Unit 2: Vehicle Engine Principles, Operation, Service and Repair

NQF Level 3: **BTEC National**

Guided learning hours: 60

Unit abstract

Although the technology in modern vehicles is under constant development, the basic principles of the internal combustion engine (ICE) have remained the same for many years. However, advances in design have produced engines that are more efficient, powerful, environmentally friendly and, with the aid of electronics, much more responsive to the needs of the user.

Developments in engine design and materials technology have significantly increased the reliability and durability of engine components and systems and, therefore, minimised failure and the need for subsequent repairs. However, the modern motor vehicle technician still needs to have a working knowledge and understanding of the engine and associated sub-systems, to enable them to carry out the necessary care, fault diagnosis and repair.

This unit will enable learners to develop an understanding of a range of engines in terms of their operating principles and processes, applications and service/repair. Two and four-stroke cycle spark and compression ignition engines will be considered together with their related sub-systems — fuel, cooling and lubrication. The unit also covers the growing concern about future supplies of fossil fuels and environmental pollution by examining current and future developments in engine designs that make use of alternative fuel and power systems.

Finally, the unit will give learners an opportunity to apply their understanding of engine principles by carrying out engine service and repair work on engines in a vehicle workshop environment. Learners will gain practical experience of using a range of tools and equipment and will work to vehicle service and repair industry standards.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of operation of an internal combustion engine

2 Understand the principles of operation of fuel supply systems

3 Understand the principles of operation of engine cooling and lubrication systems

4 Be able to carry out engine service and repair procedures.

Unit content

1 **Understand the principles of operation of an internal combustion engine**

Operating cycles: internal combustion engines (ICE) eg four-stroke spark ignition (SI) and compression ignition (CI) cycles, two-stroke cycle, Wankel (rotary); pressure-volume diagrams and engine performance diagrams (torque/power) eg the Otto cycle, identification of induction, compression, ignition, exhaust strokes, effects of bore, stroke, swept and clearance volume; engine efficiency eg engine timing, pressure charging, compression ratio

Engine configurations and layout: orientation (longitudinal/transverse); position of engine (front, mid and rear); cylinder arrangement eg single cylinder twin cylinder, four cylinder, six cylinder, eight cylinder; cylinder configuration eg in-line, vee, horizontally opposed arrangements; vehicle design and performance eg space saving, arrangements for power transmission, vehicle function (passenger, people carrier, off-road, motorsport), cost, environmental issues

Engine components/assemblies: engine types eg four-stroke SI and CI, two-stroke cycle, Wankel (rotary); components and assemblies eg cylinder block (piston, connecting rod, crankshaft and bearings), cylinder head (camshaft, inlet/exhaust valves, valve operating mechanisms such as over head valve (ohv), single over head cam (sohc), double over head cam (dohc), variable valve timing); flywheel; inlet and exhaust manifolds

2 **Understand the principles of operation of fuel supply systems**

Petrol combustion process: fuel principles eg composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio; combustion process eg mixing of fuel/air, flame spread, exhaust emissions; effects of pollutants/causes of undesirable emissions eg weak mixture, rich mixture, oil control problems; symptoms of incorrect combustion process eg detonation, pre-ignition; fuel supply method eg fuel injection, mechanical, electrical; fuel system components eg tank, petrol filter, air filter, supply/pressure pump, pressure regulator, injectors

Diesel combustion process: fuel principles eg composition of diesel, characteristics of diesel, air/fuel ratio; combustion process eg phases, delay, combustion, spontaneous burning, pressure/crank angle diagrams, diesel knock; exhaust emissions eg normal, excess air, excess fuel, effects of pollutants; fuel supply method eg rotary, inline, unit injector; fuel system components eg low pressure (tank, filter(s), supply pump), high pressure (in-line pump, governor, injector, cold start arrangements)

Alternative fuel/power: systems eg liquefied petroleum gas (LPG), natural gas, hydrogen, hybrid; adapted/additional components eg fuel tank, additional modifications, cooling system, management control system, performance; legislation eg emissions, tax, health and safety

