamics of systems undergoing acceleration

- Kinetic principles: equations for motion with uniform acceleration, including linear and angular, e.g. ($v_2 = v_1 + at$), ($\theta = \omega t + 0.5\alpha t^2$)
- Dynamic parameters, including:
  - tractive effort, thrust, impulse, impulsive force, impulsive torque, braking force, accelerating force, retarding force, e.g. aero-engine thrust, regenerative braking force in hybrid vehicles (kinetic energy recovery system (KERS))
  - coefficient of friction, friction force, friction torque, e.g. sliding surfaces
  - gravitational force, inertia, momentum, potential energy, kinetic energy.
- Dynamic principles, including:
  - Newton's three laws of motion
  - conservation of momentum, conservation of energy, D'Alembert's principle.

A2 Linear systems

- Mass (m), displacement (s), time (t), velocity (v), acceleration (a), inertia force ($F = ma$)
- Mechanical work ($W = Fs$), e.g. work done lifting an object.
- Average power $\left(P = \dfrac{W}{t}\right)$, instantaneous power ($P = Fv$)
- Linear momentum (mv).
- Impact and collision, e.g. pile driver.
- Linear kinetic energy $\left(KE = \dfrac{1}{2}mv^2\right)$, simple linear systems involving objects moving on horizontal and inclined surfaces, including free-standing wheeled vehicles, e.g. car, aircraft, and wheeled vehicles running on straight tracks, e.g. train, tram.

A3 Rotational systems

- Mass (m), displacement (θ), time (t), velocity (ω), acceleration (α)
- Radius of gyration (k), moment of inertia ($I = mk^2$), e.g. engine flywheel.
- Inertia torque ($T = I\alpha$), friction torque, e.g. disc brake.
- Mechanical work ($W = T\theta$)
- Average power $\left(P = \dfrac{W}{t}\right)$, instantaneous power ($P = T\omega$)
- Angular momentum ($I\omega$).
- Rotational kinetic energy $\left(KE = \dfrac{1}{2}I\omega^2\right)$, e.g. energy stored in a flywheel.
- Simple rotational systems, e.g. wheel, braking disc, rotating rim, flywheel, motor armature, pump rotor, turbine engine rotor.

A4 Complex systems

- Dynamic systems that combine linear and rotational motion, including free-standing vehicles on flat and inclined tracks and a lift cage and its winding gear.

Learning aim B: Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems

B1 System parameters

- Centripetal acceleration ($a = \omega^2 r$, $a = \frac{v^2}{r}$), centripetal force ($Fc = m\omega^2 r$, $Fc = \frac{mv^2}{r}$), polar axis of rotation.
- Centrifugal force, e.g. centrifuge, centrifugal clutch.

B2 Rotating systems

- Simple systems, including single mass rotating in a horizontal or vertical plane, vehicle on a hump-back bridge, aircraft in a steady turn, roller coaster.
- Complex systems, including centrifugal clutch, vehicles on curved tracks (flat and banked), sliding and overturning.
- Vehicle parameters – mass, wheel track, height of centre of gravity in relation to track surface, coefficient of friction between contact surfaces.

B3 Dynamic balancing

- Rotating masses in a two-dimensional system – mass, fixed radius and angular position, angular velocity, dynamic force representation using a vector polygon.
- Conditions for dynamic balance or equilibrium: $\Sigma mr = 0$.
- Balancing mass, including magnitude, radius, angular position.

Learning aim C: Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems

C1 Parameters of lifting machines

Kinetic parameters, including input motion, output motion, movement or velocity ratio (V.R. = input displacement of effort/output displacement of load), coefficient of friction.

Dynamic parameters:

- input effort (force, torque), output load (force, torque), mechanical advantage $\left(M.A. = \frac{\text{load}}{\text{effort}}\right)$
- work input, work output, ideal machine, efficiency $\left(\eta = \frac{M.A.}{V.R.}\right)$
- effort (ideal, actual, friction), coefficient of friction (static, dynamic), limiting efficiency
- overhauling, law of the machine.

C2 Lifting machines

- Simple systems, including:
  - inclined plane
  - screw jack – single-start thread, multi-start thread, thread pitch, lead
  - pulley blocks
  - wheel and axle
  - worm and wheel
  - simple gear train
  - winch
  - non-reversing devices – ratchet, auto-brake.
- Complex systems, including:
  - differential wheel and axle
  - Weston differential pulley block
  - compound gear train winch
  - engine hoist.

C3 Relative velocity

- Space and velocity diagrams: scale drawing, labelling.
- Vector addition and subtraction of velocities.
- Resultant velocity of an object with simultaneous velocities in different directions.
- Relative velocity between objects moving simultaneously in different directions.
- Output motion for linkage mechanisms, including slider crank, four-bar linkage, quick return.

C4 Periodic motion

- Generation of simple harmonic motion (SHM):
  - general equations for SHM derived from a consideration of uniform circular motion, including circular frequency, displacement, velocity, acceleration
  - dynamic properties of systems that exhibit SHM, including frequency of vibration (f_n), periodic time (T), displacement, instantaneous velocity and acceleration
  - mechanical linkages with output motion in the form of SHM that is produced by input uniform circular motion, e.g. scotch yoke mechanism
  - un-damped vibrating mechanical systems, including:
    - simple pendulum – angle of swing, $T = 2\pi\sqrt{\frac{l}{g}}$
    - linear mass–spring system, $f_n = \frac{1}{2}\pi\sqrt{\frac{\text{stiffness}}{\text{mass}}}$
    - torsional mass–spring system, $f_n = \frac{1}{2}\pi\sqrt{\frac{\text{torional stiffness}}{\text{rotational inertia}}}$

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems		**A.D1** Evaluate a simple linear and a simple rotational mechanical system, comparing the results from safely and accurately conducted experiments and calculations, while using the principles to model accurately a complex system in which both linear and rotational motion are present.
A.P1 Conduct experiments safely to determine the motions and energy transfers taking place in a uniformly accelerated simple linear and a simple rotational system. **A.P2** Prepare, using experimental results and calculations, models for the simple linear and simple rotational mechanical systems.	**A.M1** Conduct experiments accurately to determine the dynamic effects associated with the acceleration of a simple linear and a simple rotational system. **A.M2** Prepare, using experimental results and calculations, accurate models for the simple linear and simple rotational mechanical systems, comparing the two models.	
Learning aim B: Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems		**B.D2** Evaluate accurately the performance of simple and complex rotating systems due to the effects of centripetal acceleration, determining dynamic equilibrium for the unbalanced system.
B.P3 Calculate the centripetal acceleration and forces acting in a simple rotating system. **B.P4** Determine dynamic equilibrium for a simple system of unbalanced rotating masses.	**B.M3** Determine accurately the performance of a simple and a complex rotating system due to the effects of centripetal acceleration, determining dynamic equilibrium for the unbalanced system.	
Learning aim C: Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems		**C.D3** Evaluate the dynamic parameters and operation of a simple and a complex lifting machine and the motion of a pendulum, a spring and a linkage mechanism that exhibit a form of simple harmonic motion, comparing the theoretical calculations to safely conducted experiments where appropriate.
C.P5 Determine the kinetic and dynamic parameters of a simple lifting machine. **C.P6** Conduct experiments safely to determine the dynamic properties of a pendulum and a spring mechanical system. **C.P7** Explain, using experimental results and calculations, the dynamic properties of a pendulum and a spring system. **C.P8** Determine the output motion of at least two linkage mechanisms for given input parameters.	**C.M4** Determine accurately the kinetic and dynamic parameters of simple and complex lifting machines. **C.M5** Analyse the dynamic parameters and operation of a pendulum, a spring and a linkage mechanism that exhibit a form of simple harmonic motion, comparing the theoretical calculations to safely conducted experiments where appropriate.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aim: B (B.P3, B.P4, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, C.P7, C.P8, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- Fletcher's trolley apparatus or a linear air-track kit
- flywheel with its axle mounted horizontally so that it can be accelerated using a cord and falling mass
- centrifugal force/angular motion apparatus
- simple harmonic motion apparatus
- torsional oscillation apparatus
- lifting mechanism, e.g. scissor jack
- associated timing and displacement measuring equipment.

The practical activities should take place in a test facility with appropriate equipment and should take account of health and safety requirements.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a detailed and balanced evaluation of experimental and theoretical models, one on a linear and the other on a rotational dynamic system. Part of their evaluation will contain a comparison between the two models and a rationale will be given for any major differences between experimental and theoretical results.

Learners will use the principles from the experiments and theoretical calculations to accurately model a complex dynamic system involving both linear and rotational motion, for example a lift cage linked to its winding gear through a cable being wound onto a drum powered by an electric motor.

Overall, learners will independently select and set up the experimental equipment, working in a safe and competent manner at all times, and the evidence presented will be easy to read, logically structured and well presented. Learners will use mathematical models and terminology precisely and apply relevant units when working with dynamic systems. 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 an appropriate degree of accuracy given the particular system being explored, through the use of appropriate significant figures.

For merit standard, learners will demonstrate the correct procedure and accuracy when carrying out experimental work on linear and rotational dynamic systems. For example, learners will select measuring equipment that has appropriate resolution and will be able to record their results methodically.

Learners will prepare two accurate models of kinetic and dynamic systems, one based on the experimental results and the other using theoretical calculations. For each system, for example the linear acceleration of a vehicle on an air track, learners will compare the results for each system with values derived through theoretical analysis.

Overall, the evidence for the experimental work and theoretical models will be logically structured and technically accurate, including the correct selection of mathematical equations and correct use of terminology and relevant units. The numerical work will be to an appropriate degree of accuracy given the context of the system parameters being considered (in significant figures and decimal places).

For pass standard, learners will conduct experiments on a simple linear system and a simple rotational system safely. When learners are exploring the dynamics of linear systems, such as Fletcher's trolley, and rotational systems, they may receive some advice on the selection, set-up and use of experimental equipment. However, learners will independently collect, tabulate, process and present experimental data.

Learners will prepare two models of kinetic and dynamic systems, one based on the experimental results and the other using theoretical calculations. They will include appropriately annotated diagrams and use the correct equations.

Overall, learners' evidence will be logically structured but may be basic in parts. 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 correct use of units, but there may be a limited number of errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

Learning aim B

For distinction standard, learners will demonstrate mastery in the application of dynamic principles to the solution of given problems, involving simple and complex rotational mechanical systems and an unbalanced rotational system. Where appropriate to the complex system, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations, for example, evaluating whether a vehicle slides or rolls over as it moves around a banked circular track. Learners will correctly determine the inter-relationship of the parameters being evaluated, for example that vehicles typically slide rather than roll over, and they will understand the effect that the centre of gravity position has on the dynamics of a vehicle.

Overall, the evidence will be logically structured, use appropriate engineering terms and have the correct units applied to calculations. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model dynamic rotational systems. 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 an appropriate degree of accuracy given the type of system being investigated through the use of appropriate significant figures. Calculations will be supported with diagrams that are appropriately annotated and presented to a high standard.

For merit standard, learners will select the correct formulae and present annotated diagrams for simple and complex rotational mechanical systems and an unbalanced rotational system. They will also determine accurately the performance of a complex system, for example a centrifugal clutch.

Overall, the evidence should be logically structured, technically accurate and easy to understand, and should include the correct use of mathematical terminology and relevant units. The numerical work for all systems will be to an appropriate degree of accuracy given the context of the system being investigated, for example by using appropriate significant figures and decimal places. Evidence will be supported with correctly annotated diagrams that show the lines of action of dynamic forces.

For pass standard, learners will select the correct formulae and present annotated diagrams for the simple rotational mechanical system and an unbalanced rotational system. For the simple rotational mechanical system, they will calculate the centripetal acceleration and corresponding forces.

They will determine dynamic balance (equilibrium) in a system of three fixed radius-rotating point masses using a combination of formula manipulation, numerical work and a vector diagram.

Overall, learners' evidence will be logically structured and the method applied will be sound. However, it may be basic in parts and contain minor numerical inaccuracies, for example 'carry-through' errors in their analysis of a 2D rotating system. Learners will demonstrate an appreciation of the need for 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'.

Learning aim C

For distinction standard, learners will present a detailed and balanced evaluation of the results of experimentation and theoretical analysis and, where appropriate, will justify the differences between them. They will have accurate diagrams and theoretical figures and will use them as a benchmark against which to judge their experimental findings. They will consider aspects such as accuracy of measuring equipment, methods used and ways to improve the experimental methods if repeated, for example, by considering the effect that the angle of swing has when calculating the periodic time of a simple pendulum. If there are major differences between experimental and theoretical results there will be balanced evaluation as to why this happened. Learners will independently select and set up equipment and record the results accurately, at all times working in a safe and competent manner.

Overall, the evidence will be logically structured, use appropriate engineering terms and have the correct units applied to calculations. The numerical work will be to an appropriate degree of accuracy given the context of the system parameters being considered (in significant figures and decimal places) which may be set by the assessor.

For merit standard, learners will accurately determine the kinetic and dynamic parameters of simple lifting machines. Learners' evidence will demonstrate correct procedure and accuracy when conducting experimental work on a simple pendulum and mass-spring system safely. For example, learners will select measuring equipment that has appropriate resolution and will be able to record their results methodically. They will appreciate that simple harmonic motion only occurs when a pendulum has a small angle of swing. Learners' analysis will compare the results found experimentally, for example the measured periodic time of a mass-spring system against theoretical analysis.

Learners will also analyse theoretically a form of simple harmonic motion produced by a suitable linkage mechanism, such as a Scotch yoke.

Overall, the evidence for the experimental work and theoretical analysis will be logically structured and technically accurate, and include the correct selection of mathematical equations and correct use of terminology and relevant units. The numerical work will be to an appropriate degree of accuracy given the context of the system parameters being considered (in significant figures and decimal places) which may be set by the assessor.

For pass standard, learners will determine the kinetic and dynamic parameters of simple lifting machines, supported by annotated diagrams, for example, a screw jack and a scissor lift.

Learners' evidence for at least two linkage mechanisms, such as a quick return mechanism in a packaging machine or a shaping machine, will include hand-drawn space and velocity diagrams that are appropriately labelled. At least one of the linkage mechanisms should exhibit a form of simple harmonic motion as its output.

Learners will conduct experiments on a simple pendulum and mass-spring system safely. When learners are exploring the dynamics of these systems they may receive some advice on the selection, set-up and use of experimental equipment. However, learners will independently collect, tabulate, process and present experimental data. Learners will explain the properties of the two dynamic systems using the experimental results.

Overall, learners' evidence will be logically structured but may be basic in parts. 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 a limited number of errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 3: Engineering Product Design and Manufacture
- Unit 7: Calculus to Solve Engineering Problems
- Unit 8: Further Engineering Mathematics
- Unit 24: Maintenance of Mechanical Systems
- Unit 50: Aircraft Gas Turbine Engines.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in the application of dynamics in engineering
- contribution of ideas to unit assignment/project materials.

Unit 29: Principles and Applications of Fluid Mechanics

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the principles and behaviour of fluids and their application to static and dynamic fluid devices and systems.

Unit introduction

The principles of fluid mechanics can be applied to the design and operation of many pneumatic, hydraulic and propulsion systems and devices. For example, the design and operation of a hydraulically powered vehicle braking system is underpinned by hydrostatic fluid principles, while the power and performance of jet engines depends in part on the linear momentum and thrust forces created by the working fluid.

You will study the properties and characteristics of fluids, both liquids and gases, and then apply hydrostatic and pneumatic fluid principles to the operation of hydraulic and pneumatic components and systems. You will then explore experimentally the application of dynamic fluid principles to internal pipe flow systems and measuring instruments. Finally, you will investigate fluid linear momentum principles and their application to nozzle systems and fluid turbines.

As an engineer, you may be involved in the design, operation and selection of components for pneumatic, hydraulic and propulsion devices and systems. This unit helps prepare you for an engineering apprenticeship, a technician role, such as a fluid turbine technician or a technician with design responsibilities for pneumatic and hydraulic fluid devices or systems, and higher education.

Learning aims

In this unit you will:

A Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems

B Explore the application of dynamic fluid principles to internal fluid flows and measurement systems

C Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems	**A1** Properties and characteristics of fluids **A2** Hydrostatic fluid principles and applications **A3** Pneumatic fluid principles and applications	A report covering the nature of fluids, analysis of static fluid principles and their application in hydrostatic and pneumatic components and systems.
B Explore the application of dynamic fluid principles to internal fluid flows and measurement systems	**B1** Dynamic fluid principles **B2** Piped internal fluid flows and measurement systems	A portfolio of results gathered by experimentation when investigating fluid flows and internal fluid flow measuring instruments and associated piped systems, supported by images, observation records, graphs and mathematical analysis.
C Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation	**C1** Fluid linear momentum principles **C2** Nozzle systems and fluid turbines	A report covering the nature and analysis of fluid linear momentum principles and their application to the operation of rocket systems, nozzle systems and fluid turbines.

Content

Learning aim A: Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems

A1 Properties and characteristics of fluids

- Difference between properties of liquids and gases, including:
  - mass, weight ($W = mg$), density ($\rho = \frac{m}{V}$)
  - pressure ($p = \frac{F}{A}$) and containment, fluid pressure laws
  - compressibility, bulk modulus $\left(K = -\frac{\text{change in pressure } (\Delta p)}{\text{change in volume } \left(\frac{\Delta V}{V}\right)} \right)$
- Viscosity, including:
  - definitions and units of dynamic viscosity (μ) and kinematic viscosity $\left(v_k = \frac{\mu}{\rho} \right)$
  - relationship of shear stress (τ) to the velocity gradient and dynamic viscosity $\left(\tau = \mu \frac{\mathrm{d}v}{\mathrm{d}y} \right)$
  - variation in viscosity with temperature, viscosity index
  - viscosity measurement.
- Surface tension, coefficient and capillary action.
- Characteristics of Newtonian fluids, including air, water, lubricating oils and non-Newtonian fluids including pseudo and Bingham plastics, dilatants.
- The use of air, water and oils as fluid power mediums.

A2 Hydrostatic fluid principles and applications

- Hydrostatic mass ($m = \rho Ah$), weight ($W = \rho Agh$) and gauge pressure (ρgh), absolute pressure, atmospheric pressure.
- Pressure measurement, including mercury and aneroid barometers, U-tube manometer.
- Buoyancy, forces acting on floating, sinking and rising bodies and Archimedes' principle.
- Partially and fully immersed vertical surfaces, including:
  - thrust force ($F_T = \rho Agh_a$) where h_a = distance to centroid (centre of area)
  - distance to centre of pressure (h_c) and the one-third from base rule
  - principle of moments, line of action of net thrust
  - forces and pressures acting on vertical retaining walls of tanks and reservoirs.
- Hydrostatic components and systems, including immersed surfaces, hydraulic actuators, Bramah press, hydraulic braking system.
- Hydrostatic system parameters, e.g. cylinder dimensions, input and output forces, internal pressure, input and output motions.

A3 Pneumatic fluid principles and applications

- Expansion and compression of perfect gases, including Charles's law, Boyle's law and the combined gas laws and their parameters, isothermal expansion and compression.
- Characteristic gas equation, including units, parameters and use of the equation $pV = mRT$ or $p = \rho RT$
- Specific heat of gas, including relationships between characteristic gas constant and specific heats $R = c_p - c_v$ and the ratio of specific heats $\frac{c_P}{c_V} = \gamma$

- Adiabatic expansion and compression of a perfect gas (no heat lost during the process), including formulae pV^γ = constant, $p_1V_1^\gamma = p_2V_2^\gamma$ and $T_1 = T_2\left(\frac{V_2}{V_1}\right)^{\gamma-1}$, their parameters and units.
- Buoyancy and applications to balloons and airships.
- Application of gas laws and isothermal and adiabatic expansion and compression to pneumatic components and systems, including cylinders, receivers and braking systems.
- Pneumatic system parameters, e.g. cylinder dimensions, internal pressures and temperatures, input and output motions.

Learning aim B: Explore the application of dynamic fluid principles to internal fluid flows and measurement systems

B1 Dynamic fluid principles

- Laminar and turbulent fluid flow and relationship to Reynolds number $R_N = \frac{ud}{v_k}$, where u = mean velocity, v_k = kinematic viscosity, d = hydraulic diameter of pipe.
- Continuity equations, including parameters, units and use for steady mass flow $\dot{m} = \rho_1A_1v_1 = \rho_2A_2v_2$ and for constant density volume flow rate $Q = A_1v_1 = A_2v_2$.
- Bernoulli's equation, including parameters, units and use of Bernoulli's steady flow energy equation (SFEE) for incompressible fluid flow SFEE = $mgh_1 + \frac{1}{2}mv_1^2 + p_1V_1 = mgh_2 + \frac{1}{2}mv_2^2 + p_2V_2$, and general form of Bernoulli's SFEE = $\rho gh + \frac{1}{2}\rho v^2 + p = C$ where C = constant.

B2 Piped internal fluid flows and measuring systems

- Internal fluid flow system, including flow through pipe lengths, tapered pipes, inclined and tapered pipes.
- Piped system parameters, e.g. pressure energy losses, fluid velocities, laminar or turbulent flow determination.
- Measuring instruments and systems, e.g. Venturi meter, orifice meter, manometer, pitot-static tube, velocity meter, turbine meter.
- Measuring instrument and system parameters, e.g. mass and volume flow rates, entry and exit velocities, pressure losses, efficiencies and efficiency coefficients, instrument working section dimensions.

Learning aim C: Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation

C1 Fluid linear momentum principles

- Newton's laws, including:
  - second law and change in momentum $F = ma = \dot{m}(v - u)$ where $\dot{m}$ is the fluid mass flow rate kg/s and ($\dot{m}$) = momentum force of fluid
  - third law and reaction of the vane to the force of a fluid jet.
- Force of a jet of fluid on the surface normal to the jet, including $F = mv = \rho Av^2 = \rho Qv$ where $m = \rho Av$ and Q = volume flow rate m^3/s.
- Force of jet on inclined flat surface, including use of $F = \rho Av^2\sin\theta$
- Fluid force acting on walls of a reducer, including use of $F = p_1A_1 - p_2A_2 - \dot{m}(v_2 - v_1)$.

C2 Nozzle systems and fluid turbines

- Nozzle systems:
  - converging and diverging ducts and nozzles, including relationship with the Venturi principle and resulting changes in pressure and velocity of fluid
  - nozzle forces, including net force exerted on the fluid of a converging nozzle

    $F_N = \dot{m}\,(v_2 - v_1)$ or from the continuity equation $F_N = \left(\dfrac{\dot{m}^2}{\rho}\right)\left[\dfrac{1}{A_2} - \dfrac{1}{A_1}\right]$

    where A_1 = nozzle entry area and A_2 = nozzle exit area at throat
  - the rocket as a nozzle system, including basic operation, use of convergent/divergent duct rocket control volume for gas flow velocity and pressure changes
  - production of rocket thrust, including total thrust force = gas mass flow force plus force due to pressure differential at exhaust nozzle or $F_T = mv_j + (p_j - p_{amb})A_j$, where v_j, p_j = exhaust gas jet velocity/pressure, p_{amb} = ambient pressure, A_j = gas jet exhaust exit area.
- Fluid turbines:
  - the Pelton impulse hydraulic turbine, including function and principles of operation
  - the gas turbine engine, including basic operation, changes in pressure and temperature of the gas passing through the engine, and industrial applications.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems		**A.D1** Evaluate, using language that is technically correct and of a high standard, the application of hydrostatic and pneumatic fluid principles to determine hydrostatic and pneumatic system parameters.
A.P1 Explain the properties and characteristics of gases and liquids and how they affect their use as fluid power mediums. **A.P2** Explain hydrostatic and pneumatic fluid principles and apply them to determine hydrostatic and pneumatic component and system parameters.	**A.M1** Analyse the properties and characteristics of gases and liquids and how they affect their use as fluid power mediums. **A.M2** Analyse hydrostatic and pneumatic fluid principles and their application to determine hydrostatic and pneumatic component and system parameters.	
Learning aim B: Explore the application of dynamic fluid principles to internal fluid flows and measurement systems		**B.D2** Evaluate the behaviour and parameters of at least one tapered pipe and at least two measuring instrument fluid systems, comparing the results from safely and accurately conducted experiments against theoretical calculations.
B.P3 Conduct experiments safely to determine the behaviour and parameters of at least one tapered pipe fluid system. **B.P4** Conduct experiments safely to determine the behaviour and parameters of two measurement instrument fluid systems. **B.P5** Explain, using the results and theoretical calculations, the behaviour and parameters of fluids in at least one tapered pipe and at least two measurement instrument fluid systems.	**B.M3** Conduct experiments safely and accurately to determine the behaviour and parameters of at least one tapered pipe and at least two measurement instrument fluid systems. **B.M4** Analyse, using the results and theoretical calculations, the behaviour and parameters of fluids in at least one tapered pipe and at least two measuring instrument fluid systems.	
Learning aim C: Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation		**C.D3** Evaluate the nature of linear momentum principles and their application in determining fluid flow parameters in optimising the operation of nozzle systems and fluid turbines.
C.P6 Explain the nature of linear momentum principles and their application in determining fluid flow parameters and the operation of nozzle systems and fluid turbines.	**C.M5** Analyse the nature of linear momentum principles and their application in determining fluid flow parameters and the operation of nozzle systems and fluid turbines.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.M3, B.M4, B.D2)

Learning aim: C (C.P6, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

Note that the required physical resources may not necessarily be directly available at the centre that is delivering the unit but they can be made available at another organisation. This is particularly relevant for the Pelton hydraulic turbine, gas turbine engine and pneumatic and hydraulic systems.

For this unit, learners must have access to:

- laboratory equipment sufficient to reinforce the fluid principles and applications, to include as a minimum viscosity measurement apparatus, Boyle's law apparatus, impulse and momentum equipment
- fluid flow measurement apparatus sufficient to cover the content, for example Bernoulli equipment with a water tank and control valves, Venturi meter, orifice meter, velocity meter, turbine meter, closed section wind tunnel with manometer and other fluid flow measurement instrumentation
- view a Pelton turbine and gas turbine jet engine, on- or off-site
- pneumatic and hydraulic systems, water tanks, associated piping of variable diameters, sufficient to cover the applications of hydrostatic and pneumatic principles, on- or off-site.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate the application of fluid principles to determine hydrostatic and pneumatic system parameters. The evaluation will include an analysis of the properties and characteristics of liquids and gases and the differences between them, together with the mathematical determination of their parameters, when subjected to changes in pressure, temperature and volume. For example, when considering the characteristics of Newtonian and non-Newtonian fluids, analysis of changes to their viscosity with changes in temperature will include the mathematical determination of their parameters.

The evaluation must include the application of principles to determine parameters for both hydrostatic and pneumatic components and systems. For example, when considering buoyancy and immersed surfaces, the mathematical analysis of parameters should include bodies immersed in liquids such as water as well as those immersed in gases such as air. The evaluation should include examples of the use of principles to mathematically determine parameters such as pressure, force and motion, for hydraulic and pneumatic components and systems.

Overall, the evidence presented will be easy to read, logically structured and well presented. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions to find parameters. 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 an appropriate degree of accuracy given the particular component or system parameters being considered, through the use of appropriate significant figures.

For merit standard, learners will analyse the properties and characteristics of liquids and gases and the differences between them, and mathematically determine their parameters when subjected to changes in pressure, temperature and volume. For example, when considering air, water and oil as fluid power mediums they will use mathematical comparisons of their bulk modulus, compressibility and viscosity properties, to establish why certain oils make ideal fluids for power transmission, where high forces and system rigidity are needed.

Learners must also analyse fluid principles and their application to determine parameters for both hydrostatic and pneumatic components and systems. For example, when mathematically determining parameters such as pressure, force and dimensions for linear actuators, their use in both hydraulic and pneumatic systems must be considered.

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 component or system parameters being considered, for example by using appropriate significant figures and decimal places.

For pass standard, learners will explain the properties and characteristics of gases and liquids and how they affect their use as fluid power mediums. Example fluids could be air, water and oil.

Learners must explain hydrostatic and pneumatic fluid principles and apply them to determine hydrostatic and pneumatic system parameters. The explanation will include related calculations; for example, when considering the application of principles to tanks or reservoirs the calculation of thrust forces and pressures acting on retaining walls will be included. Also, when explaining the application of the gas laws to the expansion and compression of gases in pneumatic components, for example, the explanation will include appropriate mathematical calculations for the required parameters.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies. For example, where mathematical calculations have been given in explaining the characteristics and properties of air or water, the process followed may contain some minor arithmetic and 'carry-through' errors. These errors are acceptable provided that the basic method is sound. Learners will demonstrate an appreciation of the need for 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'.

Learning aim B

For distinction standard, learners will evaluate the behaviour and parameters of fluid flow in at least one tapered pipe system and two measuring instrument systems. The evaluation will include comparisons being made between the results of accurately conducted tests and theoretical calculations, for example, when comparing the results of a practical experiment carried out on water flow through the Venturi apparatus and appropriate and accurate theoretical calculations. Water pressure and dimensional and velocity parameters across the Venturi meter need to be compared. The nature and effect of the flow, specifically whether it is turbulent, laminar or transient, needs to be included.

The evaluation will compare all necessary parameters, for example tapered pipe and measurement instrument systems. When evaluating measuring instruments such as the Venturi meter used in the Venturi apparatus, the coefficient of performance of the Venturi meter needs to be used in calculations to ensure that accurate comparisons can be made for pressure and flow rate changes across it.

Overall, the evidence will be easy to read, logically structured and well presented. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions to find parameters. 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 an appropriate degree of accuracy given the particular system or measuring instrument parameters being considered, through the use of appropriate significant figures.

For merit standard, learners will conduct experiments safely and accurately to determine the behaviour and parameters for at least one tapered pipe fluid system and at least two measurement instrument fluid systems. For example, after setting up and ensuring the serviceability and calibration of the equipment, learners conduct an experiment on the flow of water using the Venturi meter apparatus, accurately recording the changes in behaviour of the water as it passes through the meter. Learners will also, from suitably positioned instrument gauges, accurately record the changes in water pressure and fluid flow parameters as water passes through the meter.

Learners will analyse, using experimental results and calculations, the behaviour and parameters in at least one tapered pipe and at least two measuring instrument fluid systems. For example, they will analyse the results obtained for the behaviour, fluid flow and pressure parameters for water when conducting experiments using the Venturi apparatus, backing up their analysis with relevant and accurate theoretical calculations.

Overall, the evidence for the experimental work and theoretical analysis should be logically structured and technically accurate, including the correct selection of mathematical equations and correct use of terminology and relevant units. For example, the numerical work will be to an appropriate degree of accuracy given the context of the component or system parameters being considered, for example by using appropriate significant figures and decimal places.

For pass standard, learners will conduct experiments safely to determine the behaviour and parameters of fluid flow through at least one tapered pipe system. For example, learners could conduct an experiment on a suitably instrumented hydraulic fluid pipe run that has a tapered adapter, connecting pipes of different diameters. They could take readings for pressure and fluid flow parameters before and after the adapter.

Learners will conduct experiments safely to determine the behaviour and parameters of at least two fluid flow instrument measuring systems. For example, after set-up, learners conduct an experiment on the flow of water using the Venturi meter apparatus, noting the changes in the behaviour of the water as it passes through the meter. Learners will also, from suitably positioned instrument gauges, record the changes in water pressure and fluid flow parameters as water passes through the meter.

Learners will explain, using the results from experiments and theoretical calculations, the behaviour and parameters of fluids in at least one tapered pipe and at least two measuring instrument fluid systems. For example, they will explain the results obtained for the behaviour, fluid flow and pressure parameters for water when conducting experiments using the Venturi apparatus, backing up their explanation with theoretical calculations.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies. For example, where mathematical calculations have been given in explaining the fluid flow parameters obtained experimentally, the process followed may contain some minor arithmetic and scaling errors as well as 'carry-through' errors. These errors are acceptable provided that the basic method is sound. Learners will demonstrate an appreciation of the need for 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'.

Learning aim C

For distinction standard, learners will evaluate the nature of fluid linear momentum principles and their application in determining fluid flow parameters in optimising the operation of nozzle systems and fluid turbines. The evaluation will include an analysis of fluid momentum principles and their general application to nozzle systems. For example, learners will look at how fluid momentum principles are applied to a convergent nozzle system such as the nozzle of a fire hose to determine the reaction force, pressure and flow parameters of the water jet as it exits the nozzle. The evaluation will include the application of fluid linear momentum principles to gas flow through rockets and the production of thrust.

The evaluation of applied fluid linear momentum principles to the optimised operation of the Pelton impulse hydraulic turbine and gas turbine engine will be included. For example, when evaluating the operation of the Pelton turbine, the high-speed water jet flow that impinges on the specially shaped guide vanes will be critically assessed to show how the operational performance of the turbine is optimised using these specially shaped vanes.

Overall, the evidence presented will be easy to read, logically structured and well presented. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions to find parameters. Small and large numerical values will be correctly presented in an appropriate format, for example using engineering notation or standard form.

Learners must demonstrate they are able to work to an appropriate degree of accuracy given the particular component or system parameters being considered, through the use of appropriate significant figures.

For merit standard, learners will analyse the nature of fluid linear momentum principles and their application in determining fluid flow parameters and the operation of nozzle systems and fluid turbines. Fluid momentum principles and their general application to nozzle systems, gas flow through rockets and the production of thrust will be analysed. For example, the gas flow velocity and pressure changes and the resulting creation of thrust forces will be analysed as the gas jet passes through the convergent/divergent rocket control volume and exits the rocket.

Learners will analyse the application of fluid linear momentum principles to the operation of the Pelton impulse hydraulic turbine and gas turbine engine. For example, when analysing the operating principles of the gas turbine engine, quantitative examples of changes to the gas flow pressure, temperature and velocity as it passes through the compressor, combustor, turbine and exhaust will be included to aid the analysis.

Overall, the evidence should be logically structured, easy to understand and technically accurate, including the correct use of mathematical terminology and relevant units. For example, the numerical work will be to an appropriate degree of accuracy given the context of the component or system parameters being considered, such as appropriate significant figures and decimal places.

For pass standard, learners will explain the nature of fluid linear momentum principles and their application in determining fluid flow parameters and the operation of nozzle systems and fluid turbines. For example, when explaining the application of the principles to the fluid forces and flows through nozzles, quantitative examples using Newton’s second law and the continuity equation will be included to aid the explanation.

An explanation of the nature and parameters of the gas flow through rockets and the production of thrust will also be given.

Learners will explain the application of fluid linear momentum principles to the operation of the Pelton impulse hydraulic turbine and gas turbine engine. For example, the explanation for the operation of the Pelton turbine should include details on the construction of the turbine, with qualitative examples given as to how these features aid the operation.

Overall, the evidence will be logically structured but may be basic in parts and contain minor technical inaccuracies. For example, where mathematical calculations have been given in explaining the fluid flow parameters through nozzle systems, the process followed may contain some minor arithmetic and ‘carry-through’ errors. These errors are acceptable provided that the basic method is sound. Learners will demonstrate an appreciation of the need for 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’.

Links to other units

This unit links to:

- Unit 12: Pneumatic and Hydraulic Systems
- Unit 31: Thermodynamic Principles and Practice
- Unit 50: Aircraft Gas Turbine Engines.

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 fluid mechanics
- contribution of ideas to unit assignment/project materials.

Unit 30: Mechanical Measurement and Inspection Technology

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore mechanical measurement equipment and inspection methods, including statistical process control (SPC). Also, learners undertake a process-capability study.

Unit introduction

Many of the products we use daily rely on components being manufactured accurately. The selection of a process to manufacture a product or component is sometimes chosen because of its speed or ability to shape materials, and they are always chosen because of the level of accuracy. Unfortunately, there will always be variation in these processes, and engineers must control the variation to avoid faulty products and/or components being manufactured.

In this unit, you will cover the principles and technology applied to a range of mechanical measurement equipment and inspection methods. You will develop the skills required to use a range of equipment, including comparators and gauges. You will develop and use statistical process control (SPC) charts to inspect components and determine if the process is in control. You will also undertake a process-capability study on a precision-manufacturing process to increase productivity and establish whether the process is capable.

As an engineer, you may need to understand and acquire the practical skills needed to control the manufacture of high-precision components. This unit prepares you for a mechanical or manufacturing engineering apprenticeship or for progression to higher education, and for technician-level roles in industry, such as a quality inspector or a junior production engineer involved in shop-floor machine management.

Learning aims

In this unit you will:

A Explore the principles applied to mechanical measurement and inspection methods as used in industry

B Carry out mechanical measurement and inspection methods to determine if components are fit for purpose

C Explore statistical process control to inspect components and increase productivity

D Carry out a process capability study to establish machine suitability for a given application.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the principles applied to mechanical measurement and inspection methods as used in industry	**A1** Limits and fits **A2** Tolerances **A3** Gauge types	A report focusing on gauge design and the principles of tolerancing, including notes about limits and fits. The report to be based on research and to include the design of gauges to inspect four different product features.
B Carry out mechanical measurement and inspection methods to determine if components are fit for purpose	**B1** Measuring practice **B2** Types of mechanical measurement **B3** Comparators **B4** Gauging system **B5** Component features, types and manufacturing processes	A range of practical measurement and inspection activities recorded in a developmental logbook. Evidence will be a measurement and inspection report, annotated drawings/photographs of the components and observation records/witness statements.
C Explore statistical process control to inspect components and increase productivity	**C1** Principles of statistics **C2** SPC procedure	A report covering the use of basic statistics and how these can be applied to control procedures during inspection. A capability report focusing on the outputs from a particular process, reporting on its suitability. Both reports should include notes and sketches and will be supported by a developmental logbook.
D Carry out a process capability study to establish machine suitability for a given application	**D1** Pre-process capability study procedure **D2** Process capability study	

Content

Learning aim A: Explore the principles applied to mechanical measurement and inspection methods as used in industry

A1 Limits and fits

Principles applied to the use of limits and fits:

- concepts of limits and fits
- definitions of the types of fits – clearance, transition, interference
- use of tables, e.g. ISO 286–2:1988, ANSI B32.100–2005.

A2 Tolerances

Principles applied to the use of tolerances:

- standard symbols and interpretation, maximum material condition, least materials condition, maximum variation of form
- grades of tolerance applicable to hole tolerances and shaft tolerances
- reference to British Standards, e.g. BS 969, BS 1134, BS 2634, BS 4500 or other relevant international equivalents
- type of high-precision manufacturing processes, e.g. turning, milling, grinding, honing.

A3 Gauge types

Designing gauges for inspection activities as used in industry:

- limit gauge types, including plug, ring, gap and taper; gauge materials, including high carbon, alloy steel and cemented carbide
- Taylor's principle, principle of go/no-go gauging (limit gauges)
- slip gauges as references for length standards, classification of slip gauges, multiple slip gauge use (wringing), care and maintenance required
- component features including: hole diameter, shaft diameter, other external dimension/size, tapered hole.

Learning aim B: Carry out mechanical measurement and inspection methods to determine if components are fit for purpose

B1 Measuring practice

Principles applied to measuring practice:

- precision – how close measurements are to one another
- accuracy – how close measurements are to the 'true answer'
- uncertainty – the quantification of doubt about the measurement result, tells us something about its quality
- resolution – the smallest difference in dimensions that the measuring equipment can detect or distinguish.

B2 Types of mechanical measurement

- Linear measuring equipment:
  - equipment used for linear accuracy, e.g. verniers, callipers (digital), micrometers including external, internal and depth
  - principles, including scales, sources of error, specific calibration issues.
- Surface-texture measuring equipment:
  - equipment used for surface texture measurement, e.g. Rubert gauges, stylus measuring equipment
  - principles, including surface texture symbols, roughness average, waviness, finish, amplitude parameters, spacing parameters.

- Straightness, squareness and flatness measuring equipment:
  - equipment used for determining straightness, squareness and flatness, e.g. straight edges, engineer's square, autocollimator, carriage and reflector, optical square
  - principles, including wedge method, level method, line or surface datum, optical reflection, focal point.
- Angular measurement equipment:
  - equipment used for determining angular accuracy, e.g. sine bar, angle gauges, angle dekkor, vernier bevel protractor, clinometer
  - principles, including trigonometry functions, optical reflection, focal point.

B3 Comparators

- The application of comparators to inspect manufactured features.
- Types of comparators, including:
  - mechanical type, e.g. dial test indicator (DTI), Sigma, Johansson Mikrokator, Venwick
  - electrical type, e.g. digital, Wheatstone bridge circuit
  - optical type, e.g Eden-Rolt millionth comparator
  - pneumatic type, e.g. Solex gauge.
- Principles, e.g. magnification, cosine errors, specific calibration issues.

B4 Gauging system

Gauges to inspect manufactured features:

- gauge types, including plug, ring, gap and taper
- principles involving the use of slip gauge as references for length standards, use with ancillary equipment, including DTIs, care and maintenance required, wringing.

B5 Component features, types and manufacturing processes

- Component features, including round (external or internal), linear (length, depth), texture, straightness, 900 angles and flatness.
- Types of component, including the jaw of a toolmaker's clamp, precision dowels, machine bed, vee block, vehicle engine block, piston.
- Typical manufacturing high-precision processes, e.g. grinding, milling, honing or high-volume turning.

Learning aim C: Explore statistical process control to inspect components and increase productivity

C1 Principles of statistics

Statistics used in inspection methods to increase productivity:

- Principles of statistics, including:
  - types of data concerned with precision manufacturing, e.g. variable or continuous, attribute or discrete
  - characteristics, including population, sample, sample size, frequency, mean, mode, median, range, variance, standard deviation
  - non-normal distribution curves, e.g. skewed, bimodal, flat topped
  - characteristics of a normal distribution including 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.
- Variation in manufacturing processes, e.g. between components, within components, machine to machine, batch to batch, time to time.
- Causes of variation, e.g. tool breakage and wear, voltage fluctuations and machine wear.

C2 SPC procedure

SPC in inspection:

- developing SPC procedures involving pre-process control procedures, including product/process selection, identify critical characteristics, determine type of data, define the measurement system, design check sheet/chart, data-collection plan, test procedure
- design of control procedure; calculating sample size, frequency and upper and lower control limits, e.g. variable control charts such as X and R charts, attribute charts such as np, p, c and u
- use of control procedure, and mean and range charts, including plotting data, monitoring charts, interpreting charts and identifying of out-of-control conditions
- outcomes from use, e.g. modify process conditions when necessary, audit process.

Learning aim D: Carry out a process capability study to establish machine suitability for a given application

D1 Pre-process capability study procedure

Procedures involved in designing a process-capability study:

- suitable process, e.g. grinding, milling, honing, turning
- developing specification limits and control chart limits
- use and consequence of relative precision index, e.g. high, medium, low
- equations, e.g. Cp, Cpk, sigma score (Z)
- modified control chart limits.

D2 Process-capability study

Process-capability study to establish machine suitability:

- graphical process-capability sheet
- determine process-capability and parts per million outside upper and lower specification limits
- analysis of information
- defining improvement activities to improve the process capability
- presenting findings in a process-capability report.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the principles applied to mechanical measurement and inspection methods as used in industry		**A.D1** Evaluate, using language that is technically correct and of a high standard, the design of limit gauges that are fit for purpose and rely on the principles of limits and fits, tolerances and the use of slip gauges as a reference to the standard.
A.P1 Apply the principles of limits and fits and tolerances to design a range of limit gauges.	**A.M1** Analyse, including the use of slip gauges, how different limit gauges rely on the principles of limits and fits and tolerances.	
Learning aim B: Carry out mechanical measurement and inspection methods to determine if components are fit for purpose		**B.D2** Evaluate the resolution and measurement of uncertainty for comparators and/or gauges against the mechanical measurement equipment used to inspect a range of components.
B.P2 Measure, using three different types of mechanical measurement equipment, a range of component features. **B.P3** Select two different types of comparator and gauge, and inspect a range of component features.	**B.M2** Measure accurately and precisely, using three different types of mechanical measurement equipment, a range of component features **B.M3** Compare the capabilities and use of two different types of comparator against different types of gauges used to inspect a range of component features.	
Learning aim C: Explore statistical process control to inspect components and increase productivity		**CD.D3** Evaluate how statistics have influenced the design and successful use of process control charts and a capability study to demonstrate where an improvement to the process can be achieved.
C.P4 Explain how the principles of statistics and graphical analysis are applied to represent and display variation found during inspection. **C.P5** Design and use a SPC procedure involving variable control and attribute charts.	**C.M4** Analyse, an in-control process using a SPC procedure involving variable control and attribute charts in relation to effectiveness of variation control and the outcomes from their use.	
Learning aim D: Carry out a process capability study to establish machine suitability for a given application		
D.P6 Design a process-capability study. **D.P7** Perform a process-capability study to establish if a machine is capable of producing components to the required precision.	**D.M5** Analyse as part of a process-capability study the accuracy of a process and produce a modified control chart, explaining its use.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aims: C and D (C.P4, C.P5, D.P6, D.P7, C.M4, D.M5, CD.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of gauges (limit, slip), linear measuring equipment, surface-texture measuring equipment, straightness, squareness and flatness measuring equipment, angular measuring equipment, a range of different types of comparators as required by the learning aims and unit content
- components to be measured (such as those listed under key content area B5, 'Component features, types and manufacturing processes')
- a range of British or other relevant international standards, as required by the unit content
- a range of data from different precision processes to allow control charts and process capability to be established.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce evidence that is a balanced evaluation of the gauge and design principles used, with appropriate references to the standards applicable to the design and use of limit gauges. For example, it will make reference to the types of fit and maximum metal condition/least materials condition, and Taylor's principle showing how these have influenced the gauge tolerances found in the relevant standards. The evidence will include a reasoned conclusion about the fitness for purpose of the designed gauges, and the use of slip gauges as a reference to the standard.

Overall, 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 be consistent in their analysis applied across all the requirements covering the correct use of slip gauges, and will explain clearly the reliance on the principles of limits and fits and. There will be a clear indication that the designed set of limit gauges are appropriate for the component specifications given and easy to use to inspect four different component features.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will give clear evidence that a set of limit gauges have been designed to inspect four different component features, although there may be some confusion between the use of tolerances. Learners may have applied their position across the gauge sizes incorrectly leading to some inaccuracies within the design of the gauges. For example, they may have used the wrong gauge tolerance and, when using slip gauges, the overall slip gauge size may be incorrect or more slip gauges were used than was necessary.

Overall, the explanations should be logically structured, although basic in parts and they may contain minor technical inaccuracies relating to engineering terminology, such as using the term 'block gauges' instead of 'slip gauges'. Also, the calculations may contain some minor arithmetic errors.

Learning aim B

For distinction standard, learners will produce evidence that includes a balanced evaluation of the resolution and measurement of uncertainty resulting from the measurement of components using comparators, gauges and mechanical measurement equipment. The evidence will contain a reasoned conclusion about the use of different types of inspection and measurement equipment. For example, it should include the correct use of scales during measurement and how sources of error are accommodated and why calibration is important.

Overall, the evidence on the practical activities should be logically structured, use the correct technical engineering terms and contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will select the correct measuring equipment and all measurements taken will be precise and accurate.

The comparison will be consistent across all the requirements of the correct selection and use of comparators and gauges. For example, they will refer to the principles involved for each comparator and gauge, such as the correct use of the focal point being similar when using an autocollimator or an angle dekkor. Also, reference will be made that surface texture measurement can be found by comparison to Rubert gauges or can be measured more accurately arriving at values for roughness and waviness. Learners will provide accurate and precise measurements and correct 'no' and 'no go' decisions throughout on at least three different engineering components.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will record in a logbook their results from using three different types of mechanical measurement equipment to measure at least three different features – for example, linear dimensions, surface texture, straightness, squareness, flatness or angular dimensions. Learners may not have selected the correct equipment, but will have recorded the measurements taken.

Learners will correctly select two different types of comparator and appropriate gauges. They will record the measurements and 'no' and 'no go' decisions on at least three different components covering, across these components, at least one round, linear, texture and geometric feature.

Overall, the evidence will be logically structured. It may contain some inaccuracies in the use of engineering terminology and there may be some minor inaccuracies in the results. For example, learners may only record one measurement of each feature, and some of the gauge and comparator sizes and inspection decisions may not be accurate.

Learning aims C and D

For distinction standard, learners will have information that clearly demonstrates how statistics have influenced the design of the control charts and their use in the SPC evaluation. For example, how mean and range are used as known variation control, and how the sample sizes set produces statistically sound outcomes. It should be clearly shown how the application of these principles of statistics makes the control procedure effective through the:

- accurate and precise measurement of component features and that it is representative
- use of appropriate limits that do not unnecessarily restrict the process ('over or under control').

The capability report will also demonstrate how to improve the process. This improvement will be realistic, for example a lower material machine feed rate or higher workpiece-machining speed can lead to better accuracy.

Overall, the evidence will be logically structured, use the correct technical engineering terms and contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will draw conclusions about the process being monitored and use statistics to demonstrate that the process is under control. Learners will cover the effectiveness of the control method.

Learners will produce a modified control chart that will be fit for purpose and the capability report will clearly explain the use of the modified control chart.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain clearly how the principles of statistics and graphical analysis can be used to show variation in process outcomes and give confidence to monitor the variation of a process. Also, the design and use of the control charts should contain appropriate limits and the process trends should be correct, and the charts should be appropriate for a machine operator to use.

The capability report will contain evidence of how the data and the capability equations have been used to develop specification and control chart limits for the capability study to be carried out on a suitable process.

Learners will plot the data to explain the process and its capability, and the trends in the plotted data will be correct.

Overall, the evidence should be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology, such as confusion between control limits and component tolerances. Also, there may be some minor numerical errors, for example a control chart entry may have been incorrectly plotted. The evidence should be clear to a third party who is not an engineer.

Links to other units

This unit links to:

- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and manufacturing organisations with expertise in mechanical measurement and inspection technology
- contribution of ideas to unit assignment/project materials.

Unit 31: Thermodynamic Principles and Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate and conduct tests into thermodynamic principles, consider the applications of the principles and explore energy transfer in thermodynamic systems.

Unit introduction

The principles of thermodynamics may be applied to a wide range of practical situations, including the design and operation of power plants and aircraft systems. Thermodynamics is the study of thermal energy production, its transfer and conversion into more useful forms. For example, fossil fuels provide thermal energy, which is converted into mechanical and electrical energy by mechanical machines to undertake useful work.

In this unit, you will study the principles of thermodynamics that apply to gases and consider the process parameters that apply to thermodynamic systems, and how these affect the expansion and compression of gases. You will explore how these thermodynamic parameters influence the operation of a range of open- and closed-loop thermodynamic systems found in different applications, for example in aircraft gas turbines. Finally, you will investigate experimentally and using research, the combustion process for different types of fuel, for example solid and liquid. You will conduct tests to determine the calorific values of fuels and consider the sustainability implications of the results.

As an engineer, you may be involved with the design, operation and maintenance of power plants or other thermodynamic systems. This unit helps to prepare you for an engineering apprenticeship, for progression to higher education and for employment in a technician-level role, such as an aircraft maintenance technician, or as a technician with design responsibilities for improving the efficiency of power plants.

Learning aims

In this unit you will:

A Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems

B Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems

C Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems	**A1** Thermodynamic parameters **A2** Polytropic processes	A report will focus on the thermodynamic principles related to both the expansion and compression of gases and an analysis of investigations into the outcomes of polytropic processes.
B Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems	**B1** Closed thermodynamic systems **B2** Open thermodynamic systems **B3** Applications of thermodynamic systems in engineering	A report will focus on the energy-transfer principles for both open- and closed-loop thermodynamic systems, in given engineering applications.
C Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems	**C1** Safe working practices for thermodynamic systems **C2** Combustion processes **C3** Calorific values **C4** Sustainability of fuels	A report will focus on safe practical activities, using calorimeters in the form of observation records, witness statements and annotated photographs and drawings, along notes that discuss the results of experiments and considerations of sustainability.

Content

Learning aim A: Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems

A1 Thermodynamic parameters

- Fundamental parameters of thermodynamics:
  - thermodynamic temperature, including absolute temperature
  - ratio of specific heat (ratio of heat capacity at constant pressure to heat capacity at constant volume) $\gamma = \frac{c_p}{c_v}$
  - linear thermal expansion $x = \alpha \Delta t l$
  - sensible heat
  - latent heat: latent heat of fusion, latent heat of vaporisation
  - thermal energy $Q = mc\Delta t$ and $Q = ml$
  - thermal power $\dot{Q} = \dot{m}c\Delta t$ or heat transfer rate $\dot{Q} = Q/time$
- Thermodynamic process parameters:
  - absolute pressure
  - reversible and irreversible transformations
  - constant volume (isochoric processes)
  - constant pressure (isobaric processes)
  - ideal gas laws – Boyle's law $pV=constant$ and Charles's Law $V/T = constant$
- Temperature scales (Celsius, Kelvin and Fahrenheit).
- Conversion between temperature scales.

A2 Polytropic processes

- Molecular weight of gas (ideal or a mixture of gases) M_{gas}
- Universal gas constant: $R_u = M_{gas}R$
- Characteristic gas constant: $R = kN_A$
- General gas equation: $\frac{pV}{T}$ = constant
- Characteristic gas equation: $pV = mRT$ or $p = \rho RT$
- Polytropic process equation: pV^n = constant
- Values of n, including isobaric processes ($n = 0$), isothermal processes ($n = 1$) and adiabatic processes ($n = g$).

Learning aim B: Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems

B1 Closed thermodynamic systems

- Application of first law of thermodynamics in a closed system.
- Work done, including general expression for a polytropic process and isothermal work transfer.
- Thermal energy transfer, including specific heat capacities at constant volume and constant pressure.
- Expression for change of internal energy.
- Closed system energy equation.
- Relationship between system constants.

B2 Open thermodynamic systems

- Application of first law of thermodynamics in an open system.
- Work done, including the general expression for a polytropic process and isothermal work transfer.
- Thermal energy transfer, including the expression for change in an open system: Entalpy $H = U + pV$.

B3 Applications of thermodynamic systems in engineering

- Closed thermodynamic systems, for example:
  - internal combustion engines (Otto cycle), positive displacement compressors
  - refrigeration systems.
- Piston engines, including:
  - practical four-stroke cycle
  - compression ratio
  - Stirling engines, including application as a cooling device.
- Open thermodynamic systems – for example:
  - coolers
  - rotary compressors
  - heat exchangers.
- Gas turbine engines, including:
  - the gas turbine practical cycle (Brayton cycle)
  - pressure-volume (P-V) diagrams
  - temperature-enthropy (T-s) diagrams.
- Thermodynamic systems in aircraft:
  - temperature measurement systems, including thermometers (alcohol, mercury), optical pyrometers
  - cooling systems, including vapour cycle cooling, air cycle cooling, cold boxes, equipment cooling.
- Thermodynamic systems in steam plant:
  - thermal energy transfer and work done in major steam plant elements, including boiler, superheater, turbine and condenser
  - thermal efficiency of elements in steam plants
  - conditions affecting the operation of steam plants, including:
    - feed water temperature
    - steam temperatures, pressures and flow rate
    - fuel consumption rate
    - power output
  - use of thermodynamic property tables to determine enthalpy values, including feed water, saturated water, wet steam, dry saturated steam, superheated steam.

Learning aim C: Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems

C1 Safe working practices for thermodynamic systems

- Know how to react in an emergency, including:
  - isolate power and/or heat supplies
  - fire procedures, e.g. raising fire alarms, use of fire extinguishers
  - notify the responsible person
  - follow instructions from the responsible person, including raise the alarm, notify first aider, evacuate the area.

- Safe working practices: awareness and compliance with hazard identification, risk assessments and standard operating procedures associated with experimental-based tasks, to include:
  - use of appropriate personal protective equipment (PPE), including eye and hearing protection
  - maintain personal safety, e.g. no loose clothing
  - safe working procedures for filling vessels, including correct pipes/hoses and maximum pressure values
  - electrical safety, including isolation, condition of equipment.

C2 Combustion processes

- Fuel types:
  - solid, e.g. coal, anthracite, coke
  - liquid, e.g. petrol, fuel oil, paraffin
  - gaseous, e.g. natural gas (methane), liquefied petroleum gas (LPG).
- Phases of combustion for solid fuels, including preheating phase, distillation (gas) phase and charcoal (solid) phase.
- Stoichiometric equations for complete combustion of fuel elements, including hydrogen ($2H_2 + O_2 = 2H_2O$), carbon ($C + O_2 = CO_2$), sulphur ($S + O_2 = SO_2$).
- Theoretical oxygen and air requirements for complete combustion (stoichiometric air).
- Products of combustion: excess oxygen, nitrogen, carbon monoxide and carbon dioxide, incombustible constituents of fuels.

