

Unit 13: Principles and Applications of Fluid Mechanics

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

Hydraulic and pneumatic power is widely used in the operation of engineering systems. The brakes on motor vehicles, railcar doors and hydraulic jacks and presses are typical examples. Fluid power is also widely used on aircraft, particularly for lowering and raising the undercarriage and for operating the control surfaces. Fluids often need to be stored and transported in vessels able to withstand high internal pressure. The design of sea defences and harbour installations also require a knowledge of the forces that can be exerted by a fluid. Water, oil and gas need to be transported by pipeline and each of these operations requires the design of suitable systems and the solution of engineering problems.

This unit builds upon the basic principles covered in *Unit 6: Mechanical Principles and Applications* and will introduce learners to a wider range of concepts and applications of fluid mechanics. In learning outcome 1 learners will be introduced to the properties of surface tension and viscosity. This is then followed by consideration of fluids at rest and the problems associated with hydrostatic systems.

Learning outcome 3 is concerned with the flow of fluids, particularly in pipelines and with the measurement of fluid flow. Learning outcome 4 introduces learners to the basic concepts of model testing and aerodynamics that find use in the design and testing of motor vehicles and aircraft.

Learning outcomes

On completion of this unit a learner should:

- 1 Know about the physical properties and characteristic behaviour of fluids
- 2 Be able to determine the forces acting in hydrostatic systems
- 3 Be able to determine the parameters of pipeline flow and impact of a fluid jet
- 4 Be able to determine the parameters of dynamic fluid systems.

Unit content

1 Know about the physical properties and characteristic behaviour of fluids

Surface tension: surface tension coefficient; capillary action

Viscosity: viscous behaviour eg dynamic viscosity, kinematic viscosity, effect of shearing in Newtonian fluids (water, lubricating oils) and non-Newtonian fluids (pseudoplastic, Bingham plastic, Casson plastic, dilatent); bearings eg plain journal, plain thrust; system parameters eg bearing dimensions, speed, viscosity of lubricant, viscous resistance, power loss

2 Be able to determine the forces acting in hydrostatic systems

Hydraulic devices: devices eg hydraulic jack, hydraulic press, hydraulic braking system; system parameters eg cylinder dimensions, input and output forces, internal pressure, input and output motions

Immersed surfaces: surfaces eg retaining walls of tanks and reservoirs, lock and sluice gates, immersed rectangular and circular inspection covers and hatches; system parameters eg surface dimensions, depth of immersion, hydrostatic pressure and thrust, position of centre of pressure

3 Be able to determine the parameters of pipeline flow and impact of a fluid jet

Pipeline flow: fluid principles eg equation of continuity of mass, equation of continuity of volume for incompressible flow, Bernoulli's equation, D'Arcy's equation; systems and devices eg pipes of varying section and level (such as an inclined tapering pipe), differential pressure flow measuring devices (venturi meter, orifice meter, Pitot-static tube)

Fluid jets: force exerted by a jet issuing from a stationary nozzle that impinges normally on a stationary vane eg flat plate, hemispherical cup; reaction of jet nozzle

4 Be able to determine the parameters of dynamic fluid systems

Model testing: wind-tunnel testing eg laminar and turbulent flow, flow around bluff bodies, dynamic pressure, theoretical and measured drag force, drag coefficient, application of Reynold's number, operation and use of the Pitot-static tube; test data eg measured drag force, model dimensions, air density, Pitot-static tube reading, density of manometer fluid

Aerodynamic systems: aerofoil applications eg aircraft lift surfaces, helicopter rotor blades, formula 1 racing cars; system parameters eg span, chord, angle of attack, plan area of lift surfaces, pressure distribution, stalled condition, lift force, drag force, lift and drag coefficients, airspeed, propeller efficiency, engine power requirements for an aircraft in level flight

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 describe 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 determine the surface tension coefficient for a given liquid on glass from its rise in a capillary tube	M1 calculate the viscous resistance and power loss in a lubricated plain thrust bearing from given data	D1 compare and explain the behaviour of the range of non-Newtonian fluids when they are subjected to shearing forces
P2 calculate the viscous resistance and power loss in a lubricated plain journal bearing from given system parameters	M2 determine whether the difference in levels between reservoirs connected by a pipe of given length and diameter is sufficient to supply a given flow rate	D2 compare and evaluate the uses of the venturi meter, orifice meter and Pitot-static tube for the measurement of fluid flow.
P3 determine the output force and motion of a hydraulic device from given system parameters	M3 determine the value of Reynold's number at which a particular flow pattern occurs around a model structure from given test data and the flow velocity at which the same pattern is likely to occur around the actual structure	
P4 determine the thrust on an immersed vertical retaining surface whose top edge is below the free surface of the retained liquid and the position of its centre of pressure	M4 explain the change in the flow pattern, pressure distribution and the lift and drag coefficients for an aerofoil as its angle of attack is increased.	
P5 determine the flow velocities at the inlet and exit sections of an inclined tapering pipe from differential pressure readings, and the volume and mass flow rates		