3 **Understand the principles of operation of engine cooling and lubrication systems**

Engine cooling systems: types of system eg air-cooled (cylinder construction, fan, shutters, thermostat), water-cooled (radiator, radiator cap, expansion tank, water pump, viscous/electric/mechanical fans, thermostat, hoses, types of coolant, level indication, anti-freeze protection, effects and prevention of corrosion); cooling control systems eg engine temperature sensor, ambient air temperature sensor, thermostatic control valves (mechanical and electrical), cooling air flow control (air flow control via flap for warm up); engine management system eg overheating, fuel cut-off

Engine lubrication system: system components eg wet/dry sumps, oil pump, pressure relief valve; engine oil types and filtration methods eg viscosity, Society of Automotive Engineers (SAE) rating, multi-grade oil; filters eg full flow or bypass; lubrication control systems eg sensors, level indicator (mechanical, electrical); pressure sensors eg absolute and gauge or lamp; low pressure safety system eg engine management system fuel cut-off

4 **Be able to carry out engine service and repair procedures**

Routine engine service: procedures eg changing engine lubricant, filters (air, lubricant, pollen, fuel), checking and adjusting engine timing (ignition, camshaft); working to instructions eg manufacturer's service schedules/data, dealership work schedules/job cards; use of tools and equipment eg hand tools, vehicle lift equipment, oil drainer, on-board service indicators; safe working procedures eg personal and vehicle protection (personal protective equipment, vehicle covers, mats); control of substances hazardous to health (COSHH); safe disposal of waste products

Major engine repair: procedures eg strip and inspect bore and crankshaft journals for wear, cylinder head for distortion, valves for seating and damage; working to instructions eg manufacturer's repair manuals, web-based information, dealership work schedules/job cards/supervisor's instructions; use of tools and equipment eg engine crane, chains, slings, torque wrenches, micrometers, dial test indicators (DTI), timing tools, locking devices, cleaning equipment; safe working procedures eg personal and vehicle protection (personal protective equipment, vehicle covers, mats), manual handling, use of lifting and support equipment, use of cleaning solvents; safe disposal of waste products

Grading grid

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

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating cycles of two different internal combustion engines P2 explain the vehicle design and performance implications of an engine's configuration and layout P3 explain the function, operation and construction of the components/ assemblies of one type of engine P4 explain the effects of different air fuel ratios on the petrol combustion process and exhaust emissions P5 explain the diesel combustion process P6 describe an application of an alternative fuel/power supply system	M1 identify and compare the advantages and disadvantages of the design and performance of two different engine configurations and layouts M2 identify and compare the advantages and disadvantages of two different engines in terms of their fuel, cooling and lubrication systems M3 prepare a work schedule for a major engine repair procedure, carry out the repair and evaluate the effectiveness of the work schedule.	D1 evaluate and justify the choice of an engine used for a current vehicle application, in terms of its layout, operation and performance D2 compare a conventional fuel system with that of an alternative fuel/power source.

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P7 explain the principles of operation and differences between an air and a water cooled engine P8 explain the layout, system components and operation of two different engine lubrication systems P9 carry out a routine engine service by following given instructions P10 carry out a major engine repair following given instructions.		

Essential guidance for tutors

Delivery

The unit has been designed to enable learners with no previous experience of engines to gain an insight into the principles and applications of engine technology. Tutors will need to consider the best way to take learners through the basic principles of engine cycles, fuel supply, cooling and lubrication. This will need to be done in such a way that it stretches those learners with some experience of engine technology but also provides sufficient support for those new to the topic. The method of delivery most likely to achieve this is a practical/investigative approach supported by tutor-led sessions on the relevant theories (eg Otto cycle in relation to engine types, application of power and torque in engine performance). The unit should not be seen as a purely theoretical unit with just one practical outcome and tutors should make delivery of the whole unit a 'hands-on' experience wherever possible.