C3 Calorific values

Determine the calorific value of fuels, e.g.:

- calorimeter to determine gross calorific value of solid fuels and/or fuel oils
- Boys' gas type calorimeter, to determine gross and net calorific value of gaseous fuels.

C4 Sustainability of fuels

- Relative efficiency of fuel types, including solid, liquefied and gaseous fuels.
- Environmental impacts of combustion, including air pollution and excess carbon dioxide.
- Relative cleanliness of fuels, including coal, oil and natural gas.
- Alternative fuels, including biodiesel, hydrogen and liquefied natural gas.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems		
A.P1 Explain the fundamental parameters of thermodynamics and their relationship with thermodynamic process parameters. **A.P2** Explain why different temperature scales are used in engineering applications, using examples to convert between different scales. **A.P3** Calculate the masses of gases and their final condition parameters for a range of given polytropic processes.	**A.M1** Analyse the effects of thermodynamic process parameters on thermodynamic systems, while explaining the need for and correctly converting between different temperature scales. **A.M2** Calculate accurately the masses of gases, their final condition parameters and the process index 'n', for a range of given polytropic processes.	**A.D1** Evaluate the effects of thermodynamic process parameters on thermodynamic systems, while explaining the need for and correctly converting between different temperature scales and accurately calculating unknown values, for a range of given polytropic processes.
Learning aim B: Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems		
B.P4 Explain the differences between open- and closed-loop thermodynamic systems used in given engineering applications. **B.P5** Calculate work done, thermal energy transfer and efficiency in given open- and closed-loop thermodynamic systems.	**B.M3** Analyse, using the first and second laws of thermodynamics, open- and closed-loop thermodynamic systems in given engineering applications, calculating work done, energy transfer and efficiency accurately.	**B.D2** Evaluate, using the first and second laws of thermodynamics, open- and closed-loop thermodynamic systems in given engineering applications, accurately calculating work done, energy transfer and efficiency.
Learning aim C: Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems		
C.P6 Conduct experiments safely to determine the net and gross calorific values of two fuel types, and find the mass of air required for the complete combustion of a fuel type. **C.P7** Explain, using the experimental results and theoretical calculations, the combustion process and calorific values, considering the sustainability implications of the results.	**C.M4** Conduct experiments safely and accurately to determine the net and gross calorific values of two fuel types, and find the mass of air required for the complete combustion of a fuel type. **C.M5** Analyse, using the experimental results and theoretical calculations, the combustion process and calorific values, considering the sustainability implications of the results.	**C.D3** Evaluate the combustion of two fuel types and the sustainability implications for mechanical systems, using the results from safely and accurately conducted experiments and accurate theoretical calculations.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.D1)

Learning aim: B (B.P4, B.P5, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- data on thermodynamic parameters for a range of given polytropic processes.
- a calorimeter suitable for two fuel types (from: solid, liquid and gaseous).
- mass analysis for the fuels to be tested, including data the range of combustible constituents.
- Clément and Desormes apparatus could be used for determination of the adiabatic index 'g'.

The practical activities should take place in a test facility with appropriate equipment and should take account of health and safety requirements.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and thorough evaluation of the effects of thermodynamic process parameters on thermodynamic systems, including a range of polytropic processes. They will use appropriate calculations to demonstrate how parameters can interact with each other and impact on the operation and function of a thermodynamic system. For example, they will explain how the expansion of gases and the resultant changes in pressure in a cylinder can be considered a reversible transformation, whereas the expansion of gas in a free environment would be classified as an irreversible transformation. Calculations to demonstrate that the process would be reversible may consider various parameters, including the gas laws. For each principle investigated, learners should use calculations to evaluate the effects on thermodynamic systems. Learners will also explain the need for different temperature scales in different engineering applications and where required, correctly complete conversions between the different scales as part of the calculations.

Overall, the evidence should be logically structured, technically accurate and easy to understand. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model thermodynamic systems. Small and large numerical values will be correctly presented in an appropriate format, such as engineering notation or standard form. Learners will demonstrate they can work to an appropriate degree of accuracy, given the type of system being investigated or as stated by the assessor, through the use of appropriate significant figures.

For merit standard, learners will analyse the effects of thermodynamic process parameters on thermodynamic systems in their evidence. Learners will explain the need for the three different temperature scales in different engineering contexts. While undertaking calculations, they will convert between the different temperature scales as required.

Learners will perform accurate calculations using the gas laws and other formulae on a range of polytropic processes. To complete these, they will use given data and perform the calculations to determine the polytropic process index value 'n'.

Overall, the evidence should be logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. The numerical work will be to an appropriate degree of accuracy, given the context of the system being investigated or as specified by the assessor, for example it will use appropriate significant figures or decimal places.

For pass standard, learners will present evidence that explains the fundamental parameters of thermodynamics, including expansion, sensible and latent heat, thermodynamic temperature and energy and power. They will explain the relationship between these and the thermodynamic process parameters, for example the link between thermodynamic temperature and isobaric or isochoric processes.

Learners will explain why different temperature scales are used for engineering applications – for example, Celsius for thermostats in heating systems. While undertaking calculations, learners will convert between the different temperature scales, for example Fahrenheit to Kelvin as required.

Learners will also calculate the final masses of gases once they have undergone polytropic processes.

Overall, the evidence will be logically structured, although it may be basic in parts and contain minor technical inaccuracies relating to engineering terminology. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. For example, learners may refer to Centigrade rather than Celsius when either converting between units or presenting results. Minor arithmetic errors are acceptable, as are 'carry through' errors, provided that the basic method is correct. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

Learning aim B

For distinction standard, learners will provide a balanced evaluation of open- and closed-loop thermodynamic systems in given engineering applications by using the first and second laws of thermodynamics. Calculations of work done and energy transfer will be accurate and interrelationships, advantages and disadvantages of the systems will be considered. For example, learners could evaluate the boiler in a steam plant against a Sterling engine, considering the efficiencies of each of the systems with regards to the power input and output. They would compare energy losses from both systems, with the evaluation considering the relative advantages and disadvantages of each system, and the significance of energy losses on the efficiency of the systems.

Overall, the evidence should be logically structured, technically accurate and easy to understand. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model thermodynamic systems. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners will demonstrate they are able to work to an appropriate degree of accuracy given the type of system being investigated or as stated by the assessor, through the use of appropriate significant figures.

For merit standard, learners will analyse open- and closed-loop thermodynamic systems in given engineering applications by using the first and second laws of thermodynamics. They will calculate work done and energy transfer accurately, and consider the interrelationship between the principles and parameters. For example, considering the piston engine practical four-stroke cycle, learners will use calculations to quantify energy losses in the system and therefore the efficiency of the system. They will analyse the results to suggest reasons for inefficiencies, but there will be no consideration of the significance of the energy losses.

Overall, the evidence should be logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. The numerical work will be to an appropriate degree of accuracy, given the context of the system being investigated or as specified by the assessor. For example, through the use of appropriate significant figures or decimal places.

For pass standard, learners will explain in their evidence the differences between open- and closed-loop thermodynamic systems used in given engineering applications, such as for the generation of electricity.

For the open- and closed-loop systems, learners will calculate the work done and thermal energy transfer. For example, they may consider the general expression for work transfer in an open thermodynamic system such as a steam turbine and compare the results to those obtained for a closed system, such as a Stirling engine. Furthermore, they could consider the reasons why the same expression is used for isothermal work transfer in both types of system.

Overall, evidence will be logically structured but there may be some minor inaccuracies in the recording of the results. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. For example, the incorrect magnitude of units may be used when considering energy or power, where joules or watts are given, as opposed to kilojoules or kilowatts. Minor arithmetic errors are acceptable, as are 'carry-through' errors, provided that the basic method is correct. There will also be evidence of simple checks to determine if numerical answers are reasonable.

Learning aim C

For distinction standard, learners will provide a balanced evaluation of experimental results and theoretical calculations, using stoichiometric equations, on the combustion and sustainability of two fuel types (from: solid, liquid and gaseous). For example, learners will provide results on the products of combustion, with consideration of the oxygen content and quantity of incombustible material. Part of their evaluation will contain a comparison between the two sets of results and a rationale will be given for any major differences between them. For example, differences in the results could occur because of incomplete combustion, impurities in the fuel being analysed or learners misreading values.

Learners will also include evidence of the reasons for inefficiencies that is backed up by the practical experimentation results and learners' knowledge of the laws of thermodynamics. Learners will consider the sustainability implications of the results and demonstrate how thermodynamics can lead to more sustainable mechanical systems. For example, they may consider the high relative calorific value of solid fuels such as coal and balance this with the environmental impacts, such as the ash produced or, on a larger scale as found in power generation, the effects of acid rain and climate change.

Overall, the evidence should be logically structured, technically accurate and easy to understand. Learners will use mathematical methods and terminology precisely, and apply relevant units when working with mathematical expressions for combustion processes. Small and large numerical values will be correctly presented in an appropriate format, for example, engineering notation or standard form. Learners will demonstrate they are able to work to an appropriate degree of accuracy given the type of system being investigated or as stated by the assessor, through the use of appropriate significant figures.

For merit standard, learners will set up and conduct experiments to determine the net and gross calorific value of two fuel types safely and accurately. For example, they will independently select and use appropriate equipment and will record their results methodically.

Learners will explain, using the experimental results and from research, the combustion process and net and gross calorific values of two types of fuel. They will use their results to determine the mass of the products of combustion for one of these fuel types, probably the solid fuel. Learners will include appropriately annotated diagrams and use the correct equations. They will analyse the sustainability implications of the results, for example analysing the products of incomplete combustion and identifying those elements that could be harmful to the environment when used on a large scale.

Overall, the evidence should be logically structured, technically accurate (including the correct use of mathematical terminology and relevant units) and easy to understand. The numerical work will be to an appropriate degree of accuracy given the fuel being investigated or as specified by the assessor, for example using appropriate significant figures or decimal places.

For pass standard, learners will set up and conduct experiments to determine the net and gross calorific value of two fuel types (from: solid, liquid and gaseous) safely. Learners may receive some advice on the selection, setting up and use of experimental equipment. However, learners will ensure safe working practices, for example using the correct personal protective equipment at all times, and will independently collect, tabulate, process and present experimental data.

Learners will explain, using the experimental results and from research, the combustion process and net and gross calorific values of two types of fuel. They will use their results to determine the mass of the products of combustion for one of these fuel types, probably the solid fuel. Learners will include appropriately annotated diagrams and use the correct equations. They will explain the sustainability implications of the results, for example identifying the impacts of using coal as a fuel source and the effects on the environment caused by the combustion of coal.

Overall, evidence will be logically structured but there may be some minor inaccuracies in the recording of the results. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. For example, there may be confusion between the use of joules and watts when referring to energy and power. Minor arithmetic errors are acceptable, as are 'carry-through' errors, provided that the basic method is correct. There will also be evidence of simple checks to determine if numerical answers are reasonable.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 18: Electrical Power Distribution and Transmission
- Unit 50: Aircraft Gas Turbine Engines
- Unit 51: Aircraft Propulsion 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 thermodynamic systems
- contribution of ideas to unit assignment/project materials.

Unit 32: Computer System Principles and Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will understand how computers operate securely as part of a system and will also develop a computer program to solve an engineering problem that is onscreen.

Unit introduction

Engineering in the 21st century is a fast-moving and exciting industry and the development of computer systems has helped to transform engineering products, systems and services. The cars that we drive today are designed with embedded microprocessors that manage, among many things, fuel consumption, steering and ride quality.

In this unit, you will learn about the features and functions of the components in a computer system and how system security works. You will examine how data is represented and manipulated and how microprocessors work. This should include tracing techniques that will help you to understand how data is handled in the microprocessor. You will also develop a computer program to solve an engineering problem that is onscreen.

An understanding of how computer systems work and how to program them is an essential skill for all engineers. This unit helps to prepare you for employment as an information technology (IT) engineer or IT operations technician, an apprenticeship or for a computing course in higher education. It will help to provide the underpinning knowledge in a fast-moving sector.

Learning aims

In this unit you will:

A Examine the technology and security protection measures used in computer systems for different applications

B Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function

C Examine the architecture and operation of microprocessors to appreciate how computer systems function

D Develop a computer program to solve an engineering related problem onscreen

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine the technology and security protection measures used in computer systems for different applications</td><td>A1 Applications of computer systems
A2 Typical hardware components in computer systems
A3 Software in computer systems
A4 Security of computer systems</td><td>A report that examines two computer systems from a chosen engineering specialist area that demonstrates why the hardware components, software and security are suitable for the application and where improvements could be made.</td></tr>
<tr><td>B Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function</td><td>B1 Numeric and alphanumeric data representation and manipulation</td><td rowspan="2">A report, including calculations, that analyses how data is represented and manipulated in a microprocessor, including worked examples. It should also include how a microprocessor operates, using diagrams, examples of handling data (such as an addition or a comparison), an example of how the microprocessor handles data using tracing methods and a commentary.</td></tr>
<tr><td>C Examine the architecture and operation of microprocessors to appreciate how computer systems function</td><td>C1 Operation of key components of the microprocessor
C2 Function and operation micro-architecture
C3 Registers and register handling</td></tr>
<tr><td>D Develop a computer program to solve an engineering related problem onscreen</td><td>D1 Design a computer program
D2 Computer program constructs
D3 Computer program development</td><td>Solve a screen-based engineering problem using a computer program. Evidence will include design documentation, annotated program code and test results.</td></tr>
</table>

Content

Learning aim A: Examine the technology and security protection measures used in computer systems for different applications

A1 Applications of computer systems

Types of application, including:

- manufacturing applications, e.g. robotics, environmental control, data collection, computer-aided manufacturing (CAM) systems, computer-aided design (CAD) systems and computer numerical control (CNC) machines
- aerospace applications, e.g. flight instruments (speed and altitude), fuel systems, cabin control systems (pressure, air quality, smoke detection), communication systems
- automotive applications, e.g. vehicle fuel consumption, steering systems, locking systems, engine management, braking systems
- process industries, e.g. environmental management, energy recovery, process control
- commercial and domestic, e.g. burglar alarm, electronic locks, electronic thermometer, communications devices, vending machines, photocopiers and domestic appliances.

A2 Typical hardware components in computer systems

Features and functions of typical system components.

- Internal components of a computer, including:
  - microprocessor, including the central processing unit (CPU)
  - system memory and interfaces with a microprocessor, including input/output maps; direct memory access (DMA); read-only memory (ROM); cache; random-access memory (RAM), including, static, dynamic, flash
  - buses, including system bus, address bus, control bus.
- External components, including:
  - input, e.g. keyboard, mouse, sensors (infrared, sound and touch), scanner, digital camera, switches, accelerometers, potentiometers, temperature sensors, light-dependent resistors
  - output, e.g. light-emitting diodes (LED), hard disk, printer, network card, robot arm, actuators and sound emitters (e.g. speakers and buzzers)
  - other, e.g. storage devices (solid state, optical media, magnetic; power source (mains transformer, photovoltaic cells and batteries); and mechanical structures (protective/aesthetic shell and framework).
- Similarities and differences between computer systems, including general-purpose computers, versus microcontrollers and programmable logic controllers (PLCs).

A3 Software in computer systems

- The purpose of the operating system to manage computer hardware and software and its features, including process management, interrupts, memory management and networking, file system, input/output components and security.
- The purpose and features of utility software, e.g. backup software, disk management, file management, systems monitoring.
- The purpose and features of applications software, e.g. CAD, office applications, enterprise resource planning (ERP) and integrated development environment (IDE), security software.

A4 Security of computer systems

- Security threats to computer systems that make them vulnerable to losses, including information, e.g. theft of sensitive and/or valuable information; property, e.g. hardware theft; financial, e.g. fraud; service denial to customers; and legal liability, e.g. copyright and data protection.

- Security threats to different types of computer systems including:
  - any open firewall ports, e.g. user data gram (UDP) and transport control (TCP), traffic not 'in reply' to traffic from a network
  - insecure users, e.g. users with write or execute rights, anybody with root or supervisor/super-user access and insecure passwords
  - resident Trojans, e.g. unchecked by anti-malware, Sub7, zombies
  - untrustworthy software, e.g. may not have a trust certificate, from an untrusted source, torrented software, illegal copies
  - un-updated operating system, e.g. from base installation, automatic updates, vendor security alerts.
- Security measures to protect systems from loss, while allowing the information and property to remain accessible and productive to its intended users.
- Common categories of security protection measures including:
  - users, including training on data protection, password management and an employee policy
  - software, e.g. anti-malware, anti-spyware and anti-adware applications, encryption of data, software firewall, secure sockets layer (port 443) such as the padlock in a web browser
  - hardware components and settings, e.g. physical security locks, cards, biometric scanners, firewall settings, virtual private networks, wireless encryption.

Learning aim B: Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function

B1 Numeric and alphanumeric data representation and manipulation

- Units of digital data (bit, byte, kilobyte, megabyte, gigabyte, terabyte).
- The use and interpretation of number systems, including:
  - numeric data types, to include denary, binary and hexadecimal
  - positive integer number conversion between denary and binary. Maximum size of 8 bits (from 0 to 255 in decimal).
- Binary data manipulation – maximum size of 8 bits (from 0 to 255 in denary) – to include:
  - floating-point representation
  - two's complement notation
  - addition and subtraction.
- The purpose and implications of using codes to represent alphanumeric data. The features and uses of common alphanumeric data sets: ASCII codes and Unicode.

Learning aim C: Examine the architecture and operation of microprocessors to appreciate how computer systems function

C1 Operation of key components of the microprocessor

- Key components, functions and a diagrammatic representation: CPU, memory, interfaces, clock, buses.
- Standard microprocessor architectures: Von Neumann, Harvard, multi-core processors.

C2 Function and operation micro-architecture

- Instruction cycles: fetch, decode, execute.
- Instruction execution speeds, including:
  - factors affecting execution speed
  - methods of increasing execution speed
  - implications of execution speed, e.g. excess heat and crashing the microprocessor.
- The use and choice of instruction sets.
- Pipelining.
- Cache.
- Registers, e.g. instruction register, address register, program counter, general register.
- Multiprocessing and multithreading.

C3 Registers and register handling

- The function and purpose of general and special registers, and their impact on the way computer systems perform. Types of register:
  - general-purpose register
  - special registers: accumulator, instruction register, memory address register (MAR), memory data register (MDR) and program counter.
- The role of interrupts in a computer system.

Learning aim D: Develop a computer program to solve an engineering related problem onscreen

D1 Design a computer program

- A problem definition statement.
- Structured design tools:
  - develop a list of steps using structured English or a flowchart (using standard symbols) that describe a possible solution to a problem
  - identify repeating patterns and user inputs and outputs
  - develop a set of instructions to solve the problem
  - test plan to include expected results and exceptional values.

D2 Computer program constructs

Constructs include:

- sequence
- selections (case, if... then... else) and nested constructs
- iteration (repeat – until, while... do, for *n*=1 to...)
- operators, including:
  - arithmetic [+, −, *, /, MOD and DIV]
  - relational logical [=, >, <, =>, =< and <>]
  - boolean [true and false]
  - logical [AND, OR, NOT, XOR]
- assignment
- input and output commands
- subroutines, procedures, functions (passing parameters, use of return values)
- string handling
- variables (naming conventions, scope of variables, local and global)
- data types (character, string, integer, real, byte, date/time, Boolean)
- one-dimensional arrays.

D3 Computer program development

- Use of a development environment to develop a computer program, including declare variables and constants, develop constructs, sequencing, selection, repetition.
- Commentary on the purpose of the code and how it works.
- Iterative and final testing to document actual results.
- Efficiency of the computer program, to include the simplicity of the code and the amount of system resources a program consumes, e.g. processor time or memory space.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the technology and security protection measures used in computer systems for different applications		
A.P1 Explain the features and functions of typical hardware components found in two contrasting computer systems. **A.P2** Explain the features and functions of the software used in two contrasting computer systems. **A.P3** Explain the security threats, vulnerabilities and protection measures in two contrasting computer systems.	**A.M1** Compare the suitability of technology and security-protection measures found in two contrasting computer systems.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the suitability of the technology and security-protection measures found in two contrasting computer systems, suggesting possible improvements.
Learning aim B: Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function		
B.P4 Explain, using examples, how different types of data are represented in a microprocessor and include number conversions and binary manipulation.	**B.M2** Discuss accurately, using examples, how data is represented and manipulated in a microprocessor.	**BC.D2** Critically compare the operation of two microprocessors, demonstrating how data is represented and manipulated, and how the architecture affects performance.
Learning aim C: Examine the architecture and operation of microprocessors to appreciate how computer systems function		
C.P5 Explain the standard architecture of a microprocessor. **C.P6** Explain how an instruction is typically executed in a microprocessor.	**C.M3** Discuss accurately the standard architecture of a microprocessor and how an instruction is typically executed in a microprocessor.	
Learning aim D: Develop a computer program to solve an engineering related problem onscreen		
D.P7 Design, including a test plan, the solution to an onscreen computer program using structured tools. **D.P8** Build and test a functional computer program to solve an onscreen problem.	**D.M4** Develop a functional onscreen computer program that operates as intended, while documenting alternative design solutions and embedding commentary.	**D.D3** Optimise the efficiency of a functional onscreen computer program that operates as intended and contains detailed commentary throughout.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aims: B and C (B.P4, C.P5, C.P6, B.M2, C.M3, BC.D2)

Learning aim: D (D.P7, D.P8, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- computer hardware components, including CPU, motherboards, power supply units, hard drives, RAM, expansion cards, video cards, sound cards, network cards
- input and output devices, e.g. keyboards, mice, specialist input devices, printers, speakers, screens, LEDs, robot arms
- storage devices, including hard drives, detachable drives, CDs, DVDs
- software applications, e.g. office applications, CAD and software relevant to engineering, programming language software, integrated development environments
- security software, e.g. virus protection, anti-malware, anti-spyware and anti-adware.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will give a detailed and comprehensive evaluation of the two contrasting systems, and will demonstrate how the systems work and why the hardware components and software are suitable for the application. For example, an office computer would include a keyboard, mouse and monitor to input and output data, whereas a CNC machine includes a touch screen input/output device. The office computer contains sufficient RAM (typically gigabytes (Gb) or terabytes (Tb)), to run several applications concurrently, whereas the CNC machine runs a restricted set of instructions that requires less memory (around 1 megabyte). The office computer needs to load an operating system on start-up, such as Microsoft Windows, before running applications, while the CNC machine has an embedded control system, such as Siemens or Fanuc. Other factors will be considered, such as the processor operating speed, instruction set, hard disk size, external storage.

A detailed analysis of the security threats and a justification of why the security measures proposed are suitable will be given. For example, an office computer is likely to have access to personal and financial details, and make extensive use of the internet, therefore measures are required to prevent physical sabotage, hacking and malicious attacks. Whereas the CNC machine will access industrially sensitive design data, but may have limited connectivity. Learners will suggest how the systems could be improved, for example to make them more secure or to better perform their intended purpose such as using firewalls and anti-virus software, and limiting user privileges.

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 with a high standard of written language, such as consistent use of correct grammar and spelling.

For merit standard, learners will compare how the two computer systems work and the suitability of the hardware components and software in terms of features, functions and purpose. The comparison will include technical detail of hardware and software requirements for both systems, but will not be as extensive in features considered, for example details of the instruction set and external storage may be missing. The impact of security threats to both systems will be considered, for example the need for anti-virus software and firewalls, but may not identify specific detail in terms of wider threats.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the features and functions of the hardware components found in two contrasting computer systems. For example, learners will create a table that details the hardware and software components required and their function for an office computer and a CNC machine.

Learners will explain the security threats and vulnerabilities of the two contrasting computer systems and explain what security protection methods have been used. This may be restricted to simple methods such as the use of anti-virus software on the office computer. Learners may also consider the physical safety of the equipment, for example by simulating a CNC program before running it on the machine to avoid a tool collision.

Overall, the evidence will be logically structured, although it may be basic in parts. For example, the components listed may be comprehensive, but the explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology. They may not differentiate between type or amounts of memory, for example.

Learning aims B and C

For distinction standard, learners will critically compare Von Neumann microprocessor architecture with a different type – for example, Harvard architecture used in PIC microcontrollers. They will explain how different coding systems, such as binary, hexadecimal, two's complement and floating point, are used, and demonstrate through the execution of instructions how 8-bit data can be stored and manipulated in a microprocessor, for example how the sum (55 − 23) could be executed.

Learners will explain, using examples, how architecture affects the performance of a microprocessor. For example, the word size of a microprocessor determines how many bits the central processing unit can manipulate per instruction cycle, so a microprocessor with a 64-bit word size can processes twice as many instructions in one cycle as one with a 32-bit word size (assuming all else was equal between the machines). They will explain how floating-point notation extends the range of values available for a given word length and its effect on the precision of calculations.

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 use examples to demonstrate how data is represented in a microprocessor, for example converting the decimal numbers 55 and 23 into binary and hexadecimal, and complete data manipulation, such as adding 55 to 23. They will demonstrate how to represent a negative number in two's complement format. The methods applied in calculations will be accurate, though there may be an occasional numerical error.

Learners will provide an accurate description of the components of a microprocessor and their inter-connections, using diagrams and accurate explanations of their function during the execution of an instruction. For example, what internal processes occur and how registers are used to add 54 and 23 together as binary numbers.

Overall, the evidence will be logically structured and technically accurate.

For pass standard, learners will explain how data is stored in a microprocessor using the binary and hexadecimal number systems. They will use examples to show how binary numbers are added and subtracted from each other and will represent numbers using two's complement notation. They will explain the function of floating-point representation.

Learners will explain the architecture of a microprocessor and provide a description of the key components of a microprocessor and their function. For example, the arithmetic logic unit (ALU) performs arithmetic and logical operations on integer binary numbers. Learners will explain how an instruction is typically executed in a microprocessor using an example.

Overall, the evidence will be logically structured and the example will contain the correct interpretation of numerical data. There may be minor mathematical errors and learners will not be penalised for 'carry-through' errors. For example, when carrying out the sum to add 55 and 23, they may have converted 55 as 00101111 instead of 00110111 with the consequence that the result is 01000110 rather than 01001110.

Learning aim D

For distinction standard, learners will analyse an engineering problem and provide a design, including a test plan using structured tools that explains how they intend to solve it. They will develop a high-level language program employing sequence, selection and iteration to solve the problem. The final program will allow some user choice and input, for example they may select to calculate acceleration, inputting values for force and mass from a menu offering force, mass or acceleration.

Learners will provide evidence of testing their solution against the test plan. The evidence will show the results of the tests, which demonstrate that the program operates as intended. As part of the development process, learners will provide evidence of how the program has been optimised. For example, at the design stage, learners may reduce the number of steps in the program, perhaps by passing parameters between functions, and make further refinements during development. The program will be annotated to allow third parties to understand the program structure and flow.

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 provide a design to solve a problem that will cover the operation of the program in detail. For example, they will identify the variables, for example force, mass and acceleration – required to solve a problem related to Newton's second law of motion. They will document alternative design solutions outlining how the problem could be solved in different ways, for example, by using different program structures and program constructs. They will develop a working solution using a range of programming constructs and explain how the program works by using comments. The function may be restricted to solving one problem, such as calculating force from mass and acceleration, but not having a working menu to solve any other combinations.

Learners will test the computer program against the test plan and demonstrate that the computer program functions as intended. For example, calculating force from a range of user inputs for mass and acceleration that includes user data validation.

Overall, the evidence will be logically structured and technically accurate.

For pass standard, learners will describe the solution to an engineering problem that can be solved onscreen using a problem-definition statement. Structured tools will be used to design a solution focusing on inputs, outputs and key processes. The design will cover the main functions of the program, but may contain omissions, such as not validating user inputs. They will provide a high-level test plan covering the main functions of the program, such as the expected user inputs and outputs.

The computer program will comprise a range of basic constructs, such as loops and variables that are generally appropriate and have been used correctly. The program may be inefficient. For example, learners may not use any functions to undertake specific tasks, such as to calculate force, mass or acceleration. Annotation of the program may be inconsistent and patchy.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 19: Electronic Devices and Circuits
- Unit 33: Computer Systems Security
- Unit 35: Computer Programming.

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 the operation of microprocessors and/or computer programming.
- contribution of ideas to unit assignment/project materials.

Unit 33: Computer Systems Security

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the security of engineering computer systems, and will install and configure security measures to protect a system from malicious threats.

Unit introduction

Computer security is an important issue for the economy and 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.

In this unit, you will investigate a range of computer security threats, computer system vulnerabilities, and security-protection measures that are used in the industry. You will also investigate the legal requirements placed on organisations to protect information and systems. You 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 security is important and how it can be implemented in products and systems of all types. This unit helps to prepare you for an engineering apprenticeship, for higher education and for technician-level roles, such as an information technology (IT) engineering technician or an IT operations technician.

Learning aims

In this unit you will:

A Investigate the threats to computer systems in engineering organisations and the organisations' legal responsibilities

B Investigate computer system vulnerabilities and protection measures used in engineering organisations

C Plan security measures to protect an engineering computer system from threats

D Implement security measures to protect an engineering computer system from threats.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Investigate the threats to computer systems in engineering organisations and the organisations’ legal responsibilities</td><td>A1 Computer system security threats
A2 Legal responsibilities</td><td rowspan="2">A report or presentation investigating contrasting computer systems in at least one engineering organisation. The report should cover a range of security threats, the legal requirements placed on organisations, system vulnerabilities and a range of possible security measures.</td></tr>
<tr><td>B Investigate computer system vulnerabilities and protection measures used in engineering organisations</td><td>B1 Computer system vulnerabilities
B2 Physical security measures
B3 Software and hardware security measures
B4 Policy security measures</td></tr>
<tr><td>C Plan security measures to protect an engineering computer system from threats</td><td>C1 Assessment of computers system vulnerabilities
C2 Assessment of the risk severity for each threat
C3 A security plan for a computer system</td><td rowspan="2">A plan to provide security protection for an engineering computer system.
The installation and configuration of the security measures to protect a computer system. Testing and optimisation of the system.
A portfolio of evidence, including a report, screen shots, test results, witness testimony and observation records, analysis and interpretation.</td></tr>
<tr><td>D Implement security measures to protect an engineering computer system from threats</td><td>D1 Installation and configuration of security measures for a computer system
D2 Testing a computer system’s security measures</td></tr>
</table>

Content

Learning aim A: Investigate the threats to computer systems in engineering organisations and the organisations' legal responsibilities

A1 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. 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
  - weak security measures and unsafe practices, e.g. security of computer equipment and storage devices, security vetting of visitors, visiting untrusted websites
  - accidental loss or disclosure of data, e.g. poor staff training and monitoring.
- External threats include:
  - malicious software (malware) and how they function, 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.

A2 Legal responsibilities

United Kingdom legislation or other relevant international equivalents, including:

- Data protection legislation and amendments, requirements for organisations to keep data secure
- 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
- Fraud legislation and amendments, requirements to deal with services using IT-based methods to steal information for fraudulent purposes.

Learning aim B: Investigate computer system vulnerabilities and protection measures used in engineering organisations

B1 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
  - organisational, e.g. inappropriate file permissions or privileges, password policy
  - software, e.g. from an untrusted source, torrent-downloaded software, illegal copies
  - 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.

B2 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.

B3 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 such as printers, and Linux octal file permissions
- 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 to ensure security is built-in from the development stage.

B4 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.

Learning aim C: Plan security measures to protect an engineering computer system from threats

C1 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.

C2 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 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.

C3 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 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.

Learning aim D: Implement security measures to protect an engineering computer system from threats

D1 Installation and configuration of security measures for a computer system

- Consideration of security issues during the design and development of the 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 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.

D2 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 is not hindered.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Investigate the threats to computer systems in engineering organisations and the organisations' legal responsibilities</td><td rowspan="4">AB.D1 Evaluate, using language that is technically correct and of a high standard, 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.</td></tr>
<tr><td>A.P1 Explain the different security threats that may affect contrasting engineering computer systems and the impact of any loss.
A.P2 Explain the legal responsibilities that at least one engineering organisation has for the security of their computer systems.</td><td>A.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.</td></tr>
<tr><td colspan="2">Learning aim B: Investigate computer system vulnerabilities and protection measures used in engineering organisations</td></tr>
<tr><td>B.P3 Explain what vulnerabilities exist in contrasting engineering computer systems.
B.P4 Explain how the physical, software, hardware and policy security measures protect contrasting engineering computer systems from loss.</td><td>B.M2 Justify how the physical, software, hardware and policy security measures protect vulnerabilities in contrasting engineering computer systems from loss.</td></tr>
<tr><td colspan="2">Learning aim C: Plan security measures to protect an engineering computer system from threats</td><td rowspan="4">CD.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.</td></tr>
<tr><td>C.P5 Produce a plan to protect an engineering computer system from possible threats.</td><td>C.M3 Produce a detailed plan to protect an engineering computer system from possible threats, justifying the recommendations.</td></tr>
<tr><td colspan="2">Learning aim D: Implement security measures to protect an engineering computer system from threats</td></tr>
<tr><td>D.P6 Undertake security measures safely to protect an engineering computer system.
D.P7 Test how well the engineering computer system is protected by the measures.</td><td>D.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.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, A.P2, B.P3, B.P4, A.M1, B.M2, AB.D1)

Learning aims: C and D (C.P5, D.P6, D.P7, C.M3, D.M4, CD.D2)

Further information for teachers and assessors

Resource requirements

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.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will evaluate the vulnerabilities in two contrasting computer systems. The evaluation will be detailed, well balanced, 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 with a high standard of written language, such as consistent use of correct grammar and spelling.

For merit standard, 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 the 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, learners will provide evidence that explains 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 explain the impact of the threat should it succeed, for example employee theft of sensitive information, such as designs for a new product, could result in financial loss to the organisation from lost revenue and compensation to and reputation 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 four of the pieces of legislation and regulations. For example, the Data Protection legislation and amendments places a requirement on organisations to keep data about customers secure and stored for no longer than is necessary for the purpose for it was provided.

Learners will explain the possible vulnerabilities in contrasting engineering computer systems. For example, insufficient file permissions could be exploited by employees working in an organisation to obtain information, which may result in financial fraud.

Learners will also explain the physical, software, hardware and policy measures that are available to protect a system in 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 contain minor technical inaccuracies relating to terminology. For example, the difference between 'rootkits' and 'worms' may not be clear.

Learning aims C and D

For distinction standard, 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 and convenience. 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, 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, they should set firewall settings to allow legitimate programs to operate and place user accounts in groups that provide appropriate levels of access and restriction.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, 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 user ability to save or update files.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 19: Electronic Devices and Circuits
- Unit 35: Computer Programming
- Unit 37: Computer Networks
- Unit 38: Website Production to Control Devices.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local computing organisations
- contribution of ideas to unit assignment/project materials.

Unit 34: Computer Systems Support and Performance

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will examine and carry out the support and performance monitoring of computer systems that are an essential part of every engineering organisation.

Unit introduction

Computer systems are crucial to customer satisfaction, productivity and financial profitability of engineering organisations. Individuals rely on computer systems to perform their role, for example a designer will use a computer-aided design (CAD) software package and a machine setter operator may use a computer numerical controlled (CNC) machine.

In this unit, you will examine industrial computer systems, identifying areas where support is necessary and essential, and where maintenance and upgrades can vastly improve the performance of an engineering organisation. You will plan and undertake the controlled maintenance of an industrial computer system, and delve into legislation and policies in place in engineering organisations to provide a safe and productive environment for its employees. Finally, you will reflect on your performance in supporting a computer system.

This unit will help you progress to a range of technical support roles such as an information technology (IT) engineer, and IT operations technician, or on to an apprenticeship. You may also be interested in this unit if you want to progress to higher education to study engineering or computing.

Learning aims

In this unit you will:

A Examine the computer support needs for different engineering organisations that are essential to their operation

B Develop a support plan for a new computer system, as undertaken in industry

C Carry out routine support of a computer system and improve its performance

D Review the support provided for a computer system and reflect on own performance.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine the computer support needs for different engineering organisations that are essential to their operation</td><td>A1 Purpose and policy of computer system support
A2 Safe working practice
A3 Contingency planning for computer systems
A4 Infrastructure security for computer systems</td><td>A research study supported by case studies. The study should cover four computer support characteristics: purpose of the system, policies and safe working practices, contingency planning and infrastructure security.</td></tr>
<tr><td>B Develop a support plan for a new computer system, as undertaken in industry</td><td>B1 Graphical representation of systems
B2 Contingency planning
B3 Levels of support and standard operating procedures</td><td rowspan="2">A collection of plans supported by at least one of each of the following: route map, upgrade path, schedule, Gantt chart and standard operating procedure.
A developmental log supported by observational witness statements. The log should contain task logs, documentation regarding problems encountered, applied software, hardware and firmware upgrades, test scripts and results, appropriate data sheets and where hardware components have been replaced or upgraded.</td></tr>
<tr><td>C Carry out routine support of a computer system and improve its performance</td><td>C1 Support for computer systems
C2 Software, hardware and firmware management
C3 Unit testing</td></tr>
<tr><td>D Review the support provided for a computer system and reflect on own performance</td><td>D1 Lessons learned from the support of a computer system
D2 Personal performance whilst supporting a computer system</td><td>The evidence will focus on what went well and what did not go so well when supporting engineering computer systems, reviewing the processes and reflecting on own performance.
The portfolio of evidence generated while supporting engineering computer systems and reviewing the processes and reflecting on own performance.</td></tr>
</table>

Content

Learning aim A: Examine the computer support needs for different engineering organisations that are essential to their operation

A1 Purpose and policy of computer systems support

- Purpose of computer systems support includes:
  - continuity of computer-based processes:
    - the primary computer systems of the organisation, e.g. computer aided manufacturing, computer aided design and office network
    - the processes followed using computer systems, e.g. stock control, automated manufacturing and financial management
  - productivity of the organisation:
    - benefits of and preventative maintenance measures for the computer systems in an organisation
    - how productivity could be improved with upgrades and enhancements to the systems
  - data capture:
    - security and protection of data in the system, including storage and backup procedures
    - ensuring continuity of business in the event of system failure.
- Policies on the use and care of computer equipment in organisations, including:
  - procurement of computer services and products, e.g. identification of need versus acquisition of the same services and or products, supplier availability and benefits, negotiation of contracts, logistical considerations and risk management
  - sustainability, e.g. consideration of finite resources; reduction of waste with recycling; repair of hardware and software instead of replacing; sourcing of products that reduce carbon, water and waste; and minimising waste at design level, e.g. locally sourced products
  - environmental waste management:
    - on-site destruction and implications to the local environment, including effects on ground water, air quality and nearby water sources
    - recycling to include: Waste Electrical and Electronic Equipment (WEEE) or other international equivalents and charitable organisations
  - Data protection legislation or other international equivalents, e.g. Data Protection Directive (Directive 95/46/EC)
  - security and software protection, including malware policies.

A2 Safe working practice

- Regulations or other relevant international equivalents on the use and care of computer equipment in organisations, including:
  - display screen equipment, e.g. the adjustment of screen height and angle (Current Screen equipment regulations and amendments, including:
    - disorders that can arise from negligence
    - precautions to be taken to ensure effective practice
  - Current Manual handling operations regulations (MHOR) and amendments, including:
    - lifting, carrying and lowering, and pushing and pulling
    - repetitive tasks, stretching, bending and awkward postures
  - Personal protective equipment within an engineering environment (personal protective equipment (PPE) at work regulations and amendments)
    - assessment to ensure equipment is fit for purpose, and training procedures for proper use
    - maintenance and storage
  - portable application testing (The Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments):
    - Current Electricity at work regulation and amendments
    - standards and codes of practice
  - effects on the organisation should safe working practices not be followed, e.g. legal action, employee turnover and absence.

- Computer support related health and safety hazards, including:
  - electrocution and electrostatic discharge (ESD), e.g. from an unprotected power supply
  - fire, e.g. from faulty wiring
  - injury or reduced productivity from poor workstation ergonomics.
- Hazard mitigation methods, including ESD wrist strap, ESD mat, firefighting equipment, adjustable workstation, e.g. screen height and training such as first aid.

A3 Contingency planning for computer systems

- Business continuity plan in accordance with ISO/IEC 27031 or other relevant international equivalents, including:
  - identifying areas for IT readiness
  - measure continuity, security and readiness for a potential disaster.
- Cyber incident response plan in accordance with ISO/IEC 27032 or other relevant international equivalents, including: assets in cyberspace, threats, roles and guidelines for stakeholders and cyber security controls.

A4 Infrastructure security for computer systems

- Location, to include on-site and off-site, e.g. data centres and bunkers; power, e.g. site power and uninterruptible supplies; and communications connectivity, including leased and dedicated lines.
- Environment, to include cooling by air and water.

Learning aim B: Develop a support plan for a new computer system, as undertaken in industry

B1 Graphical representation of systems

Representation of a computer system in graphical form to include: route maps, upgrade paths, schedules, Gantt charts and maintenance checklists.

B2 Contingency planning

- Scope of maintenance, e.g. software, firmware and hardware upgrades, security patches.
- Frequency of maintenance including:
  - routine, where processes are scheduled according to organisational needs due to continued use, e.g. daily data backups
  - non-routine, where processes are carried out in an ad hoc manner, e.g. software upgrade or new hardware installation.
- Security threats that occur from neglect, misuse and vandalism of hardware and software; and malicious intent, e.g. hacking, viruses, malware.
- Risks from contract staff; including from agency and freelance staff, contract terms, breach of contract and non-disclosure agreements (NDAs).
- Conformity of contingency plans to meet ISO/IEC 27031 and 27032 or other relevant international equivalents.

B3 Levels of support and standard operating procedures

- Types of technical support, including tiered (first, second and third levels) support, call-outs, remote support and outsourced.
- Standard procedures, including:
  - risk assessments for manual tasks, e.g. for moving heavy loads and handling of hazardous materials
  - control of major accident hazards for dangerous environments, e.g. for systems responsible for protection, process control, expert procedures, safety and integrity
  - attainment of International Standards Organisation (ISO) standards, and how this affects business, society, environment and government.

Learning aim C: Carry out routine support of a computer system and improve its performance

C1 Support for computer systems

Routine housekeeping operations on computer systems:

- cleaning and ventilation of hardware, including:
  - cleaning methods, e.g. standard operating procedures and health and safety at work
  - materials and portable tools, e.g. compliance with Portable Application Testing (PAT) policies
- machinery procedures for daily, quarterly, biannual, annual maintenance, e.g.:
  - CNC machines
  - CAD workstations, including displays, networking, graphics
  - random-access memory (RAM)
  - work handling machines, including robots
  - measurement machines, including magnetic, density, image analysis, sensors
- maintaining components of a system, including:
  - consumables, e.g. specialised consumables, e.g. drill bits, liquid dielectric, fuels
  - damaged components, e.g. specialised components, e.g. control boards, power supplies
  - approved disposal methods, including recycling and donation services.

C2 Software, hardware and firmware management

Improving a system's performance by upgrading its components including:

- software:
  - client and server operating systems, including commercial and free provisions
  - implementation of service packs and third-party tools to improve performance, efficiency and functionality of a system, e.g. to make existing process more autonomous
  - specialist tools firmware, including upgrades and bespoke versions from manufacturers
  - applications, e.g. CAD, computer-aided manufacturing (CAM), and integrated systems to track components, automatically measure components, monitor the use and condition of tooling, work piece location, and stock levels
- hardware:
  - common computer system components, e.g. processors, RAM, storage, power and cooling
  - storage, e.g. local, file servers, backups, data centres
  - specialised hardware components, e.g. for CNC, CAM, robots, conveyers and measurement systems.

C3 Unit testing

The testing of a system during upgrades and updates to ensure it still works as intended, giving the organisation opportunities to identify early problems and resolve them. Test plans, including:

- functionality testing
- risk analysis.

Learning aim D: Review the support provided for a computer system and reflect on own performance

D1 Lessons learned from the support of a computer system

Scope of the lessons learned should cover:

- health and safety skills, including applying safe working practices, e.g. lifting heavy equipment and following screen display procedures
- computer support skills, including routine maintenance and improvement of hardware and software
- general engineering skills, including mathematics and logical problem solving.

D2 Personal performance whilst supporting a computer system

Understand that relevant behaviours for supporting computer systems include:

- planning to ensure critical systems are available, which can take significant time and resources to change
- communication and literacy to respond to requests for support that are sometimes time critical and essential to maintain an organisation's productivity
- commercial and customer awareness to help ensure customer needs are met, relationships are maintained and future revenue is secured.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the computer support needs for different engineering organisations that are essential to their operation</td><td rowspan="2">A.D1 Evaluate, using language that is technically correct and of a high standard, the support characteristics for two contrasting computer systems, justifying where improvements could be made.</td></tr>
<tr><td>A.P1 Explain the purpose, policy and safety support characteristics for two contrasting computer systems.
A.P2 Explain the contingency planning and infrastructure security support characteristics for two contrasting computer systems.</td><td>A.M1 Analyse the support characteristics for two contrasting computer systems.</td></tr>
<tr><td colspan="2">Learning aim B: Develop a support plan for a new computer system, as undertaken in industry</td><td rowspan="4">BC.D2 Refine, during the process, the support undertaken safely for a computer system justifying the choices made to optimise the performance of a system against the detailed support plan.</td></tr>
<tr><td>B.P3 Produce a support plan for a computer system covering contingency planning, levels of support and standard operating procedures, identifying any automated tasks.</td><td>B.M2 Produce a detailed support plan covering contingency planning, levels of support and standard operating procedures, explaining which tasks could be automated.</td></tr>
<tr><td colspan="2">Learning aim C: Carry out routine support of a computer system and improve its performance</td></tr>
<tr><td>C.P4 Perform routine housekeeping and use automated tools to support a computer system safely.
C.P5 Test the performance of a supported system safely, explaining how performance could be improved.</td><td>C.M3 Perform routine housekeeping, use automated tools and upgrade a computer system safely to improve its performance, while considering alternative solutions.</td></tr>
<tr><td colspan="2">Learning aim D: Review the support provided for a computer system and reflect on own performance</td><td rowspan="2">D.D3 Demonstrate consistently good technical understanding and analysis of computer support, including the application of relevant behaviours and general engineering skills to a professional standard.</td></tr>
<tr><td>D.P6 Explain how health and safety, computing and general engineering skills were applied effectively during the support of a computer system.
D.P7 Explain how relevant behaviours were applied effectively during the support of a computer system.</td><td>D.M4 Recommend improvements to the support of the computer system and to the relevant behaviours applied.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aims: B and C (B.P3, C.P4, C.P5, B.M2, C.M3, BC.D2)

Learning aim: D (D.P6, D.P7, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- engineering computer systems, such as CNC, CAD workstations, CAM, measurement and safety systems including PAT tools. It is not essential but it would also benefit learners to have access to automated systems such as an automated material handling system
- basic and appropriate specialised hardware components together with relevant catalogues, application notes and data sheets
- software to aid the support of computer systems, e.g. client and server operating systems (free versions downloaded from the internet such as Linux variations), CAD, materials resource planning/enterprise resource planning systems (free versions are available).

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate the support for two different computer systems and contrast the support given based on the intended purpose of the system. For example, learners will evaluate the support for a CNC system and a stock control system, comparing and contrasting the different key components, inputs and outputs used and how they would be maintained. Learners will justify possible improvements to the support of an organisation's computer systems, for example upgrades to a stock control system to adapt to different material-handling devices, including using material-sensitive sensors for liquid, solid and gaseous materials.

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 terms and will be of a high standard of written language, for example with correct grammar.

For merit standard, learners will analyse the five support characteristics for two contrasting computer systems. The analysis will be thorough and consistent across the different support characteristics. For example, the contingency planning support for a CNC machine would be focused on ways to minimise lost manufacturing output, personnel time and data in the event of system failure within the machine, and for a stock control system the contingency plan would assess potential risks and areas for improvement. Learners should also identify the frequency of support required to ensure consistent functionality in the two systems.

Overall, the analysis will be logically structured, technically accurate and easy to understand.

For pass standard, learners will cover in their evidence the policy and safety support characteristics that apply to the two different systems. For example, they will explain what safety critical procedures must be followed when supporting a CNC machine and the autonomous parts of a stock control system to avoid harm to self and others in close proximity.

Learners' evidence will also cover the contingency-planning and security-support characteristics, for example the security support of a CNC system and a stock control system that require protection against external malicious threats.

Learning aims B and C

For distinction standard, learners will create a support plan and undertake maintenance for an industrial computer system, providing evidence of consideration for at least one of each route map, schedule, Gantt chart and safe working procedures. Learners will also plan for potential emergency situations to ensure continuation of operations, and the ISO/IEC standards will be applied.

They will ensure their plans meet relevant health and safety legislation for the procedures being carried out. For example, where a software upgrade is required to optimise the CNC system, the plan will contain a task risk assessment and requirements of personal protective equipment for the operator to carry out the procedure ensuring safety of self and those in close proximity, and the continued operation of the system afterwards.

As part of the support activity, learners will optimise the system's hardware and software and test the performance of the system before and after the upgrade to demonstrate the performance improvement. For example, where a software upgrade is required to optimise the performance of a CNC system, they will upgrade the existing software and simulate the manufacture of a batch of components. During the process, they will ensure they are conforming to health and safety legislation and safe working practices regarding electrical equipment and manual handling, and show how their plans meet ISO/IEC standards outlined in the unit content.

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 will use correct technical terminology.

For merit standard, learners will develop a detailed set of planning documents for the maintenance and support of an industrial computer system by analysing its intended purpose and function. For example, a maintenance plan for a stock-control system may identify the following risks to business continuity: hacking, faulty readings, sensor failures and cooling system malfunctions; learners will suggest preventative measures.

Learners will complete system maintenance according to a planned checklist, and identify areas for improvement in response to testing. For example, learners may plan and carry out the maintenance support on a stock control system, identifying potential fault areas and components that require specialised support, and suggesting how they can be prevented. Learners will also improve the performance of the system, perhaps by the automation of some routine support tasks, for example system backups and upgrades.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will create a support plan for an industrial computer system covering contingency planning, levels of support, standard operating procedures and identifying any tasks that could be automated. The plan will explain how to ensure consistent and desired functionality of the system, such as backing up any unsaved data prior to undertaking any maintenance and including a maintenance checklist. For example, for a stock-control system, the operating system's images and data would be backed up in the event of malfunction during or after the maintenance, and could be restored to ensure continuity of the system.

Learners will undertake routine housekeeping on the system and use automated tools to support the system. For example, they could create and undertake maintenance on the stock control system, identifying areas where faults and improper function could arise, such as sensors, data storage, cooling and visual display units. Learners will test the performance of the system, explaining, using the test data, how performance improvements could be made to the system. For example, for the stock-control system, a more accurate volume sensor may be installed that gives readings in microlitres instead of centilitres.

Overall, the explanations should be logically structured, although basic in parts. They may contain minor technical inaccuracies relating to terminology, such as confusing the larger and smaller volume measurements used in a stock-control system.

Learning aims D

For distinction standard, learners will show in their evidence that during the previous assignments they have demonstrated relevant behaviours and general engineering skills to a professional standard. For example, they will demonstrate professional communication and customer-awareness skills. They will also explore relevant health and safety legislation, and apply the ISO/IEC standards, considering the benefits to the organisation and society.

As part of the refinement process, the evidence will demonstrate a technical understanding and skills needed to support an industrial computer system. For example, learners will clearly differentiate risks and preventative measures between systems.

Overall, learners will use the correct technical engineering terms, clearly differentiate facts from opinion and meet all deadlines.

For merit standard, learners will give detailed examples in their evidence, for example notes, logbook or the lessons learned report, where improvements could be made to the:

- planning of the support to be given to the computer system (route map(s), schedule(s), Gantt chart(s)), for example how thorough planning helps to ensure a smooth and efficient maintenance process
- system's hardware and software, for example choosing the most appropriate hardware and software for a specific system, including research on possible pitfalls and known issues with particular parts
- application of relevant behaviours, for example how listening to instructions has resulted in an activity running smoothly or a maintenance task proceeding as intended.

Overall, their suggested improvements should be reasonable and practical, explanations will be professional and they will use engineering terminology accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will cover in their lessons-learned report the management of health and safety, the implementation of the support plan and general engineering skills, and a reflection of personal performance. The report will explain:

- what actions were taken to manage health and safety in the workplace, for example what PPE was used and whether any unforeseen issues occurred
- electrical and computer engineering skills, such as identifying components and their characteristics, and following installation procedures
- how general engineering skills were used, such as the use of IT and interpreting drawings
- what behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

Overall, the evidence will be basic in its approach with some use of technical language, but it may not be consistent and there may be some errors throughout.

Links to other units

This unit links to:

- Unit 5: A Specialist Engineering Project
- Unit 6: Microcontroller Systems for Engineers
- Unit 10: Computer Aided Design in Engineering.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speaker
- technical workshops involving staff from local organisations with experience of supporting computer systems
- contribution of ideas to unit assignment/project materials.

Unit 35: Computer Programming

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will understand how computer programs are designed and structured. They will develop a computer program to solve an engineering-based problem.

Unit introduction

Computer programming, often referred to as software development in industry, is an integral part of most engineering organisations. The advancements in modern computing have driven the need for more complex and higher functioning software program solutions, automating and facilitating common procedures from inventory control to embedded devices in cars.

In this unit, you will learn how computer programming tasks are performed in engineering organisations, the roles of individuals in typical software projects and the methodologies that can be implemented to support the design and development phases of a project. You will also analyse and design a new software program to solve an engineering-based problem, producing design documentation, user stories and test scripts for a software program. You will develop the software program in a suitable computer programming language, testing and refining the solution throughout the process, and will review and reflect on the process once complete.

An understanding of how computer programs work is an essential task for engineers, and the problem-solving skills developed in software engineering are valuable and transferable across all types of engineering. This unit will help to prepare you for employment, for example as an information technology (IT) engineer or an IT operations technician, for an apprenticeship or for progression to higher education.

Learning aims

In this unit you will:

A Examine the project structures and methods used in the development of software programs

B Design a software program based on user requirements to solve a problem

C Develop a software program to solve a problem

D Review and reflect on own performance for the development of a software program.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the project structures and methods used in the development of software programs	**A1** User requirements and typical project job roles **A2** Software development methodologies **A3** Development stages	A case study of the initial development plan of a software project to cover a typical software development life cycle, discussing the stages of development and the key roles of a development team. It will include a comparison of software development methodologies, identifying which areas may benefit from a project and where pitfalls may occur.
B Design a software program based on user requirements to solve a problem	**B1** Design documentation and system design diagrams	Design documentation and diagrams of user requirements, user interface mock-ups, other structured tools such as flow charts, and test scripts. The implementation of the designed software program, using two programming paradigms and a wide range of constructs. The testing of the software program, using test scripts to demonstrate functionality and conformance to the brief.
C Develop a software program to solve a problem	**C1** Programming standards and constructs **C2** Development tools **C3** Testing and reporting	
D Review and reflect on own performance for the development of a software program	**D1** Lessons learned from developing a software program **D2** Personal performance while developing a software program	The evidence will focus on what went well and what did not go so well when developing a software program, reviewing the processes and reflecting on own performance. A portfolio of evidence generated while developing a computer program and reviewing the processes and reflecting on own performance.

Content

Learning aim A: Examine the project structures and methods used in the development of software programs

A1 User requirements and typical project job roles

User requirements and typical project job roles in software development projects.

- User requirements, e.g. functions the software needs to perform, problems with a current system or process that need to be eased.
- Typical job roles in a software development team, including:
  - software developer – design and build computer programs to solve problems
  - testers – ensure functionality and uncover potential problem areas for the user
  - business analysts – provide a communication point of contact between the development team and project manager
  - project managers – ensure the smooth and effective running of a project's development and its resources (people, money and infrastructure)
  - product owners – stakeholders in a project, take responsibility for a project and promote it throughout the organisation.

A2 Software development methodologies

Software development methodologies commonly used to create computer programs, to include:

- waterfall model:
  - process stages – requirements, design, implementation, testing, deployment and maintenance
  - advantages and limitations, e.g. small rigid projects that have little or no outside influence and a linear approach to program development, which can be restrictive and inhibit creativity in a team
- rapid application development:
  - process stages to include requirements, user design, construction, and deployment
  - advantages and limitations, e.g. benefit is to allow customers to interact and feedback on a prototype and limitation is the capacity of the team to adapt to change under short timeframes
- agile:
  - scrum – flexible and iterative development methodology allowing a development team to work together to reach a goal during a set time 'sprint'
  - sprint planning – story points, velocity of a team and burn downs
  - epics – a large feature or function encompassing a set of user stories
  - user stories – functionality described from the perspective of the user
  - tasks – activities carried out by the developer during the implementation stage
  - methods of tracking – web-based tools and card-based boards
  - advantages and limitations, e.g. projects with unclear or unknown user requirements and the complexity of the project methodology.