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:
<p>P6 determine the resultant thrust when a jet of fluid impinges normally on a stationary vane and the reaction of the jet nozzle</p> <p>P7 determine the dynamic pressure exerted on a wind-tunnel model and its drag coefficient from given test data</p> <p>P8 determine the lift and drag forces experienced and the engine power required for an aircraft travelling in level flight from given data.</p>		

Essential guidance for tutors

Delivery

Delivery of learning outcome 1 might start with a general description of compressible and incompressible fluid properties. The phenomena of surface tension and calculation of capillary effects can then be explained in detail and reinforced by a practical investigation, if time and facilities permit.

The definition of dynamic and kinematic viscosity and its measurement in SI units (International System of units) might be accompanied by mention of other measuring systems eg SAE classification for lubricating oils and systems specific to particular items of apparatus, such as the Redwood viscometer.

The identification of common Newtonian fluids and their behaviour should lead to the calculation of viscous resistance and power dissipation in machine slides and plain bearings. The range of non-Newtonian fluids, their behaviour and rheograms should be treated qualitatively with typical examples of each type.

Delivery of learning outcome 2 might start with a review of the work done in *Unit 6: Mechanical Principles and Applications*, where the concept of second moment of area may have been encountered for beam analysis. It may also have been used as an application of integral calculus in *Unit 4: Mathematics for Technicians*. Failing this, its expressions will need to be derived for a rectangle and a circle about a plain axis through the centroid and about a parallel axis, making use of the parallel axis theorem. An expression for the depth of the centre of pressure of an immersed plane surface can then be derived.

Associated problems should include determination of the thrust and its line of action for immersed rectangular and circular retaining surfaces. These might be inspection covers, sluice gates etc which are immersed at some distance below the free surface of the retained liquid, requiring calculation of the load on their fixings.

After revision of the equations of continuity of flow covered in *Unit 6: Mechanical Principles and Applications*, delivery of learning outcome 3 can start with consideration of the energy forms that may be present in a fluid. Learners will be familiar with the expressions for gravitational potential energy and kinetic energy, but the concept of pressure-flow energy may need to be explained and developed.

There are different approaches to the derivation of Bernoulli's equation but it may be beneficial to begin by developing the full steady flow energy equation. This will be particularly useful to learners intending to take *Unit 14: Principles and Applications of Thermodynamics*. Bernoulli's equation may be derived directly from this and applied to the solution of problems on pipeline flow and differential pressure flow measuring devices.

Problems on pipeline flow should include the consideration of head loss due to pipe friction. This will warrant a discussion of laminar and turbulent flow, fluid viscosity and the associated boundary layer effects. D'Arcy's formula should be introduced as a means of estimating friction head loss and be applied to problems involving the steady flow due to gravity between reservoirs at different levels.

A revision of Newton's laws may be necessary before applying them to determine the reaction of a jet nozzle and the thrust of an impacting fluid jet. The derived expressions may be applied successively to problems involving the impact of a jet on a stationary flat plate, hemispherical cup, and a pipe bend. If time and facilities permit, practical investigations of differential pressure flow measurement, laminar and turbulent flow and the impact of a jet would be of value to reinforce delivery of this learning outcome.

The description of laminar and turbulent flow in the final learning outcome might be reinforced with video footage showing the onset of turbulence and formation of flow patterns in wind-tunnels and flow tanks. The effects of inertia and viscous resistance could then be discussed, leading to the concept of Reynold's number. Its value for fully developed laminar flow in pipes should be identified and its use in flow tank and wind-tunnel testing explained. Flow around a cylindrical body might also be described, giving the values of Reynold's number associated with changes of flow pattern.

Delivery of the final learning outcome might continue with a description of the Pitot-static tube and its operation in measuring flow velocities. This could be followed by identification of the factors that contribute to the drag force on a bluff body in a fluid stream. The relative effects of form drag and skin friction drag should be discussed followed by derivation of the expressions for dynamic pressure and drag coefficient. Problems to determine drag coefficient from wind-tunnel test data can then be solved.

An explanation of aerofoil geometry should be confined to the basic profile and the symbols commonly used for chord, span, projected plan area and angle of attack. Pressure distribution and airflow diagrams for normal flight and stalled condition should be presented and explained. Expressions may then be derived for the lift and drag forces in terms of the dynamic pressure, projected plan area the lift and drag coefficients. Typical values of lift and drag coefficient for increasing angle of attack up to the stalled condition, might be presented graphically. Problem solving should include calculation of the lift and drag forces on aircraft and the engine power required in level flight.