Tutors may consider integrating this unit with others in the programme of study (eg *Unit 8: Petrol Injection Systems for Spark Ignition Engines*, *Unit 9: Diesel Fuel Injection Systems for Compression Ignition Engines* and *Unit 11: Vehicle Engine Management Systems*). It may also be possible to integrate the delivery and/or assessment of this unit within learners' work-based role/work placement. Both of these approaches will have the potential to increase the level of practical content and relevance for learners. However, it is critical that all vehicle workshop activities within the centre reflect and simulate current industrial standards, practices and working environments. This includes dress, codes of practice, supervision and health and safety.

When planning for delivery, tutors will need to consider how much can be taught using 'live' vehicles and how much will need to be done on special training 'rigs' or specialist models (eg engine, fuel/oil pump cut away sectioned models). The first three learning outcomes are likely to rely upon a significant use of such 'rigs' and models. However, it is expected that the delivery of the final learning outcome will be carried out using 'live' vehicles and all the work undertaken should replicate industry standards as far as possible. In particular, the routine engine service and major engine repair procedures undertaken (eg changing engine lubricant, filters and strip/inspect bore and crankshaft journals for wear, etc.) should follow typical vehicle workshop working instructions and use relevant industry standard tools and equipment.

Safe working procedures must always be followed. Tutors should ensure that learners' approach to safety (and care) is embedded within everything they do in a vehicle workshop.

Assessment

Tutors should design a varied assessment strategy that could include research and investigate tasks, set piece service/repair activities and technical reporting.

While assessment methods must reflect the unit content they should also recognise the need to keep up to date with current components, systems, applications and working practices. The examples given in the unit content reflect current practice but could be replaced with more relevant and up-to-date examples as technology changes, without affecting content coverage. For example, the content for lubrication control systems provides as its example 'sensors, level indicator (mechanical, electrical)' but advances in digital/computer-based engine management systems could make mechanical sensors obsolete in the not too distant future.

There are no fixed ways in which the unit should be assessed or the number of assessment instruments that might be used. The maximum number of assignments is likely to be five, one for each of the first three outcomes and two for the last. However, there are strong links between all the pass criteria and across the merit and distinction criteria. Tutors should endeavour to make the most of these links to keep the number of assessment instruments down to a minimum.

One approach might be to design two project-style assignments that run in parallel to each other. Each project would focus on a particular engine and learners would study the engine's operating cycle, configuration and layout, combustion process, cooling and lubrication systems. They would then carry out a routine service on one engine and a major repair on the other.

To meet all the requirements of the criteria, one engine should use petrol combustion and the other diesel. Special considerations within the project brief would need to be applied to P2 and P3, which only need to be covered for one engine (although the configuration and layout of the second engine would need to be considered to achieve M1). Additional tasks would probably need to be included in the project brief to enable learners to achieve P6 (alternative fuel/power supply system), and P7 (differences between an air- and a water-cooled engine). P6 could be achieved through a 'what if' scenario within one of the projects (eg consider an alternative fuel/power supply system for the vehicle being considered). P7 could be achieved by ensuring that one engine is air-cooled and the other water-cooled. However, as this situation is unlikely to occur, a 'what if' scenario could also be set within one of the projects (eg if the water-cooled engine had been air-cooled then explain the principles of operation and differences that would apply).

Running the two projects in parallel would ensure that assessment could follow delivery and also that the criteria would not need to be fragmented (ie visited twice at different times before they could be achieved). Opportunities to achieve the merit and distinction criteria could also be built into the projects with some imagination and careful planning.

Whatever form of assessment is used, the tasks set will need to ensure that for P1 learners are able to explain the operating cycles of two different internal combustion engines (ie selecting two from the list of examples in the unit content). For each engine, learners should explain the engine's operating cycle by using suitable diagrams to indicate pressure-volume within the cycle, engine performance (torque/power) and engine efficiencies (eg engine timing, pressure charging and applicable compression ratios).

For P2, learners should be able to explain the vehicle design and performance implications of an engine's configuration and layout. They need to take into account the orientation (longitudinal/transverse), position of engine (front, mid and rear), cylinder arrangement, cylinder configuration, the purpose for which the vehicle has been designed and its expected performance (see examples in the unit content). The key question for learners to address and consider is — why that engine for that vehicle.