A3 Development stages

- Quality assurance (QA) – identifying mistakes and potential problem areas in a software solution, raising of bugs (error or a fault within the software program).
- User acceptance testing – a facility to allow a user to test and accept the features provided in a software program.
- Operational test environment(s) – a facility allowing the testing of a pre-release version of software to test for operational readiness of a software program.
- Live deployment – wide release of a software product readily available to the user.

Learning aim B: Design a software program based on user requirements to solve a problem

B1 Design documentation and systems design diagrams

- Project time plan, e.g. Gantt chart, estimated effort and duration for tasks and critical path analysis to set priorities for different tasks.
- Terms of reference and specification documentation, to include:
  - specification and user requirements of the desired program
  - structured design tools – pseudo code, flow chart (to BS4058 or other relevant international equivalent) and decision tables
  - language to be used with the reasons for the choice – interfacing with existing programs, developer preference and skill set, customer limitations on infrastructure
  - target user platform, e.g. desktop, web, mobile, embedded.
- System requirements for development and end use, e.g. minimum and recommended specifications for processor, memory, hard disk space, networking capabilities.
- User interface mock-ups, e.g. screenshots, graphical images and user stories and tasks, including developer subtasks.
- Test scripts for expected and unexpected conditions for the software program in operation.

Learning aim C: Develop a software program to solve a problem

C1 Programming standards and constructs

- Standards, to include:
  - programming paradigms:
    - event driven – a program in which the flow is determined by events, e.g. mouse clicks, key presses, sensors
    - procedural – a program in which the flow is determined by a list of instructions
    - object-orientated – a program built up using objects that contain parameters, giving them unique features, and methods, giving them actions
  - language specific syntax, e.g. annotation, commands
  - advantages and disadvantages of graphical versus text-based user interfaces (TUI)
  - quality of the software program, to include:
    - usability – more intuitive, efficient and enjoyable to use by a human
    - reliability – reduced failures and errors and improved life of the software
    - maintainability – reduced cost of maintaining the software that allows developers to focus on new software projects.
- Constructs, to include:
  - sequence
  - variables – naming conventions, scope of variables, local and global
  - operators including: arithmetic [+, -, *, /, MOD and DIV], relational logical [=, >, <, =>, =< and <>], Boolean [true and false] and logical [AND, OR, NOT, XOR]
  - conditional logic:
    - if statements
    - switch - case
  - iteration:
    - while, do-while
    - for, for each
  - algorithms – sections of code to perform a structured action, to include:
    - complexity – describing the execution time or space used to perform an action
    - reusability – modularised approach to development where common methods and parameters can be reused
  - methods and functions, to include:
    - return types – values to return from functions to the caller statement
    - parameters – passing data and logic into methods to affect the outcome
    - recursion – methods that call themselves with different or modified data

- objects and classes
- multithreading, to include:
  - main thread – the main operating process of the program, controls the flow of the program from start to finish
  - background thread – dynamic, fabricated threads allowing processing to occur 'off' the main thread without affecting the user experience, e.g. connecting to a database or a web service, or processing a large amount of data
  - benefits and limitations, e.g. beneficial – responsiveness is increased and effective use of multiple processor cores, limited – 'misbehaving' threads that can crash computer processes.

C2 Development tools

- Integrated development environments – source code editor, build tools and debugger.
- Software development kits – a set of tools and software allowing development on a specific system.
- Application programming interfaces – a set of interfaces that allow a developer to use other software without access to source code or original development tools.
- Debuggers – a process to allow a developer to interact and manipulate source code during the execution of the program.
- Source control, to include:
  - branching and merging – division of source code to allow multiple versions of code
  - latest version
  - resolution of conflicts – comparison and resolution of differences in code of the same file or class.

C3 Testing and reporting

Types of testing, to include:

- functionality and usability testing:
  - against user stories
  - against test scripts (under expected and unexpected conditions)
- regression testing and reporting:
  - summary of testing – including pass/fail/skipped details
  - steps to reproduce
  - actual, expected and unexpected scenarios.

Learning aim D: Review and reflect on own performance for the development of a software program

D1 Lessons learned from developing a software program

Scope of the lessons learned should cover:

- computer programming skills, e.g. proper use of constructs and syntax, use of procedures and functions, choice of data types and operations within a process
- general engineering skills, e.g. mathematics and logical thinking.

D2 Personal performance while developing a software program

Understand relevant behaviours for measuring and testing electronic circuits, to include:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving as problems occur, e.g. investigating the source of the problem, breaking it down into manageable chunks and areas for development, solving the problem.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the project structures and methods used in the development of software programs</td><td rowspan="2">A.D1 Evaluate, using language that is technically correct and of a high standard, the methodologies and job roles used in two different software development projects, explaining the purpose and importance of user requirements.</td></tr>
<tr><td>A.P1 Explain the methodologies and typical job roles used in two different software development projects and the purpose and importance of user requirements.</td><td>A.M1 Compare the methodologies and job roles used in two different software development projects, explaining the purpose and importance of user requirements.</td></tr>
<tr><td colspan="2">Learning aim B: Design a software program based on user requirements to solve a problem</td><td rowspan="4">BC.D2 Optimise a functional, useable, fully-annotated and efficient software program that operates as intended, with some consideration for unexpected events and using a comprehensive set of design documents, including a project plan and test scripts.</td></tr>
<tr><td>B.P2 Explain the user requirements for a new software program.
B.P3 Design a new software program with a user interface to meet a client brief, including an outline project plan and test scripts.</td><td>B.M2 Analyse the user requirements, identifying areas where potential pitfalls could occur.
B.M3 Design a new software program with an effective user interface to meet a client brief, including a project plan and test scripts.</td></tr>
<tr><td colspan="2">Learning aim C: Develop a software program to solve a problem</td></tr>
<tr><td>C.P4 Build a software program, using the designs and multiple programming paradigms to solve a problem.
C.P5 Perform tests on the software program against the user requirements, repairing functional faults.</td><td>C.M4 Build a software program with an effective user interface, using the designs and multiple programming paradigms to solve a problem.
C.M5 Perform regression tests on the software program, repairing any functional and usability faults.</td></tr>
<tr><td colspan="2">Learning aim D: Review and reflect on own performance for the development of a software program</td><td rowspan="2">D.D3 Demonstrate consistently good technical understanding and analysis of software development, including the application of relevant behaviours and general engineering skills to a professional standard script.</td></tr>
<tr><td>D.P6 Explain how health and safety, computer programming, and general engineering skills were effectively applied when developing a software program.
D.P7 Explain how relevant behaviours were effectively applied during the development of a software program.</td><td>D.M6 Recommend improvements to the development of a software program and to the relevant behaviours applied.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, B.M3, C.M4, C.M5, BC.D2)

Learning aim: D (D.P6, D.P7, D.M6, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- case study materials on software development projects
- modern, industrial programming, preferably a multi-paradigm language, for example .NET Framework languages (C#, Visual Basic), Pascal or Java
- task planning software (useful but not essential)
- commercial software tools, including free software such as PivotalTracker™
- relevant standards, as listed in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and appropriately detailed evaluation of the methodologies and job roles relevant to two contrasting software development projects. Learners will describe the characteristics of each methodology, identifying the areas that might benefit a project and individuals in the team, for example a project following the waterfall methodology may be inefficient as a change in user requirements during the development of the software program may result in the development being stopped and restarted. However, the same project following the agile scrum methodology would be able to adapt and change to meet the change in user requirements, making the approach more efficient and flexible.

Overall, learners' evidence, such as a case study, will be easy to read and understand by a third party who may be an apprentice software engineer. It will be logically structured and use technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling, and consistent reference to information sources.

For merit standard, learners will compare the methodologies and job roles relevant to at least two different software development projects, explaining the purpose and importance of user requirements in all stages of a project. For example, learners will justify the choice of a methodology for a project with respect to its flexibility due to changing user requirements.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the purpose and importance of user requirements in the stages of a software development project. They will also explain the typical job roles required, outlining the actions and responsibilities they have, for example a project manager following the waterfall methodology would have a duty to ensure developers were meeting their deadlines during the development stage.

Overall, learners' evidence will be logically structured although it may be basic in parts. Their explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology, for example a developer should not receive user requirements directly from a customer.

Learning aims B and C

For distinction standard, learners will develop a fully functional software program that has been tested for usability, functionality and against user requirements.

Learners will design the new software program with an effective user interface, ensuring the client brief is adhered to. Their project plan will cover all the main activities and the vast majority of time estimates will be reasonable. Their program design will break down key operations into relevant constructs that link logically and coherently together, including the handling of some unexpected events, and their test scripts will confirm a fully functioning software program under expected and some unexpected conditions.

Learners will build an efficient software program, using their designs, and incorporate multiple programming paradigms to produce a functional program with an effective user interface. Their software program will contain a range of appropriately selected constructs that have been used correctly. Also, the program will be concise, efficient and have the facility to handle some unexpected events, for example the program might use a known sorting algorithm to organise data in an efficient way. Annotation will be consistent and appropriate and will demonstrate a thorough understanding of the key areas of the program and the underpinning constructs. Learners' programs will be well organised, structured and formatted so that a competent third party could efficiently interpret and update them.

Learners will provide a fully detailed regression test, using the test scripts on their software program and producing documentation of the results of the testing process, including testing of some unexpected events. Any functional or usability faults that occur from the testing will be repaired and full testing will be repeated until no new faults arise. A fully supported judgement of conformity will be made by linking test results to the client brief.

Overall, the evidence will be easy to read and understand by a third party who may be a professional software engineer. It will be logically structured and use accurate technical engineering terms appropriately.

For merit standard, learners will analyse the user requirements to identify where potential pitfalls could occur during the design and development stages, for example the user may require data from a source that is not accessible or affordable within the organisation, such as address searches or mapping.

Learners will design the new software with an effective user interface, for example one that is intuitive and efficient to use, ensuring the client brief is adhered to. Their project plan will cover all the main activities and most of the time estimates will be reasonable. Their program design will break down key operations into relevant constructs that link together and their test scripts will confirm a fully functioning software program under expected conditions.

Learners will build a software program, using their designs, and incorporate multiple programming paradigms to produce a functional program with an effective user interface, for example learners could use an object-orientated language such as C#.NET or VB.NET that encompasses event driven and procedural paradigms. Their software program will contain a range of appropriately selected constructs that have been used correctly. Annotation will be present and appropriate and demonstrates understanding of key areas of the program and underpinning constructs. Learners' programs will be well organised and formatted so that a competent third party could interpret and update the program.

Learners will perform a regression test, using the test scripts, on their software program, repairing any functional and usability faults as they arise. A judgement of conformity will be supported by the test results, but they may not all be linked back to the client brief.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will design a new software solution to meet a client brief and prepare an outline project plan. Their design will cover the user interface and use structured tools, for example flow charts, and explain the user requirements. Their program design will break down key operations that link together and their outline test scripts will indicate a limited understanding of the intended software program. If centres are using the agile methodology, then user stories and developer tasks must be included.

Learners will build their software program using their designs and user requirements. Their program will use two programming paradigms and it will contain a range of more basic constructs, which are generally appropriate and have been used correctly. The program may be inefficient, for example by not using 'functions' appropriately, using long algorithms when shorter versions are possible and adding in unnecessary functionality. Annotation will be present but focused on one area of the program and will demonstrate an incomplete understanding of the key areas of the program. Their program structure may have inconsistencies in organisation and/or formatting.

Learners will perform simple tests against the user requirements, using test scripts and repairing any functional faults as they occur. If present, a judgement of conformity is not supported by test results and will not be linked back to the client brief.

Overall, learners' evidence will be logically structured although it may be basic in parts. Their explanation may be limited in places and may contain minor technical inaccuracies relating to engineering terminology, for example tests may not contain steps to reproduce the expected results and the outline project plan may miss out some important tasks.

Learning aim D

For distinction standard, learners will demonstrate relevant behaviours and general engineering skills to a professional standard throughout the activity in assignment 2, for example all assignments will be completed on time and the practical activities will be planned out in advance, with any problems encountered solved.

For lessons learned evidence (for example a report), learners will present a good technical understanding of the software program.

Overall, learners' evidence will include a balanced view about actions taken and the software development process, including health and safety compliance and possible improvements. They will use technical engineering terms correctly and consistently and 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 provide evidence, such as a lessons learned report, that gives examples of where improvements could be made to the:

- development of the software program, which could cover the program writing methods and include the choice and use of constructs, as well as testing
- application of relevant behaviours, for example regular progress reviews and time management.

Overall, the suggested improvements will be reasonable and practical, explanations will be professional and engineering terminology used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will provide evidence such as a lessons learned report of around 500 words in length. The report will explain:

- which computer programming skills were applied, such as the program constructs, instructions and debugging methods required to develop the program
- how general engineering skills were used, such as numeracy skills and logical thinking
- how behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time, as well as problem solving.

Overall, learners' 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.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 32: Computer System Principles and Practice
- Unit 33: Computer Systems Security
- Unit 36: Programmable Logic Controllers
- Unit 38: Website Production to Control Devices.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local computing organisations and engineering organisations with expertise in computer programming
- contribution of ideas to unit assignment/project materials.

Unit 36: Programmable Logic Controllers

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will apply skills and understanding to develop an industrial Programmable Logic Controller (PLC) system to solve an engineering problem.

Unit introduction

Industrial processes have become increasingly automated. PLCs are widely used to provide the control element in industrial drives. These are systems that include motors, motor control, sequencing and communications functions to optimise the operation of the motor and also the machine or process that it operates, either autonomously or as part of a larger factory automation system.

In this unit, you will understand the use and applications of PLCs, the hardware and software that makes up an industrial PLC control system, and the interaction needed between the component parts. You will gain knowledge of the range of PLCs available and how to select an appropriate one, along with the associated hardware for a given application. You will develop knowledge and practical skills essential to configure and program a PLC and investigate instruction types through writing short programs. You will also gain knowledge and skills in fault-finding and debugging methods. You will demonstrate your knowledge and skills by developing an industrial control PLC system to solve an engineering problem.

Many industries require engineering technicians and engineers with knowledge and skills in automation control. This unit will help you to prepare for employment, for example as a multi-skilled engineering technician, as part of an apprenticeship, or for entry to higher education to study manufacturing engineering.

Learning aims

In this unit you will:

A Investigate the technology used in industrial Programmable Logic Controller systems

B Explore programming structures and methods to control Programmable Logic Controllers

C Develop an industrial Programmable Logic Controller system to solve an engineering problem

D Review the development of an industrial control system and reflect on own performance.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Investigate the technology used in industrial Programmable Logic Controller systems</td><td>A1 Features and functions of PLCs
A2 PLC system hardware
A3 Internal operation of Programmable Logic Controllers</td><td>A report comparing two contrasting industrial PLC control systems.</td></tr>
<tr><td>B Explore programming structures and methods to control Programmable Logic Controllers</td><td>B1 Integrated development environment (IDE)
B2 Programming skills for PLCs
B3 Test and debug PLC programs</td><td>Collated reports and programs demonstrating the use of PLC instructions in increasingly complex situations.</td></tr>
<tr><td>C Develop an industrial Programmable Logic Controller system to solve an engineering problem</td><td>C1 Problem definition and identification of hardware requirements
C2 Physical system design and assembly
C3 Software design tools
C4 Program development
C5 Testing a PLC system</td><td rowspan="2">A portfolio of evidence covering the design and development of a PLC system to solve an engineering problem. This should be accompanied by one or more observational witness statements, photographic evidence, and formal testing of the final system.
The reflective evidence will focus on what went well and what did not go so well when developing an industrial PLC control system, reflecting on own performance and possible improvements.</td></tr>
<tr><td>D Review the development of an industrial control system and reflect on own performance</td><td>D1 Lessons learned from developing an industrial PLC system
D2 Personal performance while developing an industrial PLC system</td></tr>
</table>

Content

Learning aim A: Investigate the technology used in industrial Programmable Logic Controller systems

A1 Features and functions of Programmable Logic Controllers

PLC system requirements, including:

- power supply unit (PSU)
- central processor unit (CPU)
- at least one input/output unit.

Features and functions of PLC architecture, to include:

- CPU block diagram of components and a corresponding description, including:
  - input/output (I/O) interface between the microelectronics of the programmable controller and the real external world, providing all necessary signal conditioning and isolation functions
  - memory, to include:
    - operating system or executive memory – read-only memory (ROM)
    - memory used by the operating system – random-access memory (RAM)
    - I/O status memory mapped to inputs and outputs, giving every input and output module point a unique address (RAM)
    - data memory allocated to timers, counters (RAM)
    - user memory to store, e.g. programs, messages
    - types of memory – RAM, erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), flash
- Types of programmable logic controller, including:
  - unitary (compact), PSU, CPU, memory, (limited) input and output in a single unit
  - modular, to include:
    - small, with PSU, CPU and one or two input and output (I/O) units slotted together or on a backplane
    - medium-sized, with PSU, CPU and several modules (usually) slotted on a backplane
    - large, with PSU, CPU and several modules including more complex functions, such as communications, distributed control, supervisory control and data acquisition (SCADA)
- Choosing a suitable PLC for a given task, to include:
  - number and types of I/O
  - input/output capacity
  - size of memory
  - CPU and instruction set speed and power
  - technical support and backup
  - cost
  - complexity of the problem, e.g. involving communications and distributed control.

A2 Programmable Logic Controller system hardware

- Interfaces including:
  - input interfaces, e.g. direct current (DC) and alternating current (AC) voltage digital input circuits, pulse counters, analogue to digital converters (ADC)
  - output interfaces, e.g. relay, transistor, triac output circuit, digital to analogue converters (DAC).
- Peripheral input devices, to include:
  - digital, e.g. mechanical switches, proximity sensors
  - analogue, e.g. input transducers, including temperature, pressure, flow.

- Peripheral output devices, to include:
  - digital – indicators, electromechanical (e.g. relays and contactors), electro-pneumatic (e.g. control valves)
  - analogue, e.g. motor position and speed.

A3 Internal operation of Programmable Logic Controllers

PLC scan operation, including:

- input scan
- program scan
- output scan.

Learning aim B: Explore programming structures and methods to control Programmable Logic Controllers

B1 Integrated development environment (IDE)

- Overview of the functions of a PLC integrated development environment, including source code editor, build tools and debugger.

B2 Programming skills for Programmable Logic Controllers

- Overview of PLC programming methods, to include:
  - ladder diagrams
  - statement listing
  - functional diagrams
  - graphical programming languages
  - mimic diagrams
  - sequential function charts (SFCs).
- Use and interpretation of number systems, including numeric data types and number conversion between denary, binary, hexadecimal and binary coded decimal (BCD).
- Programming instructions using an appropriate programming method (e.g. ladder logic), to include control of outputs using:
  - input, output and internal value addressing
  - combinational logic where the output is dependent on the combination of inputs at a given instant, e.g. the Boolean expression:

    $Y_2 = (X_1 \cdot Y_1) + X_2$
  - sequential logic where the output is dependent not only on the actual inputs but on the sequence of the previous inputs and outputs, e.g. extending a pneumatic cylinder on the press of a button until it reaches a limit switch then returning to the original position
  - timers and counters, e.g. extending a pneumatic cylinder on the press of a button until it reaches a limit switch, waiting five seconds then returning to the original position
  - motion step diagrams (MSD) (sometimes called step-action or traverse-time diagrams) to describe the position of sensors and actuators in a sequence.
- Efficiency of a PLC program is programming in a manner that uses a low amount of overall resources when the program is executed. It is influenced by a number of factors, including:
  - the code structure, e.g. use of subroutines or procedures
  - commands selected and combined to create the program, e.g. some instructions use more memory or take more time to complete.

B3 Test and debug Programmable Logic Controller Programs

- Testing, including:
  - unit testing where parts of the program are treated as black box to determine if an expected output is achieved from a known input
  - program simulation and/or onscreen monitoring
  - dry run the program.
- Debugging including syntax errors, logical errors and error correction.

Learning aim C: Develop an industrial Programmable Logic Controller system to solve an engineering problem

C1 Problem definition and identification of hardware requirements

- Analysis of a client brief to select appropriate hardware, including type of PLC and input and output devices.

C2 Physical system design and assembly

- Physical system design, to include:
  - description of the system block diagram
  - wiring diagram including external devices, such as relays or limit switches, that are independent of the PLC system to provide protection for any part of the system that may cause personal injury or damage.
- Assembling the physical PLC system, including:
  - regard to safe operating procedures
  - electrical connections:
    - separation of wiring regions, primary side (power input), secondary or logic side (PLC and input/output interfaces), field side (inputs and outputs)
    - input/output connections (and common connections)
    - cable identification/markers
  - other connections, e.g. pneumatic, hydraulic.

C3 Software design tools

Structured design tools, including:

- develop a list of steps using structured English or a flow chart (using standard symbols) that describe a possible solution to the problem
- identify repeating patterns
- develop a set of instructions to solve the problem using sequence, selection and iteration constructs
- test plan to include expected results and exceptional values.

C4 Program development

- Program structures, to include:
  - sequence of instructions to be carried out
  - selection (if ... then)
  - iteration, e.g. use of a counter or timer.
- Operators, including:
  - arithmetic, e.g. add (ADD), subtract (SUB), negate (NEG), divide (DIV), multiply (MUL), modulus (MOD)
  - comparator, e.g. equal (EQ), less than(LT), greater than (GT)
  - Boolean, e.g. logic functions AND, OR, NOT, XOR give output True or False.
- Subroutines to complete frequently used and repeated instructions.
- Annotated PLC program.
- Results of testing and debugging.
- Operating instructions.

C5 Testing a Programmable Logical Controller system

- Testing and fault finding a PLC system, including checking that:
  - all connections (electrical, pneumatic, and hydraulic) to the PLC and the plant are complete, safe, to the required specification and meeting local standards
  - the incoming power supply matches the voltage setting for which the PLC is set
  - all protective devices are set to their appropriate trip settings
  - all input/output devices are connected to the correct input/output points and give the correct signals
  - the emergency stop button(s) work/s
  - the corresponding indicators on the input module operate when input devices are manipulated to give the open and closed contact conditions.
- Loading and testing the software for function and to debug, using IDE tools and other appropriate techniques.

Learning aim D: Review the development of an industrial control system and reflect on own performance

D1 Lessons learned from developing an industrial Programmable Logical Controller system

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- PLC control system skills, including selecting and assembling hardware for an industrial control system and writing computer programs
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while developing an industrial Programmable Logical Controller system

Understand relevant behaviours for developing an industrial PLC control system, including:

- time planning and management to complete all the different activities in an appropriate time and in an appropriate order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving issues as they occur, e.g. logical and syntax program errors and hardware assembly faults.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Investigate the technology used in industrial Programmable Logic Controller systems</td><td rowspan="2">A.D1 Evaluate, using language that is technically correct and of a high standard, the suitability of the technology found in two contrasting industrial PLC systems, suggesting possible improvements.</td></tr>
<tr><td>A.P1 Explain the features and functions of the technology found in two contrasting industrial PLC systems.</td><td>A.M1 Analyse the suitability of the technology found in two contrasting industrial PLC systems.</td></tr>
<tr><td colspan="2">Learning aim B: Explore programming structures and methods to control Programmable Logic Controllers</td><td rowspan="2">B.D2 Critically analyse, using example programs, how PLC instructions including timers and counters are used to efficiently control system outputs.</td></tr>
<tr><td>B.P2 Explain, using example programs, how PLC instructions including timers and counters are used to control system outputs.</td><td>B.M2 Discuss accurately, using example programs, how PLC instructions including timers and counters are used to control system outputs.</td></tr>
<tr><td colspan="2">Learning aim C: Develop an industrial Programmable Logic Controller system to solve an engineering problem</td><td rowspan="4">CD.D3 Optimise a functional, fully-annotated and efficient PLC system safely that operates as intended, whilst recommending improvements and applying relevant behaviours and general engineering skills to a professional standard.</td></tr>
<tr><td>C.P3 Design a PLC system to solve an engineering problem.
C.P4 Build and test a functional PLC system safely to solve an engineering problem.</td><td>C.M3 Develop a functional, annotated PLC system safely that operates as intended.</td></tr>
<tr><td colspan="2">Learning aim D: Review the development of an industrial control system and reflect on own performance</td></tr>
<tr><td>D.P5 Explain how health and safety, PLC system and general engineering skills were effectively applied during the development of a system.
D.P6 Explain how relevant behaviours were effectively applied during the development of an industrial PLC system.</td><td>D.M4 Recommend improvements to the development of an industrial PLC system and to the relevant behaviours applied.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.M2, B.D2)

Learning aims: C and D (C.P3, C.P4, D.P5, D.P6, C.M3, D.M4, CD.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of PLCs and input/output devices
- process rigs
- an integrated design environment to permit programming and implementation of device/applications for circuit performance and debugging
- a range of relevant manuals, reference data and manufacturers' information.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate two contrasting industrial PLC systems. The evaluation will be detailed, comprehensive and will demonstrate how the systems work and why the technology (hardware components) is suitable for the application. Learners will determine the number of inputs and outputs required and identify specific devices and hardware used in the systems. For example, a PLC system to control a single bidirectional pneumatic cylinder need only be a unitary PLC, with a limited number of inputs and outputs for start/stop buttons, limit switches such as reed switches or rocker switches, and an electro-pneumatic control valve. Learners will also identify potential improvements to the existing systems, for example actuators that are more energy efficient.

Overall, the evidence, such as a report, will be easy to read and understand by a third party who may be an apprentice engineer. It 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 analyse two contrasting industrial PLC systems with respect to the suitability of the features, the functions of the hardware components and the complexity of each system. For example, learners will justify the selection of PLC type and input/output devices with reference to the system requirements and the devices' technical specifications.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the features and functions of the hardware components found in two contrasting PLC industrial systems. For example, they will determine the generic type of PLC used and other hardware, including switches and motors. Their explanations may lack detail and/or contain omissions, for example they may describe an input as a switch, but not specify whether it is normally open (n.o.) or normally closed (n.c.).

Overall, the evidence will be logically structured although it may be basic in parts. Their explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology, for example the function of a reed switch may not indicate that it is magnetically operated.

Learning aim B

For distinction standard, learners will critically analyse the operation of PLC instructions, using example programs to demonstrate how each instruction operates, and how data is used. For example, they will explain how a timer can be pre-loaded with a value and decremented on each pass until it reaches zero. They will collate detailed evidence of progressively more complex programs, detailing the purpose. Annotation will be consistent and appropriate and demonstrate a thorough understanding of how key areas of the program work. Learners will include test results showing the program in operation. Learners will debug the code so that it is functional and they will also provide evidence of how they have improved the efficiency of the more complex programs, for example using subroutines for recurring functions.

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 analyse how PLC instructions can be combined to control system outputs. They will demonstrate how counters and timers can be used, but may not explain in detail how a counter or timer can be incremented or decremented to reach zero or a pre-determined value. They will collate detailed evidence of progressively more complex programs, detailing their purpose. Annotation will be present and appropriate and demonstrate how key areas of the program work, and test results showing the program in operation will be given. Learners will debug the code so that it is functional and may provide limited examples of how the more complex programs were made more efficient.

Overall, the evidence will be a well-organised record of the practical work carried out. It will be technically accurate and easy to understand.

For pass standard, learners will explain, using example programs, how PLC instructions, including counters and timers, can be combined to control outputs in industrial systems. They will collate detailed evidence of progressively more complex programs, detailing their purpose. Annotation will be present but it may be focused on a couple of areas of the program and it may demonstrate an incomplete understanding of how key areas of the program work or it may state the obvious, and test results showing the program in operation will be given. Learners will debug the code so that it is functional. The more complex programs may also be inefficient, for example repeating instructions in one long sequence rather than using subroutines.

Overall, the evidence will be an organised record of the practical work carried out. It will be easy to follow, but the descriptions may be basic and the use of technical language may be inconsistent. For example, the difference between normally open (n.o.) and normally closed (n.c.) contacts may not be explained.

Learning aims C and D

For distinction standard, learners will provide an in-depth analysis of an engineering problem and details of the final design solution in terms of the hardware and software. The hardware details will include specific identification of the hardware selected, block diagrams of the schematic and an annotated wiring diagram. The PLC program will be designed using structured tool(s) that break down key operations into relevant constructs that link logically and coherently together, and consideration will be given to the efficiency of the program and operation.

Learners will assemble the system safely and write the program based on their design. The PLC program will comprise a range of appropriate constructs that have been used correctly and the program will be concise and efficient. Annotation will be consistent and appropriate and demonstrate thorough understanding of the key areas of the program and underpinning constructs. The test results will demonstrate how learners' test plan has been used to verify that the system functions as intended and will provide some evidence of optimisation.

Throughout the activity, learners will demonstrate relevant behaviours and general engineering skills to a professional standard. For example, all assignments will be completed on time and the practical activities will be planned out in advance and the finished PLC system will fully function as intended by the client brief, hence demonstrating commercial awareness.

The lessons learned evidence, for example a report, will present a good technical understanding of PLC system development. Overall, the evidence will include a balanced view of the actions taken and of the PLC system's development, including health and safety compliance. Technical engineering terms will have been used correctly and consistently. 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 provide an analysis of an engineering problem with a final design solution of a PLC system covering the hardware and software. The hardware details will include identification of the hardware selected, block diagram (schematic) and connections used. The PLC program will be designed using structured tool(s) that break down key operations into relevant constructs that link together.

Learners will assemble the system safely and write the program based on their design. The PLC program will comprise a range of appropriately selected constructs that have been used correctly and will be annotated appropriately, demonstrating how key areas of the program work. The test results will demonstrate that the system functions as intended.

The evidence, such as a lessons learned report, will give examples of where improvements could be made to the:

- development of a system, which could cover the choice and use of hardware, program writing methods including the choice and use of constructs, theoretical calculations and testing
- application of relevant behaviours, for example regular progress reviews and time management.

Overall, the suggested improvements should be reasonable and practical, explanations will be professional and engineering terminology used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will provide a design solution covering the hardware and software for a PLC system to solve an engineering problem. The hardware details will include identification of the hardware selected and block diagram schematic, but it may lack detail, for example which devices are connected to which input/output terminals. The PLC program will be designed using structured tool(s) that break down key operations that link together.

Learners will assemble the system safely and write the program based on their design. The program will comprise a range of basic constructs, which are generally appropriate and have been used correctly. Annotation will be present but it may be focused on a couple of areas of the program and it may state the obvious, or demonstrate an incomplete understanding of how key areas of the program work. For example, annotation could say, 'this is a timer'. Learner evidence will demonstrate how the system has been tested, but it may not be evident from the results that the system fully functions as intended.

Learners' evidence will include a lessons learned report, of around 500 words in length. The report will explain what:

- actions were taken to manage health and safety in the workplace, for example whether any unforeseen issues occurred
- PLC electronic engineering skills, such as identifying components, using schematic diagrams and wiring circuits correctly
- program development skills, such as using program constructs, instructions and debugging methods required to develop an industrial control system
- how general engineering skills were used, such as the use of IT and numeracy skills
- how behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

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.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 19: Electronic Devices and Circuits
- Unit 33: Computer Systems Security
- Unit 35: Computer Programming.

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 Programmable Logic Controllers
- contribution of ideas to unit assignment/project materials.

Unit 37: Computer Networks

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will examine the types, applications, technologies and security of computer networking and develop a computer network system to meet a client brief.

Unit introduction

Computer networks form the core of many telecommunications, information technology and control systems in engineering. Many large engineering systems and products contain computer networks, from power stations to warships. Computer networks also offer services for e-commerce and entertainment and interact with all aspects of modern life.

In this unit, you will explore current types and applications of computer network systems and the available technologies (hardware, software, services and protocols), and evaluate their advantages and disadvantages. You will also explore how to protect the network against security threats and explore the networking protocols and standards that are used to connect computer networks. You will design and develop a basic local area network (LAN) and connect it via a complex corporate wide area network to the internet. You will construct and test a functional network using the available resources and optimise the network in terms of meeting the client brief, performance, security protection measures, and scalability.

Network engineering is a globally-recognised discipline, where a systematic and methodical approach is required and the demand for engineers is growing. As an engineer, you may need to undertake work on computer networks and systems involving computer networks. This unit will help prepare you for an engineering apprenticeship, an engineering degree in higher education, or for technician-level roles in a network engineering specialist subject.

Learning aims

In this unit you will:

A Examine the types, applications, technologies, and security of computer networks used in engineering

B Plan the implementation of a secure computer network infrastructure to meet a client brief

C Develop a secure computer network infrastructure to meet a client brief.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the types, applications, technologies, and security of computer networks used in engineering	**A1** Types and applications of computer networks in engineering **A2** Computer networking technologies – hardware, software and services **A3** Computer networking protocols and standards **A4** Network security	A report, examining current types and engineering applications of computer networks along with the enabling technologies, including the hardware, software, services, protocols and standards and network security.
B Plan the implementation of a secure computer network infrastructure to meet a client brief	**B1** Services planning **B2** Infrastructure planning **B3** Planning client support **B4** Security planning	Design documentation and planning for the development of a computer network.
C Develop a secure computer network infrastructure to meet a client brief	**C1** Construction of a computer network **C2** Security features and resources **C3** Systems testing	Completion of a practical activity to construct and test a networked computer system. Evidence should include test results, observation reports and witness statements, annotated screenshots and/or photographs of the network in operation.

Content

Learning aim A: Examine the types, applications, technologies, and security of computer networks used in engineering

A1 Types and applications of computer networks in engineering

- Types of computer networks and their characteristics:
  - scale of the network, e.g. local area network (LAN), wide area network (WAN), storage area network (SAN), internet, intranet and extranet and controller area networks (CAN)
  - network trends, e.g. IoT (Internet of Things), Industrial Internet of Things (IIoT), bring your own device (BYOD), cloud computing
  - wired, wireless transmission formats, e.g. infrastructure, speed, reliability
  - network topologies, including:
    - physical, e.g. star, bus, ring, mesh, tree and point-to-point
    - logical, e.g. Ethernet and token ring.
- Computer network models:
  - centralised computer systems, e.g. client/server
  - decentralised computer systems, e.g. peer-to-peer
  - distributed computer systems.
- Applications of computer networks in engineering:
  - data collection, analysis and modelling, e.g. manufacturing inventory systems and system efficiency and solving engineering problems
  - designing and prototyping engineered products, services, systems and processes
  - systems automation, e.g. flexible manufacturing systems, computer-aided manufacturing (CAM) and remote controllers in power plants
  - specialist software, e.g. database, computer-aided design (CAD) and CAM
  - organisational communications, e.g. messaging, collaborations and videoconferencing.
- Reasons for installing computer networks:
  - advantages, e.g. sharing data, productivity
  - disadvantages, e.g. security threats and reliance on the network.

A2 Computer networking technologies – hardware, software and services

- Networking hardware:
  - connection devices, e.g. switches, routers
  - connection media, e.g. unshielded twisted pair (UTP), fibre optic
  - end user devices both physical and virtual, e.g. workstations, printers, servers, storage devices, embedded systems and machines, e.g. computer numerical control (CNC).
- Networking software:
  - systems software – desktop and client operating systems, e.g. Windows™, Linux™, iOS™, networking monitoring software, basic Windows diagnostic commands: ping, tracert, netstat
  - networking operating systems software, e.g. Windows Server and Red Hat® Enterprise.
- Networking services:
  - directory and authentication services
  - domain name system (DNS) and dynamic host configuration protocol (DHCP) services
  - file and print services
  - mail, web and communications service
  - virtualisation.

A3 Computer networking protocols and standards

- LAN protocols:
  - IEEE 802 protocols, e.g. 802.3 Carrier sense multiple access with collision detection (CSMA/CD)
  - Ethernet frame format
  - wireless technologies, e.g. Wi-Fi, Bluetooth®
- WAN protocols:
  - Open Systems Interconnection (OSI) model – function and interaction of seven layers
  - Transmission Control Protocol/Internet Protocol (TCP/IP) suites including:
    - application layer protocols, e.g. DHCP, DNS, File Transfer Protocol (FTP), Secure Shell (SSH)
    - transport protocols, e.g. TCP, User Datagram Protocol (UDP), ports, sockets
    - internet protocols, e.g. IP (IPV4/IPV6), IP addressing, Internet Control Message Protocol (ICMP), Voice over Internet protocol (VoIP)
    - link or access layer, e.g. Address Resolution Protocol (ARP), MAC and MAC address.
- Specialised engineering protocols, e.g. Media Oriented Systems Transport (MOST).

A4 Network security

- Computer network threats and vulnerabilities:
  - physical threats, e.g. unauthorised physical access to networking hardware components and devices
  - logical and cyber threats, including:
    - unauthorised access to networking resources, e.g. databases, designs and manufacturing documents
    - malware, e.g. spyware, worms and hacking and modern industrial espionage
  - exploitation of computer network vulnerabilities, e.g. open firewall ports, and insufficient file permissions.
- Computer network protection:
  - physical security and protection, e.g. locks
  - logical security and protection, e.g. anti-malware software, demilitarised zone (DMZ) and firewall
  - intrusion protection/detection systems (IPS/IDS), software updates, Authentication, Authorisation and Accounting (AAA), security policies and security logs and audits
  - internet usage policy
  - files and folders permissions and network policies, e.g. group policies, password policies and audit policies
  - non-technical measures, e.g. training both for users and engineers.

Learning aim B: Plan the implementation of a secure computer network infrastructure to meet a client brief

B1 Services planning

Planning of network solution to meet the client's requirements:

- LAN and WAN decision
- number of users on system commissioned
- server capacity and performance
- internal network bandwidth and data throughput
- external 'internet' bandwidth requirements
- internet service provider (ISP) contention – competition for shared bandwidth in the local customer network area.

B2 Infrastructure planning

- Plan communication media.
- Communication cabinet to house all the network equipment under locked key.
- Site plan, looking at limitations of the physical environment, interference, cabling issues, cabling distance, cable runs, wireless reach, contention with other wireless networks.
- Look at issues with distance, attenuation and speed of the networking medium.
- Commission networking equipment.
- Cost of resources, protocol compliance, scalable and longer term objectives.

B3 Planning client support

- Network configuration – network card, speed, duplex setting, network cable socket and plug safe keeping.
- Desktop support, demands and requirements, what operating system is needed and how security will be implemented.
- Setting user policies, identifying user types and specific needs within the network.
- Client authentication – logging in.
- Mobile clients – differences in service requirements, authentication and anti-malware policies.
- Impact of BYOD (bring your own device) and how users may employ their own devices on your corporate system.

B4 Security planning

- Internet proxy, web filtering and intruder detection.
- User management – who has what access and when.
- Encryption services – encryption of transmitted and stored data.
- Firewall services – creation of ingress and egress rules, what the firewall will admit and the location of a DMZ (demilitarised zone) for servers.
- Access control – creating traffic filters, Quality of Service (QoS) demands.
- Anti-malware services – active security management of a live network against multiple threat vectors.

Learning aim C: Develop a secure computer network infrastructure to meet a client brief

C1 Construction of a computer network

- Creation of a system with at least one server and four clients to meet a specific organisational requirement.
- Physical structure, either wired or wireless, to support a larger system.
- Connection to external network via a router or access point.
- User authentication server.
- File and print service.
- IP schema to identify and segregate different network locations (office, floor etc.)

C2 Security features and resources

- User policy agreement.
- Implementing a firewall that prevents traffic but allows services required ingress and egress on a given network.
- Anti-malware applications, ensuring updates of malware definitions and anti-malware engine.
- Device hardening – securing all devices on the network.
- User authentication – creating a suitable level of user authentication and password strength on the network.
- Encryption services – applying encryption services as required.

C3 Systems testing

- Establish performance baseline, test criteria, user acceptance test and sign-off procedure.
- Testing the physical infrastructure:
  - cable/wireless communication.
- Testing the server:
  - load testing
  - client connection
  - use and utilisation of services
  - client authentication.
- Security testing:
  - probing network via penetration testing (Nmap – Network Mapper)
  - sniffing networking and reviewing traffic (Wireshark).

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the types, applications, technologies, and security of computer networks used in engineering		
A.P1 Explain, using examples, the types of computer networks and their applications in engineering organisations. **A.P2** Explain, using examples, the functions of computer network hardware and software used to provide network services. **A.P3** Explain, using examples, the common threats and vulnerabilities of and protection measures for computer networks.	**A.M1** Analyse, using examples, the types, applications, technologies and the security of computer networks used by engineering organisations.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the types, applications, technologies and the security of computer networks used by engineering organisations.
Learning aim B: Plan the implementation of a secure computer network infrastructure to meet a client brief		
B.P4 Plan a computer network including security protection measures to meet a given client brief.	**B.M2** Plan a computer network including security protection measures to meet a given client brief, while documenting alternative solutions, justifying the design decisions and considering scalability.	**B.D2** Optimise the design of the computer network in terms of meeting the client brief, scalability, performance and security protection measures.
Learning aim C: Develop a secure computer network infrastructure to meet a client brief		
C.P5 Build a secure computer network safely. **C.P6** Test that the computer network functions, repairing any faults.	**C.M3** Develop a secure, functional and computer network safely that meets the client brief.	**C.D3** Optimise the effectiveness of a safely developed and functional computer network in terms of meeting the client brief, performance and security protection measures.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.M2, B.D2)

Learning aim: 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:

- hardware, including computers, routers, switches and networking cabling, and potentially any related or specialised engineering devices that can be integrated in a networking environment, such as an Additive Manufacturing Machine
- software, including operating systems for both clients and servers, general purposes application software as well as related engineering application software, for example CAD and CAM
- other resources such as physical or virtualised devices, proprietary or open sources software and applications, or centres that are part of computer vendor-based programmes may fully use these resources at no cost.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of at least two engineering computer networks, including the types, applications, technologies and security of the networks. Learners' evaluations will compare the appropriateness of the two networks and reach a conclusion showing the relationship of the network to its context. Learners will evaluate the interrelations between the security and technology used in the networks and suggest alternative solutions and/or improvements to the networks. For example, learners compare the use of an in-house specialised computer network as opposed to outsourcing or even using cloud computing. The specialised network is built and supported internally, using client/server-based models, and internal support team, integrated with the engineering needs. Outsourcing using third party services, offering generic networking services to allow the different engineering functions to collaborate and communicate and share resources. Learners should differentiate between these networking models and their implications for the organisation's networking needs and requirements, as well the related security issues that might arise from their adoption.

Overall, the evidence presented will be easy to read and understand by a third party who may or may not be a network engineer. It will be logically structured, use correct engineering terms and the written language will be of a high standard.

For merit standard, learners provide an analysis that demonstrates a good and thorough understanding of computer network types, applications, technologies and security. For example, they will analyse the protocols and standards used to establish networking connections and communications in and between computer networks devices. Learners will also compare at least two of the computer networks being analysed and draw conclusions on the appropriateness of the set-up and configuration of each system. For example, the reasons why automobile electrical and electronic systems use CAN (Controller Area Networks), LINK (Local Interconnect Network), or MOST (Media Oriented Systems Transport) protocols. Learners will also explain the security threats, vulnerabilities and protection measures applied to computer networks. For example, a major concern in an engineering environment is the threat to data confidentiality, such as that caused by phishing, which normally takes advantage of email and lack of training and education, and hacking, which takes advantage of vulnerabilities inherent in software bugs or weaknesses in the security mechanisms applied in the systems.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will research one case study of computer networks used in engineering organisations and explain the types of network being used and their applications. Learners will include the advantages and disadvantages that networks bring to the operation and efficiency of engineering organisations.

Learners will explain the technologies, including the hardware, software, services, protocols and standards, used in the computer networks to allow users to access and share resources. For example, the wireless/wired technologies used within each of the functional groups in an engineering firm, such as research and development, design, manufacturing, sales etc. The protocols used to connect the LAN and WAN devices together such as Ethernet 802.3 and TCP/IP, and the networking services provided to the engineering functional groups members to communicate and share resources, such as email and collaboration workgroups, files and folders sharing, web access.

Learners will also explain the security threats, vulnerabilities and protection measures that have been applied to the computer networks.

Overall, the evidence will be logically structured, but may be basic in parts and contain minor technical omissions or inaccuracies. Learners need to demonstrate understanding of the networking protocols and their relationship without having to give details or focus on individual parts. Learners need to explain the functions of the main hardware, software components and their relationship, again without giving in-depth details, which will be covered in the merit criteria.

Learning aim B

For distinction standard, learners will optimise the design of a computer network in terms of the given client brief, scalability, performance, and security protection measures. As part of this process, learners will document their alternative designs and justify design decisions. For example, learners will document security protection measures that do not unreasonably hinder the users. Overall, the evidence will be easy to read and understand by a third party who may or may not be a network engineer.

For merit standard, learners will plan a computer network to meet a given client brief and will consider scalability as part of their design, while documenting their alternative designs and justifying design decisions. For example, in a small and growing engineering firm that is contemplating upsizing and scaling its current wired/wireless LAN-based peer-to-peer flat design network model into a hierarchical, client/server model, to allow for further scalability and security.

Overall, the design should be reasonable and practical, explanations will be professional and engineering terminology used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will plan a computer network to meet a given client brief, covering the hardware, software, protocols and secure services. A wired or wireless secure network is acceptable and it will need to support at least four users with access to shared files, folders, email, machines, for example 3D printer and intranet access. A network administrator will also need to be set up. As part of the design, learners will cover hardware and software selection, and logical and physical design schemes and diagrams that will be used to plan and prepare for the development, construction and test of the network. Overall, the evidence will be well structured and there will be some use of appropriate technical language, although there may be some inaccuracies in the terms used. Also, some parts of the evidence may be considered in greater depth than others.

Learning aim C

For distinction standard, learners will optimise the effectiveness of the safely developed and functional computer network in terms of the meeting the client brief, scalability, performance, and security protection measures. Part of the optimisation process will be to consider the trade-offs between the measures of scalability, performance and security protection and how these impact on the client brief. The test results and observation reports will demonstrate that the network meets the client brief and how the effectiveness of the network has been optimised. Learners will show how the addition of effective security through established password policy and audit policies impacts on performance.

Overall, the evidence will be easy to read and understand by a third party who may or may not be a professional network engineer. It will be logically structured and use accurate technical engineering terms appropriately.

For merit standard, learners will develop a secure and functional computer network safely that meets the client brief. As part of the development, learners will consider scaling up the network, for example increasing bandwidth, server capacity, the number of nodes and segmentation of the network. Learners' evidence will also include methodical test results for the network that, along with the observation reports, will demonstrate that the network meets the client brief and is functional.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will develop and test the system they have planned safely. Observation reports will be required, as well as learners' test results to prove the system, including an operating system, is functional. Although it may not fully meet the client brief, basic implementing networking services will be included, for example DHCP, DNS and possibly directory services running on the server. Physical and logical client connection to the LAN, wired and wireless, network user authentication and their ability to access their files and folders should all be successfully tested.

Overall, the evidence will be logically structured, but may be basic in parts, limited in places and contain minor technical inaccuracies relating to engineering terminology and/or the processes carried out. For example, there may not be sufficient tests to demonstrate that the system meets the client brief.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 32: Computer System Principles and Practice
- Unit 33: Computer Systems Security
- Unit 34: Computer Systems Support and Performance
- Unit 36: Programmable Logic Controllers
- Unit 38: Website Production to Control Devices.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with computer networking expertise
- contribution of ideas to unit assignment/project materials.

Unit 38: Website Production to Control Devices

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the languages and techniques used to produce secure websites for controlling physical devices before developing a website to control a device.

Unit introduction

There is a prevalence of web-enabled and web controlled devices and this is expanding daily. These devices rely on server-side scripting and back-end databases to provide the powerful, interactive and vibrant world of today's web. As a web developer, you will need to understand the available languages and techniques and develop practical skills in using them to create web applications.

In this unit, you will explore the nature of server-side languages: what they can do, what they cannot do and how they can breathe life into web applications. You will learn about programming constructs, together with techniques that not only save time but add security and provide valuable functionality. The understanding and skills you develop in this unit can be applied to many other non-web-based programming languages and can enable you to develop fully fledged, rich, responsive web applications usable on any device. You will gain understanding of the applications and principles of web server scripting and design, develop and evaluate a website application.

There is a high demand for computing professionals who are able to construct web-based solutions to meet the requirements of web controlled devices. Responsive web applications are vital to web-enabled technology and the ability to develop robust websites is a highly sought after skill. This unit will help to prepare you for employment, for example as an information technology technician or in a website development role, or entry to an apprenticeship or higher education to study a computing-based course.

Learning aims

In this unit you will:

A Investigate the technology used in website applications for controlling physical devices across the internet

B Investigate security measures used to protect website applications from malicious attacks

C Design a website application to remotely control a physical device across the internet

D Develop a website application to remotely control a physical device across the internet.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the technology used in website applications for controlling physical devices across the internet	**A1** Website controlled devices **A2** Web server-side scripting languages **A3** Applications of web server scripting	A report providing an introduction to scripting principles, covering security issues, and an introduction to scripting principles.
B Investigate security measures used to protect website applications from malicious attacks	**B1** Website security threats and vulnerabilities **B2** Security protection measures for website applications	
C Design a website application to remotely control a physical device across the internet	**C1** Website design **C2** Common tools and techniques used to produce websites **C3** Client-side scripting languages	Design documentation showing the planning, preparation and design for a website application. Presentation of a functional website application with supporting development and test documentation.
D Develop a website application to remotely control a physical device across the internet	**D1** Website development **D2** Common tools and techniques used in server-side scripting	

Content

Learning aim A: Investigate the technology used in website applications for controlling physical devices across the internet

A1 Website controlled devices

Devices that can be controlled over the internet:

- building management systems – lights, curtains and environment control systems such as heating and cooling
- visual devices – camera, telescope
- domestic appliances – television, washing machine and baths
- industrial – process monitoring, control and fault diagnosis
- other – wearable technology and surgical robots
- remote devices in inaccessible or dangerous locations – spacecraft, planetary landers, bomb disposal.

A2 Web server-side scripting languages

- Web server-side scripting language options – PHP, ASP, Ruby on Rails, Java, ColdFusion.
- Issues surrounding the use of scripting languages with regard to server requirements, scalability, documented support, cost, ease of use, security.

A3 Applications of web server scripting

- Application structure and how server scripting is applied to web applications, including:
  - multi-user/rank login systems
  - file uploading
  - storing data in databases – user registration details, login credentials, environment settings, error logs.
- Principles of web server scripting, including:
  - website application – usability, site layout, accessibility, spacing, navigation
  - client- and server-side scripting, content
  - database solutions – MySQLi, Oracle®
  - hosting – shared server solutions, virtual private server (VPS), dedicated server.
- The limitations of server scripting, including:
  - inability to access client-side file system
  - inability to read local client environment information.

Learning aim B: Investigate security measures used to protect website applications from malicious attacks

B1 Website security threats and vulnerabilities

- Malicious threats, including:
  - malware
  - spoofing – a user masquerading as another
  - eavesdropping – monitoring data to uncover passwords
  - spamming – denial of service (DoS) attack
  - out of band – targeting low level system functions to gain control.
- Vulnerabilities from human error, including:
  - user error – accidental deletion of software or data
  - leaving weaknesses – escalation of privileges, poor authentication and use of encryption, data not validated.
- Malfunction in hardware or software leading to vulnerabilities.

B2 Security protection measures for website applications

- Security measures in server-side scripting and how they can be applied, including:
  - data sanitisation before querying databases
  - predictable folder structures and their vulnerability
  - the use of abstraction layers when manipulating databases
  - encryption methods:
    - symmetric cryptography systems
    - asymmetric cryptography systems (public-key cryptography).
- Structured Query Language (SQL) injection prevention, to include built-in functions available through the scripting language, including:
  - MySQLi_real_escape_string()
  - use of abstraction layers, e.g. PHP data objects – writing of own protection functions that validate entered data on the server.
- The typical impact of security protection measures on website applications covers:
  - performance – increased overheads, e.g. Transport Layer Security (TLS), security products, e.g. firewalls
  - usability – use of browser extensions, e.g. supported versus not supported, use of desktop antivirus software, e.g. blocked content.

Learning aim C: Design a website application to remotely control a physical device across the internet

C1 Website design

Design documentation, including:

- problem definition statement – intended user, full summary of the problem to be solved, constraints, benefits, nature of interactivity, complexity of site
- research of similar interactive websites created by professionals who have applied different types of principle to underpin their design when solving similar problems
- initial design ideas/prototypes for an interactive website:
  - diagrammatic illustrations – wireframe, site maps
  - realistic representations
  - alternative design ideas/prototypes, including compatibility with mobile/tablet devices
- original scripting design tools and techniques – pseudo code, flow charts
- a test plan with test data, to test functionality
- technical and design constraints, e.g. browser or device compatibility.

C2 Common tools and techniques used to produce websites

Tools and techniques, including:

- The World Wide Web Consortium (W3C®) standards
- HyperText Markup Language (HTML)
- HTML5
- tables
- forms, text field, text area, buttons, radio buttons, check boxes
- navigation, menus, hyperlinks (internal and external), anchors
- interactive components – hotspots, pop-ups, buttons, menus, rollover images
- Cascading Style Sheets (CSS), e.g. background colour, background images, text formatting, borders, padding, heading styles, element position.

C3 Client-side scripting languages

- Embedding client-side scripts into web pages can allow for more interactivity and improve the usability of the website.
- Client-side scripting:
  - types of scripting languages – JavaScript, VBScript
  - uses of scripting languages – alerts, confirming choices, browser detection, creating rollovers, checking and validating input, handling forms
  - constructs – syntax, loops, decision-making functions, parameter passing, handling events, methods.

Learning aim D: Develop a website application to remotely control a physical device across the internet

D1 Website development

An interactive website, including:

- CSS, e.g. HTML tags, CSS frameworks, access CSS from HTML, DOCTYPES
- original client-side scripts
- compatibility for mobile and tablet devices
- effective use of tools and techniques – appropriate scripting, stylesheets
- functional testing – links and scripts.

D2 Common tools and techniques used in server-side scripting

- Programming constructs used in a server scripting and web application development, including:
  - logic and operators – AND, OR and NOT
  - variables – global, local, integer, float, string, server
  - sessions and cookies
  - functions (including passing data between)
  - variable and function naming conventions
  - string manipulation – concatenation, string searching
  - arrays, including two-dimensional
  - conditional statements – if/else, switch
  - loops – for, while, do/while
  - server side – libraries, menu files, header/footer files
  - programming efficiency – input validation, minimising potential for user error, bypassing unnecessary subroutines
  - mathematical manipulation of numerical data – random number generation, modulus
  - sending data using POST and GET methods.
- Security protection measures, including:
  - managed user accounts, including login credentials, session variables
  - Transport Layer Security (TLS)
  - data sanitisation
  - encryption.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Investigate the technology used in website applications for controlling physical devices across the internet</td><td rowspan="4">AB.D1 Evaluate, using language that is technically correct and of a high standard, the effectiveness of the technologies and security protection measures used in the provision of a robust and secure website application.</td></tr>
<tr><td>A.P1 Explain the technologies used in website applications for the control of physical devices.</td><td>A.M1 Compare the technologies used in website applications for the control of physical devices.</td></tr>
<tr><td colspan="2">Learning aim B: Investigate security measures used to protect website applications from malicious attacks</td></tr>
<tr><td>B.P2 Explain the security threats to and vulnerabilities of website applications and the security protection measures available.</td><td>B.M2 Analyse the security threats to and vulnerabilities of website applications and the security protection measures available, including how these impact on performance and usability.</td></tr>
<tr><td colspan="2">Learning aim C: Design a website application to remotely control a physical device across the internet</td><td rowspan="4">CD.D2 Optimise a functional, fully annotated, efficient, stable and secure website application with an effective user interface and including data storage that operates as intended, using a comprehensive set of justified design and test documentation.</td></tr>
<tr><td>C.P3 Design a secure website application to control a physical device, including a test plan and any technical constraints.
C.P4 Review the design of the secure website application to ensure that any functionality requirements from the client brief are met.</td><td>C.M3 Design a secure website to control a physical device, while justifying the design decisions made to meet the client brief and including a test plan, any technical constraints and alternative solutions.</td></tr>
<tr><td colspan="2">Learning aim D: Develop a website application to remotely control a physical device across the internet</td></tr>
<tr><td>D.P5 Build the functional and secure website application, using the design documentation, to control a physical device.
D.P6 Test, using the test plans, the secure website for functionality and data storage, repairing any faults to ensure that it meets the client brief.</td><td>D.M4 Refine the secure functional website application to meet the client brief, including an effective user interface and data storage.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, B.P2, A.M1, B.M2, AB.D1)

Learning aims: C and D (C.P3, C.P4, D.P5, D.P6, C.M3, D.M4, CD.D2)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a web server
- controllable hardware, for example web camera, robot arm, micro controller.