Assessment

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

The first assignment could cover criteria P1, P2, M1 and D1. A task to achieve P1 could require learners to develop and apply the expression used to determine surface tension coefficient from the rise of liquid in a capillary tube.

A second task to achieve P2 might involve consideration of a plane journal bearing, where learners are progressively required to determine the lubricated area and shearing velocity to meet the viscous resistance and power loss requirements.

A third task to achieve M1 could require the application of integral calculus to determine the above parameters for a plain thrust bearing.

A final task to achieve D1 could require learners to compare and explain the behaviour of non-Newtonian fluids, supported by the appropriate rheograms.

The second assignment could provide the opportunity to achieve pass criteria P3 and P4 which are associated with learning outcome 2. A task to achieve P3 should involve calculation of the output parameters of a hydraulic press, jack or braking system. A further task to cover P4 would involve consideration of the thrust and its line of action on an immersed rectangular or circular surface whose top edge is below the free surface of a liquid.

Criteria P5, P6 and M2 could be assessed by separate tasks in a third assignment. The task to achieve P5 should ask for the simultaneous solution of the continuity equation and Bernoulli's equation to determine flow velocities in an inclined and tapering pipe. These can then be used to determine flow rate. The task to achieve P6 should require calculation of the input and output velocities for a jet nozzle from a given value of either the volume flow rate or supply head. The nozzle reaction and the normal force exerted by the jet on a stationary vane can then be determined.

M2 could be covered by a task involving the calculation of likely head loss along a pipe connecting two reservoirs using D'Arcy's formula. The pipe friction coefficient should be given and the estimated friction head loss compared to the potential head difference between the reservoirs. A judgement can then be made as to whether the required flow rate is feasible without the installation of a pump.

A final assignment could provide the opportunity to achieve criteria P7, P8, M3, M4 and D2. The task to achieve P7 should require calculation of dynamic pressure from either a given flow velocity or Pitot-static tube reading. The theoretical drag force and drag coefficient for a bluff body can then be calculated using given values of projected area and measured drag force.

To achieve P8 learners will need to calculate lift and drag forces acting on an aircraft from given values of lift and drag coefficient, airspeed and projected area of the lift surfaces. The required engine power can then be determined, taking into account propeller efficiency.

The test data required for a task to achieve M3 should include the control dimensions of the test model and actual structure. The model could be of any bluff body such as a cylinder or bridge pier around which a turbulent flow pattern is seen to occur at some particular value of flow velocity. The dynamic viscosity and density of the fluid should also be supplied.

A further task to achieve M4 should require learners to provide an evaluation of aerofoil performance supported by appropriate diagrams. The final task to achieve D2 should require learners to evaluate the uses of the ranged flow measuring devices, making reference to typical applications, flow impedance, ease of installation, cost and sensitivity.

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

This unit builds on the fluid mechanics covered in *Unit 6: Mechanical Principles and Applications*. It has links with *Unit 14: Principles and Applications of Thermodynamics* and lays the foundation for further study at BTEC Higher National Certificate/Diploma level.

The unit provides some of the underpinning knowledge for the SEMTA Level 3 NVQ in Mechanical Manufacture, Level 3 NVQ in Engineering Maintenance and Level 3 NVQ in Engineering Technical Support.

Essential resources

Centres should be equipped with laboratory facilities containing the investigation and demonstration equipment necessary for delivery of the unit content. In particular, a metered hydraulics bench with attachments to investigate differential pressure flow measurement, fully developed laminar flow in pipes and the impact of a jet would be of value.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Option Units* (Newnes, 2003)
ISBN 0750657618

Douglas J, Gasiorek J and Swaffield J – *Fluid Mechanics* (Prentice Hall, 2005)
ISBN 0131292935

Douglas J and Mathews R – *Solving Problems in Fluid Mechanics* (Longman, 1996)
ISBN 0582239877

Hannah J and Hillier M J – *Mechanical Engineering Science* (Prentice Hall, 2000)
ISBN 0582326753

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. Staff 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:
<ul style="list-style-type: none"> determining the surface tension coefficient for a given liquid on glass from its rise in a capillary tube. 	N3.1 Plan an activity and get relevant information from relevant sources. N3.3 Interpret the results of your calculations, present your findings and justify your methods.
Problem solving Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> determining the flow velocities at the inlet and exit sections of an inclined tapering pipe from given differential pressure readings, and the volume and mass flow rates. 	PS3.1 Explore a problem and identify different ways of tackling it. PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.