To achieve P3 learners need to explain the function, operation and construction of the components/assemblies of one type of engine (eg a four-stroke SI engine or a four-stroke CI engine). Their explanation should include details of the engine's main components and assemblies (ie cylinder block, cylinder head, flywheel, inlet and exhaust manifolds).

Criteria P4, P5 and P6 focus on fuel systems. For P4 learners need to focus on a petrol engine and explain the effects of different air/fuel ratios on the petrol combustion process and exhaust emissions. This should include an introduction to fuel principles (eg composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio) the combustion process, effects of pollutants and causes of undesirable symptoms. Learners should also consider the fuel supply method and fuel system components (eg tank, petrol filter, air filter, etc). This could be set within the context of the particular petrol engine/vehicle being studied.

A similar approach is required for P5, but this time learners need to explain the diesel combustion process. Learners should explain diesel fuel principles, combustion process, exhaust emissions, fuel supply method and fuel system components for either low pressure or high pressure diesel fuel systems.

For P6, learners should describe an application of an alternative fuel/power supply system. This can either be given by the tutor or chosen by the learner.

Learners should describe the system (eg LPG, natural gas, hydrogen, hybrid) and the way that traditional components have been adapted and/or any necessary additional components. They should also describe the relevant aspects of legislation that apply to these alternative fuel/power supplies. This should be set within the context of a particular vehicle.

P7 and P8 are closely linked and require learners to consider the fundamental differences between common cooling and lubrication systems. They can also be extended through to M2.

For P7, learners need to explain the principles of operation of, and differences between, an air and a water-cooled engine. Learners need to identify the types of system being considered as per the unit content (eg for an air cooled engine the cylinder construction, fan, shutters etc, for a water cooled engine the radiator, radiator cap, expansion tank etc). For each engine learners will need to consider the cooling control systems used and the relevant aspects of the engine management system with respect to engine cooling.

For P8, learners need to explain the system components, layout and operation of two different engine lubrication systems. This should include the respective system components (eg wet/dry sumps, oil pump, pressure relief valve), engine oil types and filtration methods, lubrication control systems, pressure sensors and low pressure safety system.

P9 and P10 form the focus of the practical assessment for this unit. Learners need to carry out a routine engine service and a major engine repair following given instructions. Examples of typical routine servicing and major repairs are given in the unit content, although these are not exclusive. Other service activities or repairs of an equivalent level of difficulty would be acceptable.

Assessment evidence for P9 and P10 is likely to be in the form of the learner's personal log/record of the work undertaken plus relevant tutor observation records. Learners may also wish to use photographic evidence that they have suitably annotated to support both their log/record and tutor observation. The evidence must indicate the service and repair procedures carried out, the instructions followed, the tools and equipment used and the safe working procedures followed, including safe disposal of waste products.

To achieve M2, learners need to build on their understanding of fuel, cooling and lubrication systems (P4 to P8) to identify and compare the advantages and disadvantages of two engines.

For M3, learners need to prepare a work schedule for a major engine repair procedure, carry out the repair and evaluate the effectiveness of the work schedule. Learners are expected to carry out a second (and different) major engine repair to achieve the merit criterion. It is not sufficient for learners just to prepare the work schedule and carry out a single repair in order to achieve P10 and M3. The object of the assessment at pass level is to establish whether learners can competently complete a given major repair under supervision/guidance. However, at merit level they are expected to demonstrate independence and reflection.

For D1, learners need to evaluate and justify the choice of an engine for a current vehicle application. This should be done in terms of the engine's layout, operation and performance. It is expected that the evidence presented will include a detailed evaluation of the particular vehicle's engine (eg type, power, layout, main components, fuel, lubrication systems). Having evaluated the engine in this way learners should then arrive at a reasoned justification for the manufacturer's choice based upon their own findings.