If the web server is externally hosted FTP port access must be set up by your local network manager. Where this isn't possible because of firewall restrictions, the server will need to be either hosted internally or a local host server such as XAMPP could be used, which can be run from any storage solution.

When a local server is used, great flexibility can be employed as learners can replicate systems at home as well as gaining experience on how to set up server software.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will evaluate at least two different types of web controlled device, for example building management and visual devices, and two different web application development environments, for example PHP and ASP. They will evaluate how effectively the application is implemented and also consider the security issues (vulnerabilities, threats and protection measures) and how they have been dealt with, for example encryption of sensitive data and the use of abstraction layers. In terms of robustness, learners will look at the validation measures that have been used to ensure that correct data is entered by the user and sanitised before being used.

Overall, learners' evidence will be easy to read and understand by a third party who may be a computing professional. It will be logically structured and use technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling, and consistent reference to information sources.

For merit standard, learners will look in depth at two of the technologies and compare equivalent features, including examples of their use. Learners will investigate the threat to, and vulnerabilities of, website applications and commonly recommended security protection features available in web application development environments. They will analyse the resultant impact these have on the user in terms of usability of the application and any related performance issues in connection with server load and security.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will investigate the features of a range (three or more) of technologies (including web server-side scripting languages and web server scripting) and provide examples of their use. Learners will evidence an awareness of security issues and explain a range (three or more) of the vulnerabilities, threats and protection measures that apply to the website applications.

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 terminology, for example omissions from explanations of technologies or misattributed terminology.

Learning aims C and D

For distinction standard, learners will develop a fully functional and stable web application with an effective user interface and data storage that meets the client brief.

Learners will design the web application with an effective user interface, ensuring that the client brief is adhered to and that appropriate security protection measures are applied. Their program design will break down key operations into relevant constructs that link logically and coherently together, including the handling of some unexpected events. Their test scripts will confirm a fully functioning software program under expected and some unexpected conditions.

Learners will build an efficient web application, using their designs to produce a functional and secure program with an effective user interface. Their web application will contain a range of appropriately selected constructs that have been used correctly. Also, their program will be concise, efficient and will have the facility to handle some unexpected events, for example properly opening and closing all tags, conformance to W3C standards and alternative methods for non-supported browsers. Annotation will be consistent and appropriate and will demonstrate a thorough understanding of the key areas of the program and underpinning constructs. Learners' programs will be well organised, structured and formatted so that a competent third party could efficiently interpret and update the program.

Learners will provide a fully detailed regression test, using the test scripts on their web application and producing documentation of the results of the testing process, including testing of some unexpected events. Any functional or usability faults that occur from the testing will be repaired and full testing will be repeated until no new faults arise. A fully supported judgement of conformity will be made by linking test results to the client brief.

Overall, the evidence will be presented clearly and in a way that is understood by a third party who may or may not be a computing professional.

For merit standard, learners will design the web application with an effective user interface, for example one that is intuitive and efficient to use, ensuring that the client brief is adhered to. Learners will justify their design decisions and provide alternative designs. Their program design will break down key operations into relevant constructs that link together. Their test scripts will confirm a fully functioning web application under expected conditions.

Learners will build and refine a web application, using their designs, and record the changes that are made to the web application during the process. Their web application will contain a range of appropriately selected constructs that have been used correctly. Annotation will be present and appropriately used to demonstrate understanding of key areas of the program and underpinning constructs. Learners' programs will be well organised and formatted so that a competent third party can interpret and update the program.

Learners will fully test the web application: using the test scripts, repairing any functional faults as they arise and making usability improvements. A judgement of conformity will be supported by the test results but judgements may not all be linked back to the client brief.

Overall the evidence will be a well organised record of the practical work carried out. It will be technically accurate and easy to understand.

For pass standard, learners will produce a clear, logical design for a functional web application to meet the defined requirements and identify any technical constraints. Learners will produce screen designs to show the layout of the components of the application, with some consideration for usability. Learners will also produce an outline of the workflow of their application: a use case diagram is an ideal method to present this. There is an expectation that learners will carry out research for similar applications to guide and inform their design. Through the design process learners are expected to refer to the emergence of security threats, where these naturally arise, and indicate appropriate countermeasures.

As part of the design, learners will produce a test plan and a requirements specification document detailing core functionality that can be used to both design and review the website application to ensure the requirements from the brief are met. They will indicate a limited understanding of the intended web application.

Learners will produce a functional web application that includes the ability to identify a range of users (at least two authenticated user types are expected). Learners will use a range of more basic programming constructs that are generally appropriate and have been used correctly. Learners' programs may be inefficient, for example they may not properly open and close all tags, may not conform to W3C standards, and may not provide support for older browsers. Annotation will be present but focused in one area of the program and will demonstrate an incomplete understanding of the key areas of the program. Program structure may have inconsistencies in organisation and/or formatting.

Learners will provide evidence of testing both functionality and data storage and any faults found will be corrected. Learners will assess the final web application against the design to ensure that it meets the defined requirements from the client brief.

Overall, the evidence will be logically structured, although it may be basic in parts. Learners' explanations may be limited in places and may contain minor technical inaccuracies relating to engineering terminology, for example their test plan may not contain the steps to reproduce the expected results.

Links to other units

This unit links to:

- Unit 5: A Specialist Engineering Project
- Unit 6: Microcontroller Systems for Engineers
- Unit 19: Electronic Devices and Circuits
- Unit 32: Computer System Principles and Practice
- Unit 33: Computer Systems Security
- Unit 36: Programmable Logic Controllers
- Unit 37: Computer Networks.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local computing organisations
- contribution of ideas to unit assignment/project materials.

Unit 39: Modern Manufacturing Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the principles of processing systems used in manufacturing and how operations are organised to make the most efficient use of time, materials and equipment.

Unit introduction

One of the key drivers for business success in manufacturing organisations is how operations are organised and how they respond to economic, social and technological change. It is vital that appropriate manufacturing systems and processing methods are employed to manufacture products safely, sustainably and cost effectively, and that these systems and methods are reviewed and improved regularly. Organisations that have embraced business improvement techniques, such as Lean, have found them to be transformative, enabling increased efficiency and profitability across their organisations.

You will study the activities controlled by manufacturing operations and how the nature and performance of different areas may be influenced by current and future social and technological trends. You will examine how factory layouts are structured and organised and how the passage of a product through a factory is coordinated. Lastly, you will investigate Lean tools and improvement techniques before applying them to a manufacturing simulation to see their potential impact first hand.

All manufacturing industries, including aerospace, automotive, food, rail, biomedical and chemical, employ manufacturing engineers. This unit will help to prepare you for employment, for example as a manufacturing technician, for an apprenticeship or entry to higher education.

Learning aims

In this unit you will:

A Understand the functions of manufacturing operations and factors influencing their success

B Examine process systems that are commonly used in manufacturing industry

C Investigate the principles of Lean manufacturing and how these influence productivity.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Understand the functions of manufacturing operations and factors influencing their success	**A1** Manufacturing operations **A2** Performance objectives in manufacturing operations **A3** Future trends influencing manufacturing operations	A written report on the functions contained in a manufacturing operation and factors affecting the performance of a manufacturing organisation. Learners must also investigate likely future trends affecting manufacturing organisations.
B Examine process systems that are commonly used in manufacturing industry	**B1** Process types and typical industrial applications **B2** Manufacturing layout types **B3** Characteristics of effective system layout **B4** Manufacturing documentation	A written report justifying the type of manufacturing system used to manufacture contrasting products, which should include an explanation of all relevant documentation. Evidence should include diagrams and/or photographs to support an evaluation of the layout used. This would best be achieved in collaboration with an industrial partner or it could be based on case study materials.
C Investigate the principles of Lean manufacturing and how these influence productivity	**C1** The Lean philosophy **C2** Key elements of Lean **C3** Lean tools and methods	A presentation outlining the principles of Lean and its application to transform a traditional manufacturing operation. Part of the presentation will include the delivery of an activity devised by learners that illustrates a range of the principles of Lean effectively by simulating how part of a manufacturing system might be improved.

Content

Learning aim A: Understand the functions of manufacturing operations and factors influencing their success

A1 Manufacturing operations

- The operations function of a manufacturing organisation is responsible for all aspects of the manufacture and delivery of products and/or services, including:
  - health and safety, e.g. manage statutory requirements such as the Health and Safety at Work etc Act (HASAWA) 1974 and amendments, Control of Substances Hazardous to Health Regulations (COSHH) 2002 and amendments
  - environmental protection measures, e.g. manage statutory requirements such as Waste Electrical and Electronic Equipment (WEEE) Directive, Restrictions of Hazardous Substances (ROHS) Directive
  - manufacturing processes, e.g. assembly, automated processes (computer-aided manufacture (CAM), computer numerical control (CNC)), machining, fabrication
  - maintenance, e.g. preventative maintenance, servicing, breakdown recovery
  - warehousing, e.g. storage and organisation of raw materials and finished goods
  - quality management, e.g. inspection, quality control, quality assurance
  - logistics, e.g. shipping and distribution of finished goods to customers.
- Other factors that significantly influence manufacturing operations:
  - product design and development, e.g. innovation, design for manufacture, creation of new and modified products to fulfil customer needs, product or service sustainability
  - human resources, e.g. recruitment and staff training.

A2 Performance objectives in manufacturing operations

Performance in manufacturing operations is influenced by many factors:

- health and safety, to include:
  - prevention of accidents, near misses and other unplanned incidents
  - managing occupational health through good process design to eliminate long-term conditions, e.g. repetitive strain injury, hearing loss
- quality, to include:
  - the role of quality management in ensuring external customer satisfaction by providing products to the required standard on time
  - increasing internal process efficiency through elimination of waste
- lead times, to include:
  - gaining competitive advantage by having short lead times from receipt of sales order to external customer delivery
  - limitations caused by internal processes and component manufacturing lead times and how these might be reduced
- dependability, to include:
  - achieving on time delivery of products to external customers by avoiding unplanned events that may disrupt and delay the process, e.g. accidents, poor supplier on time delivery performance, machine breakdowns
- flexibility, to include:
  - reducing time to market for new products, e.g. rapid prototyping, computer-aided design (CAD), CAM, design for manufacture
  - maintaining product mix flexibility to allow the manufacture of a wide range of products to match customer requirements, e.g. fast changeover time
  - maintaining volume flexibility to allow manufacturing capacity to match demand

- sustainability and environmental, to include:
  - using energy and material resources efficiently, minimising waste
  - reducing dependence on expensive or hazardous materials through innovative use of greener alternatives
  - increasing sales by meeting customer social and environmental needs
- costs, to include:
  - low scrap rate and low rework rate driven by a commitment to quality
  - reducing work in progress (WIP) inventory levels by fast processes with short lead times
  - reducing unplanned costs by developing high dependability processes
  - reducing wasted time and/or capacity through increased flexibility.

A3 Future trends influencing manufacturing operations

Manufacturing operations may be influenced by the following future trends, including:

- additive manufacturing (AM) may replace subtractive manufacturing processes
- energy security, e.g. the impact of moving away from fossil fuels
- sustainability, e.g. choosing between simple materials that are easily repaired or recycled and complex material combinations (e.g. fibre composites) that give reduced energy consumption
- materials technology, e.g. the impact of competitive sport or defence on the development of innovative materials and manufacturing techniques
- manufacturing on demand, e.g. the technologies that must be in place to allow one-off customised products to be manufactured quickly
- robotics and automation, e.g. the impact of making robots increasingly aware of their surroundings and increasing their autonomy
- Virtual Product Creation (VPC), e.g. the impact of modelling complete complex systems such as aircraft prior to manufacture.

Learning aim B: Examine process systems that are commonly used in the manufacturing industry

B1 Process types and typical industrial applications

Principles, volume-variety characteristics and typical industrial applications of manufacturing process types:

- project processes:
  - characteristics include – 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 tunnelling machines
- jobbing processes:
  - characteristics include – 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 include – small to large batch (low to medium volume), limited variety, skilled workforce, flexible, some specialist tools and equipment
  - typical applications, e.g. clothing, automotive components
- mass processes:
  - characteristics include – 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 include – 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.

B2 Manufacturing layout types

Principles, characteristics and typical applications of manufacturing layout types and how these relate to process types:

- fixed layouts where transformed resources are in a fixed position, meaning transforming resources have to flow through the operation, e.g. shipbuilding where the product is too large to move
- process layouts that are dominated by the requirements or physical constraints of the transforming resources, e.g. a large powder coating plant may get optimal use if all coated components pass through it
- product layouts are dominated by the requirements of the transformed resources that flow along a line of transforming resources, e.g. car assembly plants
- cellular layouts where transformed resources are moved between cells with each cell completing one stage of the process, e.g. automotive component manufacture
- mixed or hybrid layouts combine elements of some or all of the basic types.

B3 Characteristics of effective system layout

- Safety to include fire exits, clear gangways, emergency equipment, controlled access to dangerous areas.
- Minimising length of flow to reduce distance travelled by transformed resources.
- Clearly visible signage, floor marking and barriers.
- Facilities for staff welfare, to include ventilation, lighting, noise control, amenities.
- Effective communications, to include location of supervisors and IT systems.
- Effective accessibility, to include ensuring access for large machinery during installation, sufficient space for servicing and maintenance.
- Efficient use of available space, including above and below manufacturing areas.
- Flexibility to accommodate operational change and expansion.
- Consequences of ineffective system layout, e.g. inefficient flow of materials, build-up of WIP, poor flexibility, wasted time, high cost.

B4 Manufacturing documentation

Documentation commonly used to control and coordinate manufacturing, including:

- work order to initiate manufacture stating part number, quantity and completion date
- routing cards to communicate the required process sequencing (route through the factory)
- materials lists to communicate component or raw material part numbers and quantity requirements
- stores requisitions used to authorise movement of required components or raw materials to work centres, e.g. a machine or workstation
- manufacturing instructions detailing standardised process methods
- visual aids, e.g. single piece engineering drawings, assembly drawings, circuit diagrams, photographs, approved sample used to exemplify the required standard.

Learning aim C: Investigate the principles of Lean manufacturing and how these influence productivity

C1 The Lean philosophy

- The aim of Lean is to meet demand instantaneously, with perfect quality and no waste.
- Characteristics of Lean in contrast to traditional manufacturing, to include:
  - goods are manufactured to exactly match customer orders, no forecast based finished goods inventory is held
  - short lead times enable rapid response to variation in demand
  - WIP and inventory buffers are kept to an absolute minimum
  - a culture of continuous improvement in all is encouraged from the top down
  - tasks across the business are performed consistently in the same way and developments in best practice are shared and implemented universally

- defects are eliminated in all processes by identifying and rectifying the root cause
- overall costs are reduced through increased efficiency, reduced space requirements and increased stock turns (high stock turns reduce the quantity of inventory held).

C2 Key elements of Lean

- Eliminating waste by the reduction of non-value added activities, to include: overproduction, waiting time, transport of materials, inappropriate or inefficient manufacturing processes, WIP inventory and stock items, unnecessary transportation or handling and defect associated waste, e.g. rework, scrap.
- Adopting team approach, to include: team problem solving, multi-skilling to allow job rotation and flexibility, encouraging process 'ownership' and responsibility and enriching roles, e.g. include maintenance and setting tasks in operator jobs.
- Continuous improvement, to include: encouraging a culture of innovation, managing change and process refinement.
- Improving quality by implementing strategies, including: quality control (QC), quality assurance (QA), total quality management (TQM).
- Increasing the dependability of internal processes and external suppliers.
- Increasing manufacturing flexibility in terms of both product mix and volume.

C3 Lean tools and methods

- Lean production systems:
  - awareness of common production systems, to include Toyota® Production System (TPS), Ford® Production System (FPS), Six Sigma.
- Widely implemented tools and methods used in Lean operations, to include:
  - standardised work practices to provide documented procedures of best practice that build in consistency and reduce process variation
  - design for manufacture to ensure optimal use of materials and processes
  - total productive maintenance (TPM) to eliminate unplanned breakdowns
  - bottleneck analysis to identify processes limiting overall throughput
  - just-in-time (JIT) to pull parts through manufacture based on customer demand, instead of pushing them through based on a forecast
  - Kanban (pull system) automatic stock replenishment systems
  - 5S to organise work areas (sort, set in order, shine, standardise, sustain)
  - continuous flow to enable smooth flow of WIP between stages without buffers
  - Kaizen (continuous improvement) to improve processes over time based on suggestions from employees working together
  - Poka-Yoke (error proofing) to incorporate error detection and/or prevention into process design
  - Takt Time to define the pace of manufacturing to match customer demand
  - set-up reduction (SUR)/Single-Minute Exchange of Die (SMED) to minimise the time required between finishing one batch of a product and completing first good product of the next batch, to include:
    - use of standard fixtures, jigs and other tooling to improve interchangeability
    - pre-setting tooling to minimise or eliminate set-up time
    - improving product handling devices to aid loading and unloading tools and dies, e.g. rollers conveyors, cranes, trolleys.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Understand the functions of manufacturing operations and factors influencing their success		**A.D1** Evaluate, using language that is technically correct and of a high standard, the functions of and factors affecting the performance of manufacturing operations and how these might change in the future.
A.P1 Explain the functions of and factors affecting the performance of manufacturing operations and how these might change in the future.	**A.M1** Analyse the functions of and factors affecting the performance of manufacturing operations and how these might change in the future.	
Learning aim B: Examine process systems that are commonly used in the manufacturing industry		**B.D2** Evaluate, using contrasting product examples, the selection of manufacturing process types, layouts and documentation used, suggesting improvements where appropriate.
B.P2 Explain, using contrasting product examples, the principles and characteristics of different manufacturing process types. **B.P3** Explain, using contrasting product examples, the principles and characteristics of different manufacturing layout types. **B.P4** Explain, using contrasting product examples, the importance and use of manufacturing documentation.	**B.M2** Analyse, using contrasting product examples, the selection of manufacturing process types, layout types and documentation used.	
Learning aim C: Investigate the principles of Lean manufacturing and how these influence productivity		**C.D3** Evaluate how a range of Lean tools and/or methods relate back to the key characteristics of Lean including the effectiveness of a Lean manufacturing simulation.
C.P5 Explain the key characteristics of Lean and the requirements needed to implement it successfully. **C.P6** Explain how at least one Lean tool and/or method can be applied. **C.P7** Demonstrate effectively at least one of the key Lean tools, using a manufacturing simulation.	**C.M3** Analyse how a range of Lean tools and/or methods relate back to the key characteristics of Lean. **C.M4** Demonstrate effectively a range of the key Lean tools and/or methods, using a manufacturing simulation.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.P4, B.M2, B.D2)

Learning aim: C (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 case study materials on the functions of and performance factors in manufacturing operations and in the process systems. Ideally, these materials could be developed in collaboration with an industrial partner and be supported with industrial site visits.

A range of proprietary Lean simulation kits are available commercially, which would be useful, if not essential, in the delivery of this unit.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of how a range of factors relate to and influence the performance of a manufacturing operation. For example, how increasing dependability will require changes in maintenance procedures to help prevent unscheduled breakdowns and action by health and safety management to help prevent accidents or incidents that might cause delays. Learners will come to a conclusion about which factor is likely to have the greatest impact on improving overall performance. For example, increased dependability is likely to be more important than flexibility where very large batches of products are manufactured. In addition, learners must also make a judgement regarding the importance of relevant social, economic or technological trends for a manufacturing operation by assessing whether their impact on performance will be significant in the future. For example, learners might consider the advantages and disadvantages of additive manufacturing (AM) when used as an alternative to die casting in the manufacture of engine components and justify an opinion on the likely uptake of this emerging technology in the automotive sector.

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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will provide a detailed analysis of how a range of factors relate to and influence the performance of a manufacturing operation. For example, how increasing flexibility will require changes to manufacturing processes that might include reducing set-up times, providing additional training to develop a mobile, multi-skilled workforce that can be redeployed quickly to eliminate bottlenecks, and employing a cellular (U shaped or serpentine) process layout. In addition, learners must analyse the potential impact of a relevant social, economic or technological trend on the performance of a manufacturing operation and how the operation might change as a consequence. For example, the drive for more sustainable manufacturing is likely to affect the choice of processes used as manufacturers seek to use less energy, less material and generate less pollution, which may lead to a move away from subtractive towards additive manufacturing processes where possible.

Overall, the evidence will be logically structured, technically accurate, methodical and easy to understand.

For pass standard, learners will provide a clear explanation of the importance of the functions in a manufacturing operation. For example, the role of maintenance is to maintain and repair equipment, human resources is to recruit and train the workforce. Learners must also explain the performance objectives of a manufacturing operation and suggest how these might be achieved. For example, how increasing flexibility allows quicker response to customer demand and how it might be improved by training multi-skilled staff. In addition, learners must explain how a manufacturing operation might change in response to relevant social, economic or technological trends over the next 20 years. For example, the drive for more sustainable manufacturing is likely to drive changes in many areas, including manufacturing processes, component design, materials, emissions and waste disposal.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example making general statements about changes to manufacturing operations without clearly explaining how these might be achieved, and may contain technical inaccuracies or omissions, such as the occasional use of non-technical language.

Learning aim B

For distinction standard, learners will provide a balanced evaluation of how the characteristics of two contrasting products influenced the selection of appropriate process and layout types and the type, complexity and use of the documentation used to coordinate manufacture. In addition, they will explain why their use is justified or suggest potential improvements. For example, learners might use the Ford Focus and Morgan Classic Plus 4 as two contrasting products. They might explain that in the Morgan factory hard copies of engineering drawings are kept on the shop floor. Learners would evaluate the advantages and disadvantages of this system and suggest possible alternatives, such as using monitors or tablets to display drawings, and explain how this might improve efficiency, reliability and speed of manufacture.

Overall, learner 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 provide a clear and detailed analysis of how the characteristics of two contrasting products influenced the selection of appropriate process and layout type for their manufacture. They will consider the complexity of the manufacturing processes involved, the volume required and wider issues such as the variety of products using the same manufacturing resources. For example, learners might use the Ford Focus and the Morgan Classic Plus 4 as two contrasting products where volume, cost and exclusivity are the main differentiators. The complex, automated, high volume Ford plant will contrast significantly with the batch oriented, highly skilled Morgan factory. Learners will also provide a detailed analysis of how the type, complexity and use of the documentation used to coordinate the manufacture of the contrasting products relates to the process type and layout in use and the complexity of the products being manufactured. For example, the complex products in the Ford plant require the coordinated delivery of raw materials via stores requisitions, sub-assemblies created via work orders from elsewhere in the factory and consumables such as screws and fixings taken from shop floor storage areas replenished using Kanban cards. This is generally far too complex to rely on a basic paper system and so computers and automated handling systems are used extensively to help coordinate stock movements.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will clearly explain how the different manufacturing process types are applied in the manufacture of at least two contrasting products. Learners will also explain how manufacturing volume influences the process type selected. For example, learners might use the Ford Focus and the Morgan Classic Plus 4 as two contrasting products and explain how mass and batch process types are employed in their manufacture.

Learner evidence will clearly explain the arrangement of manufacturing resources and how the product being manufactured moves through them, using two contrasting products as examples. For example, explain how the Ford Focus plant and Morgan factory are laid out and how the chassis move through the facilities as they are built up into finished vehicles.

Learners' evidence will clearly explain the importance of documentation to coordinate the manufacture of at least two contrasting products. In particular, evidence will outline what the documentation is used to communicate and to whom, when and how it is issued and the activities triggered, coordinated and/or managed. For example, work orders are typically issued by manufacturing planners to shop floor supervisors to trigger the manufacture of a defined number of components by a certain date. They are issued in hard copy and remain with the product until it is completed.

Overall, the evidence may be basic in parts, for example in the explanation of the characteristics of a specific process type, and contain minor technical inaccuracies or omissions. For example, learners may fail to explain the importance and use of some of the information contained in the manufacturing paperwork.

Learning aim C

For distinction standard, learners will provide a balanced evaluation of how a range of at least three Lean tools and/or methods relate back to the key characteristics of a Lean operation. In addition, they will evaluate how effective a range of at least three Lean tools and/or methods are in helping to achieve the key characteristics of Lean operations, referring in part to their experience of applying Lean tools and/or methods in a manufacturing simulation. Learners will form a clearly reasoned judgement on which of the tools and/or methods considered are able to make the most effective contribution to supporting the key characteristics of Lean.

Overall, learners' 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 analyse, in detail, how a range of at least three Lean tools and/or methods relate back to the key characteristics of a Lean operation. Each Lean tool and/or method should be explained in detail and learners will identify which problems they are designed to eliminate, the methodology involved in their use and their expected impact on the processes involved. Furthermore, learners will clearly link the outcomes of using the tools and/or methods to the principles of Lean operations. For example, a clear explanation of the application of set-up reduction methods will go on to explain how these will help achieve greater flexibility in manufacturing operations.

Learners will demonstrate a range of at least three Lean tools and/or methods effectively by applying them to one or more manufacturing simulations. The simulations must be of sufficient complexity to enable meaningful results to be seen, which in most cases will depend on the tools being applied. For example, a manufacturing simulation involving the assembly of a simple product could be used to demonstrate the effectiveness of Kanban and Bottleneck analysis in improving flow and helping to synchronise manufacturing rate with demand. In addition, a set up reduction simulation could be used to demonstrate the time saving possible when SMED (Single Minute Exchange of Die) methodologies are applied. Learners will provide evidence of how the simulation will be set up and controlled, the Lean tool and/or method being applied, the details of the problem(s) it is designed to eliminate, the expected outcome of the simulation and the actual outcome obtained.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will clearly explain the key characteristics of Lean and how these might be implemented in practice. For example, one of the principles of Lean is to operate with short lead times. Learners should explain why this gives an operation a competitive advantage and then outline how it might be worked towards by implementing a specific Lean principle, such as improving flow to eliminate waiting time between process steps and so decrease overall production time.

Learners' evidence will clearly explain how Lean tools and/or methods might be implemented in a manufacturing environment. For example, learners might provide a detailed explanation of the 5S methodology, including details of the problem(s) it is designed to eliminate, the principles of 5S itself and how it might be implemented in a scenario based on a case study.

Learners' evidence will demonstrate at least one Lean tool effectively by applying it to a manufacturing simulation. The simulation must be of sufficient complexity to enable meaningful results to be seen, which in most cases will depend on the tools being applied. For example, a manufacturing simulation involving the assembly of a simple product could be used to demonstrate the effectiveness of Kanban pull systems in improving flow and helping to synchronise manufacturing rate with demand. Learners should provide evidence of how the simulation will be set up and controlled, the Lean tool and/or method being applied, the details of the problem(s) it is designed to eliminate, the expected outcome of the simulation and the actual outcome obtained.

Overall, learner evidence, including simulation results, will be logically structured and easy to follow. The evidence may be basic in parts, for example explanations may lack detail and contain minor technical inaccuracies relating to engineering terminology, such as in the use of the acronyms common in Lean.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 11: Engineering Maintenance and Condition Monitoring Techniques
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local world class manufacturing organisations
- contribution of ideas to unit assignment/project materials.

Unit 40: Computer Aided Manufacturing and Planning

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine manufacturing-process automation and planning using computer software and technology. Learners will simulate the manufacture of a component.

Unit introduction

Computer-aided manufacturing (CAM) is used extensively to manufacture products efficiently and effectively by world-class-manufacturing organisations. CAM involves the control by software of machine tools and associated systems to produce components. These systems are used to automate and plan the manufacture of products and components, such as cars, computers and medical devices, efficiently and effectively.

In this unit, you will investigate how CAM systems are used in the efficient and effective planning and manufacture of products. They are used to increase the profitability of manufacturing organisations by reducing manufacturing costs, improving quality and being more responsive to customer needs. For example, machining metal is time consuming and expensive, so a 'right first time' approach is a crucial aspect of economic manufacture. You will explore how the manufacturing process can be automated by moving materials and components efficiently between the machine tools and workstations that make up a flexible manufacturing system (FMS). You will also simulate the manufacture of a component from a given specification, using computer-aided design (CAD) software to draw it and CAM software to simulate the manufacture.

As an engineer, it is important to understand the manufacturing planning systems and process and how to create products and/or components through the use of CAM systems. This unit will help to prepare you for a manufacturing engineering apprenticeship and will also help you if you want to work in a manufacturing technician role. Alternatively, you could choose to study engineering in higher education.

Learning aims

In this unit you will:

A Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation

B Develop a virtual component on a computer-aided manufacturing system that simulates its manufacture

C Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation	**A1** Benefits and applications of CAM systems **A2** Technology used in CAM systems	A report to investigate the benefits and technology used in industrial CAM systems that will improve the efficiency and effectiveness of the manufacturing operation. Evidence should include the benefits and applications that are related to the technology.
B Develop a virtual component on a computer-aided manufacturing system that simulates its manufacture	**B1** Model a component in preparation for manufacture **B2** Simulate the manufacture of a component **B3** Quality control checks on a virtual component	To develop a CAD suitable for manufacture, and transfer to a CAM system, to simulate a component, using graphical or virtual reality. To verify and optimise the simulated component ensuring it meets the specification and is fit for the purpose intended. The evidence should include, CAD drawings, CAM program, screenshots of the processes, and inspection documentation.
C Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation	**C1** Manufacturing plan **C2** Schedule for manufacture **C3** Product and/or component specification for manufacture	To investigate planning documentation and create a range of comprehensive industrial production – planning documents to plan for customer demand and manufacture. To produce schedules for a range of products and order quantities. The report needs to justify and create the most appropriate planning and scheduling documentation for a CAM system. Evidence should include examples of planning and scheduling documentation.

Content

Learning aim A: Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation

A1 Benefits and applications of CAM systems

CAM systems involve the control by software of machine tools and associated systems to manufacture products or components.

- Advantages of CAM, including:
  - consistency and accuracy of product/component form, remote programming, direct numerical control (DNC), simulation of the manufacturing process, responsiveness to demand and rapid prototyping, e.g. additive manufacturing (AM)
  - allows the simultaneous manufacture of products and/or components involving: parallel operation of tasks, manufacture of different parts simultaneously, reduced development times, remote product design and transfer of data, reduced changeover times of tooling and products, iteration of production schedules, consistent right first time and just in time manufacture.
- Disadvantages of CAM, including capital cost to create the system, e.g. software, hardware, machines, training and set-up times.
- Typical applications of CAM, e.g. electronic printed circuit board manufacture, rapid prototyping, manufacturing metal components (including welding), electronic discharge machining (EDM) (including punching and shearing processes).

A2 Technology used in CAM systems

The term FMS is used to define the manufacturing technology e.g. control hardware and software, machines and material handling equipment that form part of the CAM system.

FMS cells are used to manufacture products usually in low quantities, e.g. bespoke one-offs, prototypes, small- to medium batch volumes, often used widely for the aerospace and automotive production industries.

Typical technology components used in CAM systems include:

- control hardware devices, including computers/micro-controllers and communication devices for status monitoring, messaging, material movement, machine control
- flexible cells, including automatic guided vehicle (AGV), conveyors, robots, optical recognition devices, coordinate measuring machines (CMM) and machining centres, e.g. computer numerical control (CNC) machines
- control software and programming, including executive software (control programs) – downloading CNC programmes, data messaging, e.g. that a component has completed an operation or moved station, emergency messaging, e.g. an error due to a tool breakage, machine failure within real-time status communication
- material-handling system, including product storage and retrieval, loading and unloading and automatic pallet changing
- typical operational considerations of CAM systems, e.g. the product is suitable to be effectively coded by the CAM software. The software’s efficiency at planning, roughing and finishing cuts for the component, efficient tooling use and changes, consideration of the material to be cut, suitable model generation and accuracy of representation of the model
- improvement techniques, e.g. Lean manufacturing, used to reduce waste, short lead times, limited stock holding or inventory.

Learning aim B: Develop a virtual component on a computer-aided manufacturing system that simulates its manufacture

B1 Model a component in preparation for manufacture

- Suitable components could be manufactured using the following processes, e.g. printed circuit board drilling, milling, turning, additive manufacturing (3D printing), fabrication, e.g. folding, punching, shearing or forming, e.g. polymer injection moulding.
- Model a component on a CAD system, e.g. 3D CAD package, configuration of the parametric modeller, creation of 2D sketches, 2D sketch to a 3D model or 2D orthographic drawings.
- CAD software commands, e.g.:
  - 3D drawing commands, e.g. line, arc, circle, pan, zoom, extend, rotate cube, cylinder, extrude, and revolve
  - 2D drawing command, e.g. line, arc, pan and zoom, erase, trim, move, copy and stretch.
- Transfer of data, including:
  - CAD to CAM file transfer system, e.g. suitable file translators – IGES, CADL, DXF, ASCII, compatibility and accuracy of the results
  - post-process, e.g. creation of a data file that a compatible CAM/CNC system can read and execute the data to be able to manufacture.

B2 Simulate the manufacture of a component

- Set up the parameters of the CAM system, including:
  - tool paths, e.g. allowing for different tooling to be used depending on its availability
  - tool changes, e.g. allowing for optimal tool changes such as tools are not changed unnecessarily multiple times, tool selection is realistic, unnecessary multiple-sized tooling is avoided
  - tool sizes, e.g. selection of appropriate tooling by material and appropriate speeds and feeds, access tooling libraries
  - cycle times, e.g. consideration of timing and reduction of cycle times, machine knowledge, machining cycles manually planned or planned by the computer software, reduce dead times, checking the CNC code
  - roughing and finishing cycles, e.g. optimising roughing and finishing cycle time and the use of tooling
  - reduce waste, e.g. minimising swarf, reusing offcuts, consideration of alternative process (additive manufacturing).
- Simulate the manufacture of a component on a CAM system, including:
  - graphical simulation
  - tool collision detection
  - tool paths.

B3 Quality control checks on a virtual component

Quality control checks on a virtual component manufactured using simulation, including:

- correct component features were created, e.g. radii, angles, pockets
- incorrect component features are not present, e.g. no gouges or false cuts or folds
- graphical image of the simulated component represents the initial design drawing
- the component was safe to manufacture, e.g. machine tools did not collide.

Learning aim C: Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation

C1 Manufacturing plan

- A manufacturing plan covers the products and/or components that need to be manufactured, based on actual and forecast customer demand over a period of time. It should detail when and how much product to make as well as where to make it and what materials and resources are required.
- Product manufacturing volume is the amount of product made in a period of time, including: bespoke one-offs (prototype), batch processes (low-to medium volume), e.g. automotive cylinder blocks, mass production (low variety and flexibility), e.g. car assembly and continuous (high volume low variety), e.g. steel rolling.
- Manufacturing capacity, including, e.g. matching customer orders to capacity, available machine and/or workstation time, available person hours, product throughput time and product mix.
- Manufacturing planning considerations, e.g. minimise costs and machine cycle times, throughput of the workload against minimal inventories of raw material and component availability, operating costs and labour, minimise changes in production rates, maximise the utilisation of machinery and equipment.

C2 Schedule for manufacture

- A manufacturing schedule is derived from the manufacturing plan and it typically covers a shorter time horizon.
- The purpose of a schedule is to try to optimise three conflicting objectives to ensure that manufacturing jobs are completed just-in-time (JIT), to minimise the amount of time required from the release of a work order to the manufacture of a quantity of a product and to maximise the economic use of resources, e.g. machines.
- Software can be used to simulate and optimise the schedule to make it efficient and effective.
- The schedule covers how best to manufacture a product based on the sequence of work required on each resource, e.g. machines, and to synchronise manufacture while taking into account priorities and constraints, e.g. machine set-up times and managing change, e.g. late arrival of materials or machine break down.
- A schedule:
  - format, e.g. Gantt chart, critical path network, line-balancing technique
  - deadlines, e.g. machine changeover and set-up times, maintenance activities, manufacturing runs
  - is based on customer requirements, e.g. product delivery dates, product mix requirements, product volume
  - considers resource capacity available, e.g. factory capacity, production rates, volume of required machines, machine status (operational or downtime), efficiency of machinery
  - the availability of tooling- and work-holding devices.

C3 Product and/or component specification for manufacture

A product and/or component manufacturing specification contains the information needed to manufacture a product and it includes:

- engineering drawings, e.g. orthographic projection, isometric projection, assembly drawing, three dimensional model
- process description, e.g. turning, milling, grinding, drilling, forming, punching, blanking, forging
- manufacturing process and parameter requirements, e.g. facing, milling steps, turning radii, thread grinding, bending sheet metal, correct tooling, speeds and feeds
- measurements and manufacturing volume, e.g. dowelled holes – controlled dimensions to allow other attributes and dimensions to be manufactured
- tolerances, surface texture and other quality requirements.
- bill of materials (BOM) required, e.g. components, bearings, fixings, sub-assemblies, seals
- works order internal document to track an order, e.g. the quantity of the product to be manufactured, the amount of raw material required, labour requirement, machine utilisation.

Assessment criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation</td><td rowspan="2">A.D1 Evaluate, using vocational and high-quality written language, the benefits and operation of and technology used in at least two different CAM systems, relating the choices made to the context.</td></tr>
<tr><td>A.P1 Explain the benefits of two different CAM systems.
A.P2 Explain the technology used in and operation of at least two different CAM systems.</td><td>A.M1 Analyse the benefits and operation of and technology used in at least two different CAM systems.</td></tr>
<tr><td colspan="2">Learning aim B: Develop a virtual component on a Computer Aided Manufacturing system that simulates its manufacture</td><td rowspan="2">B.D2 Optimise, using a CAM system, the virtual manufacture of a realistic graphical component safely and efficiently, while correcting any errors and ensuring the component conforms to the specification.</td></tr>
<tr><td>B.P3 Create a realistic graphical model of a component, suitable for manufacture using a CAM system.
B.P4 Simulate, using a CAM system, the virtual manufacture of a component safely.</td><td>B.M2 Simulate, using a CAM system, the virtual manufacture of a realistic graphical component safely, while correcting any errors and ensuring the component conforms to the specification.</td></tr>
<tr><td colspan="2">Learning aim C: Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation</td><td rowspan="2">C.D3 Optimise the manufacturing plan and schedule for a range of products and order quantities, creating an accurate manufacturing specification for a product that is suitable for a CAM system.</td></tr>
<tr><td>C.P5 Create an effective manufacturing plan for a range of products considering a fixed order quantity.
C.P6 Create an effective manufacturing schedule for a range of products considering a fixed order quantity and a manufacturing specification for a product that is suitable for a CAM system.</td><td>C.M3 Create an effective manufacturing plan and schedule for a range of products and order quantities, creating an accurate manufacturing specification for a product that is suitable for a CAM system.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: 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:

- CAD systems, as required by the learning aims and unit content
- suitable CAD workstations and output devices, e.g. printers and plotters
- 2D CAD software that that is capable of professional 2D drawings and their output, e.g. AutoCAD 2D™, AutoCAD Lt™, TurboCAD Deluxe™, and DraftSight™
- 3D-modelling software that is capable of producing professional solid 3D models and fabricated models, that creates assemblies and outputs 2D drawings, e.g. AutoCAD 3D™, AutoCAD Inventor™, SolidWorks®, SolidEdge™
- CAM software packages: Techsoft®, Denford, solidCAM
- a range of health and safety legislation and regulations, as required in the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide in their evidence a balanced evaluation of how two different CAM systems can benefit the manufacturing organisations, the technology used and the operation of each system. Learners should focus their evaluation on how the CAM systems are efficient and effective and how they have been optimised for their specific process or have the flexibility to manufacture several different components at the same time. For example, a company may have invested in a multi-axis machining centre to meet the versatility of their product range, producing components for the automotive industry, while a separate company may have invested in a specialist additive manufacturing process to manufacture aerospace brackets in titanium.

Learners will compare the technology used in the CAM systems and the operation of the systems. For example, learners could evaluate the type of personnel used to run the CAM systems, where a manufacturer might employ computer programmers to control the machines to optimise component accuracy, reduce waste and minimise machining times, rather than the traditional approach of employing skilled craftspeople.

Overall, the evidence 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 technical engineering terms and be of a high standard of written language.

For merit standard, learners will include in their evidence an analysis of the benefits and operation of, and the technology used, in two different CAM systems. For example, they might analyse how changes to planned and unplanned manufacturing runs can be accommodated. The evidence will also show analysis of how the system can be modified during the process to reduce downtime. For example, a coordinate measuring machine (CMM) will record all dimensional changes over time and a machining centre can be modified accordingly, for example to replace worn-out tooling and to facilitate tool changeovers.

Overall, the analysis should be logically structured and be technically accurate and easy to understand.

For pass standard, learners will explain the benefits of two different CAM systems used to manufacture products and components. For example, a CAM system can reduce the lead time of developing a component to bring it to the marketplace, by the use of an additive manufacturing process (3D printing) to produce a CAD model or a CNC subtractive process producing a model in a high-density foam, both requiring less time than a skilled toolmaker which would require the use of specialist and expensive tooling.

Learners' evidence will also cover the operation of and the technology used in two different CAM systems. For example, the planning and programming for a multi axis machining centre requires a skilled technician to optimise tooling paths and processes and electrical discharge machining requires an operator with specialist skills to typically machine materials like hardened steels and titanium over relatively long cycle times, and the machine has limited travel in the z-axis.

Overall, the evidence, such as a report, will be logically structured although basic in parts. The report may contain minor technical inaccuracies in engineering terminology, for example mentioning 'polar robot' instead of 'Cartesian robot'.

Learning aim B

For distinction standard, learners will optimise the virtual manufacture of a component that has been modelled using 2D- or 3D CAD and transferred to a simulation package either offline or a machine's CAM graphical simulation system. Learners will set up the CAM system software parameters accurately to manufacture the component. For example, setting tooling lengths, offsets, and tool nose radii.

The part program will be graphically simulated and edited to ensure the finished virtual component conforms to specification. For example, it may be necessary to return to the initial CAD drawing or CAM package to change the order of machining features, for example to ensure that a radii is not removed by further machining process.

The process will be optimised for efficient manufacture. Optimised efficiency can be achieved by considering the correct selection of tooling, the order of tool selection, setting machine parameters correctly, such as speeds and feeds and the distance travelled by the tooling and components from initial storage to finished component. For example, it may be necessary to return to the initial CAD drawing or CAM package to change the machining order to ensure a required pocket is not produced prior to the face it is created in, resulting in the use of unnecessary tooling and tool changes.

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 simulate the manufacture of a virtual component using a CAM system that has been modelled using 2D or 3D CAD software. The part program will be graphically simulated using software and physically simulated by virtual reality or on a machining centre, such as a CNC machine, and as a result the program will be edited to ensure that the manufacture is safe. For example, tooling is always changed in a safe working zone, particularly when long drills are revolved in a turret on a CNC lathe. The virtual finished component will conform to the specification, whereby the drawing or program may have to be altered to correct any errors or omissions, for example if an array of holes was produced in a 4 by 5 rather than a 5 by 4 matrix.

Overall, the evidence will clearly demonstrate how working accurately and safely was considered by learners throughout the machining process.

For pass standard, learners will create a realistic graphical model of a component that can be manufactured using a CAM system. The model should be produced in a suitable CAD software package and saved in a file format which can be transferred to a CAM system. For example, a file could be transferred using DXF, IGES or STL, the integrity of the program created will need to be checked due to translation errors involving colours and layers.

The part program will be graphically simulated using CAM software offline or simulated on a machining centre, for example a CNC machine, and as a result the program will be edited to ensure that the manufacturing process is safe, for example that machine tools do not collide, that the feed rates are realistic and would not burn out or break real tooling. Learners may make limited reference to accuracy and the finished components may not completely conform to the specification, for example a minor feature such as a radii might be missing or of an incorrect size.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results, in the form of screen dumps, drawings, modifications and program.

Learning aim C

For distinction standard, learners will optimise the manufacturing plan and schedule that will be accurate and concise for a range of order quantities. Learners may incorporate the product or component designed as part of learning aim B in the plan and schedule it with at least two other products. The manufacturing plan will incorporate estimated sales volume and the relevant resources required. For example, an automotive manufacturer will need to ensure that stock is available at the required time and rate. This may include pre-ordering proprietary components or arranging the manufacture of specialist components in-house or via sub-contractors. These factors will need to be considered in relation to the required order quantities. For example, the workflow, and stock inventories required will be different for different batch sizes.

Optimisation of time and resources in the plan and schedule is fundamental to prevent waste, for example idle machines and human resources. The correct cycle times with optimised tool movement, against reduced inventories and cutting times will be used appropriately. For example, castings of automotive cylinder blocks will be ordered to meet the manufacturing cycle, these will be related to the manufacturing cells process cycle times with a minimum stock holding. The planning documentation will need to specify appropriate volumes so that the manufacturing process is efficient and effective.

The schedule will reflect the requirements of a high-technology company in relation to a lower-technology company, an example of this may be the development of Critical Path Analysis to aid the material flow through the FMC and the integration of planning and scheduling software to support the manufacturing activity.

The product specification for manufacture will be a comprehensive and accurate document that enables a technically-skilled third party to understand the manufacturing process and/or successfully manufacture the product. It would, for example, specify an optimal flow of processes such as milling and turning, and optimise the machining process, such as facing and the creation of radii, identifying the most appropriate speeds and feeds for each operation.

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 create an effective manufacturing plan and schedule. They may incorporate the product or component designed as part of learning aim B with at least two other products, for a large batch or mass manufacturing volume. For example, the manufacturing planning document will highlight alternative machinery or tooling if the primary machinery or tooling becomes unavailable and the program code to be run to accommodate this.

The schedule will reflect the requirements of a high-technology company in relation to a lower-technology company, for example the creation of automatic works orders, and bills of material (BOM), this could be part of a paperless office, compared to the storage of paper schedules, plans and drawings. Learners will also link machine set-up times to availability to ensure that there is no disruption to current or future manufacture, while allowing for machine breakdown and routine maintenance.

The product or component specification for manufacture will be an accurate document that enables a technically-skilled third party to understand the manufacturing process and/or successfully manufacture the product. For example, the creation of machine dowel holes to be used as location points will be specified accurately, as will the secondary operation to tap them for their use in the final product.

Overall, the analysis should be logically structured and be technically accurate and easy to understand.

For pass standard, learners will create a manufacturing schedule and plan that will effectively show all the processes of manufacture. Learners may incorporate the product or component designed as part of learning aim B with at least two other products, for a large batch or mass manufacturing volume. For example, the planning documentation will highlight the necessity for a CMM to check the component's critical dimensions and record the data on the company's statistical data system. The schedule will reflect the requirements of a high-technology company, for example the integration of software to control the FMS process but not full integration with the ordering and stock control systems.

The product or component specification for manufacture will be a document that enables a technically-skilled third party to understand the manufacturing process and/or manufacture the product. For example, learners interpret the surface texture requirement incorrectly and specify a feed rate for cutting the component on the machine that is too fast, resulting in a surface texture that would be too rough for the specification.

Overall, the evidence, such as a report, will be logically structured although basic in parts. It may contain minor technical inaccuracies relating to engineering terminology such as mentioning 'mass' instead of 'continuous' manufacturing.

Links to other units

This unit links to:

- Unit 3: Engineering Product Design and Manufacture
- Unit 5: A Specialist Engineering Project
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local world class manufacturing organisations
- contribution of ideas to unit assignment/project materials.

Unit 41: Manufacturing Secondary Machining Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore and carry out secondary machining processes to manufacture shapes by the safe removal of material.

Unit introduction

Many of the products and components we use daily rely on secondary machining processes. These processes are sometimes easy to spot in manufactured components or products, such as a machine bearing or the nut holding a brake shoe in place on a bicycle.

In this unit, you will cover the technology used in, and characteristics of, a range of traditional machining processes such as turning, and specialist machining processes such as broaching. You will develop knowledge of the health and safety requirements for working on secondary machining processes, and gain practical skills and understanding to be able to set up and operate traditional secondary machining processes to manufacture a component. Finally, you will reflect on the skills and understanding of secondary machining processes that you have acquired and the behaviours applied while manufacturing a component.

As an engineer, you need to understand machining processes and have practical skills in using a range of machines. This knowledge and the practical skills gained from the unit will enable you to create feasible solutions to engineering problems. This unit prepares you for a mechanical or manufacturing engineering apprenticeship, for progression to higher education, and for employment in technician-level roles, for example as a machine setter and setter operator.

Learning aims

In this unit you will:

A Examine the technology and characteristics of secondary machining processes that are widely used in industry

B Set up traditional secondary processing machines to manufacture a component safely

C Carry out traditional secondary machining processes to manufacture a component safely

D Review the processes used to machine a component and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and characteristics of secondary machining processes that are widely used in industry	**A1** Traditional secondary machining processes **A2** Specialist secondary machining processes **A3** Sustainability characteristics of secondary machining processes	A report focusing on three different traditional processes and an analysis of research case studies on three different specialist processes.
B Set up traditional secondary processing machines to manufacture a component safely	**B1** Health and safety requirements when setting up secondary process machines **B2** Risk assessment **B3** Setting up secondary process machines	A practical activity involving a risk assessment and the setting up of at least two traditional machining processes and the machining of a component. Evidence will include: a developmental logbook, risk assessment, observation records/witness statements, the finished component, annotated photographs and drawings, set up planning notes, and complete quality control documents.
C Carry out traditional secondary machining processes to manufacture a component safely	**C1** Features of traditional secondary machining processes **C2** Parameters of traditional secondary machining processes **C3** Quality control methods	
D Review the processes used to machine a component and reflect on personal performance	**D1** Lessons learned from machining a component **D2** Personal performance while machining a component	The evidence will focus on what went well and what did not go so well when machining a component, and a conclusion of improvements that could be made. The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.

Content

Learning aim A: Examine the technology and characteristics of secondary machining processes that are widely used in industry

A1 Traditional secondary machining processes

Technology and characteristics of secondary machining processes.

- Drilling:
  - machine type and batch size, including single spindle machines, e.g. pillar (one-off to small batch sizes) and radial (small to medium batch sizes)
  - features of the component, e.g. countersinking, counterboring, spot facing, taping, holes (including through, blind and reamed holes)
  - accuracy of components – typical dimensional tolerances = ±0.3 mm to ±0.05 mm and typical surface texture = 6.3 μm to 1.6 μm.
- Turning:
  - machine type and batch size, including centre lathe (one-off to small batch size) and turret (small to large batch size)
  - features of the component, e.g. flat faces, diameters (including parallel, stepped and tapered diameters), holes (including drilled, bored and reamed holes), profile forms, threads, parting off, chamfers, knurls, undercuts
  - accuracy of components – typical dimensional tolerances = ±0.05 mm to ±0.0125 mm and typical surface texture = 3.2 μm to 0.8 μm.
- Milling:
  - machine type and batch size, including horizontal (one-off to small batch size), vertical (one-off to small batch size), universal (one-off to small batch size)
  - features of the component, e.g. faces, steps/shoulders, slots, holes, and profile forms
  - accuracy of components – typical dimensional tolerances = ±0.1 mm to ±0.025 mm and typical surface texture = 3.2 μm to 0.8 μm.
- Grinding:
  - machine type and batch size, including surface (one-off to small batch size), cylindrical (one-off to small batch size), centreless (medium to large batch size), universal (one-off to small batch size)
  - features of the component, e.g. faces, slots, diameters and bores
  - accuracy of components – typical dimensional tolerances = ±0.0125 mm to ±0.002 mm and typical surface texture = 0.8 μm to 0.2 μm.

A2 Specialist secondary machining processes

Technology and characteristics of specialist machining processes.

- Presswork:
  - machine type and batch size, including single action (small to medium batch size), multiple action (medium batch to mass manufacturing)
  - features of the component, e.g. blanking, notching, piercing, cropping/shearing, bending/forming
  - accuracy of components – typical dimensional tolerances = ±0.3 mm to ±0.05 mm.
- Electro discharge:
  - machine type and batch size, including spark erosion (small to large batch size), wire erosion (small to large batch size)
  - features of the component, e.g. holes, faces, forms and other features (including engraving, cavities, radii/arcs, slots)
  - accuracy of components – typical dimensional tolerances = ±0.1mm to ±0.05mm and typical surface texture = 6.3 μm to 0.4 μm.

- Broaching:
  - machine type and batch size, including horizontal (one-off to medium batch size), vertical (one-off to medium batch size)
  - features of the component, e.g. keyways, holes, and splines
  - accuracy of components – typical dimensional tolerances = ±0.05mm to ±0.01mm and typical surface texture = 6.3 μm to 0.4 μm.
- Honing and lapping:
  - machine types and batch size, including horizontal and vertical honing (one-off to medium batch size) and rotary disc and reciprocating lapping (one-off to medium batch size)
  - features of the component, e.g. holes, faces
  - accuracy of components – typical dimensional tolerances = ±0.01 mm to ±0.005 mm and typical surface texture = 0.2 μm to 0.03 μm.

A3 Sustainability characteristics of secondary machining processes

- Energy consumption to remove material, including power requirements to operate the machine, condition of machine, condition of tooling.
- Use and disposal of cutting fluids/electrolytes and waste materials.

Learning aim B: Set up traditional secondary processing machines to manufacture a component safely

B1 Health and safety requirements when setting up secondary process machines

Key features of regulations or other relevant international equivalents, including:

- Current Personal protective equipment (PPE) at work regulations and amendments, e.g. personal safety, identification of appropriate protective clothing and equipment, work area kept clean and tidy
- Current Manual handling operations regulations and amendments, e.g. safe set up of moving parts, repetitive loading of materials into the machine, setting stops, avoid sharp edges on sheet steel
- Current Control of substances hazardous to health (COSHH) regulations and amendments, e.g. use of barrier cream, choice and handling of cutting fluids/dielectric flow rate, hygiene measures including adequate washing facilities, general ventilation.

B2 Risk assessment

Risk assessment of the working environment and specific secondary machining processes. To include hazard identification and classification.

- Defining a hazard by inspection of the work environment and consideration of specific manufacturing processes, e.g. moving parts of machinery, sharp objects, electricity, slippage and uneven surfaces, dust and fumes, handling and transporting, contaminants and irritation, and unshielded processes.
- Defining risk by determining how hazards may cause injury, e.g. tools, materials or equipment in use, spillages of oil and chemicals, not reporting accidental breakages of tools or equipment, and not following working practices and procedures.
- Putting control measures in place to reduce risk, e.g. issue of eye protection for use when removing material, having guards in place.
- Health and Safety Executive (HSE) guidance on risk assessment to include the five steps to risk assessment and the use of standard pro forma for recording risk assessments.

B3 Setting up secondary process machines

- Tooling, including:
  - materials and form – solid high-speed steel, tungsten carbide, abrasive stone, composite wheels
  - for drilling – drill bit, counterboring tool, centre drill, reamer, tap
  - for turning – turning tools, chamfer tools, centre drills, twist drills, taps

  - for milling – face mills, side and face cutters, slotting cutters, end mills, slot drills
  - for grinding – straight-sided wheel, recessed and double-recessed wheel and dressing of wheels.
- Workpiece-holding devices, including:
  - chucks – hard three jaw, magnetic
  - for drilling – clamping direct to machine table, machine vice, vee block and clamps
  - for turning – drive plate and centres, faceplates, fixed steadies
  - for milling – clamping direct to machine table, machine vice, angle plate, vee block and clamps
  - for grinding – centres, face plate, machine vices, arbors.
- Speeds and feeds, including:
  - for drilling – tooling revolutions per minute, linear feed rate
  - for turning – workpiece revolutions per minute, linear feed rate, depth of cut for roughing and finishing
  - for milling – linear/table feed rate, milling cutter revolutions per minute, depth of cut for roughing and finishing
  - for grinding – linear/table feed rate, depth of cut for roughing and finishing, cross feed.

Learning aim C: Carry out traditional secondary machining processes to manufacture a component safely

C1 Features of traditional secondary machining processes

- For drilling – through holes, counterboring, tapped hole, reamed hole.
- For turning – parallel diameters, chamfers, drilled and tapped blind hole.
- For milling – flat face, shoulder, slot and profile forms.
- For grinding – parallel diameter, flat surface.

C2 Parameters of traditional secondary machining processes

- Cutting fluid application, swarf removal, workpiece removal.
- For drilling – tool revolutions per minute, feed rate, swarf clearance.
- For turning – workpiece revolutions per minute, tool feed rate, depth of cut for roughing and finishing.
- For milling – linear/table feed rate, tool revolutions per minute, depth of cut for roughing and finishing.
- For grinding – linear/table feed rate, depth of cut for roughing and finishing, cross feed, dressing of wheels.

C3 Quality control methods

Quality control methods, including:

- components to be free from burrs, sharp edges and false cuts
- checks for accuracy:
  - use of equipment to check dimensional tolerance, e.g. external micrometer, gap gauge, slip gauges and comparator
  - use of equipment to check surface texture, e.g. comparators (Rubert gauges), portable surface roughness measuring instruments.

Learning aim D: Review the processes used to machine a component and reflect on personal performance

D1 Lessons learned from machining a component

Scope of the lessons learned should cover:

- health and safety skills, including setting and using machines, using appropriate personal protective equipment, keeping the work area clean and tidy
- traditional secondary machining skills, including the effectiveness and efficiency of setting and operating machines, sustainability considerations, e.g. waste materials and energy usage and the use of quality control methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while machining a component

Understand that relevant behaviours cover:

- taking initiative and responsibility for own actions to monitor, adjust and control the machines continually, often while working independently
- communication and literacy skills to ensure health and safety in the workplace, and to follow and implement instructions appropriately and to explain own intentions
- problem solving as problems occur, e.g. replacing a broken or worn-out tool, deciding which actions to take when setting up and using secondary machining processes.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the technology and characteristics of secondary machining processes that are widely used in industry		**A.D1** Evaluate, using language that is technically correct and of a high standard, the use of contrasting traditional and specialist secondary machining processes to sustainably manufacture components in different batch sizes.
A.P1 Explain how different traditional and specialist secondary machining processes are used to manufacture different features on components.	**A.M1** Analyse how different traditional and specialist secondary machining processes are used to sustainably manufacture different features on components to the intended accuracy.	
Learning aim B: Set up traditional secondary processing machines to manufacture a component safely		**BC.D2** Refine during the process the safe set up and parameters of the traditional secondary processing machines to effectively and efficiently manufacture a component.
B.P2 Explain what health and safety requirements apply when machining a component and conduct a risk assessment of the work environment. **B.P3** Set up safely at least two traditional secondary processing machines.	**B.M2** Use the correct tooling, work-holding devices and speeds and feeds to set up safely at least two traditional secondary processing machines.	
Learning aim C: Carry out traditional secondary machining processes to manufacture a component safely		
C.P4 Manufacture the component safely using at least two different traditional secondary machining processes and containing at least six features.	**C.M3** Manufacture accurately the component containing at least six features.	
Learning aim D: Review the processes used to machine a component and reflect on personal performance		**D.D3** Demonstrate consistently good technical understanding and analysis of traditional secondary machining processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P5 Explain how health and safety, traditional secondary machining, and general engineering skills were applied effectively during the manufacturing process. **D.P6** Explain how relevant behaviours were applied effectively during the manufacturing process.	**D.M4** Recommend improvements to the set up and use of traditional secondary machining processes and to the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, B.M2, C.M3, BC.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- pillar and/or radial drills, centre and/or turret lathes, horizontal, vertical and/or universal milling machines, surface, cylindrical, centreless and/or universal grinding machines, as required in the unit content
- auxiliary equipment, such as that listed under 'tooling' and 'workpiece-holding devices' in the content
- a range of equipment suitable for measuring the dimensional accuracy and surface texture of the work pieces to be machined
- a range of health and safety regulations, as required by the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce evidence that includes a balanced evaluation of the secondary machining processes, including energy consumption, disposal of fluids and waste material for different batch sizes and why particular processes were chosen. The evidence will detail how each process will accommodate different tolerances and batch sizes and how they relate to sustainable manufacture of components.

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 using correct grammar.

For merit standard, learners will analyse consistently across all the processes covered and include details about energy consumption, disposal of fluids and waste material, and the tolerances achievable.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will be clear in their explanation that three traditional and three specialist processes have been covered.

Overall, the explanations should be logically structured, although basic in parts. They may contain minor technical inaccuracies relating to engineering terminology, such as mentioning 'smoothness' instead of 'surface texture' and making 'edges' instead of 'chamfers'.

Learning aims B and C

For distinction standard, learners will refine throughout the process the machine set-up and parameters. For example, the application of cutting fluid, the tool feed rate and the position of tools, such as correct tool overhang, to ensure the process continues to operate efficiently and effectively, and produces a component that is accurate. Other parameters should be considered to control:

- effectiveness, for example optimising the order of tools and distance travelled by the tools, and machining the component in a realistic time
- efficiency, for example replacing worn tools, using correct cutting fluid and monitoring the machining processes.

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 use the correct tooling and workpiece-holding devices, and select appropriate speeds and feeds to machine a component, involving at least two traditional machining processes. Learners will show which measurements were taken for each of the features and which adjustments were made to ensure dimensional and surface texture accuracy. Additionally, evidence such as observation records will show clearly how working accurately was considered by learners.

For pass standard, learners will explain how health and safety is managed for the machines they intend to use and what regulations should be met. They will also produce a risk assessment, which will include consideration of all significant hazards, be laid out on in an appropriate template and include suitable control measures.

Learners will ensure the safe set-up of processes, including workpiece-holding devices and machine parameters. The vast majority of the speeds and feeds, tooling and workpiece-holding devices will be set up correctly. Learners will use traditional machining processes safely to manufacture a component and will apply cutting fluid (where relevant), remove swarf, and remove the workpiece from the machine correctly. The six features on the component must be free from burrs, sharp edges and false cuts.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results. They may make limited reference to accuracy and the finished components, which may not be completely to the desired tolerance or surface texture.

Learning aim D

For distinction standard, learners will give a balanced evaluation about the actions taken, traditional machining skills and the general engineering skills applied. Relevant behaviours will be consistently applied to a professional standard. For example, learners will take the initiative and responsibility for their own actions, such as when they are setting and adjusting the machines.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. For example, learners will consistently demonstrate a good technical understanding of machining processes that includes correct technical engineering terms and information about improvements.

For merit standard, learners will give in their notes or a logbook, and especially in their lessons learned evidence, detailed examples of where improvements could be made to the:

- set-up and use of the machining processes and equipment to make manufacture of the components more efficient, accurate and/or sustainable
- application of the relevant behaviours, for example, how listening to instructions has resulted in a worn tool being replaced and an activity running smoothly.

Overall, the suggested improvements 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 pass standard, learners will write a technical report around 500 words in length, detailing the lessons learned during the manufacture of a machined component. The report will explain which:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- traditional secondary machining skills were used, for example how the intended surface texture was achieved, how dimensional accuracy was achieved and how holes were centred accurately
- general engineering skills were used, for example understanding Cartesian coordinates, interpreting drawings and recognising technical parts of machines
- behaviours were used, with an analysis of how successfully they were applied.

Overall, the evidence should be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology and with spelling and grammar.

Links to other units

This unit links to:

- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 42: Manufacturing Primary Forming Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local manufacturing organisations with expertise in machining
- contribution of ideas to unit assignment/project materials.

Unit 42: Manufacturing Primary Forming Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore some of the primary forming processes found in engineering that are used to make a range of different components.

Unit introduction

Almost everything we touch in the world of technology has been created through some technique or process associated with primary forming, which is about 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. Over the years, these processes have been refined to suit the introduction of new materials and the demands for quantity manufacture. In some processes, the shaped component is almost ready for use while in others it is produced slightly oversize with further machining required to produce accurate dimensions.

In this unit, you will investigate a range of primary forming manufacturing processes. Specifically, you will investigate moulding processes for metals, ceramics and polymers, and deformation processes for metals and polymers. As the use of primary forming processes can be dangerous and hazardous to health, you will learn about relevant health and safety practice and regulations. You will also justify the selection of primary forming processes for a range of products.

As an engineer, it is important to understand a range of different manufacturing processes. This unit will help to prepare you for an engineering apprenticeship, for higher education and for technician-level roles in manufacturing, such as a machine setter operator, a planning, process and manufacturing technician and a quality assurance technician.

Learning aims

In this unit you will:

A Examine how moulding processes involving metals, ceramics and polymers are used in industry

B Examine how deformation processes involving metals and polymers are used in industry

C Investigate the suitability of forming processes to manufacture products using safe working practices.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how moulding processes involving metals, ceramics and polymers are used in industry	**A1** Metal moulding processes **A2** Ceramic moulding processes **A3** Polymer moulding processes	A portfolio containing written responses and diagrams showing moulding techniques for each material type. This activity could be supported by a PowerPoint presentation.
B Examine how deformation processes involving metals and polymers are used in industry	**B1** Metal deformation processes **B2** Polymer deformation processes	A portfolio containing written responses and diagrams showing deformation processes for metals and polymers. This activity could be supported by a PowerPoint presentation.
C Investigate the suitability of forming processes to manufacture products using safe working practices	**C1** Safe working practices for primary forming processes **C2** Forming process selection	A portfolio containing a written commentary and diagrams justifying the selection of forming processes to manufacture a range of products, and about health and safety and risk reduction approaches that apply to the processes. Evidence could also be in the form of a PowerPoint presentation.

Content

Learning aim A: Examine how moulding processes involving metals, ceramics and polymers are used in industry

A1 Metal moulding processes

- Casting processes:
  - sand casting, including:
    - characteristics, e.g. suitable for high melting point alloys, complex geometry, rough surface finish
    - applications, e.g. engine blocks, pump housings and valves
  - die (gravity, pressure) casting, including:
    - characteristics, e.g. good dimensional accuracy, smoother surface finish and improved mechanical properties
    - applications, e.g. cylinder heads, brackets and gas turbine engine parts
  - investment casting, including:
    - characteristics, e.g. suitable for most metallic materials, complex geometry and smooth surface finish
    - applications, e.g. exhaust manifolds, turbine blades and brass connectors.
- Metallic materials applicable to process, including:
  - ferrous, e.g. carbon steels, stainless steels, cast iron
  - non-ferrous, e.g. aluminium, copper, brass, zinc, titanium, alloys.
- The function of additives, e.g. pig iron, scrap, ore, ingots, recycled material, metal composition, trace elements, coke, limestone.
- Mould features, including patterns, cores, dies, moulding parts (boxes, sand, reinforcements, releasing agents, runners, risers, sprues).
- Component removal and finishing, including knock out, ejection and fettling.
- Sustainability of casting processes, including use of coal fired or electric furnaces, water contamination, fumes and particle release and raw material extraction.

A2 Ceramic moulding processes

- Ceramic moulding processes:
  - sintering, including:
    - characteristics, e.g. suitable for high melting point ceramics, complex geometry, good dimensional accuracy
    - applications, e.g. gears, carbide tip tools and driveshafts
  - injection moulding, including
    - characteristics, e.g. excellent batch to batch repeatability, high surface finish quality, high hardness and mechanical strength
    - applications, e.g. diagnostic equipment, surgical instruments and bearings.
- Ceramic materials applicable to process, e.g. metallic carbides, nitrides, oxides.
- Powder metallurgy (PM), including blending and compacting.
- Secondary process operations, including infiltration, sizing, coining, machining, impregnation, plating, heat treatment.
- Sustainability of ceramic moulding processes, including use of coal fired or electric furnaces, water consumption during processing, particle release and raw material extraction.

A3 Polymer moulding processes

- Polymer moulding processes:
  - compression moulding, including:
    - characteristics, e.g. low-cost tooling, suitable for thermoset materials, suitable for small manufacturing volumes
    - applications, e.g. wellington boots, seals and gaskets
  - transfer moulding, including:
    - characteristics, e.g. high cavity count, design flexibility, short manufacturing cycle
    - applications, e.g. rubber face seals for gas valves and connector seals for spark plug leads

- injection moulding, including:
  - characteristics, e.g. suitable for mass manufacturing, good dimensional accuracy, complex geometry
  - applications, e.g. refuse bins, chair seats and toolboxes
- rotational moulding, including:
  - characteristics, e.g. suitable for the manufacture of large hollow products, minimal material wastage, multi-layered products are possible
  - applications, e.g. large storage tanks, toys and leisure craft
- blow moulding, including:
  - characteristics, e.g. one piece construction is achieved, suitable for low and high manufacturing volumes of hollow products
  - applications, e.g. containers, drinks bottles and toys.

- Polymer materials applicable to process:
  - thermoplastics, e.g. acrylonitrile butadiene styrene (ABS), polymethyl methacrylate (acrylic), polystyrene, polyethylene, nylon, and polypropylene
  - thermosetting plastics, e.g. Bakelite, melamine formaldehyde, epoxy resin, polyester resin and urea formaldehyde.
- The function of additives, e.g. stabilisers, flame retardants, fillers (cotton flock, fibres, mica, graphite, wood flour), plasticisers, antistats, colourants, lubricants.
- Mould features, including two plate, three plate, combination/composite, split, unscrewing.
- Moulding parameters, including temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation.
- Sustainability of polymer moulding processes, including use of electricity, refining of petroleum, recycling materials and recovering energy through waste incineration.

Learning aim B: Examine how deformation processes involving metals and polymers are used in industry

B1 Metal deformation processes

- Metal deformation processes:
  - extrusion, including:
    - types, e.g. direct, indirect, and impact
    - characteristics, e.g. elongated grain structure, good dimensional accuracy and high geometric change of work piece
    - applications, e.g. box section, tubing and window frames
  - forging, including:
    - types, e.g. drop, pressure, and upset
    - characteristics, e.g. uniform grain flow, low operational costs and high mechanical strength
    - applications, e.g. crankshafts, hand tools and golf clubs
  - rolling, including:
    - types, e.g. hot and cold
    - characteristics, e.g. wide range of material thicknesses produced, high hardness and mechanical strength
    - applications, e.g. lintels, flat bar and sheet material
  - presswork, including:
    - types, e.g. forming, bending, deep drawing
    - characteristics, e.g. suitable for mass manufacturing, good dimensional accuracy and use with sheet material
    - applications, e.g. car body panels, brackets and computer hardware panels
  - metal spinning, including:
    - types, e.g. shear, internal and external tube
    - characteristics, e.g. low volume, low set-up costs and high surface finish quality
    - applications, e.g. ornaments, saucepans and musical instruments.
- Metals applicable to process, including:
  - ferrous, e.g. carbon steels and stainless steels
  - non-ferrous, e.g. aluminium, copper and brass.

B2 Polymer deformation processes

- Polymer deformation processes:
  - vacuum forming, including:
    - characteristics, e.g. low tooling costs, speed of manufacture, uses plastic sheet instead of granules
    - applications, e.g. chocolate box inserts, door panels and document holders
  - extrusion, including:
    - characteristics, e.g. suitable for high manufacturing volumes, single piece uniform products, complex geometry
    - applications, e.g. window frames, tubes and storage racks
  - calendaring, including:
    - characteristics, e.g. low thermal degradation, suitable for use with a range of thermoplastic materials, good dimensional accuracy
    - applications, e.g. sheet material such as shower curtains, floor tiles and roof panels.
- Polymers applicable to process are thermoplastics, e.g. polycarbonate, polysulfone, acrylic, polyvinyl chloride, ABS.
- Function of additives, including plasticisers, antistats, lubricants, heat stabilisers.
- Mould features, including double curvatures, shapes (male, female), stiffened mouldings, section shape.
- Mould parameters, including temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation.

Learning aim C: Investigate the suitability of forming processes to manufacture products using safe working practices

C1 Safe working practices for primary forming processes

- Key features of health and safety regulations, or other relevant international equivalents:
  - Current Control of substances hazardous to health (COSHH) regulations and amendments, e.g. requirements on the safe storage and use of hazardous substances, manufacturer's safety data sheets, hazard symbols, protection from contact with hazardous substances
  - Current Protective personal equipment (PPE) at work regulations and amendments, e.g. employers' responsibility to provide appropriate equipment, such as eye protection, barrier creams, disposable gloves, protective clothing, dust masks, respirators
  - Current Manual handling operations regulations (MHOR) and amendments, e.g. safe set-up of moving parts, repetitive loading of materials into the machine, setting stops, avoid sharp edges
  - Current Control of noise at work regulations, e.g. hearing protection and hearing protection zones and noise surveillance measures.
- Awareness of risk assessment of the primary forming work environment, including hazard identification and classification:
  - Health and Safety Executive (HSE) guidance on risk assessment, including the five step approach to risk assessment
  - risk reduction, e.g. training, work environment housekeeping and appropriate maintenance activities.

C2 Forming process selection

Objective criteria used to determine the choice of forming process:

- manufacturing volume or scale, e.g. one-off, small batch, large batch, mass and continuous
- product form, including complexity (low, medium or high), physical dimensions, tolerances and surface finish
- product material properties, e.g. mechanical, electrical, thermal and physical
- constraints, e.g. budget, time, and regulatory
- sustainability – throughout the product's lifecycle, carbon footprint and energy usage
- operational environment, e.g. safety critical, corrosive, temperature, humidity.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how moulding processes involving metals, ceramics and polymers are used in industry		**A.D1** Evaluate, using language that is technically correct and of a high standard, the use of different moulding processes to manufacture components from metallic, ceramic and polymer materials.
A.P1 Explain the moulding processes used to manufacture components from metallic materials. **A.P2** Explain the moulding processes used to manufacture components from ceramic materials. **A.P3** Explain the moulding processes used to manufacture components from polymer materials.	**A.M1** Compare the different moulding processes used to manufacture components from metallic, ceramic and polymer materials.	
Learning aim B: Examine how deformation processes involving metals and polymers are used in industry		**B.D2** Evaluate, using language that is technically correct and of a high standard, the use of different deformation processes to manufacture components from metallic and polymer materials.
B.P4 Explain the deformation process used to manufacture a metallic-based component. **B.P5** Explain the deformation process used to manufacture a polymer-based component.	**B.M2** Compare the different deformation processes used to manufacture components from metallic and polymer materials.	
Learning aim C: Investigate the suitability of forming processes to manufacture products using safe working practices		**C.D3** Evaluate, consistently, a range of components, using objective criteria to justify appropriate primary forming processes and explain in detail which safe working practices would apply.
C.P6 Select, using objective criteria, acceptable primary forming processes to manufacture a range of components and describe which safe working practices would apply.	**C.M3** Analyse a range of components, using objective criteria to recommend appropriate primary forming processes and explain which safe working practices would apply.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.P5, B.M2, B.D2)

Learning aim: C (C.P6, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of cast, ceramic-moulded, polymer-moulded and process-deformed components or products
- some equipment and machines to practically demonstrate some of the primary processes covered by the unit content, although this is not essential (centres may also consider industrial visits or, alternatively, video and other presentation resources)
- a range of health and safety regulations and guidance documents, as specified in the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will give a balanced, clear and detailed evaluation for the use of different moulding processes to manufacture components from metallic, ceramic and polymer materials. The detailed evaluations will cover the characteristics of the processes and other considerations, giving reasons for the choice of process and comparing the different processes. For example, for metallic materials, sand casting skateboard trucks with complex geometry from aluminium alloy. Learners will go on to explain the importance of the characteristics and other considerations for each of the process and materials being considered.

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 with a high standard of written language (consistent use of correct grammar and spelling).

For merit standard, learners will compare the characteristics of and other relevant considerations for different moulding processes used to manufacture components from metallic, ceramic and polymer materials. For example, learners could select the die casting moulding process and will clearly explain the mechanical properties, manufacturing volumes, tooling costs and environmental impact of the moulding process and make comparisons with the sand casting process. Learners would go on to perform a similar analysis on moulding processes that use ceramic and polymer materials.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will give clear, qualitative explanations of the characteristics, sustainability, function of additives, process features and parameters, secondary processing requirements and other considerations relevant to different moulding processes when manufacturing components from metallic, ceramic and polymer materials. For example, learners could explain that injection moulding is a suitable process to use for high-volume manufacturing of polymer-based components coupled with the low cost per unit, which makes this process economically viable. The process also allows for intricate parts to be manufactured, often on a 'tree' that allows multiple parts to be produced at one time. Learners will then make links between the general characteristics of this process and their application in a range of engineering sectors.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example, lacking detail about the key material properties required when moulding is performed, and the evidence may contain technical inaccuracies or omissions, such as the occasional use of non-technical language or incorrect terms.

Learning aim B

For distinction standard, learners will give a balanced, clear and detailed evaluation for the use of different types of deformation processes to manufacture components from metallic materials and will compare the characteristics and other relevant considerations of different processes.

For example, forging a crankshaft for a sports car which requires superior mechanical properties from a carbon steel and explaining which type of process would be the preferred. Learners will go on to explain the importance of the characteristics for each of the deformation processes used when manufacturing components from polymer materials.

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 with a high standard of written language (consistent use of correct grammar and spelling).

For merit standard, learners will compare the types of deformation processes used to manufacture a range of metallic and polymer materials. For example, learners could consider selecting a deformation process such as vacuum forming and clearly explain the mechanical properties, manufacturing rates, tooling costs and environmental impact of the deformation process and compare them to an extrusion process. Learners would go on to perform a similar analysis on a deformation process that uses metallic materials.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will give clear explanations of the types of different deformation processes and their characteristics used to manufacture components from metallic materials. For example, learners could explain that presswork encompasses a number of processes, including forming, bending and deep drawing and examine the need for these processes when manufacturing components. Learners will also give clear explanations of the deformation processes and their characteristics for polymer materials. For example, learners could explain that blow moulding is a suitable process to use when one piece construction of components with a relatively low unit cost are required. The process also allows for intricate parts to be manufactured with a short cycle time.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example lacking detail about the characteristics of the many different types of deformation processes for metallic components, and the evidence may contain technical inaccuracies or omissions, such as the occasional use of non-technical language or incorrect terms. Learners will then make links between the general characteristics of these processes and their application in a range of engineering sectors.

Learning aim C

For distinction standard, learners will give a balanced evaluation of primary forming processes and will make reasoned judgements to select appropriate processes for a range of given, unlabelled products. They will also make supported judgements showing the relationships of the products to their application(s). For example, when deciding on what processes to choose to manufacture components for a bicycle, learners will consider the type of bicycle (such as road, mountain, child's, commuter), the quantity required, the complexity of each component (such as the gears, frame, brake calipers, wheels, mudguards), the material for each component, the cost and sustainability considerations. Learners will also produce a clear and detailed explanation about the safe working practices for the processes that they have selected, for example explanations for a range of PPE when forging the caliper arms for the bicycle brakes.

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 merit standard, learners will consistently analyse possible primary forming processes that could be used to manufacture a range of components and make an appropriate recommendation on the preferred processes. They will consider how the selection criteria interrelate. For example, when choosing a process for a mobile phone casing, learners will first consider the material type, such as a metal alloy or polymer, and move onto other criteria such as the volume required. Once selected, learners will explain which safe working practices and risk reduction approaches apply, for example what PPE would be needed to protect operatives from contact with hazardous substances used during the sintering process.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will research the forming processes they think could have been used to manufacture a range of products and will use objective criteria to select acceptable primary forming processes. For example, they could research the primary forming processes which may have been used to manufacture parts from a cordless screwdriver. Objective criteria include: the scale of manufacture, the environment it could be used in, the material properties and the complexity of each part. Learners will also describe the safe working practices associated with each primary forming process they have selected, for example explaining appropriate manual handling techniques for sand casting.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example lacking detail about how some aspects of the selection criteria are linked together. Although the process selection may be acceptable, it may not be the most appropriate. The evidence may also contain technical inaccuracies or omissions, such as the occasional use of non-technical language or incorrect terms.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacture
- Unit 25: Mechanical Behaviour of Metallic Materials
- Unit 26: Mechanical Behaviour of Non-metallic Materials
- Unit 45: Additive Manufacturing Processes
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 49: Aircraft Workshop Methods and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local manufacturing organisations with expertise of primary forming processes
- contribution of ideas to unit assignment/project materials.

Unit 43: Manufacturing Computer Numerical Control Machining Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine the principles of Computer Numerical Control (CNC) machining, and develop a computer part program and manufacture a component using a CNC machine.

Unit introduction

Many of the products and components we use daily rely on CNC machining processes. Manufacturers use CNC for highly complex components difficult to manufacture by traditional methods, for example mould manufacture, valves, and automotive and aerospace components. CNC machines are also used for the batch production of components, where it is more economical than traditional methods.

You will examine how CNC control systems work and the computer programming methods used to create products and components. You will investigate a range of theoretical and practical activities to plan and program a CNC machine tool to manufacture a product or component. As part of the process, you will edit and modify part programs, and use simulation software to safely determine if the program is fit for purpose. Finally, you will reflect on the skills and understanding you have acquired while building, modifying and testing analogue circuits, and the behaviours you have applied.

As an engineer, it is important to understand the manufacturing systems and mechanisms of planning and creating products and components through programming CNC machine tools. This unit helps to prepare you for employment, for example as a manufacturing technician, for an apprenticeship and for entry to higher education to study engineering.

Learning aims

In this unit you will:

A Examine the control systems used in Computer Numerical Control machines and different computer programming methods

B Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely

C Carry out Computer Numerical Control machining processes to manufacture a component safely

D Review the processes used to machine a component and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the control systems used in Computer Numerical Control machines and different computer programming methods	**A1** CNC machine tool control systems **A2** Open and closed loop feedback systems **A3** Part programming methods and program efficiency	A written report to investigate the control mechanism of a typical industrial CNC machine, based around open loop and closed loop systems, and its relationship to achieving accuracy via a computer program.
B Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely	**B1** CNC processes for milling and turning **B2** Tooling parameters **B3** Component parameters **B4** Machine set-up parameters **B5** Development of a CNC part program **B6** Sustainability considerations	Preparation activities and documents prior to CNC machining a product or component, to include: machine tool set-up sheet and a computer part program, and simulation of the program. Input the part program and set up the CNC machine, to produce a component, using multiple tooling. Carry out quality control checks to verify that the component meets the specification and is fit for the intended purpose.
C Carry out Computer Numerical Control machining processes to manufacture a component safely	**C1** Manufacture of a component using a CNC machine **C2** Safe working practices **C3** Component quality checks	
D Review the processes used to machine a component and reflect on personal performance	**D1** Lessons learned from programming and machining a component **D2** Personal performance while machining a component	The evidence will focus on what went well and what did not go so well when programming and machining a component, and a conclusion of improvements that could be made. The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.

Content

Learning aim A: Examine the control systems used in Computer Numerical Control machines and different computer programming methods

A1 CNC machine tool control systems

The role and function of key components and devices in a CNC machine tool control system, including:

- machine control unit
- drive mechanisms, including: lead screw, ball screw, stepper motors, alternating current servomotors and direct current servomotors
- transducers, including: linear, rotary and optical encoders.

A2 Open and closed loop feedback systems

- Understand the process of open and closed loop systems used in a CNC machine tools including: feedback, correction and error detection.

A3 Part-programming methods and program efficiency

- The two types of CNC part programming methods are:
  - non-conversational or manual programming – a program written in the same language and code that a CNC machine will execute it in
  - conversational programming – a system where parameters are input into pre-defined fields and the software typically interprets the information into code that a CNC machine can execute.
- Efficiency of the CNC program is influenced by a number of factors, including:
  - the quality of the product or component determined by the desired surface texture and tolerance
  - code structure and commands selected and combined to create the part program
  - material type and the complexity of the product/component form data interface, e.g. manual data input (MDI), data exchange format (DXF), and CAD/CAM link.

Learning aim B: Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely

B1 CNC processes for milling and turning

- Complex milling processes include: drilling cycle, peck drilling, tool offsets, boring, part radii, tapers, blended radii, tool diameter compensation, pocket cycles, polar coordinates, slots, holes on a PCD, and curved profiles.
- Complex turning processes include: part radii, radii blended to a taper, tool nose radius compensation, tool offsets, roughing cycle and turning cycle, boring, external threading cycle, internal threading cycle, drilling cycles, undercuts, grooves, and parting off.

B2 Tooling parameters

- Feed rates for the material to be machined, e.g. aluminium.
- Cutting speeds for the material to be machined, e.g. aluminium.
- Roughing operations.
- Finishing operations.
- Cutter compensation for the required code, e.g. G40, G41, G42.

B3 Component parameters

Calculations, including:

- cutter path coordinates for intersections that require the use of calculations, e.g. trigonometric functions, sine, cosine, tangent
- arc centres use of required calculations, e.g. trigonometric functions, sine, cosine, tangent

- work (product or component) holding, e.g. machine vice, fixtures, chucks, pneumatic or magnetic table, direct clamping to machine table
- canned cycles, and the selection and use of the correct canned cycles for efficient programming, e.g. G70 or G71 for a roughing cycle
- component materials, preparation of the material, e.g. blank sizes, pre-machining
- suitability of the machine and program to achieve the required tolerance and surface texture.

B4 Machine set-up parameters

- Work holding, and selection of the correct work-holding device.
- Tool change positions, and selection of a safe tool change position.
- Tool mounting, and use of optimal positions in turrets for efficiency and safety.
- Machine datum, and relationship to the program datum.
- Program datum, and safe positioning for machining and tool change activities.

B5 Development of a CNC part program

- Auxiliary functions, including:
  - metric/imperial unit selection for appropriate computer programming system
  - tool selection to meet the specification
  - cutting fluids selection depending on the material to be machined
  - workpiece loading and holding, and billet sizes and locations
  - tool changing sequences and safe machine operation
  - safety block to reset the coding, e.g. cancel compensation
  - edit a part program for coding errors, including logical errors, syntax errors.
- CNC codes, including:
  - G and M codes, e.g. G00, G01, M06
  - axis coordinates, e.g. milling X, Y, Z and secondary axis if available, and turning X, Z and secondary axis if available
  - absolute, incremental programming use of G90, and G91
  - preparatory commands, modal linear interpolation, circular interpolation, e.g. G02 and G03 with cutter compensation and non-modal, e.g. G04 dwell, inch and metric programming
  - program structure and efficiency, e.g. sub-routines/sub-programs, do loops.
- Simulate the CNC part program to check the tool cutter paths and for logical errors, e.g. graphical software simulation or a dry run.

B6 Sustainability considerations

- Disposal of materials, e.g. cutting fluids and swarf.
- Use of resources, e.g. paperless, coding and editing on screen, use of graphics for proving purposes, correct tool life parameters in use, re-using material to test program operation, e.g. wax.

Learning aim C: Carry out Computer Numerical Control machining processes to manufacture a component safely

C1 Manufacture of a component using a CNC machine

- Entry of datums into the program and set them on the machine tool.
- Secure work-holding devices.
- Program tool offsets or enter them into the MCU.
- Tooling prepared and located in the respective turrets, check tooling is in good condition and correct tooling selected or compensation allowed if not available.
- Check tool-change positions are safe.

- Simulate a CNC machining process using the machine control unit (MCU), and using suitable approaches, including:
  - graphical software simulation of the machining process to check the tool cutter paths
  - step through the program single block by single block with or without a component in situ
  - run the program at reduced feed rates
  - machine the component using a foam or wax material
  - machining of the component using the intended material.

C2 Safe working practices

Safe working practices include:

- use of personal protective equipment (PPE), e.g. overalls, safety glasses, safety boots, ear defenders
- in place and secure machine guards
- operational interlocks
- speed and feed over-rides set correctly
- speed and feeds are programmed or set correctly for manual data input (MDI)
- appropriate coolant is available.

C3 Component quality checks

- Dimensional tolerance equivalent to BS 4500, BS 1916 or other relevant international equivalent.
- Surface texture Grade 7 63 µin or 1.6 µm.
- Reamed and bored holes within H8.
- Angles within +/− 0.5°.
- Screw threads BS medium fit or other relevant international equivalent.

Learning aim D: Review the processes used to machine a component and reflect on personal performance

D1 Lessons learned from programming and machining a component

The scope of the lessons learned and improvements could be:

- health and safety skills including setting and using machines, using appropriate personal protective equipment and keeping the work area clean and tidy
- programming and machining skills, including the effectiveness and efficiency of programming, setting and operating machines, sustainability considerations, e.g. waste materials and energy usage and the use of quality control methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while machining a component

Understand that relevant behaviours for machining a component include:

- taking initiative and responsibility for own actions to monitor, adjust and control the machines continually, while often working independently
- communication and literacy skills to ensure health and safety in the workplace, to follow and implement instructions appropriately and to explain own intentions to others
- problem solving of issues as they occur, for example to re-code or compensate for unavailable tooling or deciding actions to take when setting up and using the CNC machining processes.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the control systems used in Computer Numerical Control machines and different computer programming methods		**A.D1** Justify the selection of the control system, feedback system and programming methods for different CNC machining applications.
A.P1 Explain the control system, feedback system and programming methods used in CNC machines.	**A.M1** Analyse how the interaction of the control system, feedback system and programming methods influence the CNC machining process.	
Learning aim B: Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely		**BC.D2** Optimise the processes to effectively and efficiently develop and manufacture safely a component using at least six complex CNC processes and at least three different cutting tools.
B.P2 Create a machine tool set-up sheet for a component using at least six complex CNC processes and at least three different cutting tools. **B.P3** Create a part program to machine a component safely using at least six complex CNC processes and at least three different cutting tools and simulate for any syntax and logical errors.	**B.M2** Produce an accurate machine tool set-up sheet for a component using at least six complex CNC processes and at least three different cutting tools. **B.M3** Create a part program to machine a component safely and efficiently, using at least six complex CNC processes and at least three different cutting tools and simulate for any syntax and logical errors.	
Learning aim C: Carry out Computer Numerical Control machining processes to manufacture a component safely		
C.P4 Simulate the CNC machining of a component safely, correcting any syntax and logical errors. **C.P5** Manufacture a component safely using at least six complex CNC processes and at least three different cutting tools.	**C.M4** Manufacture accurately a component using at least six complex CNC processes and at least three different cutting tools, incorporating improvements from the simulation.	
Learning aim D: Review the processes used to machine a component and reflect on personal performance		**D.D3** Demonstrate consistently good technical understanding and analysis of CNC programming and machining processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Explain how health and safety, CNC programming, machining and general engineering skills were applied effectively during the manufacturing process. **D.P7** Explain how relevant behaviours were applied effectively during the manufacturing process.	**D.M5** Recommend improvements to the set up and use of CNC programming and machining processes and to the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, B.M3, C.M4, BC.D2)

Learning aim: D (D.P6, D.P7, D.M5, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- CNC lathes, or CNC milling machines, or a machining centre, as required by the learning aims and unit content
- auxiliary equipment (such as that listed in the content under 'tooling' and 'workpiece-holding devices')
- a range of equipment suitable for measuring the dimensional accuracy and surface texture of the work pieces to be machined
- access to a range of health and safety legislation and regulations, as required by the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide in their evidence a balanced evaluation of a CNC control system. For example, the evidence may cover why some manufacturers fit a linear system and some adopt a rotary control system, and what the consequences of a broken lead screw are. The evaluation will also cover different types of feedback system. For example, they may cover the consequences of a CNC machine hunting while locating a tool position in a closed-loop control system. Learners will detail how each system will accommodate accuracy and how it is applicable to different machine systems and programming methodologies.

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 using, for example, correct grammar.

For merit standard, learners will analyse in their evidence the CNC control system, feedback system and programming methodologies consistently. For example, they might observe that programming using the conversational method is easier, requires less skill and is quicker to complete, but it may not be as efficient once interpreted, compared to the non-conversational method. The evidence will demonstrate how the system can influence the machining process, for example stepper motors are often found in open-loop systems, and these devices move in discrete steps resulting in a possible lack of positional accuracy.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain in their evidence how CNC machine control, feedback and programming methodology are used to manufacture products and components. For example, they might explain that the CNC machine's hardware safety system will stop over travel, and the software package has over-travel limits built in to ensure safe operation. This mitigates against possible programming errors.

Overall, the evidence, such as a report, will be structured logically although basic in parts. It may contain minor technical inaccuracies relating to engineering terminology, such as mentioning 'stepper motor' instead of 'servo motor'.

Learning aims B and C

For distinction standard, learners will produce an accurate and concise machine tool set-up sheet. The part program will be graphically simulated using software and physically simulated on the CNC machine, and as a result the program will be edited and optimised. The work-holding and machining parameters will also be refined during the set-up and CNC manufacture of the component. For example, the correct cutting speed and tool feed rates will be used throughout the machining process to ensure the component is safely, efficiently and effectively manufactured. Also, the tools should be checked for the correct location in the turret and all tool offsets correctly set. Other parameters should be refined to optimise the:

- effectiveness, for example by considering the order of tool selection and the distance travelled by the tools
- efficiency, for example by replacing worn tools or providing suitable tool compensation, using correct cutting fluid and monitoring the machining processes.

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 produce an accurate machine tool set-up sheet containing correct data, tooling parameters, feeds and speeds and work-holding parameters required to manufacture a component sustainably on a CNC machine.

Learners will create an efficient part program considering alternative approaches to machine the component using at least six complex processes and at least three tools. For example, to achieve this learners could produce the program using a conversational language and manually insert sub-routines to improve the efficiency.

Learners will accurately manufacture the component, incorporating improvements from the simulation. They will take measurements for each of the machining processes and record any adjustments required to ensure dimensional and surface texture accuracy, for example compensation is correctly applied to allow for tool wear.

Overall, the evidence, including observation records, will clearly demonstrate how working accurately and safely was considered by learners throughout the machining process.

For pass standard, learners will create a machine tool set-up sheet, containing data, tooling parameters, feeds and speeds, work-holding parameters and will consider sustainability for the manufacture of a component on a CNC machine. For example, the machine tool set-up will identify the tooling parameters of tool diameters, tooling material (high speed steel (HSS)/carbide) and tool number. Also, learners will identify the separation and correct disposal of the ferrous and non-ferrous swarf. Tool calculations for speed in revolutions per minute (RPM) may be inaccurate, but are safe to run.

Learners will create a part program for a component containing at least six complex CNC processes and using at least three different tools. During the process, learners will simulate the part program using graphical software for syntax and logical errors. The program will be modified as required. For example, the programmer may see an error of a linear interpolation (G01) in the XY axes without the tooling being lowered previously in Z, thus creating an angular cut.

Learners will set up safely the CNC machine, including work-holding devices and machine parameters. They will simulate the physical machining of a component using a CNC machine and the part program. As required, they will correct any syntax and logical errors. Consequently, the vast majority of the coding, speeds and feeds, tooling and workpiece-holding devices will be set up correctly. However, the part program may not be as efficient as it could be. For example, code G01 (linear interpolation) may have been used when a code G00 (rapid traverse) would be more appropriate.

Learners will manufacture a component safely using the CNC machine and will apply cutting fluid (where relevant), remove swarf, and remove the workpiece from the machine correctly.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results. They may make limited reference to accuracy, and the finished components may not be completely to the desired tolerance or surface texture.

Learning aim D

For distinction standard, learners will consistently demonstrate a good technical understanding of CNC processes. Evidence, such as notes or a logbook, and especially the lessons learned report, including information about improvements, will consistently contain concise and high-quality written language that includes correct technical engineering terms. The narrative will differentiate facts from opinion.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. A balanced view and evaluation will be given about the actions taken, CNC programming, machining skills and general engineering skills. Also, relevant behaviours will be consistently applied to a professional standard, for example taking initiative and responsibility for their own actions including setting and adjusting the machines and submitting work on time.

For merit standard, learners should show in their evidence, such as notes or a logbook and especially in their lessons learned report, detailed examples of where improvements could be made to the:

- set-up documentation, programming and use of the machining processes and equipment to manufacture the component more efficiently and accurately while considering sustainability
- application of the relevant behaviours.

Overall, improvements suggested should be reasonable and practical and the explanations will be professional and easy to understand using engineering terminology accurately. Some parts of the evidence may have more emphasis than others, creating an unbalanced viewpoint, and making it more difficult for a third party to understand and implement any improvements.

For pass standard, the evidence, such as notes or a logbook, and especially the lessons learnt report, which should be around 500 words in length, will detail the lessons learnt during the manufacture of a CNC-machined component. It will explain which:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- CNC machining skills were used, for example that the tooling was set correctly for their datum position, offsets and compensation
- general engineering skills were used, for example understanding Cartesian coordinates, interpreting drawings and recognising technical parts of machines
- behaviours were used, with an analysis of how successfully they were applied.

Overall, the evidence, such as a lessons learned report, will be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology and spelling and grammar.

Links to other units

This unit links to:

- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes
- Unit 45: Additive Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in Computer Numerical Control machining processes
- contribution of ideas to unit assignment/project materials.

Unit 44: Fabrication Manufacturing Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore and carry out fabrication processes to safely manufacture products from sheet metal.

Unit introduction

Fabrication processes are used to manufacture sheet metal products and components in a wide range of industries and applications. For example, sheet metal products and components are found in oil rigs, ships and aircraft, desktop computer cases, fridges and filing cabinets.

In this unit, you will cover the four main stages of manufacturing a sheet metal product: preparation, cutting out blank components, forming up the components and joining them into an assembled product. You will learn the safe use of a range of industrial hand tools, machinery and other equipment associated with fabrication processes. You will apply this knowledge in the manufacture of a sheet product, for example tool box, desktop computer or console casing, or a portable wood-burning stove. Finally, you will reflect on how your skills, knowledge, behaviours and organisational skills were applied during the fabrication of a product.

It is important that engineers have an appreciation of the materials and processes involved in manufacturing sheet metal products, and are capable of creating solutions to engineering-based problems. This unit will help prepare you for a mechanical or manufacturing engineering apprenticeship, higher education and for employment in a technician-level role in the sheet metal fabrication industry.

Learning aims

In this unit you will:

A Examine the processes and technology used in sheet metal fabrication that are widely used in industry

B Carry out the preparation necessary to manufacture a fabricated product safely

C Carry out fabrication processes to manufacture a fabricated product safely

D Review the processes used to manufacture a fabricated product and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the processes and technology used in sheet metal fabrication that are widely used in industry	**A1** Fabricated products **A2** Sheet materials **A3** Cutting processes **A4** Forming processes **A5** Joining processes **A6** Finishing processes	A written report on at least two different types of fabrication processes and how these might be applied, based on the requirements of researched case studies.
B Carry out the preparation necessary to manufacture a fabricated product safely	**B1** Health and safety requirements **B2** Risk assessment **B3** Interpreting design specifications	A series of practical activities to fabricate a product. Evidence will include: a developmental logbook, the physical fabricated product, risk assessments, forming gauges, observation records/witness statements, annotated drawings, inspection records and notes explaining health and safety requirements.
C Carry out fabrication processes to manufacture a fabricated product safely	**C1** Using fabrication manufacturing processes **C2** Alignment and clamping **C3** Quality control procedures	
D Review the processes used to manufacture a fabricated product and reflect on personal performance	**D1** Lessons learned from manufacturing a fabricated product **D2** Personal performance while manufacturing a fabricated product	The evidence will focus on what went well and what did not go so well when carrying out fabrication processes, and a conclusion discussing improvements that could be made. The portfolio of evidence will be generated while fabricating a product, and reviewing the processes and reflecting on personal performance.

Content

Learning aim A: Examine the processes and technology used in sheet metal fabrication that are widely used in industry

A1 Fabricated products

- Examples of fabricated products, e.g. desktop computer case, washing machine, tool box, industrial lighting.

A2 Sheet materials

- Sheet materials in common usage, including mild steel, hot dipped galvanised mild steel, Zintec, aluminium and stainless steel.
- Common grades of mild steel, e.g. CR4, stainless steel, e.g. 304, 316, and sheet thicknesses, e.g. 0.5 mm, 0.7 mm, 0.9 mm, 1.2 mm.
- Factors governing material choice, including density, ductility, stiffness, cost, corrosion resistance and environmental considerations.

A3 Cutting processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal cutting processes, including:

- nibbling, e.g. hand, power
- shearing, e.g. hand, bench, power
- presswork, including blanking, piercing, tool design, e.g. punch, die and stripper
- sawing, e.g. bandsaw, hacksaw, reciprocating saw
- material removal, e.g. drilling, filing, grinding
- non-traditional cutting processes, including laser cutting and computer numerical control (CNC) punch press.

A4 Forming processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal forming processes, including:

- principles of sheet metal forming, including minimum bend radii as a function of material thickness, consideration of springback, use of forming gauges
- manual forming methods, including bar folder, bench-mounted forming brakes, e.g. straight, box, finger, fly press with V-block tooling, hammer and former, and bench-mounted bending rolls
- press brake forming, including V-block and blade tooling, e.g. standard, swan neck, letterbox, air bending and bottoming dies
- non-traditional forming processes, including CNC press brake (with V-block and blade tooling) and CNC bending rolls.

A5 Joining processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal joining processes, including:

- permanent joining processes, including spot welding, metal inert gas (MIG) welding, and brazing
- mechanical fixings, including nuts, bolts, self-tapping screws, pop rivets
- non-traditional joining processes, including CNC robotic spot welding.

A6 Finishing processes

- Applications, limitations, and principles of operation of sheet metal finishing processes, including galvanising, powder coating, painting, plating, e.g. chromium.

Learning aim B: Carry out the preparation necessary to manufacture a fabricated product safely

B1 Health and safety requirements

Key features of regulations, or other relevant international equivalents, including:

- Current Provision and use of work equipment regulations (PUWER) and amendments, e.g. maintaining and inspecting work equipment, provision of training to employees, clearly marked machine controls, use of appropriate guarding
- Current Manual handling operations regulations (MHOR) and amendments, e.g. training in manual handling methods to avoid personal injury, provision of a suitable working environment and appropriate equipment
- Current Control of noise at work regulations, e.g. elimination and/or reduction of noise, acceptable limits, signage, upper exposure action value, hearing protection
- Current Personal protective equipment (PPE) at work regulations and amendments, e.g. employers responsibility to provide appropriate equipment, types of equipment.

B2 Risk assessment

Risk assessment of the general working environment and specific fabrication manufacturing processes, including hazard identification and classification:

- defining a hazard by inspection of the work environment and consideration of specific manufacturing processes, e.g. entrapment in press brakes, manual handling of tooling and sheet material, noise, sheet material sharp edges and corners
- defining risk by determining how hazards may cause injury, e.g. sharp edges likely to cause cuts
- putting control measures in place to reduce risk, e.g. using leather gloves when handling sheet material
- Health and Safety Executive (HSE) guidance on risk assessment, including the five steps to risk assessment and the use of a standard pro forma for recording risk assessments.

B3 Interpreting design specifications

- Interpreting engineering drawings, including reading and understanding individual component, sub-assembly and general assembly drawings to BS8888 or other international equivalents.
- Developing blanks, including bend allowance calculations using standard approximation formulae and drawing out accurately developed blanks.
- Use of bend relief holes or slots to prevent material tearing when forming close to an edge.
- Preparing forming gauges.
- Modelling, including verifying accuracy of blanks by modelling components and creating mock-ups.
- Marking out accurately with appropriate equipment, e.g. steel rule, protractor, set square, compasses, dividers, scriber, engineer's blue, marker pen.
- Nesting multiple component blanks by careful positioning and marking out on stock sheet material to ensure efficient and sustainable use of each sheet, minimising waste.

Learning aim C: Carry out fabrication processes to manufacture a fabricated product safely

C1 Using fabrication manufacturing processes

- Use of workshop equipment, including cutting component blanks, forming sheet metal components, joining formed components into a fabricated product.

C2 Alignment and clamping

- Trial assembly, e.g. offering up, alignment, clamping, dimensional checks, adjustment.
- Work holding, e.g. mitre clamps, toggle clamps, jigs, G-clamps, magnetic clamping devices, fixtures.

C3 Quality control procedures

- Checks for accuracy using measuring equipment to check dimensional tolerance, e.g. ruler, vernier or digital callipers, vernier or digital protractor, templates, forming gauges.
- Identifying critical dimensions as indicated on given engineering drawings. These are component specific and critical to the correct assembly, form and function of a product. These specific dimensions must be checked during inspection.
- Visual checks, e.g. finish, visual appearance, joint quality.
- Design and use of pro forma inspection record sheets.

Learning aim D: Review the processes used to manufacture a fabricated product and reflect on personal performance

D1 Lessons learned from manufacturing a fabricated product

Scope of the lessons learned and improvements could be:

- health and safety skills, including assessing risk, using appropriate personal protective equipment and keeping the work area clean and tidy
- fabrication manufacturing skills, including the effectiveness and efficiency of using hand tools and machines, sustainability considerations, e.g. efficient use of materials, energy usage, and waste products
- general engineering skills, e.g. mathematics applied when developing blanks, interpreting engineering drawings.

D2 Personal performance while manufacturing a fabricated product

Understand that relevant behaviours cover:

- taking initiative and responsibility for own actions when applying the knowledge and practical skills required to manufacture sheet metal components safely, efficiently and independently, e.g. selecting and using appropriate processes
- communication and literacy skills to ensure health and safety in the workplace and to follow and implement instructions appropriately, and to explain own intentions to others
- problem solving of issues as they occur, e.g. adjusting press settings when forming bends to compensate for material springback.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the processes and technology used in sheet metal fabrication that are widely used in industry		**A.D1** Evaluate, using language that is technically correct and of a high standard, the use of contrasting fabrication processes to sustainably manufacture sheet metal components in different batch sizes.
A.P1 Explain how different fabrication processes are used to manufacture sheet metal components.	**A.M1** Analyse how different fabrication processes are used to sustainably manufacture sheet metal components to the intended accuracy.	
Learning aim B: Carry out the preparation necessary to manufacture a fabricated product safely		**BC.D2** Refine, during the process, the blank design, set-up and parameters of the fabrication equipment to safely, effectively and efficiently manufacture a fabricated product.
B.P2 Explain which health and safety requirements apply when using fabrication processes and conduct a risk assessment of the work environment. **B.P3** Set up safely at least two cutting, two forming and two joining processes.	**B.M2** Analyse component blanks through modelling and safely and accurately mark components out.	
Learning aim C: Carry out fabrication processes to manufacture a fabricated product safely		
C.P4 Manufacture at least four fabricated formed components safely using at least two cutting processes and at least one forming process. **C.P5** Manufacture a fabricated product safely containing at least four formed components joined using at least two processes.	**C.M3** Manufacture a fabricated product accurately containing at least four formed components joined using at least two processes.	
Learning aim D: Review the processes used to manufacture a fabricated product and reflect on personal performance		**D.D3** Demonstrate consistently good technical understanding and analysis of fabrication processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Review the processes used to manufacture a fabricated product and reflect on personal performance. **D.P7** Explain how relevant behaviours were applied effectively during the manufacturing process.	**D.M4** Recommend improvements to the set up and use of fabrication processes and the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, C.M3, BC.D2)

Learning aim: D (D.P6, D.P7, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- shear (bench or powered) machine(s), forming press (fly press, box former and/or press brake with appropriate tooling), and welding equipment (spot or MIG welding)
- general fabrication workshop facilities, including tools and equipment as required by the learning aims and unit content
- a range of equipment suitable for measuring the dimensional accuracy of the components manufactured
- a range of health and safety regulations, as required by the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and well-thought-through evaluation (probably between 500 and 1000 words maximum) of different fabrication processes as applied to different batch sizes. The criteria used as the basis of discussion will include sustainability, cost, accuracy and overall suitability. For example, it may be appropriate to produce a single component blank using only hand tools, small batches by laser cutting or large numbers using a dedicated hard tool. Each scenario will be explored in detail. For at least one of the example products, learners must demonstrate the ability to compare and contrast alternative processes.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. For example, it 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 highlight in their analysis the preparation, set-up and use of each process according to best practice, to minimise waste and ensure the maximum possible accuracy. The analysis will consider consistent criteria for each process and will include suitable batch size, energy consumption, waste materials and achievable tolerances.

Overall, the analysis will be logically structured, technically accurate and easy to understand.

For pass standard, learners will demonstrate an understanding of how three types of hand/bench equipment and three larger pieces of industrial equipment operate and are used to fabricate sheet metal products.

Overall, the explanations will be logically structured, although may be basic in parts. They may contain minor technical inaccuracies or omissions relating to engineering terminology, such as mistakes when labelling equipment diagrams or perhaps using non-technical language like 'making holes' when 'punching' or 'piercing' would be more appropriate.

Learning aims B and C

For distinction standard, learners will refine throughout the process the blank design, set-up and parameters of the fabrication equipment to safely, effectively and efficiently manufacture the product. For example, learners will:

- demonstrate how the modelling process helped to confirm the calculated blank dimensions and fully explain any adjustments or changes made
- add stress-relieving features, such as bend relief slots to prevent components tearing or distorting during forming
- adjust stops on a power shear to give required blank size
- adjust the power setting and wire feed to optimise the weld quality.

Overall, the evidence should be presented clearly and in a manner that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will determine the blank dimensions through calculation and should be verified by the production of neat and accurate component models. Any issues with the initial calculations will be addressed at the modelling stage and any necessary alterations made. Learners will then work safely, clearly and accurately using appropriate equipment and techniques to mark out the components on sheet steel stock. When marking out, appropriate tolerances for linear dimensions are +/− 0.5 mm and for angular dimensions +/− 1 °.

The component and joined assembly will be manufactured safely and accurately with dimensions recorded in a table, and compared with the required critical dimensions and associated tolerances given on the engineering drawings. In each case and throughout the manufacturing process, it will be stated if a critical dimension is within the required tolerance and, if not, what corrective actions will be taken.

For pass standard, learners will explain how health and safety is managed for the machines they intend to use and what regulations will be met. They will produce a risk assessment for two cutting, two forming and two joining processes, which will include consideration of all significant hazards, be laid out on in an appropriate template and include suitable control measures.

Component blanks will be developed and card templates will be made for each component and the assembled product. Where appropriate, manufacturing aids like forming or rolling gauges will be retained and notes made on their use. Learners will ensure the safe set up of processes, including work-holding devices and machine parameters, with evidence of actions taken.

Learners will cut, using two different processes, and form, using two different processes, at least four components safely. They will safely join together at least four components using at least two joining processes, for example by using spot welding and pop riveting.

Learners will record what they are doing and their results in a logbook. Overall, there may be limited reference to accuracy and only some of the critical dimensions will be measured and recorded by marking up copies of component drawings. Although the finished components and products may not be completely within the desired tolerance, the finished product must be functional and be fit for purpose. For example, a tool box that includes a hinged lid must still close.

Learning aim D

For distinction standard, learners will give a balanced evaluation about the actions taken, fabrication skills and general engineering skills applied. Also, relevant behaviours will be consistently applied to a professional standard. For example, learners will take initiative and responsibility for their own actions, such as when they are setting and adjusting the machines, and by submitting work on time.

Overall, learners will consistently demonstrate a good technical understanding of fabrication processes. Evidence, such as a logbook and reports, will consistently contain concise and high-quality written language that includes correct technical engineering terms and information about improvements. It will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will recommend where improvements could be made to the:

- set-up and use of the fabrication processes and equipment to make manufacture of the components more efficient, accurate and sustainable
- management of health and safety to decrease the risk of harm to self and others when carrying out workshop activities
- application of relevant behaviours, for example adjusting press settings when forming bends to compensate for material springback.

Overall improvements suggested will be reasonable and practical, 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 pass standard, learners will have evidence, typically a report of between circa 500 and 1000 words, detailing the lessons learned during the manufacture of a fabricated product. The evidence will explain the:

- actions taken to manage health and safety in the workplace, such as conducting risk assessments, use of PPE and how any unforeseen safety issues were dealt with
- fabrication skills applied, such as using specialised equipment and how the intended accuracy was achieved when marking out blanks, performing cutting operations and forming components
- general engineering skills applied, such as interpreting engineering drawings, working with tolerances and using workshop equipment appropriately
- relevant behaviours that were applied when working in a fabrication workshop, such as time management to ensure completion of work to deadlines.

Overall, the explanations will be logically structured, although basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 13: Welding Technology
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in fabrication
- contribution of ideas to unit assignment/project materials.

Unit 45: Additive Manufacturing Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners cover the principles and practical methods used in additive manufacturing (AM) and develop a component using additive processes.

Unit introduction

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 63 000 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.

Learning aims

In this unit you will:

A Examine the technology and characteristics of additive manufacturing processes as used in industry

B Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes

C Develop a component using additive manufacturing processes safely.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and characteristics of additive manufacturing processes as used in industry	**A1** AM processes **A2** Safe working practices for AM processes	A report examining the technology and characteristics of AM processes, including sustainability and safe working practices.
B Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes	**B1** Design considerations for AM processes **B2** Component finishing processes post-additive manufacturing	A report focusing on the product or component design considerations and finishing processes required to manufacture a component effectively using additive processes.
C Develop a component using additive manufacturing processes safely	**C1** Component design for additive manufacture **C2** Manufacture of a component using an AM process	Design and manufacturing evidence for the development of a product or component using additive processes. To include: a developmental logbook, observation records/witness statements, the finished component, annotated photographs and/or drawings, set-up planning notes, and complete quality control documents.

Content

Learning aim A: Examine the technology and characteristics of additive manufacturing processes as used in industry

A1 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.

A2 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.

Learning aim B: Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes

B1 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.

B2 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 dispertion
- 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.

Learning aim C: Develop a component using additive manufacturing processes safely

C1 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.