Evidence for D1 is most likely to be in a written format but learners could also include diagrams, photographs or other visual means to illustrate their work. Where images are not learners' own work credit must be given to the originator. Learners should have suitably annotated such images to indicate how they support their report.

For D2, learners should compare a conventional fuel system with that of an alternative fuel/power source. This can be linked with the work undertaken for P4, P5 and P6 and M2 (in part). The comparison should be in terms of the same aspects covered for the pass criteria (eg the fuel/power principles, combustion process, adapted/additional components, effects of pollutants/causes of undesirable emissions, fuel/power supply methods, fuel/power system components, relevant legislation). Again, evidence for this criterion is likely to be in the form of a written report and learners may make use of suitable images, as detailed for D1 above.

Links to National Occupational Standards (NOS), other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit covers some of the knowledge and understanding associated with the Level 3 Automotive Skills National Occupational Standards in Vehicle Maintenance and Repair, particularly:

- Unit G1: Contribute to Workplace Good Housekeeping
- Unit MR01: Carry out Routine Vehicle Maintenance
- Unit MR05: Conduct Pre and Post Work Vehicle Inspections
- Unit MR06: Inspect Vehicles
- Unit MR08HV: Diagnose and Rectify Commercial Vehicle Chassis System Faults
- Unit MR11: Overhaul Mechanical Units.

The unit also provides some of the knowledge and understanding for the following units in the Level 3 SEMTA National Occupational Standards in Automotive Engineering:

- Unit 101: Stripping and Rebuilding Engines for Motorsport Vehicles
- Unit 102: Building Engines for Motorsport Vehicles
- Unit 105: Dressing Engines for Motorsport Vehicles.

This unit can be linked with *Unit 3: Vehicle Fault Diagnosis and Rectification*, *Unit 8: Petrol Injection Systems for Spark Ignition Engines*, *Unit 9: Diesel Fuel Injection Systems for Compression Ignition Engines* and *Unit 11: Vehicle Engine Management Systems*.

Essential resources

Centres will need to provide learners with access to a suitably equipped vehicle workshop, equipped to modern standards with live vehicles, test rigs and components that reflect current technology and working practices.

Indicative reading for learners

Hillier V and Coombes P — *Hillier's Fundamentals of Motor Vehicle Technology* (Nelson Thornes, 2004) ISBN 0748780823

Nunney MJ — *Light and Heavy Vehicle Technology* (Butterworth-Heinemann, 2006) ISBN 0750680377

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Tutors should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• taking measurements of engine bore, strokes, swept and clearance volume, wear calculations • preparing feedback on calculations and test procedures.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use this information to carry out multi-stage calculations to do with: a amounts or sizes b scales or proportion c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.
Communication Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• researching information on the principles of operation of an internal combustion engine, fuel, lubricating and servicing/repair procedures • preparing written evidence on the principles of operation of an internal combustion engine, fuel, lubricating and servicing/repair procedures.	C3.2 Read and synthesise information from at least **two** documents about the same subject. Each document must be a minimum of 1000 words long. C3.3 Write **two** different types of documents each one giving different information about complex subjects. One document must be at least 1000 words long.

Information and communication technology Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• researching the principles of operation of an internal combustion engine, fuel, lubricating and servicing/repair procedures • preparing and presenting evidence on the principles of operation of an internal combustion engine, fuel, lubricating and servicing/repair procedures.	ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case. ICT3.2 Enter and develop the information and derive new information. ICT3.3 Present combined information such as text with image, text with number, image with number.
Improving own learning and performance Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• preparing for and carrying out servicing and repair procedures, following given instructions.	LP3.1 Set targets using information from appropriate people and plan how these will be met. LP3.2 Take responsibility for your learning, using your plan to help meet targets and improve your performance. LP3.3 Review progress and establish evidence of your achievements.
Working with others Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• carrying out a routine engine service and major repair, following given instructions.	WO3.1 Plan work with others. WO3.2 Seek to develop co-operation and check progress towards your agreed objectives. WO3.3 Review work with others and agree ways of improving collaborative work in the future.