C2 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine the technology and characteristics of additive manufacturing processes as used in industry		**A.D1** Justify, using vocational and high-quality written language, the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably.
A.P1 Explain the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably.	**A.M1** Compare the technology and characteristics of at least two additive processes used to manufacture components safely and sustainability.	
Learning aim B: Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes		**B.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.
B.P2 Explain how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes. **B.P3** Explain what finishing processes could be applied to two components if they were manufactured using additive processes instead of traditional manufacturing processes.	**B.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.	
Learning aim C: Develop a component using additive manufacturing processes safely		**C.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.
C.P4 Design a component encompassing a hollow section and/or a support that can be manufactured safely using an additive process. **C.P5** Manufacture a component encompassing a hollow section and/or a support, safely using an additive and suitable finishing process. **C.P6** Check the finished component for dimensional accuracy against the original design.	**C.M3** Design a component encompassing a hollow section and/or a support that can be manufactured safely and effectively using an additive process. **C.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.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

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 aims and unit content.

Essential information for assessment decisions

Learning aim A

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 × 500 mm 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 aim B

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 aim C

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.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 10: Computer Aided Design in Engineering
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local manufacturing organisations with expertise in AM processes
- contribution of ideas to unit assignment/project materials.

Unit 46: Manufacturing Joining, Finishing and Assembly Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore and investigate joining, finishing and assembly processes used in the manufacture of products, such as cars and mobile phones.

Unit introduction

Engineered products can be complex and may contain a large number of components. These components need to be joined, finished and assembled to meet the manufacturer's exact specification and the customer's needs. For example, car and mobile phone manufacturers are supplied with components (and sub-assemblies) by original equipment manufacturers (OEMs) and they join, finish and assemble them into finished products. The technology, maintainability, cost, performance and sustainability are all factors that the manufacturers must consider when selecting which processes to use.

In this unit, you will explore through practical activities and investigate through researching the joining, finishing and assembly processes used to create products. You will produce mechanical and adhesive sample joints for specific applications that you have researched, test them and justify why they are appropriate for the application. For finishing processes, you will produce sample finishes, such as painted and, after undertaking some research, justify why they are appropriate for particular applications. Finally, you will investigate different assembly processes and the social and economic effects that different assembly methods have on organisations and employees.

As an engineer, you will need to understand these processes and acquire the practical skills needed to be able to join, finish and assemble products. This unit helps to prepare you for an apprenticeship, for higher education and for technician-level roles in industry.

Learning aims

In this unit you will:

A Explore the joining processes that are often used to connect components into sub-assemblies and products

B Explore the finishing processes that are used to improve the appearance and function of products

C Investigate the processes used to assemble products and the economic and social consequences associated with them.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the joining processes that are often used to connect components into sub-assemblies and products	**A1** Mechanical joining processes **A2** Adhesive joining processes **A3** Safe working practices when using joining processes **A4** Perform joining and testing processes	A series of practical activities to join components together and test their mechanical properties. Evidence will include test results, a logbook, images, and observation records. A written report on the characteristics of at least two different types of joining process and how they might be applied based on the operating requirements of researched case studies.
B Explore the finishing processes that are used to improve the appearance and function of products	**B1** Hot finishing processes **B2** Anodising finishing processes **B3** Plating finishing processes **B4** Paint finishing processes **B5** Safe working practices when using finishing processes **B6** Performing finishing processes safely	A series of practical activities to finish materials or artefacts. Evidence will include a logbook, images, and observation records. A written report on the characteristics and environmental considerations of at least two different types of each finishing process and how they might be applied based on researched case studies.
C Investigate the processes used to assemble products and the economic and social consequences associated with them	**C1** Manual assembly processes **C2** Automatic and robotic assembly processes **C3** Selection of assembly processes **C4** Social and economic effects of assembly processes	A written report considering the physical resources required for different assembly processes, the reasons for manufacturers choosing particular assembly methods and the social and economic effects that different assembly methods have on organisations and employees.

Content

Learning aim A: Explore the joining processes that are often used to connect components into sub-assemblies and products

A1 Mechanical joining processes

The characteristics and applications of mechanical joining processes.

- Design requirements for mechanical joints, including permanent or temporary joints, geometry of joint surfaces, location and dimension of fasteners, operating conditions, e.g. humidity, materials being joined, and cost.
- Types of screwed fastener, including:
  - physical form, e.g. type, head shape, thread standards
  - mechanical properties, e.g. tensile, shear, torsional strength.
- Use of screwed fasteners, including:
  - tightening methods, e.g. torque control, angle control
  - locking systems, e.g. mechanical and thread-locking adhesives.
- Other types of mechanical fastener, including latches (including snap and compression), detent pins and rivets (solid and hollow).
- Other mechanical joining processes, including snap joints used in plastic components.
- Sustainability considerations, including the number, size and material of fasteners.
- Applications that typically require some form of fastening and unfastening and which can withstand high force, e.g. cases/lids, small and large electrical products.

A2 Adhesive joining processes

The characteristics and applications of adhesive joining processes.

- Design requirements for adhesive joints, including choice of adhesive, geometry of joint surfaces, operating conditions, strength requirements, materials being joined and cost.
- Types of joint, e.g. plain butt, single lap, double strap, double lap.
- Types of adhesive, including chemically reactive, evaporative or diffusive, hot melt, tape and film, pressure sensitive.
- Properties of adhesives, e.g. physical form, anaerobic, cure times, cure temperature.
- Preparation methods, including surface treatments for metals and plastics, mixing.
- Application methods, including those used for liquids, pastes, powders, films and hot melts.
- Sustainability considerations, including toxicity, replacement of organic solvents with water, replacement of petroleum-derived polymers, disassembly for recycling.
- Applications, e.g. automotive, aerospace, marine, architectural.

A3 Safe working practices when using joining processes

Key features of regulations or other relevant international equivalents, including:

- Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments, e.g. maintaining and inspecting work equipment, provision of training, clearly marked machine controls, use of appropriate guarding.
- Control of Substances Hazardous to Health (COSHH) Regulations 2002 and amendments, e.g. identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information.
- Personal Protective Equipment (PPE) at Work Regulations 1992 and amendments, e.g. appropriate if risk cannot be controlled in any other way, types of PPE, assessing suitable PPE given the hazard, supply, instructions and training, correct use, maintenance and storage.
- other safe working practices, including material data sheets, health and safety procedures, and emergency procedures.
- safety hazards, e.g. dust, solvents, adhesives, and entrapment.

A4 Perform joining and testing processes

- Selection of suitable substrate material.
- Selection of appropriate joining materials or components.
- Safe working practices, e.g. the use of PPE.
- Preparation of substrate material, e.g. drilling holes and cleaning surfaces.
- Use of workshop equipment and practices to produce:
  - mechanically secured joints, e.g. screwed fasteners and/or rivets
  - adhesively bonded joints, e.g. butt and/or single lap.
- Use of workshop equipment to perform comparative mechanical tests, e.g.:
  - joints in tension to BS EN 1465:2009, BS 7608:2014, BS EN ISO 527-2 or other international equivalents
  - joints in cleavage to BS 5350-C1 (1986) or other international equivalents
  - joints in shear to BS 5350 Part C5 (2002): ISO 12996:2013 or other international equivalents
  - joints in peel to BS EN 1464:2010 or other international equivalents.
- Analysis of results, including:
  - determination of appropriate standard specimen specifications, e.g. surface area of bonded joints, diameter of mechanical fastening, thickness of substrate
  - collection and recording of data
  - comparison of the characteristics for joints made from the same substrates, e.g. the tensile force required to break a lap joint on aluminium sheet joined using rivets and chemically reactive adhesive.

Learning aim B: Explore the finishing processes that are used to improve the appearance and function of products

B1 Hot finishing processes

The characteristics and applications of hot finishing processes.

- Hot dip processes:
  - manufacturing methods including surface preparation, coating methods and cooling
  - materials deposited, including zinc, tin and aluminium.
- Powder coating:
  - manufacturing methods to include fluidised bed and electrostatic
  - materials applied, including thermoplastics and thermosets.
- Sustainability, including:
  - the environmental advantages and disadvantages of galvanising and powder coating over the life cycle of a product
  - hazards, e.g. the elimination of volatile organic compounds (VOCs) and of material reuse for powder coating
  - relevant regulations or other relevant international equivalents, e.g. Pollution Prevention and Control Act 1999, EN ISO 1461.
- Applications, including galvanising of structural steel components and powder coating for architectural fittings.

B2 Anodising finishing processes

The characteristics and applications of anodising finishing processes.

- Manufacturing methods to include sulphuric acid anodising, hard anodising and chromic acid anodising, sealing.
- Sustainability, including:
  - the environmental advantages, and disadvantages of anodising coatings over the life cycle of a product
  - hazards, e.g. fumes and chemicals containing chromium
  - relevant regulations or other relevant international equivalents, e.g. compliance with Restriction of Hazardous Substances (RoHS) Regulations 2012, DEF STAN 03-24.
- Applications to include architectural, defence and aerospace.

B3 Plating finishing processes

The characteristics and applications of plating finishing processes.

- Manufacturing methods to include electroplating, mechanical and electroless nickel.
- Materials deposited to include those chosen for aesthetic, mechanical and corrosion resistance.
- Sustainability, including:
  - the environmental advantages, and disadvantages of plating coatings over the life cycle of a product
  - hazards, e.g. 2003 Control of Major Accident Hazards Regulations (COMAH) 1999 and amendments or other relevant international equivalents
  - relevant regulations or other relevant international equivalents, e.g. Environmental Permitting (England and Wales) Regulations 2010, ISO 4527.
- Applications, including plating for aesthetic and functional reasons.

B4 Paint finishing processes

- The characteristics and applications of paint finishing processes:
  - application methods to include spreading, spraying, dipping and electrostatic
  - materials applied, including air drying, one-pack chemical-resistant paint, and two-pack chemical-resistant paints.
- Sustainability, including:
  - the environmental advantages and disadvantages of paint coatings over the life cycle of a product
  - hazards, e.g. titanium dioxide, and the volatile organic compounds in paints, varnishes
  - relevant regulations or other relevant international equivalents, e.g. Volatile Organic Compounds in Paints, Varnishes and Vehicle Refinishing Products Regulations 2012 and amendments, ISO 12944.
- Applications, including painting for aesthetic and functional reasons.

B5 Safe working practices when using finishing processes

Key features of regulations and or other relevant international equivalents, including:

- Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments, e.g. maintaining and inspecting work equipment, provision of training, clearly marked machine controls, use of appropriate guarding
- Control of Substances Hazardous to Health (COSHH) 2002 and amendments, e.g. identification of hazards including safety data sheets, analysis of risk, use of control measures
- Personal Protective Equipment (PPE) at Work Regulations 1992 and amendments, e.g. protection from mechanical and chemical hazards.

B6 Performing finishing processes safely

- Selection of suitable substrate material.
- Selection of appropriate finishing materials and application equipment.
- Preparation of substrate material, e.g. mechanical and chemical cleaning.
- Safe working practices, e.g. the use of PPE.
- Using workshop equipment and practices to produce a finish.
- Cleaning and storage of equipment after use.

Learning aim C: Investigate the processes used to assemble products and the economic and social consequences associated with them

C1 Manual assembly processes

- Understanding methods used to ensure efficiency and prevent ill health for operatives performing manual assembly tasks, including ergonomics, design of task, workstation layout and manual handling.

C2 Automatic and robotic assembly processes

- Understanding the features and characteristics of automatic assembly hardware devices, including part-feeding devices, vibratory bowl feeders, orientation devices, transfer devices and indexing devices.
- Understanding the features and characteristics of robotic assembly hardware devices, including power systems, degrees of freedom, actuators, sensors and control systems.

C3 Selection of assembly processes

Understanding the reasons for selecting manual, automatic or robotic assembly methods, including:

- quality of product
- rate of production
- safety
- flexibility.

C4 Social and economic effects of different assembly processes

- Understanding how the different assembly processes impact on organisations and their employees.
- Social and economic factors affecting organisations, e.g. set-up costs, return on investment, availability of skilled workforce, demand for product, equipment maintenance requirements.
- Social and economic factors affecting employees, e.g. reduced employment opportunities, higher salaries, higher skill requirements, patterns of working hours, job satisfaction.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the joining processes that are often used to connect components into sub-assemblies and products		**A.D1** Evaluate, using language that is technically correct and of a high standard, the characteristics of each mechanical and adhesive joint, based on the results from safely and accurately conducted tests and research and suggest potential improvements to the solution.
A.P1 Produce mechanical and adhesive sample joints safely for different applications. **A.P2** Conduct mechanical tests safely on mechanical and adhesive sample joints. **A.P3** Explain, using test results and research, the characteristics of both mechanical and adhesive joints, describing how they are appropriate for the application.	**A.M1** Produce sample mechanical and adhesive joints safely and accurately, conducting accurate mechanical tests on each one. **A.M2** Analyse, using the test results and research, the characteristics of each joint, explaining why each one is appropriate for the application.	
Learning aim B: Explore the finishing processes that are used to improve the appearance and function of products		**B.D2** Evaluate the characteristics of and environmental considerations and control methods for four different types of finishing process, based on the practical results of finishes produced safely and accurately, and research, while justifying why they are appropriate for the application.
B.P4 Produce two different finishes on materials safely for use in different known applications. **B.P5** Explain, using practical results and research, the characteristics of and environmental considerations for four different types of finishing process, describing how they are appropriate for the application.	**B.M3** Produce two different realistic finishes on materials safely and accurately for use in different known applications. **B.M4** Compare, using practical results and research, the characteristics of and environmental considerations and control methods for four different types of finishing process, explaining why they are appropriate for the application.	
Learning aim C: Investigate the processes used to assemble products and the economic and social consequences associated with them		**C.D3** Evaluate the equipment required by a manufacturer to operate manual, automatic and robotic assembly processes and the social and economic implications for organisations and personnel using them.
C.P6 Explain the equipment required by a manufacturer to operate manual, automatic and robotic assembly processes. **C.P7** Explain the social and economic effects the adoption of manual, automatic and robotic assembly processes have on the organisations and personnel using them.	**C.M5** Compare the equipment required by a manufacturer to operate manual, automatic and robotic assembly processes and the social and economic advantages and disadvantages on the organisations and personnel using them.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.D1)

Learning aim: B (B.P4, B.P5, B.M3, B.M4, B.D2)

Learning aim: C (C.P6, C.P7, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

The special resources needed for this unit are:

- general workshop facilities to include tools and equipment as required in the learning aims and unit content
- access to examples of a range of mechanical- and adhesive-jointed products
- access to the equipment and materials required to produce mechanical and adhesive joints
- test equipment to measure the destructive forces required to break joined materials
- equipment and materials required to apply at least two different types of finish
- accompanying documentation for the equipment referred to above and relevant health and safety regulations and documentation.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and well-thought-through evaluation of joining methods for the chosen applications. The findings from the evidence will be based on the results of the mechanical tests and research, which will be accurate throughout.

Learners will also suggest potential improvements to the processes used and/or identify other approaches to solving the jointing problem. They will recognise that there is a trade-off between the characteristics and performance of each joint used in the chosen application. For example, a latch may be easier for a user to open than a screwed joint but it would increase the cost and size of the joint.

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 merit standard, learners will produce safely, sample mechanical and adhesive joints that represent applications in which they are interested. The joint samples will be an accurate representation of the actual joint, for example a sample lap joint would be produced to represent the joint between a car-door skin and frame. Learners will complete accurate and safe mechanical tests using the samples. Limited help may be given in setting up the equipment and learners will, independently, gather and process their test results, which will be accurate.

Learners will analyse the characteristics of the joints, including the design of the joints, the manufacturing processes used, the materials being joined, the operating demands of the joints and performance of the joints in the chosen application. Learners will explain why the chosen joints are appropriate for the application.

Overall, the analysis will be logically structured, and technically accurate and easy to understand.

For pass standard, learners will research mechanical and adhesive joint applications that they are interested in, for example, the joint used to attach a car-door skin to its frame. Learners will produce at least three samples of each mechanical and adhesive joint safely, which represent each application in which they are interested.

Learners will conduct mechanical tests to destruction, for example a tensile test, on each of the prepared sample joints. Throughout the delivery of the tests learners will demonstrate safe working practice. Although learners may have help to set up equipment, learners will gather and record their own test results independently.

Learners will use the results of the practical tests and their own research to explain the characteristics of the joint and describe how the joint is appropriate for the application. For example, they should explain the type of joint and joining method used and the load the sample joint is likely to be able to withstand to destruction.

Overall, learners' explanations will be logically structured, although they may be basic in parts. The evidence may contain minor technical inaccuracies or omissions relating to engineering terminology, such as using non-technical language like 'goes off' when 'curing' would be more appropriate.

Learning aim B

For distinction standard, learners will provide a balanced and well-thought-through evaluation of the finishing process characteristics and a justification of the reasons for selecting particular processes for the chosen applications. The findings from the evidence will be based on the results of applying a finish safely and accurately, and individual research. The evaluation will include suggestions for alternative processes for finishing the materials.

Learners' evidence will evaluate how manufacturers comply with the environmental regulations relevant to each process. They will recognise that there is a balance between the environmental damage caused by the finish and the environmental benefits of the product having the finish. For example, galvanising steel may release pollutants into atmosphere but the galvanised product will last longer, reducing the need to manufacture replacements with their associated environmental impacts, including increasing the carbon footprint. Learners will evaluate the environmental advantages, disadvantages and hazards associated with the processes.

Overall, the evidence presented will be easy to read, logically structured, use the correct technical engineering terms and be well presented. Charts, tables and illustrations will be clear and easy to understand.

For merit standard, learners will produce two realistic sample material finishes safely and accurately for the applications in which they are interested. An assessment of accuracy might include suitable surface preparation tasks, applying the correct amount of paint and not preparing excess finish material. The finished materials will be a realistic representation of the actual finish, for example the powder coating on a steel garden bracket.

Learners will compare the characteristics of the two finished materials, including the material types and processes used and the functional and appearance changes the finish imparts on the product. Learners will compare for each process the environmental advantages, disadvantages, hazards and regulations associated with the process and the methods used to reduce the hazards. For example, water-based paints are used for vehicle finishing to reduce the impact of volatile organic compounds on the environment. Learners will explain why the processes are appropriate for the application.

Overall, the comparison will be logically structured, technically accurate and easy to understand.

For pass standard, learners will research all four finishing processes (hot, anodising, plating and painting finish processes) for specific applications, for example, the anodising of a bicycle crank arm. Learners will produce safely two material finishes, using two different processes that represent the applications they are interested in.

Learners will use the practical results of the finished materials and their research to explain the characteristics of the finishes and will describe how they are appropriate for the application. For each example they could describe the functional and appearance changes that the finish imparts on the material. Learners will also explain the environmental advantages, disadvantages, hazards and regulations associated with each of the four different processes.

Overall, their explanations will be logically structured, although they may be basic in parts. The evidence may contain minor technical inaccuracies or omissions relating to engineering terminology, such as using 'voltage' when 'current' would be more appropriate for the anodising process.

Learning aim C

For distinction standard, learners will provide a balanced and well-thought-through evaluation of the reasons a manufacturer would select manual, automatic or robotic assembly processes. For example, a manufacturer of components used in the automotive industry would need to consider if the cost of investing in the flexibility of a robotic assembly process would increase profit sufficiently to justify the replacement of the existing automated process.

Learners will report on the factors that manufacturers take into account when deciding which type of process to use. Learners will present evaluations of the social and economic advantages and disadvantages of each assembly process for the organisation and employees in relation to an identified application; for example, the lifestyle disadvantages for employees working a 24-hour shift pattern, compared to the advantages provided by the enhanced salaries associated with working these unsocial hours.

Overall, the evidence presented will be easy to read, logically structured and well presented. The research will be balanced and accurate.

For merit standard, learners will compare the equipment required by a manufacturer to operate manual, automatic and robotic assembly processes. Learners will report on the characteristics of each process and consider the manufacturing advantages/disadvantages of each one. Learners will compare the relative costs of using manual, automatic or robotic processes with income generated as a result of using them. Learners will consider the social effects on the workforce employed by organisations that use different assembly processes.

Overall, the analysis will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the key characteristics of the equipment required for an organisation to operate manual, automatic and robotic assembly processes for applications they are interested in, for example, the characteristics and equipment used in the manufacture of different types of car. Learners will explain the economic decisions the organisation needs to consider when determining the suitability of different assembly methods for a given application. Learners will explain how the different types of assembly process affect the social and economic attributes of the workforce.

Overall, their explanations will be logically structured, although they may be basic in parts. The evidence may contain minor technical inaccuracies or omissions relating to engineering terminology, such as using non-technical language like 'money made' when 'profit' would be more appropriate.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 13: Welding Technology
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes
- Unit 44: Fabrication Manufacturing Processes
- Unit 45: Additive Manufacturing Processes
- Unit 47: Composites Manufacture and Repair Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local world-class manufacturing organisations
- contribution of ideas to unit assignment/project materials.

Unit 47: Composites Manufacture and Repair Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the wet and dry lay-up processes used to manufacture and repair fibre-based composite materials.

Unit introduction

We may not realise it but most of us come into contact with products or components made from fibre-reinforced polymer (FRP) composite materials on a daily basis. Whether it is the diving board at your local pool or the aeroplane flying overhead, their use is commonplace and becoming more prevalent. Glass fibre-reinforced polymers (GFRP) have all but replaced conventional materials, such as wood in the construction of speedboat hulls as they reduce manufacturing complexity, and carbon fibre-reinforced polymers (CFRP) have replaced aluminium alloy in motorsport structural components by providing the required tensile strength and stiffness and a considerable weight saving.

In this unit, you will explore the nature of FRP composites and their applications across a number of engineering sectors. You will also use different techniques to manufacture components from FRP composites and repair components that have sustained damage in service.

As an engineer it is important to understand the properties and applications of FRP composites and the techniques that can be used to repair them. This unit helps to prepare you for employment, for example as a manufacturing or maintenance technician, for an apprenticeship and for entry to higher education to study engineering.

Learning aims

In this unit you will:

A Examine the characteristics and applications of fibre-reinforced polymer composites that are widely used in industry

B Investigate the processes used to manufacture and repair fibre-reinforced polymer composites

C Carry out processes to manufacture and repair fibre-reinforced polymer composite components.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics and applications of fibre-reinforced polymer composites that are widely used in industry	**A1** Characteristics of fibre materials **A2** Characteristics of polymer resin matrix materials **A3** Structure and mechanical properties of FRP composites **A4** Applications of FRP composites	An illustrated written report covering the characteristics and applications of FRP composites. Where possible case study material should be used to illustrate the applications of fibre-based composites where they have replaced traditional materials.
B Investigate the processes used to manufacture and repair fibre-reinforced polymer composites	**B1** Safe working practices for FRP composites **B2** Characteristics of wet and dry lay-up manufacturing processes **B3** Repairing FRP composites	A written report to evaluate wet and dry lay-up manufacturing processes and those used to repair damaged components.
C Carry out processes to manufacture and repair fibre-reinforced polymer composite components	**C1** Applying wet and dry lay-up manufacturing processes **C2** Applying FRP composite repair processes	A written report, including annotated sketches and photographs, showing learners manufacturing an FRP composite component using wet or dry lay-up processes and applying appropriate repair processes to worn or damaged fibre-based composite components. Learners' evidence should be supported with observation records.

Content

Learning aim A: Examine the characteristics and applications of fibre-reinforced polymer composites that are widely used in industry

A1 Characteristics of fibre materials

Characteristics of typical fibres used in FRP composites, including:

- types, e.g. glass, carbon and Kevlar® (aramid)
- properties, e.g. tensile strength, toughness, stiffness, ductility, thermal expansion, service temperatures
- qualities, e.g. availability, cost, environmental impact.

A2 Characteristics of polymer resin matrix materials

Characteristics of typical thermosetting polymer resins used in FRP composites, including:

- types – epoxy, polyester
- curing characteristics – temperature, pressure, duration
- properties – tensile strength, toughness, stiffness, ductility, thermal expansion, service temperatures
- qualities – availability, cost, environmental impact, toxicity.

A3 Structure and mechanical properties of FRP composites

- Structure of FRP composites, including:
  - thin continuous or discontinuous (chopped) fibres embedded in a polymer matrix material
  - functions of the polymer matrix, to include supporting the material structure, transmitting forces between fibres, protecting fibres from handling and the environment, providing ductility and toughness
  - function of the fibres, including providing stiffness and tensile strength.
- Mechanical properties of FRP composites, including:
  - desirable properties of FRP composites – low density (light weight), high stiffness, high tensile strength, low thermal expansion, high fatigue resistance
  - limiting factors – maximum/minimum service temperature
  - mechanical properties depend on material and processing parameters – fibre orientation, fibre/matrix ratio, fibre diameter and length, fibre/matrix bonding.
- Other important characteristics of FRP composites, including components that have thin-walled hollow structures or sheets and thatend-of-life FRP composites are extremely difficult to recycle.

A4 Applications of FRP composites

Applications to include the following sectors:

- aerospace, e.g. wings and other high-performance structural components
- marine, e.g. speedboat hulls, jet skis, instrument panels
- automotive, e.g. body panels, suspension struts, and body shells
- renewables, e.g. wind turbine blades, marine turbine blades.

Learning aim B: Investigate the processes used to manufacture and repair fibre-reinforced polymer composites

B1 Safe working practices for FRP composites

Key features of health and safety regulations, or other relevant international equivalents, including:

- Control of Substances Hazardous to Health (COSHH) Regulations 2002 and amendments, 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 1992 and amendments, e.g. employer responsibility to provide appropriate equipment, e.g. eye protection, barrier creams, disposable gloves, protective clothing, dust masks, respirators
- Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments, e.g. maintaining and inspecting work equipment, provision of training to employees, clearly marked machine controls, use of appropriate guarding.

B2 Characteristics of wet and dry lay-up manufacturing processes

- Characteristics of wet lay-up processes**,** including:
  - typical design parameters – material thickness 1.0 mm to 15.0 mm, dimensional tolerance −0.0/+2.5 mm, minimum corner radius 3.0 mm, minimum draft angle 1.0°, surface finish matches tooling on tool side
  - wet lay-up uses dry fibre matting applied and then infused with liquid resin
  - resin has a shelf life that is activated with the addition of a catalyst immediately prior to use
  - layers of fibre and resin are built up to the required thickness as per the design specification
  - resins cure at room temperature and pressure so no specialist equipment is required
  - moulds can be expensive, reusable and made in a variety of materials, e.g. glass fibre-reinforced plastic (GFRP), medium density fibreboard (MDF), aluminium, steel
  - resin and fibres are both potentially harmful.
- Potential processing errors with wet lay-up, including:
  - poor fibre wetting causing poor adhesion between fibres
  - not achieving the design resin/fibre ratio
  - inclusions, voids or other flaws caused by poor technique, e.g. working in a dirty environment, insufficient rolling to expel air pockets
  - not using the correct resin/catalyst ratio or poor mixing causing premature or delayed curing.
- Characteristics of the dry lay-up processes, including:
  - typical design parameters – material thickness 1.0 mm to 15.0 mm, dimensional tolerance −0.0/+0.3 mm, minimum corner radius 3.0 mm, minimum draft angle 1.0°, surface finish matches tooling surface on tool side
  - dry lay-up uses sheets of woven fibre matting pre-impregnated with resin called prepreg
  - layers of prepreg are cut to size according to a prepared pattern and built up in the right order
  - resins used in dry lay-up cure at elevated temperatures and/or pressures meaning they must be cured in an oven or autoclave
  - prepreg sheets have a limited shelf life and have to be stored at low temperatures to prevent the resin from curing prematurely
  - factory prepared prepreg sheets have excellent fibre wetting and controlled fibre/matrix ratio
  - use of vacuum bags and elevated pressure eliminate voids and ensures good laminate adhesion
  - moulds are made from materials stable at elevated temperatures, e.g. aluminium, steel.

- Potential processing errors with dry lay-up, including:
  - inclusions, voids or other flaws caused by poor technique, e.g. working in a dirty environment, poorly sealed or leaking vacuum bags
  - incorrect positioning, alignment or ordering of layers
  - incorrect storage of prepreg materials leading to partial curing prior to use.

B3 Repairing FRP composites

- Damage assessment methods, including:
  - characteristics of external impact damage that can be detected visually and using simple tap test, including:
    - high energy impact through-hole penetration, local delamination and loose fibre ends
    - medium energy impact causing fibre/matrix crushing at the point of impact, hidden internal delamination and fibre fracturing on the back surface
  - non-destructive testing techniques used to detect internal damage, e.g. inclusions, hidden delamination, and voids, include ultrasound.
- Damage removal methods for composite repairs, including:
  - removal of paint or outer coatings to expose full extent of damage, including hand sanding, grit, plastic media or wheat starch blasting
  - damage removal and preparation for repair, including routing to remove damage around areas of through-hole penetration, sanding to remove less severe damage to surface plies, removal of damage in circular or oval shapes avoiding sharp corners.
- Repair types and their characteristics, including:
  - laminated patch repair – general purpose, simple, fast, can be unsightly, limited strength
  - scarf joint repair – used in strength critical applications including aerospace, restores original surface profile and up to 90% of original strength
  - adhesive bonded doubler – used a pre-cured FRP composite patch secured with an appropriate resin adhesive, used in temporary repair to prevent damage worsening
  - adhesive bonded tapered plug repair – is relatively inexpensive, limited to repair of small through-hole punctures, limited strength.

Learning aim C: Carry out processes to manufacture and repair fibre-reinforced polymer composite components

C1 Applying wet and dry lay-up manufacturing processes

- Wet lay-up manufacturing processes, including:
  - tools and equipment – moulds, brushes, rollers, release agents, resin and catalyst, e.g. polyester resin, gel coat, fibre matting, e.g. chopped strand, woven and appropriate PPE
  - general wet lay-up process procedure, including:
    - mould preparation
    - application of release agent to surface of mould to prevent resin from adhering
    - application of gel coat to form the smooth, tough outer skin of the component
    - resin preparation and mixing according to manufacturer's guidance
    - application of resin and fibre matting
    - rolling to expel trapped air and ensure thorough fibre wetting
    - further application of resin and fibre matting to give the required material thickness
    - resin curing in a suitable environment according to manufacturer's guidance
    - removal of fully cured component from mould
    - trimming off excess material to finish the component.
- Dry lay-up manufacturing processes, including:
  - tools and equipment – shears, release agent, moulds, vacuum bagging film, vacuum bagging tape, breather cloth, autoclave or oven, prepreg sheets with specific fibre alignment, weave and fibre/matrix ratio and appropriate PPE

- general dry lay-up process procedure, including:
  - mould preparation
  - cutting prepreg layer size and shape in accordance with component cutting templates
  - application of release agent to mould surface to prevent resin from adhering
  - application of pre-cut surface and then backing plies into mould in accordance with component design
  - application of release film and breather cloth
  - bagging and sealing into a vacuum bag and fitting through bag connector
  - application of a vacuum compressing prepreg layers into the required shape
  - using an autoclave or oven to apply appropriate elevated temperature and/or pressure for a prescribed period according to manufacturer's guidelines to cure the resin
  - removal of the fully cured component from vacuum bag and mould
  - trimming off excess material to finish the component.

C2 Applying FRP composite repair processes

General repair procedure, including:

- damage assessment
- damage removal
- selection of repair style to be applied
- cleaning, degreasing and drying the composite material in the area to be repaired
- preparing repair and reinforcement patches to appropriate size and fibre orientation
- resin preparation and mixing according to manufacturer's guidance
- application of the repair, ensuring good fibre coating and eliminating voids
- resin curing in a suitable environment according to manufacturer's guidance
- final inspection and testing, e.g. visual inspection, tap test, ultrasound.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the characteristics and applications of fibre-reinforced polymer composites that are widely used in industry		**A.D1** Justify, using language that is technically correct and of a high standard, the application of at least two different FRP composite materials.
A.P1 Explain the characteristics and applications of at least two different FRP composite materials.	**A.M1** Compare the characteristics and applications of at least two different FRP composite materials.	
Learning aim B: Investigate the processes used to manufacture and repair fibre-reinforced polymer composites		**B.D2** Evaluate the characteristics of FRP composite manufacturing and repair processes, including the safe working practices that apply.
B.P2 Explain the characteristics of the wet and dry lay-up composite manufacturing processes, including what safe working practices apply. **B.P3** Explain the processes used to repair both surface and through-hole damage in FRP composite components, including what safe working practices apply.	**B.M2** Compare the characteristics of the wet and dry lay-up composite manufacturing processes, including the safe working practices that apply. **B.M3** Compare the processes used to repair both surface and through-hole damage in FRP composite components, including the safe working practices that apply.	
Learning aim C: Carry out processes to manufacture and repair FRP composite components		**C.D3** Refine, during the process, the wet or dry lay-up manufacture and the repair of surface and through-hole damage of FRP composite components safely, effectively and accurately.
C.P4 Manufacture safely an FRP composite component using a wet or dry lay-up process. **C.P5** Complete the repair safely of both surface and through-hole damage to FRP composite components.	**C.M4** Manufacture safely and accurately an FRP composite component using a wet or dry lay-up process. **C.M5** Complete the repair safely and accurately of both surface and through-hole damage to FRP composite components.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aim: C (C.P4, C.P5, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- appropriate workshop facilities and equipment suitable for the safe manufacture of FRP composite components, e.g. moulds, brushes, rollers, release agents, resin and catalyst, gel coat, fibre matting shears, release agent, moulds, vacuum bagging film, vacuum bagging tape, breather cloth, autoclave or oven, prepreg sheets and appropriate PPE
- design data, drawings and moulds for a range of basic components
- a range of damaged composite components to repair. These might be obtained through links with an industrial partner.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will give a clear and detailed justification in their evidence for the use of contrasting FRP composites in two applications where they have replaced traditional materials. Learners will give details of the materials that were used prior to the development of FRP composites and explain the properties of the FRP composites that made them an attractive alternative, which will form a large part of the justification. For example, the lightweight magnesium alloy used in safety critical structural components in Formula 1® motorsport was superseded by CFRP, which has a higher strength/weight ratio and increased stiffness. Learners will go on to explain the importance of the characteristics of CFRP in the application being considered.

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 with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will compare the characteristics in their evidence of two FRP composite materials and their applications. For example, learners might consider GFRP and CFRP and clearly explain the relative strength, density, toughness, stiffness, cost and environmental impact of the two materials. They would then clearly link these characteristics to the use of the materials in specific applications. For example, CFRP is primarily used in Formula 1 motorsport for safety-critical structural components because of its high strength to weight ratio, stiffness and the relative ease with which large thin-walled components like a monocoque chassis can be manufactured. Learners would go on to perform a similar analysis of the use of GFRP in a specific application.

Overall, the evidence will be logically structured, technically accurate, methodical and easy to understand.

For pass standard, learners will give in their evidence a clear qualitative explanation of the characteristics of typical fibre and resin matrix materials and their functions when combined into at least two FRP composite materials. For example, learners might explain that CFRP is made up from carbon fibres embedded in an epoxy resin matrix. The fibres provide stiffness and tensile strength whilst the resin matrix supports the material structure and provides ductility and toughness. Learners will also explain how fibre orientation and fibre/matrix ratio will affect the mechanical properties of the component. Learners will make links between the general characteristics of specific FRPs and their application in a range of components from a range of engineering sectors.

Overall, the evidence will be logically structured. It may be basic in parts, for example lacking detail about the key material properties required in a particular application and how these might be achieved by altering the fibre orientation, fibre/matrix ratio. The evidence may contain technical inaccuracies or omissions, such as the occasional use of non-technical language or incorrect terms.

Learning aim B

For distinction standard, learners will clearly evaluate in their evidence the dry lay-up and wet lay-up manufacturing processes used to manufacture FRP composite materials safely and the processes used to repair damaged components safely. They will explain the advantages and disadvantages of each process when applied to the manufacture or repair of FRP components, including the requirements for safe working practices. For example, learners might explain that the use of prepreg in dry lay-up ensures optimum fibre/resin ratio, fibre orientation and fibre coating. Also, the use of vacuum bagging helps eliminate voids and inclusions, which gives more consistent and reliable results. On the other hand, using dry lay-up requires specialist equipment such as ovens, autoclaves and vacuum pumps, a spotless working environment and storage of the prepreg sheets at low temperatures. Even when stored correctly prepreg sheets have a limited shelf life and tend to be expensive. Learners will provide similar evidence for the wet lay-up process, and the processes used to repair through-hole and surface damage. To complete the evaluation, learners will explain specific circumstances in which each of the processes would be most appropriately applied. For example, the dry lay-up process would be most appropriate for safety critical structural components such as Formula 1 suspension rods, where the expense and process complexity is outweighed by the reliable, defect-free results. Learners should provide similar evidence for wet lay-up and two repair processes.

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 merit standard, learners will compare in their evidence the characteristics, including the safety requirements, of both wet lay-up and dry lay-up manufacturing processes. For example, they will compare dry lay-up when manufacturing a CFRP component and wet lay-up when manufacturing a GFRP component. They will consider the relative safety, speed, skill, equipment and working environment in each case and compare the typical applications of the components made using the two processes.

Learners' evidence will compare the characteristics, such as component preparation and repair processes, as well as the safety requirements that might be applied to through-hole and surface damaged FRP composite components. For example, they might compare the process of carrying out a scarf joint repair to a component with surface damage to the repair of a through-hole using an adhesive bonded plug. They will consider the relative safety, speed, skill and working environment required and compare the strength and typical applications of the repair type in each case.

Overall, the evidence will be logically structured, technically accurate, methodical and easy to understand.

For pass standard, learners will explain in their evidence the characteristics of both wet lay-up and dry lay-up manufacturing processes. The explanation of the processes should include typical design parameters, the basic processes involved and any potential problems that might be encountered, their causes and how to avoid them. It must also explain the safety requirements that should be considered when working with FRP composites. For example, learners might discuss the proper care and handling of resin and catalyst materials, the provision and use of PPE and the legislation and regulations, such as the Health and Safety At Work etc Act 1974 and COSHH, which regulate safety in the workplace.

Learners' evidence must explain the methods of assessing the extent of damage to an FRP component, what needs to be done to prepare the component for repair and the types of repair available. In addition, learners will explain the additional safety requirements that should be considered when repairing FRP composites. For example, exposure to cured resin and fibre dust particles when sanding in preparation for repair will require a breathing mask.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example making general comments about repair types without clearly explaining the circumstances in which they should be used, and may contain technical inaccuracies or omissions, such as the occasional use of non-technical terms.

Learning aim C

For distinction standard, learners will show in their evidence that they have worked safely, accurately and effectively to manufacture a FRP component using either dry lay-up or wet lay-up and repaired through-hole and surface damage. An assessment of effectiveness might include whether learners worked methodically, skilfully and confidently during the practical phase of the assessment to ensure that the processes were carried out using best practice techniques to produce a good-quality, reliable result, free of flaws. Learners' evidence will also show that they were able to refine the processes as they worked to help ensure they were as safe, accurate and effective as possible. For example, when carrying out wet lay-up of GFRP they might change the amount of resin prepared in each batch to match the pace at which they are working. Mixing an excess that cures before being applied is wasteful and inefficient.

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 merit standard, learners will show in their evidence that they have worked safely and accurately to manufacture an FRP composite component using either dry lay-up or wet lay-up. An assessment of accuracy might include measuring critical component dimensions once the component is trimmed and finished, examining surface finish and measuring the component thickness at several points to ensure it is consistent and within design tolerances.

Learners' evidence will show that they have worked safely and accurately to repair both surface and through-hole damage to FRP composite components. An assessment of accuracy might include the shape, size and finish of a hole prepared for repair and, once all damaged material has been removed, examining the surface finish of the repaired component and/or measuring the repair thickness, which should be consistent and within design tolerances.

Overall, the evidence will be logically structured, technically accurate, methodical and easy to understand.

For pass standard, learners will show in their evidence how they carried out the safe manufacture of an FRP composite component using either dry lay-up or wet lay-up. It will provide a detailed explanation of how the preparation and manufacturing processes were carried out and provide evidence of the safety precautions taken.

Learners' evidence will also show how they carried out the safe repair of an FRP composite component with surface damage and another with through-hole damage. Learners will demonstrate carrying out damage assessment, damage removal and repair processes and explain the safety precautions taken.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example not recording all the steps of the processes being carried out, and may contain technical inaccuracies or omissions, such as the occasional use of non-technical language.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacturing
- Unit 26: Mechanical Behaviour of Non-metallic Materials
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 49: Aircraft Workshop Methods and Practice
- Unit 52: Airframe Construction and Repair
- Unit 55: Aircraft First Line Maintenance Operations.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops with staff from local manufacturing organisations involved with the construction and repair of composites
- contribution of ideas to unit assignment/project materials.

Unit 48: Aircraft Flight Principles and Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the principles and practice of aircraft flight. This involves experiments about aircraft lift and drag forces.

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 aims

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 aim	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.

Content

Learning aim 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 (C_v) and constant pressure (C_P), the ratio of specific heats $\gamma = \frac{C_P}{C_V}$
  - numerical values of R, C_V, C_P 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 $\dot{m} = \rho_1 A_1 v_1 = \rho_2 A_2 v_2$
- 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, 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.

Learning aim 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
  - Eefects 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.

Learning aim 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine the atmosphere, 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.
Learning aim 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 aim 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. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.D1)

Learning aim: B (B.P4, B.P5, B.M3, B.M4, B.D2)

Learning aim: 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 aim 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 aim 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 aim 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 1: Engineering Principles
- Unit 52: Airframe Construction and Repair
- Unit 53: Airframe Mechanical Systems
- Unit 54: Aircraft Electrical and Instrument Systems
- Unit 55: Aircraft First Line Maintenance Operations.

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 49: Aircraft Workshop Methods and Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners carry out mechanical and electrical inspection and fitting processes in a workshop environment, using appropriate components and tools.

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, you 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. You will develop practical skills by carrying out a series of mechanical and electrical workshop inspection and fitting activities. Finally, you will be asked to reflect on how your general engineering skills, workshop inspection and fitting skills and behaviours were applied during the unit.

This unit will help to prepare you for an aircraft engineering apprenticeship as well as, more specifically, assisting you in gaining employment in an aircraft technician role. Alternatively, you could choose to continue your studies in higher education.

Learning aims

In this unit you will:

A Explore safe working practices and suitable component selection in an aircraft workshop environment

B Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness

C Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness

D Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore safe working practices and suitable component selection in an aircraft workshop environment	**A1** Workshop safety procedures and housekeeping **A2** Workshop information sources and standards **A3** Tool management **A4** Hardware and consumable components	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.
B Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness	**B1** Preparation for mechanical hardware inspection and fitting processes **B2** Mechanical hardware inspection and fitting processes	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.
C Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness	**C1** Preparation for electrical hardware inspection and fitting processes **C2** Electrical hardware inspection and fitting processes	
D Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance	**D1** Lessons learned from workshop inspection and fitting processes **D2** Personal performance while carrying out workshop inspection and fitting processes	The evidence will focus on what went well and what did not go so well when carrying out mechanical and electrical inspection and fitting 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.

Content

Learning aim A: Explore safe working practices and suitable component selection in an aircraft workshop environment

A1 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.

A2 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, presentedin 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.

A3 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.

A4 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.

Learning aim B: Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness

B1 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.

B2 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.

Learning aim C: Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness

C1 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.

C2 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.

Learning aim D: Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance

D1 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.

D2 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 criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Explore safe working practices and suitable component selection in an aircraft workshop environment</td><td rowspan="2">A.D1 Justify, using language that is technically correct and of a high standard, 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.</td></tr>
<tr><td>A.P1 Explain how information sources and standards are effectively applied to ensure aircraft airworthiness.
A.P2 Explain how effective tool management and the correct selection of hardware and consumable components ensure aircraft airworthiness.</td><td>A.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.</td></tr>
<tr><td colspan="2">Learning aim B: Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness</td><td rowspan="4">BC.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.</td></tr>
<tr><td>B.P3 Inspect and fit two appropriate mechanical hardware components safely.</td><td>B.M2 Inspect and fit accurately and efficiently two appropriate mechanical hardware components.</td></tr>
<tr><td colspan="2">Learning aim C: Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness</td></tr>
<tr><td>C.P4 Inspect and fit two appropriate electrical hardware components safely.</td><td>C.M3 Inspect and fit accurately and efficiently, two electrical hardware components.</td></tr>
<tr><td colspan="2">Learning aim D: Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance</td><td rowspan="2">D.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.</td></tr>
<tr><td>D.P5 Explain how health and safety, mechanical and electrical inspection and fitting processes, and general engineering skills were applied effectively in an aircraft workshop.
D.P6 Explain how relevant behaviours were applied effectively to mechanical and electrical inspection and fitting processes.</td><td>D.M4 Recommend improvements to the mechanical and electrical hardware component inspection and fitting activities and to the relevant behaviours applied.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary with suitable forms of evidence. Further information on setting assignments is given on our website. *Section 6* gives information on setting assignments.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aims: B and C (B.P3, C.P4, B.M2, C.M3, BC.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

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 aims 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 aims 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.

Essential information for assessment decisions

Learning aim A

For distinction standard, 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, and will be of a high standard of written language and be, for example, grammatically correct.

For merit standard, 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 pass standard, learners will know workshop safety procedures and practices that apply to mechanical and electrical inspection and fitting activities. Specifically, they will be able to explain how information sources and laid-down standards are applied to ensure safe working practice. Finally, they will be able to 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.

Learning aims B and C

For distinction standard, 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 merit standard, learners will accurately and efficiently inspect and fit two 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 pass standard, 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.

Learning aim D

For distinction standard, 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.

For merit standard, 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 pass standard, 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.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 52: Airframe Construction and Repair
- Unit 53: Airframe Mechanical Systems
- Unit 54: Aircraft Electrical and Instrument Systems
- Unit 55: Aircraft First Line Maintenance Operations.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local aeronautical engineering organisations with expertise in the maintenance of aircraft
- contribution of ideas to unit assignment/project materials.

Unit 50: Aircraft Gas Turbine Engines

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will examine the scientific principles, operation and performance of aircraft gas turbine engines that produce thrust and consider their impact on the environment.

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, you 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. You will also compare the function, operation and construction of the different types of gas turbine engine. Next, you will explore the function and operation of the principal components and systems that make up the modern gas turbine engine. Finally, you 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 you want to work in the aeronautical sector. This unit will help to prepare you for an aircraft engineering apprenticeship, as well as helping you to gain employment in an aircraft technician role. Alternatively, you could choose to continue to study this area in higher education.

Learning aims

In this unit you will:

A Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust

B Examine the function and operation of gas turbine engine components and systems that produce thrust

C Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust	**A1** Scientific principles relating to gas turbine engines **A2** Types 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.
B Examine the function and operation of gas turbine engine components and systems that produce thrust	**B1** Function and operation of turbine engine components **B2** Function and operation of engine starter and fluid systems	A report covering the function and operation of aircraft gas turbine engine components, and starting and fluid systems.
C Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion	**C1** Aircraft gas turbine engine performance **C2** Environmental impact of gas turbine engines	A report covering the factors that affect the performance of aircraft gas turbine engines and the nature of, and measures being taken to help reduce, the adverse effects of gas turbine engine pollutants.

Content

Learning aim A: Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust

A1 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 $F_N = \dot{m}\,(v_j - v_a)$ where $\dot{m}$ = mass flow rate of the air moving rearwards, v_j = is the velocity of the gas stream at exit/exhaust from engine and v_a = the velocity at the engine inlet
  - total net flight thrust (TNFT) (subsonic) = $F_N = \dot{m}\,(v_j - v_a) + \dot{m}_f v_i$ where $\dot{m}_f$ = mass flow rate of the fuel
  - Supersonic flow at propelling nozzle, chocked nozzles:
  - TNFT (supersonic) = $\dot{m}\,(v_j - v_a) + \dot{m}_f v_i + A(p_c - p_{amb})$ where A = cross-sectional area of propelling nozzle, p_c = chocked pressure of gas at propelling nozzle, p_{amb} = ambient air pressure.

A2 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.

Learning aim B: Examine the function and operation of gas turbine engine components and systems that produce thrust

B1 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.

B2 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.

Learning aim C: Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion

C1 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.

C2 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 (CO_2), water vapour (H_2O), contrails and the production of (H_2O) and sulphuric acid (H_2SO_4), carbon monoxide (CO), oxides of nitrogen (NO_x) and sulphur (SO_x) 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 (NO_x).

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust		
A.P1 Explain the application of scientific principles to aircraft gas turbine engine cycles and thrust production. **A.P2** Explain the operation of two types of aircraft gas turbine engines.	**A.M1** Analyse the application of scientific principles to aircraft gas turbine engine cycles and thrust production. **A.M2** Analyse the operation of two types of aircraft gas turbine engines, making comparisons between types.	**A.D1** Evaluate, using vocational and high-quality written language, the application of scientific principles to the cycles, operation and thrust production of two types of aircraft turbine engines, making comparisons between types.
Learning aim B: Examine the function and operation of gas turbine engine components and systems that produce thrust		
B.P3 Explain the function and operation of gas turbine engine components. **B.P4** Explain the function and operation of gas turbine starter and fluid systems.	**B.M3** Analyse the function and operation of gas turbine engine components, and engine starter and fluid systems, making comparison between component types.	**B.D2** Evaluate the function and operation of gas turbine engine components, and engine starting and fluid systems, making comparisons between component and system types.
Learning aim C: Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion		
C.P5 Explain, using research, how gas turbine engine performance is measured and improvements in thrust production and fuel efficiency are achieved in turbofan engines. **C.P6** Explain, using research, the nature of environmental pollutants produced from gas turbine engines and the methods used to mitigate their effects.	**C.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.	**C.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 information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aim: B (B.P3, B.P4, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, C.M4, 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 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.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine the parameters. They will also 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 in comparing this engine with the function and operation of a turbo-shaft 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, use correct engineering terms and will demonstratea high standard of written language. 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 merit standard, learners will analyse the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine parameters. They will also 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.

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 pass standard, learners will explain the cycles, operation and thrust production in gas turbine engines, using the gas laws to mathematically determine parameters. They will also 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.

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'.

Learning aim B

For distinction standard, 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. This will include comparison between different types of a particular system and consideration of the layout and function of system components, for example by comparing the relative operational advantages/disadvantages of air turbine versus 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 merit standard, 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 also 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 pass standard, 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 also explain 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.

Learning aim C

For distinction standard, 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 up their analysis with quantitative examples demonstrating these improvements with the turbofan engine, and by comparing them with their pure turbojet counterpart.

Learners will also 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.

For merit standard, 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 pass standard, 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 also explain 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, 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'.

Links to other units

This unit links to:

- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 48: Aircraft Flight Principles and Practice
- Unit 51: Aircraft Propulsion Systems
- Unit 55: Aircraft First Line Maintenance Operations.

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 gas turbine engines
- contribution of ideas to unit assignment/project materials.

Unit 51: Aircraft Propulsion Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will examine the function and operation of aircraft propulsion systems that support the operation of aircraft power plant.

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, you 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. You will examine the function and operation of electromechanical and electronic engine control systems. You will then examine the function and operation of the engine lubrication and air systems, and their components. Finally, you 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 you want to work in the aeronautical sector. This unit will help to prepare you for an aircraft engineering apprenticeship, or to gain employment in an aircraft technician role. Alternatively, you could choose to continue your studies in higher education.

Learning aims

In this unit you will:

A Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation

B Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation

C Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation	**A1** Aircraft fuels and fuel supply systems **A2** Engine fuel systems **A3** Engine electromechanical and electronic 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.
B Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation	**B1** Engine lubrication systems **B2** Engine internal air systems	A report covering the nature of aircraft engine lubricants, the function and operation of engine lubrication, internal air systems and their components, and their contribution to power plant operation.
C Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation	**C1** Fire protection systems and components **C2** 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.

Content

Learning aim A: Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation

A1 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.

A2 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.

A3 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.

Learning aim B: Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation

B1 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.

B2 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, for example:
  - labyrinth, brush and leaf, carbon, ring and hydraulic rotating seals
  - static seals and sealing
  - effects of external bleed air requirements on internal air system.

Learning aim C: Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation

C1 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.

C2 Ice protection systems

- Nature and effects of ice formation including rim ice, glaze ice, hoar frost and snow.
- Operation of ice detector systems; for example, 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation		**A.D1** Evaluate, using language that is technically correct and of a high standard, 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.
A.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. **A.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.	**A.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. **A.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.	
Learning aim B: Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation		**B.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.
B.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. **B.P4** Explain the function and operation of an engine's internal air system and its components, identifying their contribution to power plant operation.	**B.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.	
Learning aim C: Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation		**C.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.
C.P5 Explain the function and operation of an aircraft fire protection system and its components, identifying their contribution to power plant operation. **C.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.	**C.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.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.M2, A.D1)

Learning aim: B (B.P3, B.P4, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, 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:

- 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.

Essential information for assessment decisions

The word 'operation' for all learning aims that follow, includes the identification, construction, layout and features of the system being considered. For system components, only their 'identification', 'function' and system 'layout' is required, as detailed in the content.

The word 'power plant' refers to installed engine(s) and auxiliary power unit(s), complete with intake, pod, fan, propeller, exhaust unit, jet pipe, ancillary equipment, cowls and fairings, as appropriate.

Learning aim A

For distinction standard, 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, use correct engineering terms and the written language will be of a high standard.

For merit standard, 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.

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 pass standard, 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.

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.

Learning aim B

For distinction standard, 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 of the relief valve and full-flow recirculatory lubrication 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 merit standard, 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 pass standard, 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.

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.

Learning aim C

For distinction standard, 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 and will demonstrate a high standard of written language. 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.

For merit standard, 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 pass standard, 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.

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, 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 may incorrectly identify the priority of the cabin fire or icing warning.

Links to other units

This unit links to:

- Unit 50: Aircraft Gas Turbine Engines
- Unit 53: Airframe Mechanical Systems
- Unit 54: Aircraft Electrical and Instrument Systems
- Unit 55: Aircraft First Line Maintenance Operations.

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 propulsion systems
- contribution of ideas to unit assignment/project materials.

Unit 52: Airframe Construction and Repair

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore airframe (fuselage, wings and empennage) construction, repair and protection methods, and develop the practical skills needed to inspect and repair the airframe.

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 aims

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 aim	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.

Content

Learning aim 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.

Learning aim 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 2002 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 1992 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) 1992 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 2005 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.

Learning aim 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine the construction and protection methods used to ensure airworthiness of airframe structures		**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.
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.	**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.	
Learning aim B: Examine how inspection and repair methods are used in the maintenance of composite airframes and components		**B.D2** Justify the inspection and repair methods chosen for the detection and repair of damage to a given airframe composite structure or component.
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.	**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.	
Learning aim C: Carry out processes to inspect and repair safely an airframe composite structure or component that will help to ensure airworthiness		**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.
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.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: 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 aim 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 aim 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 aim 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 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacture
- Unit 26: Mechanical Behaviour of Non-metallic Materials
- Unit 47: Composites Manufacture and Repair Processes
- Unit 48: Aircraft Flight Principles and Practice
- Unit 49: Aircraft Workshop Methods and Practice
- Unit 55: Aircraft First Line Maintenance Operations.

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 53: Airframe Mechanical Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners carry out practical investigation of hydraulically-powered airframe systems and examine environmental control, fuel and protection systems.

Unit introduction

When aircraft takeoff, 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 aims

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 aim	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.

Content

Learning aim 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.

Learning aim 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.

Learning aim 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 Aircraft anti-icing and de-icing systems

- Ice formation, rim ice, glaze ice and Hoare 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, auxiliry 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 criteria

Pass	Merit	Distinction
Learning aim A: Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight		**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.
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.	**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.	
Learning aim B: Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew		**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.
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.	**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.	
Learning aim C: Examine how the operation of airframe fuel, ice- and fire-protection systems contribute 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.
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.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: 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 aim 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 aim 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 aim 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 50: Aircraft Gas Turbine Engines
- Unit 51: Aircraft Propulsion Systems
- Unit 54: 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 54: Aircraft Electrical and Instrument Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine electrical power generation and distribution systems and carry out practical exploration of the construction and operation of aircraft flight instruments.

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 aims

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 aim	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.

Content

Learning aim 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.

Learning aim 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.

Learning aim 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, attitude direction indicator, horizontal situation indicator, altimeter, radio magnetic indicator and VSI.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how electrical power generation and distribution systems support the safe operation of aircraft		**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.
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.	**A.M1** Analyse how DC and AC electrical power is produced, controlled, distributed and converted under normal and emergency conditions for safe flight.	
Learning aim B: Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight		**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.
B.P3 Explain the operation, application and contribution to safe flight of aircraft electric motors, actuators and loading, control and warning systems.	**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.	
Learning aim C: Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight		**C.D3** Justify, using the practical findings from safe 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.
C.P4 Inspect 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 inspection 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.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.M2, B.D2)

Learning aim: 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 aim 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 aim 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 aim 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 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 inspect 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 inspect (look carefully at as part of the teacher's demonstration) one gyroscopic and two air data instruments safely to explore their operation. For example, learners will inspect (look carefully at as part of the teacher's demonstration) an unlabelled instrument such as an airspeed indicator (ASI), vertical speed indicator (VSI) or Machmeter, with the screen masked or removed. They will inspect 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.

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 1: Engineering Principles
- Unit 15: Electrical Machines
- Unit 16: Three Phase Electrical Systems
- Unit 48: Aircraft Flight Principles and Practice
- Unit 49: Aircraft Workshop Methods 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 55: Aircraft First Line Maintenance Operations

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine safe maintenance operations and administrative procedures of aircraft and carry these out in a first-line maintenance environment.

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, you 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. You 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 you to put into practice what you have learned and carry out a number of practical first-line maintenance operations. You will reflect on the processes undertaken, and on your own personal performance, so you can make improvements next time.

This unit will help prepare you for an aircraft engineering apprenticeship, as well as more specifically assisting you in gaining employment in an aircraft maintenance technician role. Alternatively, you could choose to continue your studies in higher education.

Learning aims

In this unit you will:

A Examine aircraft safe maintenance operations in a first-line engineering environment

B Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations

C Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition

D Review aircraft first-line maintenance operations and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine aircraft safe maintenance operations in a first-line engineering environment	**A1** Safety procedures for aircraft first-line maintenance operations **A2** Types of aircraft first-line maintenance operations	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.
B Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations	**B1** Maintenance planning and quality processes **B2** Administrative procedures for aircraft maintenance	
C Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition	**C1** Preparation for aircraft first-line maintenance operations **C2** Aircraft general first-line maintenance operations **C3** Aircraft specialist first-line maintenance operations	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.
D Review aircraft first-line maintenance operations and reflect on personal performance	**D1** Lessons learned from aircraft first-line maintenance operations **D2** Personal performance while carrying out aircraft first-line maintenance operations	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.

Content

Learning aim A: Examine aircraft safe maintenance operations in a first-line engineering environment

A1 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) 1989 and amendments
- 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) 2002 and amendments
- Control of Substances Hazardous to Health Regulations (COSHH) 2002 and amendments, including Personal Protective Equipment (PEE) at Work Regulations 2002 and amendments , aircraft fuel, engine and hydraulic oils, de-icing fluids, liquid oxygen (LOX)
- procedures, hazards and precautions when working at height (Work at Height Regulations 2005) 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.

A2 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, liquid oxygen (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.

Learning aim B: Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations

B1 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:
    - 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.

B2 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.

Learning aim C: Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition

C1 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.

C2 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.

C3 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).

Learning aim D: Review aircraft first-line maintenance operations and reflect on personal performance

D1 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.

D2 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 criteria

Pass	Merit	Distinction
Learning aim A: Examine aircraft safe maintenance operations in a first-line engineering environment		**AB.D1** Evaluate, using language that is technically correct and of a high standard, how safety procedures, planning, quality processes and administrative procedures combine to impact on the safe and efficient delivery of aircraft maintenance operations.
A.P1 Explain what safety procedures and actions are required to complete general and specialist maintenance operations.	**A.M1** Assess what safety procedures and actions are required to reduce the hazards present when completing general and specialist maintenance operations.	
Learning aim B: Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations		
B.P2 Explain the functions and roles of planning and quality processes on aircraft maintenance operations. **B.P3** Explain the functions and roles of the administrative procedures used to support aircraft maintenance operations.	**B.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.	
Learning aim C: Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition		**C.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.
C.P4 Complete three general and three specialist aircraft maintenance operations safely and using the correct processes, including appropriate inspections, checks and tests.	**C.M3** Complete safely, accurately and efficiently three general and three specialist aircraft maintenance operations using the correct processes, including appropriate inspections, checks and tests.	
Learning aim D: Review aircraft first-line maintenance operations and reflect on personal performance		**D.D3** Demonstrate consistently good technical understanding and analysis of the aircraft maintenance operations, including the application of relevant behaviours to a professional standard.
D.P5 Explain how health and safety procedures and aircraft maintenance operations were applied effectively in an aircraft maintenance environment. **D.P6** Explain how relevant behaviours were applied effectively to aircraft maintenance operations.	**D.M4** Recommend improvements to the aircraft maintenance operations and to the relevant behaviours applied.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, B.P2, B.P3, A.M1, B.M2, AB.D1)

Learning aim: C (C.P4, C.M3, C.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.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:

- 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.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, 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, use correct engineering terms and will demonstrate a high standard of written language; for example, being grammatically correct.

For merit standard, learners will assess the most relevant safety and operational procedures, and the actions required to undertake first-line maintenance operations safely. They will also consider the consequences of not taking the appropriate action. Learners will also 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 pass standard, 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 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.

Learning aim C

For distinction standard, 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 carried out.

For merit standard, 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 pass standard, 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.

Learning aim D

For distinction standard, learners will demonstrate in their analysis, 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.

For merit standard, 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 pass standard, 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. 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.

Links to other units

This unit links to:

- Unit 49: Aircraft Workshop Methods and Practice
- Unit 53: Airframe Mechanical Systems
- Unit 54: 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 the first-line maintenance of aircraft
- contribution of ideas to unit assignment/project materials.

Unit 56: Industrial Robotics

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the health and safety and maintenance requirements and the operation and design principles of industrial robotics. Learners will develop a program for a robot to solve an engineering-based problem.

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 aims

In this unit you will:

A Investigate the health and safety and maintenance requirements associated with industrial robots

B Investigate the operation and design of industrial robots for different applications

C Investigate the operation of industrial robot sensors and end effectors

D Produce a program for an industrial robot to solve an engineering problem.

Summary of unit

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Investigate the health and safety and maintenance requirements associated with industrial robots</td><td>A1 Health and safety requirements
A2 Maintenance</td><td>A report or presentation evaluating the safety systems and maintenance requirements in place for an industrial robot or robot work cell.</td></tr>
<tr><td>B Investigate the operation and design of industrial robots for different applications</td><td>B1 Principles of operation and their applications
B2 Design principles
B3 Control systems</td><td rowspan="2">A report of findings from research, evaluating an industrial robot installation in terms of its design, operation and control from a case study.</td></tr>
<tr><td>C Investigate the operation of industrial robot sensors and end effectors</td><td>C1 Sensors
C2 End effectors</td></tr>
<tr><td>D Produce a program for an industrial robot to solve an engineering problem</td><td>D1 Integrated development environment (IDE)
D2 Programming principles and implementation</td><td>A program to control a robot that solves an engineering problem.</td></tr>
</table>

Content

Learning aim A: Investigate the health and safety and maintenance requirements associated with industrial robots

A1 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.

A2 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.

Learning aim B: Investigate the operation and design of industrial robots for different applications

B1 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.

B2 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.

B3 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.

Learning aim C: Investigate the operation of industrial robot sensors and end effectors

C1 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.

C2 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.

Learning aim D: Produce a program for an industrial robot to solve an engineering problem

D1 Integrated development environment (IDE)

- Overview of the functions on IDE, e.g. simulator, pure code, available tools.

D2 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 programing.
- 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 criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Investigate the health and safety and maintenance requirements associated with industrial robots</td><td rowspan="2">A.D1 Evaluate the maintenance procedures and use of a safety system for a specific application of industrial robots.</td></tr>
<tr><td>A.P1 Describe the health and safety requirements for the safe operation of given industrial robots.
A.P2 Describe maintenance procedures on given industrial robots.</td><td>A.M1 Justify the benefits of maintenance procedures and the use of a safety system for a specific application of industrial robots.</td></tr>
<tr><td colspan="2">Learning aim B: Investigate the operation and design of industrial robots for different applications</td><td rowspan="4">BC.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.</td></tr>
<tr><td>B.P3 Explain the operating and design principles of at least two different applications for industrial robots.
B.P4 Describe the control systems, including input, output and feedback signals, used in at least two different applications for industrial robots.</td><td>B.M2 Compare the design, operation and control of at least two different industrial robots, including drive systems.</td></tr>
<tr><td colspan="2">Learning aim C: Investigate the operation of industrial robot sensors and end effectors</td></tr>
<tr><td>C.P5 Explain the operating principles of three different types of robotic sensors for different applications.
C.P6 Explain the operating principles of two different types of robotic end effectors for different applications.</td><td>C.M3 Assess the use of robotic sensors and end effectors for different applications.</td></tr>
<tr><td colspan="2">Learning aim D: Produce a program for an industrial robot to solve an engineering problem</td><td rowspan="2">D.D3 Optimise a functional program for an industrial robot by testing that it performs efficiently, safely and operates as intended.</td></tr>
<tr><td>D.P7 Design an industrial robot program to solve a problem.
D.P8 Produce a program for an industrial robot that is tested in simulation mode and which may only partially solve a problem safely.</td><td>D.M4 Develop a functional program for an industrial robot that operates as intended to solve a problem safely.</td></tr>
</table>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aims: B and C (B.P3, B.P4, C.P5, C.P6, B.M2, C.M3, BC.D2)

Learning aim: D (D.P7, D.P8, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

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.

Essential information for assessment decisions

Assessment evidence could be gathered from a variety of tests, assignments, case studies and practical activities involving industrial or training robots. Where possible, when there are clear links between them, assessment instruments should cover multiple assessment criteria, for example D.P7, D.P8, D.M4 and D.D3.

Learning aim A

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'.

Learning aims B and C

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'.

Learning aim D

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.

Links to other units

This unit links to:

- Unit 36: Programmable Logic Controllers
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 43: Manufacturing Computer Numerical Control Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- educational visits to manufacturing plants
- guest speakers
- technical workshops involving staff from local automation specialists
- contribution of ideas to unit assignment/project materials.

Unit 57: Sustainable Transport

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate alternative forms of transport that do not rely on the use of petroleum-based fuels. They will examine the impact on the environment, the economy and the general population.

Unit introduction

Transport is important and matters to everyone. In addition to people needing to travel by vehicle for business, leisure or personal needs, most things we use or consume every day will have been moved by a freight operator. As well as the need to meet these demands in an economically viable way, there is an environmental and social cost in terms of noise, congestion, air pollution and safety. Most transport vehicles still rely on petroleum-based, with significant effects on individuals, the community and the environment.

In this unit you will develop your understanding of the necessity to balance the demand for efficient transport services with the long-term effects on sustainability. You will explore sustainable alternatives to petroleum-based fuel powered vehicles as well as ways to access goods and services that could help to reduce the distanced travelled by transport vehicles. The unit introduces toolkits and instruments for conducting an emissions comparison, and you will be able to use these resources in a practical way. You then go on to investigate the barriers to adopting sustainable transport as well as possible incentives and penalties to influence the adoption of sustainable modes of transport. Finally you will also gain knowledge and understanding in exercising j udgement as to the suitability of alternatives for transport needs and develop a campaign tool.

This unit will help to prepare you for an engineering apprenticeship, a higher education engineering degree or for a technician-level role in a wide range of specialist engineering areas.

Learning aims

In this unit you will:

A Investigate the sustainability of alternative power sources for transport vehicles

B Investigate the wider benefits of reducing the distance travelled by transport vehicles

C Investigate how barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport

D Investigate ways to improve the sustainability of leisure travel.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the sustainability of alternative power sources for transport vehicles	**A1** Alternative power sources for different modes of transport **A2** Assessing sustainable options **A3** Sustainability	An individually prepared presentation on alternative power sources to petroleum-based fuels for transport vehicles and on the benefits of reducing the use of transport vehicles in a given location, for example a small town.
B Investigate the wider benefits of reducing the distance travelled by transport vehicles	**B1** Economic benefits **B2** Environmental benefits **B3** Social benefits	
C Investigate how barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport	**C1** Barriers to use **C2** Incentives to encourage demand **C3** Penalties to reduce demand	Report, backed up by research, detailing how barriers, incentives and penalties could affect the demand for and use of sustainable transport at a given location.
D Investigate ways to improve the sustainability of leisure travel	**D1** Leisure travel **D2** More sustainable options **D3** Investigation **D3** Campaign tools	A campaign tool to encourage people to reduce their private car use to a specific leisure destination and primary research used to refine the campaign tool.

Content

Learning aim A: Investigate the sustainability of alternative power sources for transport vehicles

A1 Alternative power sources for different modes of transport

- Modes of transport, e.g. cars, lorries, trains, planes and boats.
- Alternative power sources than petroleum, e.g. biodiesel, biogas, ethanol, hydrogen fuel cell, solar, battery.

A2 Assessing sustainable options

- Options:
  - holistic approach to sustainability
  - the effect on the environment, local and wider, current and future
  - the economic cost and benefit to how the social fabric of society will be enhanced
  - considering detrimental effect to the social fabric, local and extended, current and future.
- Sustainability assessment tools, e.g. Brundtland sustainability portal, environmental audit, ecological footprint, social impact assessment, sustainability indicators.

A3 Sustainability

- Economic.
- Environmental.
- Social.
- Meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Learning aim B: Investigate the wider benefits of reducing the distance travelled by transport vehicles

B1 Economic benefits

- Increased use of public transport by paying passengers makes routes more viable.
- Walking, cycling, liftshare schemes reduce personal expenditure on fuel costs.

B2 Environmental benefits

- Reduced drain on the Earth’s resources, e.g. petroleum-based fuels.
- Less need for highways maintenance.
- Reduction in wildlife deaths due to collision with vehicles.

B3 Social benefits

- Health and wellbeing.
- Improved air quality.
- Reduced traffic congestion in built-up areas.
- Ease of movement for pedestrians.
- Reduced incidences of traffic accident.
- Increase in social interaction, e.g. walking, bus, park and ride, community minibus, walk to school week, liftshare schemes.

Learning aim C: Investigate how the barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport

C1 Barriers to use

- Barriers, including:
  - cost
  - availability of public transport
  - safety, e.g. travelling late at night
  - communication of timetables
  - service reliability, e.g. not knowing when or whether the transport will arrive
  - efficiency of vehicle
  - storage, e.g. places to put accessories, laptops, luggage, shopping
  - support and assistance, e.g. few staff on buses or trains, help for people with disabilities, the elderly or people with children.

C2 Incentives to encourage demand

- For individual members of the public, including:
  - bus passes
  - free or reduced travel
  - shopper buses
  - coupons in media or with sponsorship
  - cycling, e.g. racks, paths, showers at work, purchase loans and cycle training
  - car share scheme.
- For transport providers including travel plan grants, freight grant for taking freight from road and encouraging rail or water use, bus company subsidies.

C3 Penalties to reduce demand

- Schemes, e.g. car parking tickets, clamping towaway zone.
- Congestion zone charges, toll roads, high car park prices, shorter time allowances for town centre car parks, tax on fuel.

Learning aim D: Investigate ways to improve the sustainability of leisure travel

D1 Leisure travel

- Holidays, social activity, non-essential trips, by transport vehicles, e.g. private car, aeroplane.

D2 More sustainable options

- Alternatives to using car or plane, e.g. train, walking, cycling, public transport.
- Comparing the carbon dioxide emissions of the four main modes of transport (car, rail, bus/coach, plane) for a journey using web-based toolkits.
- Case studies, e.g. Department for Transport Sustainable Travel Towns Study.

D3 Investigation

- Case studies, surveys, press articles, advertising literature.
- Using assessment toolkits to measure carbon dioxide (CO_2) impact of various modes of transport.
- Primary research into the effectiveness of campaign tools, e.g. surveys and interviews.

D4 Campaign tools

- Leaflets, posters, websites, advertisements.
- Social networking.
- Incentives, e.g. competitions, loyalty cards (rail user cards, discounted travel).
- Awareness campaigns, promoting wider benefits.
- Effectiveness of campaign tools, e.g. target audience, message, accuracy, visual impact.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the sustainability of alternative power sources for transport vehicles		**AB.D1** Evaluate alternative power sources to petroleum-based fuels for transport vehicles and the benefits of reducing transport vehicle use at a given geographical location.
A.P1 Describe alternative power sources to petroleum-based fuels for transport vehicles, in terms of their economic, environmental and social sustainability.	**A.M1** Compare alternative power sources to petroleum-based fuels for transport vehicles, in terms of their economic, environmental and social sustainability.	
Learning aim B: Investigate the wider benefits of reducing the distance travelled by transport vehicles		
B.P2 Describe the economic, environmental and social benefits of reducing transport vehicle use at a given geographical location.	**B.M2** Explain the economic, environmental and social benefits of reducing transport vehicle use at a given geographical location.	
Learning aim C: Investigate how the barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport		**C.D2** Evaluate the barriers to use and the effectiveness of incentives and penalties that affect the demand for sustainable vehicle transport at a specific location.
C.P3 Explain the barriers to use and incentives for an individual that could affect the demand for sustainable vehicle transport at a specific location. **C.P4** Explain the incentives and penalties for a given transport provider that could affect the use of sustainable vehicle transport at a specific location.	**C.M3** Discuss the barriers to use, incentives and penalties that affect the demand for sustainable vehicle transport at a specific location.	
Learning aim D: Investigate ways to improve the sustainability of leisure travel		**D.D3** Develop an effective campaign tool that compares the benefits and drawbacks of alternative sustainable modes of transport to a leisure destination, making justified refinements based on primary research.
D.P5 Create a campaign tool for an alternative sustainable mode of transport to a leisure destination. **D.P6** Conduct primary research into the effectiveness of the campaign tool.	**D.M4** Develop a campaign tool that compares the benefits of alternative sustainable modes of transport to a leisure destination, making refinements based on primary research.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, B.P2, A.M1, B.M2, AB.D1)

Learning aim: C (C.P3, C.P4, C.M3, C.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

Learners need access to computers to research information on the internet and through the media. Access to video footage of real-life schemes would be beneficial. Transport will be required for site visits to organisations that have promoted or implemented sustainable transport use.

Access to case studies would also be beneficial. For example, how individuals, groups of people or organisations have implemented sustainable transport or travel initiatives.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will evaluate alternative power sources to petroleum-based fuels by considering the advantages and disadvantages of each for use at a given geographical location. They will use sustainability assessment tools and provide a justified conclusion for the most appropriate power source.

Learners will also evaluate the economic, environmental and social benefits of reducing the use of transport vehicles in a specific geographical location. They will provide a justified conclusion that identifies the most important actions that are likely to produce the biggest benefits in terms of sustainability. All three wider benefits must be covered and relevant examples given.

For merit standard, learners will compare alternative power sources to petroleum-based fuels and use sustainability assessment tools and other sources of information to make the economic, environmental and social comparison. The comparison will be for a mode of transport at a given geographical location.

Learners will also explain, for a given geographical location, what the economic, environmental and social benefits are for reducing the use of transport vehicles. The explanation must cover all three different types of wider benefit and be explicitly focused on the locality, with specific relevant examples evident. Learners' explanations will need to link many of the points being made with appropriate reasoning.

For pass standard, learners need to describe appropriate alternative power sources to petroleum-fuels for different types of transport vehicle used at a given geographical location. At least three different alternative power sources must be covered in terms of their economic, environmental and social sustainability.

Learners will also need to describe the benefits of reducing the use of transport vehicles at a given geographical location. All three types of wider benefit (economic, environmental and social) must be covered with some relevant examples given.

Learning aim C

For distinction standard, learners must evaluate the barriers as well as the effectiveness of incentives and penalties that affect the demand for and use of sustainable transport at a given location. For example, the barriers, incentives and penalties related to the use of the London Congestion Charge Zone, commenting on its effectiveness to increase the demand for sustainable transport. The evaluation must cover intended and unintended impacts and a justified conclusion, with appropriate data, must be given, and the response must cover individuals and private transport providers.

For merit standard, learners need to discuss the barriers as well as incentives and penalties that affect the demand for and use of sustainable transport at a given location. Where appropriate, learners should cover how the points being made interrelate and provide data (where possible) about the size of the impact that they may have. The response must cover individuals and private transport providers, but a conclusion is not required.

For pass standard, learners need to explain about appropriate barriers as well as incentives and penalties that affect the demand for and use of sustainable transport at a given location. They will need to clearly state which are for an individual and which are for the given private transport provider. Learners will need to show they are aware of incentives and penalties currently in existence, such as free or subsidised public transport and car share schemes to encourage reduced car use.

Learning aim D

For distinction standard, learners will develop an effective campaign tool that compares the benefits and drawbacks of at least two alternative sustainable modes of travel to a leisure destination. The information provided in the campaign tool will be supported by appropriate and referenced research. In addition, primary research/peer review will be completed once an appropriate outline idea has been selected. It will focus on the effectiveness of the outline idea in terms of target audience, message, accuracy and visual impact and will be used to justify the need for refining the campaign tool further during its development.

For merit standard, learners will develop a campaign tool that compares at least two alternative sustainable modes of travel to a leisure destination. Learners will need to cover and compare the wider benefits of choosing the sustainable transportation alternatives, for example social, health and wellbeing benefits, in addition to the more obvious environmental benefits. Primary research/peer review will have been completed to inform any further refinement of the campaign tool during its development but changes may not be justified.

For pass standard, learners will create a campaign tool for an alternative sustainable mode of transport to a leisure destination. For example, a learner may select train travel as an alternative mode of transport to using a private car for a domestic or close foreign holiday. Learners will support their decisions with evidence about the sustainability of the mode of transport chosen, but are likely to focus on the environmental benefits rather than other wider benefits. Learners will also conduct primary research/peer review into the effectiveness of the campaign tool, but it may not have been used to justify any further refinement to the campaign tool during development and it may lack detail.

Links to other units

This unit links to:

- Unit 58: Energy Management.

Employer involvement

This unit would benefit from employer involvement in the form of:

- educational visits to manufacturing plants or transport offices
- guest speakers
- technical workshops involving staff from local transportation specialists
- contribution of ideas to unit assignment/project materials.

Unit 58: Energy Management

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the uses of energy in organisations and concepts of energy management. They will examine the increasing requirement to conserve energy and identify ways of using energy in a more efficient and effective manner.

Unit introduction

Energy management is becoming increasingly important in terms of climate change and energy conservation and is relevant to all human activity. Greater gains, both environmentally and economically, can be achieved by cutting down on waste, recycling and maximising the efficient use of energy. This means developing both a cultural and behavioural change. Managers in organisations require an awareness of current legislation, and through their leadership have to raise awareness of the need to conserve energy, establish policies and procedures and reward employees who have good ideas about energy efficiency. Software is now available to enable organisations to track their energy performance and set future targets.

You will gain a knowledge of energy conservation, including energy conservation awareness for both an organisation and the personnel employed. The principal focus for the unit is establishing and developing an energy audit in the context of an organisational environment. You will develop the skills and techniques needed to carry out an energy management audit and monitor the processes adopted.

This unit will help to prepare you for an engineering apprenticeship, a higher education engineering degree or for a technician-level role in a wide range of specialist engineering areas.

Learning aims

In this unit you will:

A Know about energy management

B Be able to plan for an energy management audit

C Be able to conduct an energy management audit

D Understand how to monitor and target energy savings.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Know about energy management	**A1** Legislation and international agreements **A2** Sectors **A3** Terminology **A4** Energy conservation techniques **A5** Energy technologies	Create materials for a client on energy conservation, produce a leaflet or booklet covering all the main points on energy management.
B Be able to plan for an energy management audit	**B1** Energy source suppliers **B2** Organisational policies **B3** Practices and procedures **B4** Employer/employees **B5** Buildings/equipment/ materials/transport vehicles **B6** Actions **B7** Audit procedures	Create a template energy management audit plan. Present this plan and explain the importance of the audit.
C Be able to conduct an energy management audit	**C1** Energy audit **C2** Energy usage checklist **C3** Information and data collection	Using an organisation's energy conservation performance, detail strengths, areas for improvements and recommendations in a written report. Present your findings to the group.
D Understand how to monitor and target energy savings	**D1** Targeting **D2** Monitoring **D3** Review	Create a written report that outlines how an organisation can set targets and monitor energy savings.

Content

Learning aim A: Know about energy management

A1 Legislation and international agreements

- UK legislation (Climate Change Act).
- International protocols and accords.

A2 Sectors

- Business and public sector.
- Energy intensive industries.
- Small businesses.
- Energy suppliers.

A3 Terminology

- Key terminology, e.g. low carbon economy.
- Carbon footprint.
- Global emissions.
- Energy consumption.
- Risk.

A4 Energy conservation techniques

- Saving energy, e.g. insulation, equipment, lighting, waste management, recycling, resource management, heating, ventilation and air conditioning, energy generation methods.

A5 Energy technologies

- Saving energy, e.g. advanced photovoltaic cells, industrial energy efficiency accelerator, low carbon buildings accelerator.

Learning aim B: Be able to plan for an energy management audit

B1 Energy source suppliers

- Fossil and non-fossil fuels.
- Electricity.
- Gas.
- Costs.

B2 Organisational policies

- Energy policy statements.

B3 Practices and procedures

- Energy usage, daytime, night-time, weekends.
- Transport notices.
- Communication.
- Rewards.

B4 Employer/employees

- Attitudes.
- Commitment.
- Leadership.
- Communication.
- Organisational structure.
- Accountability.

B5 Buildings/equipment/materials/transport vehicles

- Insulation.
- Usage.
- Age.
- Alternatives.
- Life cycle replacement.

B6 Actions

- Approval.
- Aims.
- Objectives.
- Checklist.

B7 Audit procedures

- Checklist.
- Logs.
- Metering and measurements.
- Frequency.

Learning aim C: Be able to conduct an energy management audit

C1 Energy audit

- Tours with key staff.
- Employer and employee discussions.

C2 Energy usage checklist

- Energy suppliers.
- Energy tariff.
- Range of quantifiable procedures and practices.
- Costing procedure.
- Equipment age and maintenance.
- Materials used.
- Buildings, doors, windows, insulation, lighting.
- Recycling.
- Waste.

C3 Information and data collection

- Qualitative and quantitative information.
- Database.
- Report.
- Benchmarking.
- Patterns.
- Deviations.
- Results analysis.
- Strengths and areas for improvement.
- Recommendations for energy savings.

Learning aim D: Understand how to monitor and target energy savings

D1 Targeting

- Performance indicators, benchmarking.
- Patterns.
- Deviations.

D2 Monitoring

- Collection techniques.
- Timelines.
- Frequency.
- Data analysis.
- Patterns.
- Accuracy.

D3 Review

- Practices.
- Policies.
- Procedures.
- Employer/employee commitment.
- Targets versus actual energy savings.
- Energy wastage.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Know about energy management		
A.P1 Describe the main features of current legislation, agreements and accords/protocols for energy. **A.P2** Describe, using appropriate terminology, four types of energy conservation technique.		
Learning aim B: Be able to plan for an energy management audit		
B.P3 Complete an appropriate plan for an energy management audit. **B.P4** Carry out an energy management audit for a selected organisation.	**B.M1** Explain the importance of planning for an energy management audit. **B.M2** Explain relevant results from an energy management audit.	**B.D1** Analyse relevant results from an energy management audit.
Learning aim C: Be able to conduct an energy management audit		
C.P5 Describe relevant results from an energy management audit. **C.P6** Describe strengths and proposed areas for improvement from an energy management audit.	**C.M3** Explain strengths and proposed areas for improvement from an energy management audit.	**C.D2** Justify recommendations for improvements in energy management following an audit.
Learning aim D: Understand how to monitor and target energy savings		
D.P7 Explain how to set and monitor targets for energy savings for a selected organisation.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of four summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2)

Learning aim: B (B.P3, B.P4, B.M1, B.M2, B.D1)

Learning aim: C (C.P5, C.P6, C.M3, C.D2)

Learning aim: D (D.P7)

Further information for teachers and assessors

Resource requirements

Learners need access to appropriate computer facilities, software, tutorial support and library resources. Learners also require access to small organisations to complete the real or virtual energy management audit. The use of case studies should be encouraged.

Essential information for assessment decisions

Learning aim A

For pass standard, learners need to demonstrate knowledge of the main features of current, relevant legislation/agreements and accords/protocols in energy conservation and management and describe four techniques used to conserve energy, which must include insulation, waste management, recycling and one other.

Learning aim B

For distinction standard, learners need to analyse the results from the energy management audit by detailing how factors identified in the audit contribute to the results and how they are related.

For merit standard, learners need to explain the importance of planning for an energy management audit. In their explanation, learners must cover why it is so important to have the correct resources to carry out an audit, and to consult an organisation's staff for information about buildings, employer attitudes etc.

Learners also need to explain the results from their audit in detail, including any patterns/deviations. Correct terminology and units must be used.

For pass standard, learners need to complete an appropriate plan to enable them to carry out an energy management audit. The plan should cover the unit content as stated under Learning aim B.

Learners also need to carry out an energy management audit for a selected organisation and describe relevant results. The energy management audit to be conducted can be real or virtual. The audit should cover the unit content as stated under Learning aim C.

So that learners can generate the required evidence, the unit should be adapted to suit the resources within a centre and to enable learners to work with an organisation to complete a real or virtual energy management audit. Evidence could be provided using secondary sources of information/data in case studies, verifiable performance indicators/benchmark sources and interpretation exercises. Literature searches and reviews would also be appropriate.

Learning aim C

For distinction standard, learners need to justify recommendations they make for further improvements following an energy management audit. Learners should give reasons and further evidence to support their opinions or views to clearly show how they arrived at their conclusions.

For merit standard, learners need to explain the strengths and proposed areas for improvement following the energy management audit with examples that are specific to the selected organisation.

For pass standard, learners need to use the results from the audit to describe strengths and proposed areas for improvement, which must include recommendations for energy savings.

Learning aim D

For pass standard, learners need to explain how to set and monitor realistic targets for energy savings for the selected organisation. Learners should provide details that are specific to the possible energy savings identified from the audit.

Links to other units

This unit links to:

- Unit 57: Sustainable Transport
- Unit 59: Principles of Electrical Machines
- Unit 60: Autonomous Mobile Robotics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from energy management teams
- contribution of ideas to unit assignment/project materials.

Unit 59: Principles of Electrical Machines

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the safe operation of electrical machines such as direct current (DC) motors and their practical applications in industry.

Unit introduction

Electrical machines are an important but often unseen part of modern engineering products and systems. For example, the air-conditioning system on an aircraft contains an electric motor at its heart, while in the home, food processors and fan ovens have electric motors.

All electrical machines use applications of electro-magnetic principles where electric currents create magnetic fields that either attract or repel each other. This is the basis of all electric motors, whether they operate on direct current (DC) or alternating current (AC).

In this unit you will investigate the safe operation, including construction, of the most common electrical machines, from step-up/down transformers commonly used in stabilised power supplies, through to DC and AC motors. You will study single-phase machines and the more common three-phase induction machines used in industry, including their control systems and circuitry.

This unit prepares you for an electrical, electronic or mechatronic-based engineering apprenticeship, for higher education and for technician-level roles such as that of electrician and electrical fitter. As an electrical engineer you may need to safely operate, maintain and repair electrical machines, and consequently the requirement for a solid theoretical knowledge and understanding of them is vital.

Please note that you may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, you cannot take both.

Learning aims

In this unit you will:

A Investigate the operation and applications of direct current (DC) electrical machines as used in industry

B Investigate the operation and applications of alternating current (AC) electrical machines as used in industry

C Investigate how electrical machine control circuitry and systems operate safely.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the operation and applications of direct current (DC) electrical machines as used in industry	**A1** Operation of DC motors and generators **A2** Applications and developments for DC machines	A portfolio containing written responses, diagrams and calculations related to the operation and applications of three different types of DC electrical machines. The portfolio could be supplemented by a PowerPoint presentation.
B Investigate the operation and applications of alternating current (AC) electrical machines as used in industry	**B1** Operation of single-phase AC transformers **B2** Operation of single-phase AC machines **B3** Operation of three-phase AC induction motors **B4** Applications and developments for AC machines	A portfolio containing written responses, diagrams and calculations related to the operation and applications of four different types of AC electrical machines. The portfolio could be supplemented by a PowerPoint presentation.
C Investigate how electrical machine control circuitry and systems operate safely	**C1** Health and safety requirements for the safe operation of electrical machines **C2** Control systems **C3** Control circuits used in DC motors **C4** Control circuits used in AC motors **C5** Risk assessment	A portfolio containing written responses, diagrams and risk assessments related to safety, control circuitry and systems for DC and AC electrical machines. The portfolio could be supplemented by a PowerPoint presentation.

Content

Learning aim A: Investigate the operation and applications of direct current (DC) electrical machines as used in industry

A1 Operation of DC motors and generators

- Purpose of pole segments and field windings to create a fixed magnetic field, as determined by Fleming's right-hand rule.
- Interaction of the fixed magnetic field with an armature winding to create movement, as determined by Fleming's left-hand rule and rotation due to the armature being fixed at a central pivot point.
- Connection of the field and armature windings to create three types of DC motor – series, shunt and compound – and the difference in operation between all three.
- Construction of the rotor with conductor coils embedded within a laminated iron core to increase magnetic field strength and reduce power losses due to eddy currents.
- Purpose of input voltage commutation and how the commutator component achieves this.
- Starting issue with the use of single commutator segments and how these issues are minimised.
- Current contact with the armature windings through carbon brushes and the reasons for using carbon, to include good electrical conductivity, self-lubricating material and reduced switching noise.
- Causes and consequences of overheating motors, including reduced power output.
- Methods for cooling motors to include:
  - fins on the yoke to increase surface area
  - fan on the rotor to create forced air cooling during operation.
- Measurement of speed and torque characteristics in DC motors (series, shunt and compound) to include:
  - input current and input voltage
  - power output $P_{out} = \frac{2\pi\tau N}{60}$ and motor efficiency $\eta = \frac{P_{out}}{P_{in}}$
  - the effect of cogging torque on the motor and how it can be minimised, including using skewed poles.
- Measurement of speed and torque characteristics in DC generators:
  - terminal voltage and current
  - voltage regulation of the generator using a fixed speed and a range of output loads.

A2 Applications and developments for DC machines

- The selection of DC motors and generators for different applications, including:
  - a shunt motor is used as an electric vehicle drive motor, in a robot arm and as part of an aircraft's autopilot system
  - a series motor is used as a car starter motor
  - a DC generator (dynamo) is used as a power source for bicycle lights.
- Developments for DC machine technology, including digital switched reluctance motors.

Learning aim B: Investigate the operation and applications of alternating current (AC) electrical machines as used in industry

B1 Operation of single-phase AC transformers

- Construction of primary and secondary windings to include the diameter of the wire and insulation methods, e.g. varnish or shellac, to avoid short circuiting.
- Principles of mutual induction, where an alternating current creates a changing magnetic field around one coil that creates a changing current in the secondary coil.
- Both coils being wound on a ferromagnetic core (soft iron) to increase the efficiency of the transformer through increasing the flux density.
- Transformer efficiency to include transformer losses, eddy currents, magnetic leakage and power losses, I^2R.
- Different methods for winding the coils to help reduce leakage losses, including shell, core and toroidal types of transformer.
- Lamination of the soft iron core to reduce eddy current power losses.
- Additional secondary windings on the same primary core allowing for multiple output voltages from a single input and negligible voltage losses.
- Measurement of single-phase transformer characteristics to include:
  - input and output voltage, current and power
  - ideal transformer equation $\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
  - transformer efficiency $\eta = \frac{P_{out}}{P_{in}}$.

B2 Operation of single-phase AC machines

- Field windings in a single-phase AC motor generate a magnetic field.
- The smoothness of the machine's rotation is determined by the number of pole pairs that each create an additional magnetic field.
- The rotor has conductors embedded in a laminated iron core, which needs a permanent connection to the power supply to operate, which is achieved through the use of slip rings and carbon brushes.
- Single-phase AC motors require starting circuitry to set up a magnetic field allowing the motor to operate.
- Single-phase AC generators produce an AC waveform, where the terminal voltage is proportional to the speed of rotation.

B3 Operation of three-phase AC induction motors

- The stator in three-phase induction motors generates a rotating magnetic field.
- Synchronous speed is calculated by $n_{sync} = \frac{f \times 60}{P}$.
- Wound rotors and squirrel-cage rotors use laminations in the core to reduce power losses
- Understand how a current is induced in the rotor bars or windings and how this current produces torque in the rotor.
- For wound rotor motors the purpose of slip rings and brushes is to continuously connect the windings to the alternating power supply during operation – benefits of wound rotor motors in using starting circuits include access to the windings so that increased resistance can be added and removed in resistance starters.
- Definition of slip speed is the difference between shaft speed and synchronous speed and also how to determine slip as a percentage of the rated speed $\frac{n_{sync} - n_m}{n_{sync}}$.
- Speed control of three-phase induction motors to include variable frequency drives, inverters and pulse width modulation (PWM) systems.

- Measurement of single- and three-phase induction motor characteristics to include:
  - single-phase motor currents on start-up and the phase shift required to self-start
  - synchronous speed for an induction motor with a known number of poles
  - motor shaft speed and motor slip
  - torque versus speed for induction motors.
- Input power, current and voltage using $\sqrt{3V_1}\ V_1 \cos\varphi$ and output power using $P_{out} = \frac{2\pi\tau N}{60}$ to calculate the efficiency of the induction motor.

B4 Applications and developments for AC machines

- The selection of AC motors, transformers and generators for different applications, including:
  - a three-phase induction motor is used as a lathe drive motor and as part of an air-conditioning unit in cars and aircraft
  - a step-up/down transformer is used as a laptop power supply and machine power supply
  - a single-phase generator is used as an alternator in a car engine.
- Developments for AC machine technology, including axial flux motors, synchronous reluctance and permanent magnets motors.

Learning aim C: Investigate how electrical machine control circuitry and systems operate safely

C1 Health and safety requirements for the safe operation of electrical machines

- Key features of regulations, or other relevant international equivalents, including:
  - Electrical Equipment (Safety) Regulations 1994 and amendments, for example outlining how equipment is safe, well maintained and constructed to CE (Communauté européenne) standards
  - machinery directives, including British and International Standards (BS 7671 and 19th Edition IEE Wiring Regulations), e.g. covering the correct rating of protection devices.
- Guidance notes or other relevant international equivalents, including:
  - GS38 electrical test equipment for use by electricians, e.g. outlining safe isolation procedures and when working live is permitted
  - codes of practice for specific industries, for example Civil Aviation Authority (CAA) for aeronautical engineers and the Institution of Electrical Engineers (IEE) for electrical and electronic engineers.
- Safety procedures, including:
  - isolation (switch off, lock off, display notices, testing for dead with test lamp and proving unit)
  - earthing
  - interlocking
  - warning notices
  - permit to work.

C2 Control systems

- Start/stop/retain relay control, including:
  - relay/contactor with retaining/latching contact
  - start, stop, overload, ‘inch’ (non-latching) control
  - safety relays for production/manufacturing equipment, e.g. several guards/closed sensors, oil level detectors, temperature sensors, body heat passive infra-red detectors
  - 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.

C3 Control circuits used in DC motors

- Speed control methods for DC machines to include field weakening and rheostat (variable resistor) control.
- The use of starting circuitry in DC motors to avoid large spike in current on start-up created by the absence of back electromotive force (emf) and understanding the operation of a faceplate starter circuit to help overcome this problem.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips and how these devices are connected to the control circuitry.

C4 Control circuits used in AC motors

- Types of single-phase AC motor starting circuits, including capacitor start, capacitor start and run, shaded pole and split phase and understanding how each method creates two separate magnetic fields that are out of phase with each other, causing the rotor to start moving.
- Circuit diagrams and operation of starter circuits to include direct on line (DOL), star-delta and rotor resistance.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips and how these devices are connected to the control circuitry.

C5 Risk assessment

- Risk assessment of the working environment and specific requirements to operate and test DC and AC electrical machines, to include hazard identification and classification:
  - defining a hazard, including any that can cause an adverse effect, e.g. rotating machinery causes an entrapment hazard to loose clothing/hair
  - defining risk of the severity of any hazard, normally calculated as a risk rating of likelihood multiplied by severity
  - putting control measures in place to reduce risk, e.g. using correctly rated and shrouded cables and guarding rotating components
  - five steps of a risk assessment as defined in the Health and Safety Executive (HSE) template, including identifying the hazards, deciding who might be harmed and how, evaluating the risks and taking action to prevent them, recording findings, reviewing the risk assessment as required.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the operation and applications of direct current (DC) electrical machines as used in industry		**A.D1** Evaluate, using theoretical data, the conditions for optimal performance and suitable applications for three different types of DC electrical machine.
A.P1 Describe adequately, using theoretical data, the operation of two different types of DC motor and a DC generator.	**A.M1** Analyse, using theoretical data, the operation of three different types of DC electrical machine.	
Learning aim B: Investigate the operation and applications of alternating current (AC) electrical machines as used in industry		**B.D2** Evaluate, using theoretical data, the conditions for optimal performance and suitable applications for four different types of AC electrical machine.
B.P2 Describe adequately, using theoretical data, the operation of a single-phase transformer, motor and generator and a three-phase motor.	**B.M2** Analyse, using theoretical data, the operation of four different types of AC electrical machine.	
Learning aim C: Investigate how electrical machine control circuitry and systems operate safely		**C.D3** Evaluate the suitability of control circuitry and systems for DC and AC electrical machines, including how they impact safe and efficient operation.
C.P3 Describe adequately how one regulation and one guidance note relate to the safe operation of electrical machines. **C.P4** Explain the operation of speed control methods and other control circuitry for DC electrical machines. **C.P5** Explain the operation of starting circuits and other control circuitry for AC electrical machines. **C.P6** Produce an adequate risk assessment for the safe operation of a DC electrical machine and an AC electrical machine.	**C.M3** Analyse why control circuitry and systems are used for DC and AC machines, fully preparing for the safe operation of the electrical machines.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.M2, B.D2)

Learning aim: C (C.P3, C.P4, C.P5, C.P6, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- equipment/machinery to practically demonstrate some of the electrical machines covered by the unit content, although this is not essential (centres may also consider industrial visits or, alternatively, video and other presentation resources)
- a range of health and safety regulations and guidance documents, as specified in the learning aims and unit content, as well as catalogues, data sheets and relevant equipment specifications.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate how each of the DC electrical machines operates, which will include a justification of the theoretical curves and calculations, for example by using different values for input current and voltage. The evaluation will also include evidence on the conditions for optimum machine performance for each, for example to ensure that the variable loss is equal to the constant loss.

Based on the evaluation of how the DC electrical machines operate, learners should justify at least two suitable applications for each type of electrical machine.

Overall, the evidence will be logically structured and will use the correct technical engineering terms about the operation of the DC electrical machines.

For merit standard, learners will use at least three reputable sources of information, which have been correctly referenced, to confirm the validity of their descriptions of the operation of each DC electrical machine. For example, learners will use diagrams from an online source and identify the range of components on each DC electrical machine, including their purpose and their effect on overall operation.

Learners will also use theoretical calculations and standard data curves to accurately analyse the operation of each DC electrical machine, including the speed and torque characteristics for each.

For pass standard, learners will prepare evidence on the operation of the DC electrical machines. The evidence will include details about how the machines are constructed and the materials used. Reference will be made to the underpinning theory and standard curves, including the measurement of speed and torque characteristics, for each. For example, the:

- DC shunt motor operates at a relatively constant speed and reasons why will have been described
- DC series motor operates at variable speeds and reasons why will have been described
- DC generator should include a description of how Faraday's law applies.

Learners will also cover the causes and consequences of overheating and methods used for cooling.

Overall, the descriptions should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will evaluate how each of the AC electrical machines operates, which will include a justification of the theoretical curves and calculations, for example by using different values for input power, current and voltage. The evaluation will also include evidence on the conditions for optimum machine performance for each, for example to ensure that the variable loss is equal to the constant loss.

Based on the evaluation of how the AC electrical machines operate, learners should justify at least two suitable applications for each type of electrical machine.

Overall, the evidence will be logically structured and will use the correct technical engineering terms about the operation of the AC electrical machines.

For merit standard, learners will use at least four reputable sources of information, which have been correctly referenced, to confirm the validity of their descriptions of the operation of each AC electrical machine. For example, learners will use diagrams from an online source and identify the range of components on each AC electrical machine, including their purpose and their effect on overall operation.

Learners will also use theoretical calculations and standard data curves to accurately analyse the operation of each AC electrical machine, including the characteristics for each, for example efficiency for a single-phase transformer.

For pass standard, learners will prepare evidence on the operation of the AC electrical machines. The evidence will include details about how the machines are constructed and reference will be made to the underpinning theory and standard curves. For example, the:

- single-phase transformer description will cover the application of Faraday's and Lenz's laws
- single-phase motor description will cover the effect of phase shift in creating a pseudo-rotating magnetic field
- single-phase generator description will cover the link between speed of rotation and frequency of the AC signal and the effect of increasing the number of poles in the machine
- three-phase induction motor description will cover synchronous speed and slip as well as determining the torque versus speed characteristic.

Overall, the descriptions should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

Learning aim C

For distinction standard, learners will produce evidence that evaluates the relative merits of using different control circuitry and systems for at least two applications of DC electrical machines and at least two applications of AC electrical machines, by comparing and contrasting the advantages and limitations of the existing control circuitry and systems, and of using other possible control circuitry and systems. Learners will provide detailed and justified reasons as to which control circuitry and systems are the most effective and efficient by referring to the specific requirements of the application, for example by considering why a direct on line (DOL) start may be more appropriate than a star-delta start.

Learners will also produce a professional, balanced evaluation of their risk assessments, including the identification of hazards, justification of how they have determined the risk rating and how they selected the control measures. Overall, the evaluation will use correct technical engineering terms and will be written in a way that is easy for a third party, who may or may not be an engineer, to understand. Learners should evaluate possible alternative approaches, including those found in locally produced risk assessments (by the school or college), that could have been used to improve efficiency or reduce impact on the operator, while meeting relevant regulations and following guidance notes. For example, learners could suggest placing physical guarding around the entire machine, but that would increase the time it takes to operate the machine.

For merit standard, learners will produce evidence that shows they can give detailed reasons why specific control circuitry and systems have been chosen for at least two applications of DC electrical machines and at least two applications of AC electrical machines. The analysis will be consistent across all the electrical machines and will include a contextual commentary. For example, for each application it will refer to starting circuits and other control circuitry, such as overload protection, short circuit protection, interlocks and trips.

Learners will also produce an analysis of their risk assessments against the local control measures (produced by the school or college) already in place to eliminate and reduce the hazards. The analysis will discuss the practicalities of implementing control measures, including the principle contained in the regulation and guidance documents of being ‘reasonably practicable’, but not necessarily covering any additional measures highlighted in the risk assessments.

For pass standard, learners will provide evidence describing, for example, that as part of the Electrical Equipment (Safety) Regulations 1994 and amendments, all equipment should be checked for the CE or BS Kitemark stamp and to check that it is not damaged, before undertaking any work. Learners’ evidence may contain some errors in the engineering terminology used, for example stating that current runs ‘across a device’ rather than ‘through’ it, and the descriptions may be basic in parts. There must be a clear demonstration of knowledge and understanding of the relevant safety documents and their use in the specific sector being studied, for example the aerospace or manufacturing pathway.

For DC machines, learners will also explain the operation of at least two speed control methods and how starting circuitry operates in a DC motor to avoid a large spike in current on start-up created by the absence of back electromotive force. The evidence will also include an explanation of other control circuitry, such as overload protection and interlocks, and how these devices are connected to the control circuitry.

For AC machines, learners will explain the operation of at least three types of single-phase AC motor starting circuits, such as capacitor start, capacitor start and run, shaded pole or split phase, and the operation of at least two three-phase starter circuits, such as direct on line (DOL), star-delta or rotor resistance. The evidence will also include an explanation of other control circuitry, such as short circuit protection and trips, and how these devices are connected to the control circuitry.

Learners will identify all significant hazards and calculate the associated risks for operating a DC electrical machine and an AC electrical machine. For example, when operating an electrical machine, a low likelihood of shock multiplied by a high severity of injury would result in a medium risk. Risks must be documented on an agreed risk assessment pro forma. The risk assessments may not identify all the associated hazards, for example each risk assessment will cover the direct risks, such as electrical shock and entrapment in rotating parts, but it might not include manual handling of the machines.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 16: Three Phase Electrical Systems
- Unit 17: Power and Energy Electronics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise of electrical machines
- contribution of ideas to unit assignment/project materials.

Unit 60: Autonomous Mobile Robotics

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate autonomous mobile robots (AMRs) and develop an autonomous mobile robot solution to complete an activity.

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.

Ideally, *Unit 6: Microcontroller Systems for Engineers* or *Unit 35: Computer Programming* should be well under way or completed before starting this unit, and possibly *Unit 7: Calculus to Solve Engineering Problems* and *Unit 56: Industrial Robotics*.

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 aims

In this unit you will:

A Investigate the use of different types of autonomous mobile robot

B Investigate the software and hardware used in autonomous mobile robots

C Develop an autonomous mobile robot to complete an activity defined in a client brief.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the use of different types of autonomous mobile robot	**A1** Types and use of autonomous mobile robots **A2** Benefits and limitations of operating autonomous mobile robots	A written report with annotated diagrams/photographs.
B Investigate the software and hardware used in autonomous mobile robots	**B1** Hardware devices and their features used in autonomous mobile robots **B2** Software and hardware integration used in autonomous mobile robots	A written report with annotated diagrams/photographs.
C Develop an autonomous mobile robot to complete an activity defined in a client brief	**C1** Design specification and program design for an autonomous mobile robot **C2** Build an autonomous mobile robot **C3** Development and testing of a control program	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.

Content

Learning aim A: Investigate the use of different types of autonomous mobile robot

A1 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.

A2 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.

Learning aim B: Investigate the software and hardware used in autonomous mobile robots

B1 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 I^2C) 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.

B2 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.

Learning aim C: Develop an autonomous mobile robot to complete an activity defined in a client brief

C1 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).

C2 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.

C3 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 criteria

Pass	Merit	Distinction
Learning aim A: Investigate the use of different types of autonomous mobile robot		**A.D1** Evaluate in detail how different types of autonomous mobile robot are used, including relevant benefits and limitations.
A.P1 Describe adequately how different types of autonomous mobile robot are used. **A.P2** Describe adequately the benefits and limitations of using different types of autonomous mobile robot.	**A.M1** Explain adequately how different types of autonomous mobile robot are used, including the benefits and limitations.	
Learning aim B: Investigate the software and hardware used in autonomous mobile robots		**B.D2** Evaluate how software and hardware operate in an autonomous mobile robot for a given purpose, suggesting improvements.
B.P3 Describe adequately how software and hardware operate in an autonomous mobile robot for a given purpose.	**B.M2** Explain adequately how software and hardware operate in an autonomous mobile robot for a given purpose.	
Learning aim C: Develop an autonomous mobile robot to complete an activity defined in a client brief		**C.D3** Optimise the performance of an autonomous mobile robot to successfully complete an activity that functions safely and as intended.
C.P4 Produce an adequate specification and high-level program design for an autonomous mobile robot to complete an activity. **C.P5** Build and program adequately and safely a partially functioning autonomous mobile robot to attempt an activity, using a microcontroller or microprocessor. **C.P6** Test adequately and safely a partially functioning autonomous mobile robot to attempt an activity, recording the outcomes of the tests.	**C.M3** Develop an autonomous mobile robot to successfully complete an activity that functions safely and as intended.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.M2, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M3, C.D3)

Further information for teachers and assessors

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.

Essential information for assessment decisions

Learning aim A

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.

Learning aim B

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.

Learning aim C

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.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 7: Calculus to Solve Engineering Problems
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 19: Electronic Devices and Circuits
- Unit 32: Computer System Principles and Practice
- Unit 35: Computer Programming
- Unit 56: Industrial Robotics.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

4 Planning your programme

How do I choose the right BTEC National qualification for my learners?

BTEC Nationals come in a range of sizes, each with a specific purpose. You will need to assess learners very carefully to ensure that they start on the right size of qualification to fit into their 16–19 study programme, and that they take the right pathways or optional units that allow them to progress to the next stage.

If a learner is clear that they want to progress to the workplace they should be directed towards an occupationally-specific qualification, such as a BTEC National Diploma, from the outset.

Some learners may want to take a number of complementary qualifications or keep their progression options open. These learners may be suited to taking a BTEC National Certificate or Extended Certificate. Learners who then decide to continue with a fuller vocational programme can transfer to a BTEC National Diploma or Extended Diploma, for example for their second year.

Some learners are sure of the sector they want to work in and are aiming for progression into that sector via higher education. These learners should be directed to the two-year BTEC National Extended Diploma as the most suitable qualification.

As a centre, you may want to teach learners who are taking different qualifications together. You may also wish to transfer learners between programmes to meet changes in their progression needs. You should check the qualification structures and unit combinations carefully as there is no exact match among the different sizes. You may find that learners need to complete more than the minimum number of units when transferring.

When learners are recruited, you need to give them accurate information on the title and focus of the qualification for which they are studying.

Is there a learner entry requirement?

As a centre it is your responsibility to ensure that learners who are recruited have a reasonable expectation of success on the programme. There are no formal entry requirements but we expect learners to have qualifications at or equivalent to Level 2.

Learners are most likely to succeed if they have:

- five GCSEs at good grades and/or
- BTEC qualification(s) at Level 2
- achievement in English and mathematics through GCSE or Functional Skills.

Learners may demonstrate ability to succeed in various ways. For example, learners may have relevant work experience or specific aptitude shown through diagnostic tests or non-educational experience.

What is involved in becoming an approved centre?

All centres must be approved before they can offer these qualifications – so that they are ready to assess learners and so that we can provide the support that is needed. Further information is given in *Section 8*.

What level of sector knowledge is needed to teach these qualifications?

We do not set any requirements for teachers but expect that centres will assess the overall skills and knowledge of the teaching team to ensure that they are relevant and up to date. This will give learners a rich programme to prepare them for employment in the sector. As part of the requirements of the programme are to involve employers in delivery this should support centres in ensuring that they are following up to date practices when delivering the programme.

What resources are required to deliver these qualifications?

As part of your centre approval you will need to show that the necessary material resources and work spaces are available to deliver BTEC Nationals. For some units, specific resources are required. This is indicated in the units.

Which modes of delivery can be used for these qualifications?

You are free to deliver BTEC Nationals using any form of delivery that meets the needs of your learners. We recommend making use of a wide variety of modes, including direct instruction in classrooms or work environments, investigative and practical work, group and peer work, private study and e-learning.

What are the requirements for meaningful employer involvement?

Requirements

This BTEC National Extended Diplomas in Engineering are intended as Tech Level qualifications. As an approved centre you are required to ensure that during their study, every learner has access to meaningful activity involving employers. Involvement should be with employers from the engineering sector and should form a significant part of the delivery or assessment of the qualification. Each centre's approach to employer involvement will be monitored in two ways. It will be monitored at centre level in the first term each year as part of the annual quality management review process that addresses centre strategy for delivery, assessment and quality assurance, when we will ask you to show evidence of how employer involvement is provided for all learners. You will need to show evidence in order to gain reporting clearance for certification. It will be monitored also at programme level as part of the standards verification process to confirm that plans for employer involvement meet the requirements of the specification. These approaches are designed to ensure additional activities can be scheduled where necessary so learners are not disadvantaged (see *Section 8: Quality assurance*).

We know that the vast majority of programmes already have established links with employers. In order to give you maximum flexibility in creating and strengthening employer involvement, we have not specified a particular level of input from employers. However, meaningful employer involvement, as defined below, should contribute significantly to at least **three** units of which one must be a mandatory unit.

Unit 5: A Specialist Engineering Project has a strong link to employer delivery and/or assessment and the following optional units also provide opportunities to link delivery and/or assessment to employers:

- Unit 9: Work Experience in the Engineering Sector
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 24: Maintenance of Mechanical Systems
- Unit 35: Computer Programming
- Unit 36: Programmable Logic Controllers
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 45: Additive Manufacturing Processes
- Unit 49: Aircraft Workshop Methods and Practice
- Unit 55: Aircraft First Line Maintenance Operations.

There are suggestions in many of the units about how employers could become involved in delivery and/or assessment but these are not intended to be exhaustive and there will be other possibilities at local level.

Employer involvement is subject to verification as part of the standards verification process (see *Section 8*).

Definition

Activities that are eligible to be counted as meaningful engagement are:

- structured work experience or work placements that develop skills and knowledge relevant to the qualification
- projects or assessments set with input from industry practitioners
- master classes or guest lectures from industry practitioners
- 'expert witness' reports from practitioners that contribute to the assessment of a learner's work.

There may be other ways in which learners can benefit from contact with employers or prepare for employment, such as listening to careers talks or working in simulated environments. While they provide benefits to learners they do not count as meaningful engagement.

Support

It is important that you give learners opportunities that are high quality and directly relevant to their study. We will support you in this through guidance materials and by giving you examples of best practice.

What support is available?

We provide a wealth of support materials, including curriculum plans, delivery guides, authorised assignment briefs, additional papers for external assessments and examples of marked learner work.

You will be allocated a Standards Verifier early on in the planning stage to support you with planning your assessments. There will be extensive training programmes as well as support from our Subject Advisor team.

For further details see *Section 10*.

How will my learners become more employable through these qualifications?

All BTEC Nationals are mapped to relevant occupational standards (see *Appendix 1*).

In the mandatory content and the selected optional units that focus on technical preparation learners will be acquiring the key knowledge and skills that employers need. Also, employability skills, such as team working and entrepreneurialism, and completing realistic tasks have been built into the design of the learning aims and content. This gives you the opportunity to use relevant contexts, scenarios and materials to enable learners to develop a portfolio of evidence that demonstrates the breadth of their skills and knowledge in a way that equips them for employment.

5 Assessment structure and external assessment

Introduction

BTEC Nationals are assessed using a combination of *internal assessments*, which are set and marked by teachers, and *external assessments* which are set and marked by Pearson:

- mandatory units have a combination of internal and external assessments
- all optional units are internally assessed.

We have taken great care to ensure that the assessment method chosen is appropriate to the content of the unit and in line with requirements from employers and higher education.

In developing an overall plan for delivery and assessment for the programme, you will need to consider the order in which you deliver units, whether delivery is over short or long periods and when assessment can take place. Some units are defined as synoptic units (see *Section 2*). Normally, a synoptic assessment is one that a learner would take later in a programme and in which they will be expected to apply learning from a range of units. Synoptic units may be internally or externally assessed. Where a unit is externally assessed you should refer to the sample assessment materials (SAMs) to identify where there is an expectation that learners draw on their wider learning. For internally-assessed units, you must plan the assignments so that learners can demonstrate learning from across their programme. A unit may be synoptic in one qualification and not another because of the relationship it has to the rest of the qualification.

We have addressed the need to ensure that the time allocated to final assessment of internal and external units is reasonable so that there is sufficient time for teaching and learning, formative assessment and development of transferable skills.

In administering internal and external assessment, the centre needs to be aware of the specific procedures and policies that apply, for example to registration, entries and results. An overview with signposting to relevant documents is given in *Section 7*.

Internal assessment

Our approach to internal assessment for these qualifications will be broadly familiar to experienced centres. It offers flexibility in how and when you assess learners, provided that you meet assessment and quality assurance requirements. You will need to take account of the requirements of the unit format, which we explain in *Section 3*, and the requirements for delivering assessment given in *Section 6*.

External assessment

A summary of the external assessment for this qualification is given in *Section 2*. You should check this information carefully, together with the unit specification and the sample assessment materials, so that you can timetable learning and assessment periods appropriately.

Learners must be prepared for external assessment by the time they undertake it. In preparing learners for assessment you will want to take account of required learning time, the relationship with other external assessments and opportunities for retaking. You should ensure that learners are not entered for unreasonable amounts of external assessment in one session. Learners may resit an external assessment to obtain a higher grade of near pass or above. If a learner has more than one attempt, then the best result will be used for qualification grading, up to the permitted maximum. It is unlikely that learners will need to or benefit from taking all assessments twice so you are advised to plan appropriately. Some assessments are synoptic and learners are likely to perform best if these assessments are taken towards the end of the programme.

Key features of external assessment in engineering

In engineering, after consultation with stakeholders, we have developed the following.

- *Unit 1: Engineering Principles*, learners are expected to solve a range of mechanical and electrical/electronic problems as multi-skilled engineers do in practice. The knowledge and understanding contained in the unit can be reliably and validly assessed through an external exam. The range of content covered and the rigor of this assessment approach is approved by industry and higher education.
- *Unit 3: Engineering Product Design and Manufacture*, the assessment task simulates the work environment where design activities involve research, working to a client brief and improving the design of a product. This is completed in a set time period to reflect industry practice.
- *Unit 6: Microcontroller Systems for Engineering*, it is important for all types of engineer to understand how physical digital electronics systems are developed and work, as the trend in technology is for more complex, connected systems that will interact seamlessly together, providing enhanced features and customer benefits. The assessment task simulates the work environment where electronic systems are designed and developed in a set period of time to meet a client brief.

Units

The externally-assessed units have a specific format which we explain in *Section 3*. The content of units will be sampled across external assessments over time through appropriate papers and tasks. The ways in which learners are assessed are shown through the assessment outcomes and grading descriptors. External assessments are marked and awarded using the grade descriptors. The grades available are Distinction (D), Merit (M), Pass (P) and Near Pass (N). The Near Pass (N) grade gives learners credit below a Pass, where they have demonstrated evidence of positive performance which is worth more than an unclassified result but not yet at the Pass standard.

Sample assessment materials

Each externally-assessed unit has a set of sample assessment materials (SAMs) that accompanies this specification. The SAMs are there to give you an example of what the external assessment will look like in terms of the feel and level of demand of the assessment. In the case of units containing synoptic assessment, the SAMs will also show where learners are expected to select and apply from across the programme.

The SAMs show the range of possible question types that may appear in the actual assessments and give you a good indication of how the assessments will be structured. While SAMs can be used for practice with learners, as with any assessment the content covered and specific details of the questions asked will change in each assessment.

A copy of each of these assessments can be downloaded from our website. An additional sample of each of the Pearson-set units will be available before the first sitting of the assessment to allow your learners further opportunities for practice.

6 Internal assessment

This section gives an overview of the key features of internal assessment and how you, as an approved centre, can offer it effectively. The full requirements and operational information are given in the *Pearson Quality Assurance Handbook*. All members of the assessment team need to refer to this document.

For BTEC Nationals it is important that you can meet the expectations of stakeholders and the needs of learners by providing a programme that is practical and applied. Centres can tailor programmes to meet local needs and use links with local employers and the wider vocational sector.

When internal assessment is operated effectively it is challenging, engaging, practical and up to date. It must also be fair to all learners and meet national standards.

Principles of internal assessment

Assessment through assignments

For internally-assessed units, the format of assessment is an assignment taken after the content of the unit, or part of the unit if several assignments are used, has been delivered. An assignment may take a variety of forms, including practical and written types. An assignment is a distinct activity completed independently by learners that is separate from teaching, practice, exploration and other activities that learners complete with direction from, and formative assessment by, teachers.

An assignment is issued to learners as an assignment brief with a defined start date, a completion date and clear requirements for the evidence that they need to provide. There may be specific observed practical components during the assignment period. Assignments can be divided into tasks and may require several forms of evidence. A valid assignment will enable a clear and formal assessment outcome based on the assessment criteria.

Assessment decisions through applying unit-based criteria

Assessment decisions for BTEC Nationals are based on the specific criteria given in each unit and set at each grade level. To ensure that standards are consistent in the qualification and across the suite as a whole, the criteria for each unit have been defined according to a framework. The way in which individual units are written provides a balance of assessment of understanding, practical skills and vocational attributes appropriate to the purpose of qualifications.

The assessment criteria for a unit are hierarchical and holistic. For example, if an M criterion requires the learner to show 'analysis' and the related P criterion requires the learner to 'explain', then to satisfy the M criterion a learner will need to cover both 'explain' and 'analyse'. The unit assessment grid shows the relationships among the criteria so that assessors can apply all the criteria to the learner's evidence at the same time. In *Appendix 2* we have set out a definition of terms that assessors need to understand.

Assessors must show how they have reached their decisions using the criteria in the assessment records. When a learner has completed all the assessment for a unit then the assessment team will give a grade for the unit. This is given simply according to the highest level for which the learner is judged to have met all the criteria. Therefore:

- to achieve a Distinction, a learner must have satisfied all the Distinction criteria (and therefore the Pass and Merit criteria); these define outstanding performance across the unit as a whole
- to achieve a Merit, a learner must have satisfied all the Merit criteria (and therefore the Pass criteria) through high performance in each learning aim
- to achieve a Pass, a learner must have satisfied all the Pass criteria for the learning aims, showing coverage of the unit content and therefore attainment at Level 3 of the national framework.

The award of a Pass is a defined level of performance and cannot be given solely on the basis of a learner completing assignments. Learners who do not satisfy the Pass criteria should be reported as Unclassified.

The assessment team

It is important that there is an effective team for internal assessment. There are three key roles involved in implementing assessment processes in your centre, each with different interrelated responsibilities, the roles are listed below. Full information is given in the *Pearson Quality Assurance Handbook*.

- The Lead Internal Verifier (the Lead IV) has overall responsibility for the programme, its assessment and internal verification to meet our requirements, record keeping and liaison with the Standards Verifier. The Lead IV registers with Pearson annually. The Lead IV acts as an assessor, supports the rest of the assessment team, makes sure that they have the information they need about our assessment requirements and organises training, making use of our guidance and support materials.
- Internal Verifiers (IVs) oversee all assessment activity in consultation with the Lead IV. They check that assignments and assessment decisions are valid and that they meet our requirements. IVs will be standardised by working with the Lead IV. Normally, IVs are also assessors but they do not verify their own assessments.
- Assessors set or use assignments to assess learners to national standards. Before taking any assessment decisions, assessors participate in standardisation activities led by the Lead IV. They work with the Lead IV and IVs to ensure that the assessment is planned and carried out in line with our requirements.

Effective organisation

Internal assessment needs to be well organised so that the progress of learners can be tracked and so that we can monitor that assessment is being carried out in line with national standards. We support you through, for example, providing training materials and sample documentation.

It is particularly important that you manage the overall assignment programme and deadlines to make sure that learners are able to complete assignments on time.

Learner preparation

To ensure that you provide effective assessment for your learners, you need to make sure that they understand their responsibilities for assessment and the centre's arrangements.

From induction onwards, you will want to ensure that learners are motivated to work consistently and independently to achieve the requirements of the qualifications. Learners need to understand how assignments are used, the importance of meeting assignment deadlines, and that all the work submitted for assessment must be their own.

You will need to give learners a guide that explains how assignments are used for assessment, how assignments relate to the teaching programme, and how learners should use and reference source materials, including what would constitute plagiarism. The guide should also set out your approach to operating assessment, such as how learners must submit work and request extensions.

Setting effective assignments

Setting the number and structure of assignments

In setting your assignments, you need to work with the structure of assignments shown in the *Essential information for assignments* section of a unit. This shows the structure of the learning aims and criteria that you must follow and the recommended number of assignments that you should use. For some units we provide authorised assignment briefs, for all the units we give you suggestions on how to create suitable assignments. You can find these materials along with this specification on our website. In designing your own assignment briefs you should bear in mind the following points.

- The number of assignments for a unit must not exceed the number shown in *Essential information for assignments*. However, you may choose to combine assignments, for example to create a single assignment for the whole unit.
- You may also choose to combine all or parts of different units into single assignments, provided that all units and all their associated learning aims are fully addressed in the programme overall. If you choose to take this approach, you need to make sure that learners are fully prepared so that they can provide all the required evidence for assessment and that you are able to track achievement in the records.
- A learning aim must always be assessed as a whole and must not be split into two or more tasks.
- The assignment must be targeted to the learning aims but the learning aims and their associated criteria are not tasks in themselves. Criteria are expressed in terms of the outcome shown in the evidence.
- You do not have to follow the order of the learning aims of a unit in setting assignments but later learning aims often require learners to apply the content of earlier learning aims and they may require learners to draw their learning together.
- Assignments must be structured to allow learners to demonstrate the full range of achievement at all grade levels. Learners need to be treated fairly by being given the opportunity to achieve a higher grade if they have the ability.
- As assignments provide a final assessment, they will draw on the specified range of teaching content for the learning aims. The specified content is compulsory. The evidence for assessment need not cover every aspect of the teaching content as learners will normally be given particular examples, case studies or contexts in their assignments. For example, if a learner is carrying out one practical performance, or an investigation of one organisation, then they will address all the relevant range of content that applies in that instance.

Providing an assignment brief

A good assignment brief is one that, through providing challenging and realistic tasks, motivates learners to provide appropriate evidence of what they have learned.

An assignment brief should have:

- a vocational scenario, this could be a simple situation or a full, detailed set of vocational requirements that motivates the learner to apply their learning through the assignment
- clear instructions to the learner about what they are required to do, normally set out through a series of tasks
- an audience or purpose for which the evidence is being provided
- an explanation of how the assignment relates to the unit(s) being assessed.

Forms of evidence

BTEC Nationals have always allowed for a variety of forms of evidence to be used, provided that they are suited to the type of learning aim being assessed. For many units, the practical demonstration of skills is necessary and for others, learners will need to carry out their own research and analysis. The units give you information on what would be suitable forms of evidence to provide learners with the opportunity to apply a range of employability or transferable skills. Centres may choose to use different suitable forms for evidence to those proposed. Overall, learners should be assessed using varied forms of evidence.

Full definitions of types of assessment are given in *Appendix 2*. These are some of the main types of assessment:

- written reports
- projects
- time-constrained practical assessments with observation records and supporting evidence
- recordings of performance
- sketchbooks, working logbooks, reflective journals
- presentations with assessor questioning.

The form(s) of evidence selected must:

- allow the learner to provide all the evidence required for the learning aim(s) and the associated assessment criteria at all grade levels
- allow the learner to produce evidence that is their own independent work
- allow a verifier to independently reassess the learner to check the assessor's decisions.

For example, when you are using performance evidence, you need to think about how supporting evidence can be captured through recordings, photographs or task sheets.

Centres need to take particular care that learners are enabled to produce independent work. For example, if learners are asked to use real examples, then best practice would be to encourage them to use their own or to give the group a number of examples that can be used in varied combinations.

Making valid assessment decisions

Authenticity of learner work

Once an assessment has begun, learners must not be given feedback on progress towards fulfilling the targeted criteria.

An assessor must assess only learner work that is authentic, i.e. learners' own independent work. Learners must authenticate the evidence that they provide for assessment through signing a declaration stating that it is their own work.

Assessors must ensure that evidence is authentic to a learner through setting valid assignments and supervising them during the assessment period. Assessors must take care not to provide direct input, instructions or specific feedback that may compromise authenticity.

Assessors must complete a declaration that:

- the evidence submitted for this assignment is the learner's own
- the learner has clearly referenced any sources used in the work
- they understand that false declaration is a form of malpractice.

Centres can use Pearson templates or their own templates to document authentication.

During assessment, an assessor may suspect that some or all of the evidence from a learner is not authentic. The assessor must then take appropriate action using the centre's policies for malpractice. Further information is given in *Section 7*.

Making assessment decisions using criteria

Assessors make judgements using the criteria. The evidence from a learner can be judged using all the relevant criteria at the same time. The assessor needs to make a judgement against each criterion that evidence is present and sufficiently comprehensive. For example, the inclusion of a concluding section may be insufficient to satisfy a criterion requiring 'evaluation'.

Assessors should use the following information and support in reaching assessment decisions:

- the *Essential information for assessment decisions* section in each unit gives examples and definitions related to terms used in the criteria
- the explanation of key terms in *Appendix 2*
- examples of assessed work provided by Pearson
- your Lead IV and assessment team's collective experience, supported by the standardisation materials we provide.

Pass and Merit criteria relate to individual learning aims. The Distinction criteria as a whole relate to outstanding performance across the unit. Therefore, criteria may relate to more than one learning aim (for example A.D1) or to several learning aims (for example DE.D3). Distinction criteria make sure that learners have shown that they can perform consistently at an outstanding level across the unit and/or that they are able to draw learning together across learning aims.

Dealing with late completion of assignments

Learners must have a clear understanding of the centre policy on completing assignments by the deadlines that you give them. Learners may be given authorised extensions for legitimate reasons, such as illness at the time of submission, in line with your centre policies.

For assessment to be fair, it is important that learners are all assessed in the same way and that some learners are not advantaged by having additional time or the opportunity to learn from others. Therefore, learners who do not complete assignments by your planned deadline or the authorised extension deadline may not have the opportunity to subsequently resubmit.

If you accept a late completion by a learner, then the assignment should be assessed normally when it is submitted using the relevant assessment criteria.

Issuing assessment decisions and feedback

Once the assessment team has completed the assessment process for an assignment, the outcome is a formal assessment decision. This is recorded formally and reported to learners.

The information given to the learner:

- must show the formal decision and how it has been reached, indicating how or where criteria have been met
- may show why attainment against criteria has not been demonstrated
- must not provide feedback on how to improve evidence
- must be validated by an IV before it is given to the learner.

Resubmission of improved evidence

An assignment provides the final assessment for the relevant learning aims and is normally a final assessment decision, except where the Lead IV approves one opportunity to resubmit improved evidence based on the completed assignment brief.

The Lead IV has the responsibility to make sure that resubmission is operated fairly. This means:

- checking that a learner can be reasonably expected to perform better through a second submission, for example that the learner has not performed as expected
- making sure that giving a further opportunity can be done in such a way that it does not give an unfair advantage over other learners, for example through the opportunity to take account of feedback given to other learners
- checking that the assessor considers that the learner will be able to provide improved evidence without further guidance and that the original evidence submitted remains valid.

Once an assessment decision has been given to the learner, the resubmission opportunity must have a deadline within 15 working days in the same academic year.

A resubmission opportunity must not be provided where learners:

- have not completed the assignment by the deadline without the centre's agreement
- have submitted work that is not authentic.

Retake of internal assessment

A learner who has not achieved the level of performance required to pass the relevant learning aims after resubmission of an assignment may be offered a single retake opportunity using a new assignment. The retake may only be achieved at a pass.

The Lead Internal Verifier must only authorise a retake of an assignment in exceptional circumstances where they believe it is necessary, appropriate and fair to do so. For further information on offering a retake opportunity, you should refer to the *BTEC Centre Guide to Assessment*. We provide information on writing assignments for retakes on our website (www.btec.co.uk/keydocuments).

Planning and record keeping

For internal processes to be effective, an assessment team needs to be well organised and keep effective records. The centre will also work closely with us so that we can quality assure that national standards are being satisfied. This process gives stakeholders confidence in the assessment approach.

The Lead IV must have an assessment plan, produced as a spreadsheet. When producing a plan, the assessment team may wish to consider:

- the time required for training and standardisation of the assessment team
- the time available to undertake teaching and carry out assessment, taking account of when learners may complete external assessments and when quality assurance will take place
- the completion dates for different assignments
- who is acting as IV for each assignment and the date by which the assignment needs to be verified
- setting an approach to sampling assessor decisions though internal verification that covers all assignments, assessors and a range of learners
- how to manage the assessment and verification of learners' work so that they can be given formal decisions promptly
- how resubmission opportunities can be scheduled.

The Lead IV will also maintain records of assessment undertaken. The key records are:

- verification of assignment briefs
- learner authentication declarations
- assessor decisions on assignments, with feedback given to learners
- verification of assessment decisions.

Examples of records and further information are given in the *Pearson Quality Assurance Handbook.*

7 Administrative arrangements

Introduction

This section focuses on the administrative requirements for delivering a BTEC qualification. It will be of value to Quality Nominees, Lead IVs, Programme Leaders and Examinations Officers.

Learner registration and entry

Shortly after learners start the programme of learning, you need to make sure that they are registered for the qualification and that appropriate arrangements are made for internal and external assessment. You need to refer to the *Information Manual* for information on making registrations for the qualification and entries for external assessments.

Learners can be formally assessed only for a qualification on which they are registered. If learners' intended qualifications change, for example if a learner decides to choose a different pathway specialism, then the centre must transfer the learner appropriately.

Access to assessment

Both internal and external assessments need to be administered carefully to ensure that all learners are treated fairly, and that results and certification are issued on time to allow learners to progress to chosen progression opportunities.

Our equality policy requires that all learners should have equal opportunity to access our qualifications and assessments, and that our qualifications are awarded in a way that is fair to every learner. We are committed to making sure that:

- learners with a protected characteristic are not, when they are undertaking one of our qualifications, disadvantaged in comparison to learners who do not share that characteristic
- all learners achieve the recognition they deserve for undertaking a qualification and that this achievement can be compared fairly to the achievement of their peers.

Further information on access arrangements can be found in the Joint Council for Qualifications (JCQ) document *Access Arrangements, Reasonable Adjustments and Special Consideration for General and Vocational Qualifications*.

Administrative arrangements for internal assessment

Records

You are required to retain records of assessment for each learner. Records should include assessments taken, decisions reached and any adjustments or appeals. Further information can be found in the *Information Manual.* We may ask to audit your records so they must be retained as specified.

Reasonable adjustments to assessment

A reasonable adjustment is one that is made before a learner takes an assessment to ensure that they have fair access to demonstrate the requirements of the assessments. You are able to make adjustments to internal assessments to take account of the needs of individual learners. In most cases this can be achieved through a defined time extension or by adjusting the format of evidence. We can advise you if you are uncertain as to whether an adjustment is fair and reasonable. You need to plan for time to make adjustments if necessary.

Further details on how to make adjustments for learners with protected characteristics are given on our website in the document *Supplementary guidance for reasonable adjustment and special consideration in vocational internally-assessed units.*

Special consideration

Special consideration is given after an assessment has taken place for learners who have been affected by adverse circumstances, such as illness. You must operate special consideration in line with our policy (see previous paragraph). You can provide special consideration related to the period of time given for evidence to be provided or for the format of the assessment if it is equally valid. You may not substitute alternative forms of evidence to that required in a unit, or omit the application of any assessment criteria to judge attainment. Pearson can consider applications for special consideration in line with the policy.

Appeals against assessment

Your centre must have a policy for dealing with appeals from learners. These appeals may relate to assessment decisions being incorrect or assessment not being conducted fairly. The first step in such a policy could be a consideration of the evidence by a Lead IV or other member of the programme team. The assessment plan should allow time for potential appeals after assessment decisions have been given to learners. If there is an appeal by a learner, you must document the appeal and its resolution. Learners have a final right of appeal to Pearson but only if the procedures that you have put in place have not been followed. Further details are given in the document *Enquiries and appeals about Pearson vocational qualifications and end point assessment policy*.

Administrative arrangements for external assessment

Entries and resits

For information on the timing of assessment and entries, please refer to the annual examinations timetable on our website.

Access arrangements requests

Access arrangements are agreed with Pearson before an assessment. They allow students with special educational needs, disabilities or temporary injuries to:

- access the assessment
- show what they know and can do without changing the demands of the assessment.

Access arrangements should always be processed at the time of registration. Learners will then know what type of arrangements are available in place for them.

Granting reasonable adjustments

For external assessment, a reasonable adjustment is one that we agree to make for an individual learner. A reasonable adjustment is defined for the individual learner and informed by the list of available access arrangements.

Whether an adjustment will be considered reasonable will depend on a number of factors, to include:

- the needs of the learner with the disability
- the effectiveness of the adjustment
- the cost of the adjustment; and
- the likely impact of the adjustment on the learner with the disability and other learners.

Adjustment may be judged unreasonable and not approved if it involves unreasonable costs, timeframes or affects the integrity of the assessment.

Special consideration requests

Special consideration is an adjustment made to a student's mark or grade after an external assessment to reflect temporary injury, illness or other indisposition at the time of the assessment. An adjustment is made only if the impact on the learner is such that it is reasonably likely to have had a material effect on that learner being able to demonstrate attainment in the assessment.

Centres are required to notify us promptly of any learners who they believe have been adversely affected and request that we give special consideration. Further information can be found in the special requirements section on our website.

Conducting external assessments

Centres must make arrangements for the secure delivery of external assessments. External assessments for BTEC qualifications include examinations, set tasks and performance.

Each external assessment has a defined degree of control under which it must take place. Some external assessments may have more than one part and each part may have a different degree of control. We define degrees of control as follows.

High control

This is the completion of assessment in formal invigilated examination conditions.

Medium control

This is completion of assessment, usually over a longer period of time, which may include a period of controlled conditions. The controlled conditions may allow learners to access resources, prepared notes or the internet to help them complete the task.

Low control

These are activities completed without direct supervision. They may include research, preparation of materials and practice. The materials produced by learners under low control will not be directly assessed.

Further information on responsibilities for conducting external assessment is given in the document *Instructions for Conducting External Assessments*, available on our website.

Dealing with malpractice in assessment

Malpractice means acts that undermine the integrity and validity of assessment, the certification of qualifications, and/or that may damage the authority of those responsible for delivering the assessment and certification.

Pearson does not tolerate actions (or attempted actions) of malpractice by learners, centre staff or centres in connection with Pearson qualifications. Pearson may impose penalties and/or sanctions on learners, centre staff or centres where incidents (or attempted incidents) of malpractice have been proven.

Malpractice may arise or be suspected in relation to any unit or type of assessment within the qualification. For further details regarding malpractice and advice on preventing malpractice by learners, please see Pearson's *Centre guidance: Dealing with malpractice and maladministration in vocational qualifications*, available on our website.

The procedures we ask you to adopt vary between units that are internally-assessed and those that are externally assessed.

Internally-assessed units

Centres are required to take steps to prevent malpractice and to investigate instances of suspected malpractice. Learners must be given information that explains what malpractice is for internal assessment and how suspected incidents will be dealt with by the centre. The *Centre Guidance: Dealing with Malpractice* document gives full information on the actions we expect you to take.

Pearson may conduct investigations if we believe that a centre is failing to conduct internal assessment according to our policies. The above document gives further information, examples and details the penalties and sanctions that may be imposed.

In the interests of learners and centre staff, centres need to respond effectively and openly to all requests relating to an investigation into an incident of suspected malpractice.

Externally-assessed units

External assessment means all aspects of units that are designated as external in this specification, including preparation for tasks and performance. For these assessments centres must follow the JCQ procedures set out in the latest version of *JCQ Suspected Malpractice in Examinations and Assessments Policies and Procedures* (www.jcq.org.uk).

In the interests of learners and centre staff, centres need to respond effectively and openly to all requests relating to an investigation into an incident of suspected malpractice.

Learner malpractice

Heads of Centres are required to report incidents of any suspected learner malpractice that occur during Pearson external assessments. We ask that centres do so by completing a *JCQ Form M1* (available at www.jcq.org.uk/exams-office/malpractice) and emailing it and any accompanying documents (signed statements from the learner, invigilator, copies of evidence, etc.) to the Investigations Team at candidatemalpractice@pearson.com. The responsibility for determining appropriate sanctions or penalties to be imposed on learners lies with Pearson.

Learners must be informed at the earliest opportunity of the specific allegation and the centre's malpractice policy, including the right of appeal. Learners found guilty of malpractice may be disqualified from the qualification for which they have been entered with Pearson.

Teacher/centre malpractice

Heads of Centres are required to inform Pearson's Investigations Team of any incident of suspected malpractice by centre staff, before any investigation is undertaken. Heads of centres are requested to inform the Investigations Team by submitting a *JCQ Form M2(a)* (available at www.jcq.org.uk/exams-office/malpractice) with supporting documentation to pqsmalpractice@pearson.com. Where Pearson receives allegations of malpractice from other sources (for example Pearson staff or anonymous informants), the Investigations Team will conduct the investigation directly or may ask the head of centre to assist.

Incidents of maladministration (accidental errors in the delivery of Pearson qualifications that may affect the assessment of learners) should also be reported to the Investigations Team using the same method.

Heads of Centres/Principals/Chief Executive Officers or their nominees are required to inform learners and centre staff suspected of malpractice of their responsibilities and rights; see Section 6.15 of the *JCQ Suspected Malpractice in Examinations and Assessments Policies and Procedures* document.

Pearson reserves the right in cases of suspected malpractice to withhold the issuing of results and/or certificates while an investigation is in progress. Depending on the outcome of the investigation results and/or certificates may be released or withheld.

You should be aware that Pearson may need to suspend certification when undertaking investigations, audits and quality assurances processes. You will be notified within a reasonable period of time if this occurs.

Sanctions and appeals

Where malpractice is proven we may impose sanctions or penalties.

Where learner malpractice is evidenced, penalties may be imposed such as:

- mark reduction for external assessments
- disqualification from the qualification
- being barred from registration for Pearson qualifications for a period of time.

If we are concerned about your centre's quality procedures we may impose sanctions such as:

- working with you to create an improvement action plan
- requiring staff members to receive further training
- placing temporary blocks on your certificates
- placing temporary blocks on registration of learners
- debarring staff members or the centre from delivering Pearson qualifications
- suspending or withdrawing centre approval status.

The centre will be notified if any of these apply.

Pearson has established procedures for centres that are considering appeals against penalties and sanctions arising from malpractice. Appeals against a decision made by Pearson will normally be accepted only from Heads of Centres (on behalf of learners and/or members of staff) and from individual members (in respect of a decision taken against them personally). Further information on appeals can be found in our *Enquiries and appeals about Pearson vocational qualifications and end point assessment policy*, which is on our website. In the initial stage of any aspect of malpractice, please notify the Investigations Team by email via pqsmalpractice@pearson.com who will inform you of the next steps.

Certification and results

Once a learner has completed all the required components for a qualification, even if final results for external assessments have not been issued, then the centre can claim certification for the learner, provided that quality assurance has been successfully completed. For the relevant procedures please refer to our *Information Manual*. You can use the information provided on qualification grading to check overall qualification grades.

Results issue

After the external assessment session, learner results will be issued to centres. The result will be in the form of a grade. You should be prepared to discuss performance with learners, making use of the information we provide and post-results services.

Post-assessment services

Once results for external assessments are issued, you may find that the learner has failed to achieve the qualification or to attain an anticipated grade. It is possible to transfer or reopen registration in some circumstances. The *Information Manual* gives further information.

Changes to qualification requests

Where a learner who has taken a qualification wants to resit an externally-assessed unit to improve their qualification grade, you firstly need to decline their overall qualification grade. You may decline the grade before the certificate is issued. For a learner receiving their results in August, you should decline the grade by the end of September if the learner intends to resit an external assessment.

Additional documents to support centre administration

As an approved centre you must ensure that all staff delivering, assessing and administering the qualifications have access to this documentation. These documents are reviewed annually and are reissued if updates are required.

- *Pearson Quality Assurance Handbook*: this sets out how we will carry out quality assurance of standards and how you need to work with us to achieve successful outcomes.
- *Information Manual*: this gives procedures for registering learners for qualifications, transferring registrations, entering for external assessments and claiming certificates.
- *Lead Examiners' Reports*: these are produced after each series for each external assessment and give feedback on the overall performance of learners in response to tasks or questions set.
- *Instructions for the Conduct of External Assessments (ICEA)*: this explains our requirements for the effective administration of external assessments, such as invigilation and submission of materials.
- *Regulatory policies*: our regulatory policies are integral to our approach and explain how we meet internal and regulatory requirements. We review the regulated policies annually to ensure that they remain fit for purpose. Policies related to this qualification include:
  - adjustments for candidates with disabilities and learning difficulties, access arrangements and reasonable adjustments for general and vocational qualifications
  - age of learners
  - centre guidance for dealing with malpractice
  - recognition of prior learning and process.

This list is not exhaustive and a full list of our regulatory policies can be found on our website.

8 Quality assurance

Centre and qualification approval

As part of the approval process, your centre must make sure that the resource requirements listed below are in place before offering the qualification.

- Centres must have appropriate physical resources (for example, equipment, IT, learning materials, teaching rooms) to support the delivery and assessment of the qualification.
- Staff involved in the assessment process must have relevant expertise and/or occupational experience.
- There must be systems in place to ensure continuing professional development for staff delivering the qualification.
- Centres must have in place appropriate health and safety policies relating to the use of equipment by learners.
- Centres must deliver the qualification in accordance with current equality legislation.
- Centres should refer to the teacher guidance section in individual units to check for any specific resources required.

Continuing quality assurance and standards verification

On an annual basis, we produce the *Pearson Quality Assurance Handbook.* It contains detailed guidance on the quality processes required to underpin planning for delivery including appropriate employer involvement, and for robust assessment and internal verification.

The key principles of quality assurance are that:

- a centre delivering BTEC programmes must be an approved centre, and must have approval for the programmes or groups of programmes that it is delivering
- the centre agrees, as part of gaining approval, to abide by specific terms and conditions around the effective delivery and quality assurance of assessment; it must abide by these conditions throughout the period of delivery
- Pearson makes available to approved centres a range of materials and opportunities, through online standardisation, intended to exemplify the processes required for effective assessment, and examples of effective standards. Approved centres must use the materials and services to ensure that all staff delivering BTEC qualifications keep up to date with the guidance on assessment
- an approved centre must follow agreed protocols for standardisation of assessors and verifiers, for the planning, monitoring and recording of assessment processes, and for dealing with special circumstances, appeals and malpractice.

The approach of quality-assured assessment is through a partnership between an approved centre and Pearson. We will make sure that each centre follows best practice and employs appropriate technology to support quality-assurance processes, where practicable. We work to support centres and seek to make sure that our quality-assurance processes do not place undue bureaucratic processes on centres. We monitor and support centres in the effective operation of assessment and quality assurance.

The methods we use to do this for BTEC Level 3 include:

- making sure that all centres complete appropriate declarations at the time of approval
- undertaking approval visits to centres
- making sure that centres have effective teams of assessors and verifiers who are trained to undertake assessment
- undertaking an overarching review and assessment of a centre's strategy for ensuring sufficient and appropriate engagement with employers at the beginning of delivery of any BTEC programme(s)
- undertaking a review of the employer involvement planned at programme level to ensure its appropriateness at a time when additional activities can be scheduled where necessary
- assessment sampling and verification, through requested samples of assessments, completed assessed learner work and associated documentation

- an overarching review and assessment of a centre's strategy for delivering and quality assuring its BTEC programmes, for example making sure that synoptic units are placed appropriately in the order of delivery of the programme.

Centres that do not fully address and maintain rigorous approaches to delivering, assessing and quality assurance cannot seek certification for individual programmes or for all BTEC Level 3 programmes. An approved centre must make certification claims only when authorised by us and strictly in accordance with requirements for reporting.

Centres that do not comply with remedial action plans may have their approval to deliver qualifications removed.

9 Understanding the qualification grade

Awarding and reporting for the qualification

This section explains the rules that we apply in awarding a qualification and in providing an overall qualification grade for each learner. It shows how all the qualifications in this sector are graded.

The awarding and certification of these qualifications will comply with regulatory requirements.

Eligibility for an award

In order to be awarded a qualification, a learner must complete all units, achieve a Near Pass (N) or above in all external units and a pass or above in all mandatory units unless otherwise specified. Refer to the structure in *Section 2*.

To achieve any qualification grade, learners must:

- complete and **have an outcome** (D, M, P, N or U) for all units within a valid combination
- achieve the **required units at pass or above** shown in *Section 2*, and for the Diploma achieve a minimum of 600 GLH and Extended Diploma achieve a minimum 900 GLH at Pass or above (or N or above in external units)
- achieve the **minimum number of points** at a grade threshold.

It is the responsibility of a centre to ensure that a correct unit combination is adhered to. Learners who do not achieve the required minimum grade (N or P) in units shown in the structure will not achieve a qualification.

Learners who do not achieve sufficient points for a qualification or who do not achieve all the required units may be eligible to achieve a smaller qualification in the same suite provided they have completed and achieved the correct combination of units and met the appropriate qualification grade points threshold.

Calculation of the qualification grade

The final grade awarded for a qualification represents an aggregation of a learner's performance across the qualification. As the qualification grade is an aggregate of the total performance, there is some element of compensation in that a higher performance in some units may be balanced by a lower outcome in others.

In the event that a learner achieves more than the required number of optional units, the mandatory units along with the optional units with the highest grades will be used to calculate the overall result, subject to the eligibility requirements for that particular qualification title.

BTEC Nationals are Level 3 qualifications and are awarded at the grade ranges shown in the table below.

Qualification	Available grade range
Certificate, Extended Certificate, Foundation Diploma	P to D*
Diploma	PP to D*D*
Extended Diploma	PPP to D*D*D*

The *Calculation of qualification grade* table, shown further on in this section, shows the minimum thresholds for calculating these grades. The table will be kept under review over the lifetime of the qualification. The most up to date table will be issued on our website.

Pearson will monitor the qualification standard and reserves the right to make appropriate adjustments.

Learners who do not meet the minimum requirements for a qualification grade to be awarded will be recorded as Unclassified (U) and will not be certificated. They may receive a Notification of Performance for individual units. The *Information Manual* gives full information.

Points available for internal units

The table below shows the number of **points** available for internal units. For each internal unit, points are allocated depending on the grade awarded.

	Unit size	
	60 GLH	**90 GLH**
U	0	0
Pass	6	9
Merit	10	15
Distinction	16	24

Points available for external units

Raw marks from the external units will be awarded **points** based on performance in the assessment. The table below shows the **minimum number of points** available for each grade in the external units.

	Unit size	
	90 GLH	**120 GLH**
U	0	0
Near Pass	6	8
Pass	9	12
Merit	15	20
Distinction	24	32

Pearson will automatically calculate the points for each external unit once the external assessment has been marked and grade boundaries have been set. For more details about how we set grade boundaries in the external assessment please go to our website.

Claiming the qualification grade

Subject to eligibility, Pearson will automatically calculate the qualification grade for your learners when the internal unit grades are submitted and the qualification claim is made. Learners will be awarded qualification grades for achieving the sufficient number of points within the ranges shown in the relevant *Calculation of qualification grade* table for the cohort.

Calculation of qualification grade

Applicable for registration from 1 September 2016.

Certificate		Extended Certificate		Foundation Diploma		Diploma		Extended Diploma	
180 GLH		**360 GLH**		**540 GLH**		**720 GLH**		**1080 GLH**	
Grade	**Points threshold**	**Grade**	**Points threshold**	**Grade**	**Points threshold**	**Grade**	**Points threshold**	**Grade**	**Points threshold**
U	0	U	0	U	0	U	0	U	0
Pass	18	P	36	P	54	PP	72	PPP	108
						MP	88	MPP	124
								MMP	140
Merit	26	M	52	M	78	MM	104	MMM	156
						DM	124	DMM	176
								DDM	196
Distinction	42	D	74	D	108	DD	144	DDD	216
						D*D	162	D*DD	234
								D*D*D	252
Distinction*	48	D*	90	D*	138	D*D*	180	D*D*D*	270

The table is subject to review over the lifetime of the qualification.

Examples of grade calculations based on table applicable to registrations from September 2016

Example 1: Achievement of an Extended Diploma with a PPP grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Pass	12
Unit 2	60	Int	Pass	6
Unit 3	120	Ext	Pass	12
Unit 4	60	Int	Merit	10
Unit 5	60	Int	Pass	6
Unit 6	120	Ext	Pass	12
Unit 7	60	Int	Pass	6
Unit 8	60	Int	Merit	10
Unit 9	60	Int	U	0
Unit 14	60	Int	Pass	6
Unit 15	60	Int	Pass	6
Unit 16	60	Int	Pass	6
Unit 17	60	Int	Pass	6
Unit 24	60	Int	Pass	6
Unit 25	60	Int	Merit	10
Totals	**1080**		**PPP**	**114**

The learner has achieved N or higher in Units 1, 3 and 6 and P or higher in Units 2 and 4

The learner has sufficient points for a PPP grade

Example 2: Achievement of an Extended Diploma with a DDD grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Near Pass	8
Unit 2	60	Int	Pass	6
Unit 3	120	Ext	Distinction	32
Unit 4	60	Int	Distinction	16
Unit 5	60	Int	Distinction	16
Unit 6	120	Ext	Merit	20
Unit 7	60	Int	Distinction	16
Unit 8	60	Int	Distinction	16
Unit 9	60	Int	Merit	10
Unit 14	60	Int	Distinction	16
Unit 15	60	Int	Distinction	16
Unit 16	60	Int	Merit	10
Unit 17	60	Int	Merit	10
Unit 24	60	Int	Distinction	16
Unit 25	60	Int	Merit	10
Totals	**1080**		**DDD**	**218**

The learner has sufficient points for a DDD grade

Example 3: An Unclassified result for an Extended Diploma

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Pass	12
Unit 2	60	Int	Pass	6
Unit 3	120	Ext	Merit	20
Unit 4	60	Int	Merit	10
Unit 5	60	Int	Pass	6
Unit 6	120	Ext	Merit	20
Unit 7	60	Int	Pass	6
Unit 8	60	Int	Merit	10
Unit 9	60	Int	Distinction	16
Unit 14	60	Int	Merit	10
Unit 15	60	Int	Unclassified	0
Unit 16	60	Int	Pass	6
Unit 17	60	Int	Unclassified	0
Unit 24	60	Int	Unclassified	0
Unit 25	60	Int	Unclassified	0
Totals	**1080**		**U**	**122**

The learner has 240 GLH at U.

The learner has sufficient points for a PPP and has achieved a N or above in Units 1, 3 and 6, and P and higher in Units 2 and 4 but has not met the minimum requirement for 900 GLH at Pass or above.

10 Resources and support

Our aim is to give you a wealth of resources and support to enable you to deliver BTEC National qualifications with confidence. On our website you will find a list of resources to support teaching and learning, and professional development.

Support for setting up your course and preparing to teach

Specification

This **specification** (for teaching from September 2016) includes details on the administration of qualifications and information on all the units for the qualification.

Delivery Guide

This free guide gives you important advice on how to choose the right course for your learners and how to ensure you are fully prepared to deliver the course. It explains the key features of BTEC Nationals (for example employer involvement and employability skills). It also covers guidance on assessment (internal and external) and quality assurance. The guide tells you where you can find further support and gives detailed unit-by-unit delivery guidance. It includes teaching tips and ideas, assessment preparation and suggestions for further resources.

Schemes of work

Free sample schemes of work are provided for each mandatory unit. These are available in Word™ format for ease of customisation.

Curriculum models

These show how the BTECs in the suite fit into a 16–19 study programme, depending on their size and purpose. The models also show where other parts of the programme, such as work experience, maths and English, tutorial time and wider study, fit alongside the programme.

Study skills activities

A range of case studies and activities is provided; they are designed to help learners develop the study skills they need to successfully complete their BTEC course. The case studies and activities are provided in Word™ format for easy customisation.

Support for teaching and learning

Pearson Learning Services provides a range of engaging resources to support BTEC Nationals, including:

- textbooks in e-book and print formats
- revision guides and revision workbooks in e-book and print formats
- teaching and assessment packs, including e-learning materials via the Active Learn Digital Service.

Teaching and learning resources are also available from a number of other publishers. Details of Pearson's own resources and of all endorsed resources can be found on our website.

Support for assessment

Sample assessment materials for externally-assessed units

Sample assessments are available for the Pearson-set units. One copy of each of these assessments can be downloaded from the website/available in print. For each suite an additional sample for one of the Pearson-set units is also available, allowing your learners further opportunities for practice.

Further sample assessments will be made available through our website on an ongoing basis.

Sample assessment materials for internally-assessed units

We do not prescribe the assessments for the internally-assessed units. Rather, we allow you to set your own, according to your learners' preferences and to link with your local employment profile.

We do provide a service in the form of Authorised Assignment Briefs, which are approved by Pearson Standards Verifiers. They are available via our website.

Sample marked learner work

To support you in understanding the expectation of the standard at each grade, examples of marked learner work at PM/MD grades are linked to the Authorised Assignment Briefs.

Training and support from Pearson

People to talk to

There are many people who are available to support you and provide advice and guidance on delivery of your BTEC Nationals. These include:

- Subject Advisors – available for all sectors. They understand all Pearson qualifications in their sector and so can answer sector-specific queries on planning, teaching, learning and assessment
- Standards Verifiers – they can support you with preparing your assignments, ensuring that your assessment plan is set up correctly, and support you in preparing learner work and providing quality assurance through sampling
- Curriculum Development Managers (CDMs) – they are regionally based and have a full overview of the BTEC qualifications and of the support and resources that Pearson provides. CDMs often run network events
- Customer Services – the 'Support for You' section of our website gives the different ways in which you can contact us for general queries. For specific queries, our service operators can direct you to the relevant person or department.

Training and professional development

Pearson provides a range of training and professional development events to support the introduction, delivery, assessment and administration of BTEC National qualifications. These sector-specific events, developed and delivered by specialists, are available both face to face and online.

'Getting Ready to Teach'

These events are designed to get teachers ready for delivery of the BTEC Nationals. They include an overview of the qualifications' structures, planning and preparation for internal and external assessment, and quality assurance.

Teaching and learning

Beyond the 'Getting Ready to Teach' professional development events, there are opportunities for teachers to attend sector- and role-specific events. These events are designed to connect practice to theory; they provide teacher support and networking opportunities with delivery, learning and assessment methodology.

Details of our training and professional development programme can be found on our website.

Appendix 1 Links to industry standards

BTEC Nationals have been developed in consultation with industry and appropriate sector bodies to ensure that the qualification content and approach to assessment aligns closely to the needs of employers. Where they exist, and are appropriate, National Occupational Standards (NOS) and professional body standards have been used to establish unit content.

In the engineering sector, the following approaches have been used.

- The qualifications have been aligned to employer requirements as identified as part of the Apprenticeship Reform process.
- Content has been mapped to the requirements stated for EngTech registration as stated in UK-SPEC along with the output standards identified in the Approval of Qualifications and Apprenticeships Handbook produced by the Engineering Council.

A detailed mapping to the UK-SPEC can be found on our website.

Appendix 2 Glossary of terms used for internally-assessed units

This is a summary of the key terms used to define the requirements within units.

Term	Definition
Carry out (when used in learning aim)	Learners demonstrate skills through practical activities.
Design (when used in learning aim)	The process of deciding on the look and functioning of a product or process.
Develop (when used in learning aim)	Learners acquire and apply skills through practical activities.
Examine (when used in learning aim)	Learners are expected to select and apply knowledge to less familiar contexts.
Explore (when used in learning aim)	Learners apply their skills and/or knowledge to practical testing or trialling.
Implement (when used in learning aim)	Learners put a plan or decision into effect/execution.
Interpret (when used in learning aim)	Learners demonstrate and apply understanding of something to convey a particular meaning.
Investigate (when used in learning aim)	Learners' knowledge is based on personal research and development.
Modify	Learners make partial or minor changes to something.
Plan (when used in learning aim)	Learners map outcomes related to a given or limited task. Learners create a way of doing a task or a series of tasks to achieve specific requirements or objectives showing progress from start to finish.
Reflect on	Learners draw conclusions from their own learning, skills and development.
Review (when used in learning aim)	Process for learning (knowledge or skills) through research, peer review or reflection.
Select (when used in learning aim)	Learners make the best or most suitable choice of something for a specific purpose.
Set up (when used in learning aim)	Learners set the way in which something, for example equipment, is organised, planned or arranged.
Undertake (when used in learning aim)	Learners demonstrate skills. Often referring to given processes or techniques.
Accurate	Free from error, defect or within a tolerance that is appropriate for the context.
Adapt	To change something to suit different conditions or uses.
Analyse	Learners present the outcome of methodical and detailed examination either: • breaking down a theme, topic or situation in order to interpret and study the interrelationships between the parts and/or • of information or data to interpret and study key trends and interrelationships.
Application	The action of putting something into operation.
Apply	Bring or put into operation or use.

Term	Definition
Assemble	Fit together the separate component parts of (a machine or other object).
Assess	Learners present careful consideration of varied factors or events that apply to a specific situation, or identify those which are the most important or relevant and arrive at a conclusion.
Build	Construct (something) by putting parts or material together.
Calculate	Produce a numerical answer, showing relevant working.
Capabilities	The ability of a machine/product to meet specified requirements.
Capture	To represent an electronic circuit accurately using software.
Carry out (when used in assessment criterion)	To do or complete something, as in a process to produce an outcome.
Characteristic	A feature or quality belonging typically to an object or thing and serving to identify them.
Check	Examine (something) in order to determine its accuracy, quality, or condition, or to detect the presence of something.
Client brief	A document produced by a client specifying the requirements for a product they are commissioning.
Compare (and contrast)	Learners can identify the main factors relating to two or more items/situations or aspects of a subject that is extended to explain the similarities, differences, advantages and disadvantages. This is used to show depth of knowledge through selection and isolation of characteristics.
Complete	Make or do something to completion.
Component	A part or element of a larger whole, especially a part of a machine or product.
Conduct	The undertaking a series of activities as part of a task.
Consistently	In every case or every occasion.
Constraints	The state of being restricted or confined within prescribed bounds.
Construct	Build or make something.
Create	Bring something into existence, e.g. drawings.
Critically analyse	In a way that involves the objective analysis and evaluation of an issue to form a judgement.
Demonstrate	Learners' work shows the ability to carry out and apply knowledge, understanding and/or skills in a practical situation.
Describe	Learners' work gives a clear, objective account in their own words showing recall and, in some cases application, of the relevant features and information about a subject.
Design (when used in assessment criterion)	The process of creating the form, function and characteristics of a product, system or process.
Determine (the characteristics of…)	To discover the facts or truth about a process or product.
Develop (when used in assessment criterion)	To design, build/manufacture and test a product, circuit or system.

Term	Definition
Diagnose	Identify the nature of a problem or fault by examination of the situation or artefact.
Diagram	A simple plan that represents a machine, system, or idea, etc., often drawn to explain how it works.
Discuss	Learners consider different aspects of: • a theme or topic • how they interrelate • the extent to which they are important. A conclusion is not required.
Draw	Make a graphical representation of engineering data or information.
Evaluate	Learners draw on varied information, themes or concepts to consider aspects such as: • strengths or weaknesses • advantages or disadvantages • alternative actions • relevance or significance. Learners' enquiries should lead to a supported judgement showing relationship to its context. This will often be in a conclusion.
Examine (when used in assessment criterion)	To test or assess the characteristics of a process or product.
Experiment	A test done in order to learn something or to discover if something works or is true.
Explain	Learners' work shows clear details and gives reasons and/or evidence to support an opinion, view or argument. It could show how conclusions are drawn.
Explore (when used in assessment criterion)	To enquire into or discuss something (for example an option or possibility) in detail.
Feature	A distinctive attribute or aspect of an object or thing.
Find	Ascertain by calculation or enquiry or to discover the facts about something.
Hazards	Something that is dangerous and likely to cause damage to an object or harm to an individual(s).
Identify	Learners indicate the main features or purpose of something by recognising it and/or being able to discern and understand facts or qualities.
Implement (when used in assessment criterion)	Learners consider the relevant factors to put a plan into practice, requiring self-direction of selection of outcome, planning, research, exploration, outcome and review.
Inspect	Look at (someone or something) closely, typically to assess their condition or to discover any shortcomings.
Interpret (when used in assessment criterion)	Learners are able to state the meaning, purpose or qualities of something through the use of images, words or other expressions.
Investigate (when used in assessment criterion)	Learners' work tests the following through practical exploration: • qualities of materials • techniques • processes or contexts

Term	Definition
Justify	Learners give reasons or evidence to: • support an opinion; or • prove something right or reasonable.
Label	Add text to a graphical representation to identify specific parts.
List	Learners provide information as an item by item record of names or things.
Manage	Learners engage with and influence an activity or process.
Manufacture	To make something using machinery, tools and materials.
Measure	The action of measuring something, for example dimensions, surface finish and voltage.
Methods	A particular procedure for accomplishing or approaching something, especially a systematic or established one.
Models	A representation, either in a graphical, physical or numerical format of something.
Optimise	The process of improving and perfecting a process or product by incremental steps to achieve the best performance possible (given constraints).
Organisation	An organised group of people with a particular purpose, such as a business, company or government department.
Outline	Learners' work, performance or practice provides a summary or overview or a brief description of something.
Perform	Learners can carry out or execute what has to be done to complete a given activity.
Plan (when used in assessment criterion)	Learners create a way of doing a task or a series of tasks to achieve specific requirements or objectives showing progress from start to finish.
Practical	Learners apply knowledge and demonstrate skills to a given task to produce an outcome.
Prepare	Learners gather materials, tools and procedures ready to undertake a process and/or make something ready for use.
Present	To give, provide, or make something known.
Principles	A general scientific theorem or law that has numerous special applications.
Procedure	A set of actions that is the official or accepted way of doing something.
Processes	A series of actions or steps taken in order to achieve a particular end.
Produce	Learners' knowledge, understanding and/or skills are applied to develop a particular type of evidence, for example a plan or report.
Product	A product contains one or more than one component and is offered for sale or use.
Quality control	The process of looking at products or components when they are being manufactured to make certain that all the items are of the intended standard.
Recommend	To suggest that a particular action should be done.
Refine	To improve an idea, method, system, product etc. by making small changes.

Term	Definition
Repair	Restore (something damaged, faulty, or worn) to a good condition.
Research	An analysis of substantive research organised by learners from secondary and if applicable primary sources.
Review (when used in assessment criterion)	Learners make a formal assessment of their work. They appraise existing information or prior events, or reconsider information with the intention of making changes if necessary.
Risks	The possibility of something, most likely negative, happening or a future event which could adversely or positively impact project processes or outcomes.
Select	Learners choose the best or most suitable option whether this is of materials, techniques, equipment or processes. The options and choices should be based on specific criteria.
Set up (when used in assessment criterion)	To set up a machine or process ready for operation or to assemble.
Simulate	A representation, either in a graphical or numerical format, of something or a realistic work situation.
Solve	Find an answer to, explanation for, or means of effectively dealing with an engineering problem.
State	Declare definitely or specifically.
Sustainability	The ability of a product or process to be sustained, supported, upheld, or confirmed over a long period of time.
System(s)	An assemblage or combination of things or parts forming a complex or unitary whole.
Test	Take measures to check the quality, performance, or reliability of something, especially before putting it into widespread use or practice.
Tolerance	The permissible range of variation in a dimension of a product or component as determined by the constraints.
Undertake (when used in assessment criterion)	Learners select and apply knowledge to demonstrate skills.
Use	Take, hold, or deploy (something) as a means of accomplishing or achieving something; employ. Learners' practice evidences the ability to carry out and apply knowledge, understanding and skills in a practical situation.

This is a key summary of the types of evidence used for BTEC Nationals.

Type of evidence	Definition and purpose
Artefact	An object or output from a human devised process.
Case study	A specific example to which all learners must select and apply knowledge. Used to show application to a realistic context where direct experience cannot be gained.
Design documentation	A way to communicate the design itself, the rationale for decisions made, and the tools for clients to carry on once the project is complete.

Type of evidence	Definition and purpose
Logbook	A record made by learners of how a process of development was carried out,including experimental stages,testing,selection and rejection of alternatives,practice or development steps.
Observation record	An observation record is used to provide a formal record of a judgement of learners’ performance (for example during presentations, practical activities) against the targeted assessment criteria. It must be completed by the assessor of the unit or qualification. An observation record alone does not confer an assessment decision.
Portfolio of evidence	A collection of documents which demonstrate knowledge-based skills and work that has been undertaken to be assessed as evidence to meet required skills outcomes.
Practical task	Learners undertake a defined or self-defined task to produce an outcome of a defined quality.
Production of plan	Learners produce plans as an outcome related to a given or limited task.
Project management	A large-scale activity requiring self-direction of selection of outcome, planning, research, exploration, outcome and review.
Reflective account/development log or logbook	A record kept by learners to show the process of development. Used to show method, self-management, skill development, experimental stages, testing, selection and rejection of alternatives, practice or development steps.
Report/research report	A self-directed, large-scale activity requiring, planning, research, exploration, outcome and review. Used to show self-management, project management and/or deep learning, including synopticity.
Research project	An analysis of substantive research organised by learners from secondary and if applicable primary sources.
Test plan	A document detailing the objectives and processes for a specific test for a product. The plan typically contains a detailed understanding of the eventual workflow.
Witness statement	Can be used to provide a written record of learners’ performance against targeted assessment criteria. Anyone within the work experience placement who has witnessed the skills being demonstrated can complete a witness statement, including staff who do not have direct knowledge of the qualification, unit or evidence requirements, but who are able to make a professional judgement about learners’ performance in the given situation.

Pearson
BTEC Level 3 Nationals
in
Engineering

Certificate in Engineering

Extended Certificate in Engineering

Foundation Diploma in Engineering

Diplomas in:
- Engineering
- Electrical and Electronic Engineering
- Mechanical Engineering
- Computer Engineering
- Manufacturing Engineering
- Aeronautical Engineering

Extended Diplomas in:
- **Engineering**
- **Electrical and Electronic Engineering**
- **Mechanical Engineering**
- **Computer Engineering**
- **Manufacturing Engineering**
- **Aeronautical Engineering**

For more information about Edexcel, BTEC or LCCI qualifications
visit qualifications.pearson.com

Pearson Education Limited. Registered in England and Wales No. 872828
Registered Office: 80 Strand, London WC2R 0RL
VAT Reg No GB 278 537121

Cover image © VLADGRIN/Shutterstock

ISBN 978-1-4469-5114-9