UNIT 514 ANALYSIS OF THE MECHANICS OF FLUIDS

Lesson 1: Introduction and basic principles

Suggested Teaching Time: 3 hours

Learning Outcome: Understand the principles of fluid mechanics

Topic	Suggested Teaching	Suggested Resources
Introduction and basic principles	• The tutor should go through the unit specification and explain the need for an understanding of the principles of fluid mechanics and the way in which they influence mechanical engineering. The progressive link between the four learning outcomes should be stressed. A short question and answer session should be used to check learner understanding of what is to be covered, but it is clearly not a requirement for learners to understand the content before it is taught. • The learners should be provided with a glossary of the terms to be used in the unit and encouraged to align each term against specific assessment criteria, as and where relevant. Each term will of course be fully explained later, at the appropriate stage of the teaching and learning process. • The tutor should use the unit specification to explain how the unit is to be assessed. This should deal with whether the assessment is to be external or internal, by examination or assignment, and the nature of the evidence that will need to be provided.	• Unit specification • Glossary of terms • Sample assessment materials **Websites:** www.imeche.org (Institution of Mechanical Engineers) www.engc.org.uk (Engineering Council) www.instituteofwater.org.uk (Institute of Water)

Lesson 2: Conservation equations of fluid mechanics **Suggested Teaching Time:** 8 hours

Learning Outcome: Understand principles of fluid mechanics

Topic	Suggested Teaching	Suggested Resources
Conservation equations of fluid mechanics (AC 1.1)	• The tutor must introduce the leaners to the concepts implied by conservation laws i.e. that particular measurable properties of an isolated physical system do not change as the system evolves. This should include the conservation of mass, energy and momentum as applied to fluids. • Learners should be split into small groups and given a specific subject to research. These should include the conservation of mass and what this implies, the conservation of energy and how this relates to the first law of thermodynamics, and the conservation of momentum and how this relates to Newton's second law of motion. • Each group should make a short presentation of their findings and be prepared to answer questions. Hard copies of the presentations should be circulated to the whole class. • This should be followed by a whole-class, tutor-led discussion about how conservation equations link to principles of continuity, Bernoulli's equation, specific energy and force. • All of the above could be usefully underpinned by laboratory demonstrations of streamlined and turbulent flow, the relevance of Reynold's number, Bernoulli's theorem and applications of same.	**Books:** Massey, Bernard S., and Ward-Smith, John, *Mechanics of Fluids* 9th edition, Taylor and Francis Ltd (2011), ISBN-10: 0415602599, ISBN-13: 978-0415602594 **Websites:** Energy and momentum http://www.most.gov.mm/techuni/media/CE_04016_chap2.pdf Demonstrations of energy and momentum http://education-portal.com/academy/topic/energy-and-momentum.html Equations in fluid mechanics www.engineeringtoolbox.com/fluid-mechanics-equations-d_204.html

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Lesson 3: Kinematics of fluid motion

Suggested Teaching Time: 8 hours

Learning Outcome: Understand principles of fluid mechanics

Topic	Suggested Teaching	Suggested Resources
Kinematics of fluid motion (AC 1.2)	• The tutor should clearly differentiate between vectors and scalars and emphasise the relevance of each in kinematics. • This should be developed into an understanding of how fluid flow can be characterised by 3-D velocity vector fields, and how these can be described by field lines such as flow nets, particle paths, streamlines, streamtubes and streaklines. • The class should be split into small groups with each group researching a specific field line, and then either accessing or producing graphs or tables of each. • These should be used to inform short group presentations to the rest of the class. Each group will need to answer questions. • The terms rotational and irrotational flow, circulation and vorticity should be defined by the tutor, but not in mathematical terms. It is sufficient to know that rotational flow implies deformation of the fluid, that irrotational flow implies a fluid rotating as a **whole**, that circulation is a scalar measure of the macroscopic rotation of that rotation and vorticity is a microscopic vector measure of the 'tendency to spin'. • Learners should undertake independent research into the weblinks suggested in the resources column to the right.	**Books:** Massey, Bernard S., and Ward-Smith, John, *Mechanics of Fluids* 9th edition, Taylor and Francis Ltd (2011), ISBN-10: 0415602599, ISBN-13: 978-0415602594 **Websites:** http://www.physicsclassroom.com/class/1DKin/Lesson-1/Scalars-and-Vectors http://www.youtube.com/watch?v=TOUylg7Eyec http://www.ess.uci.edu/~yu/class/ess228/lecture.4.vorticity.all.pdf https://www.youtube.com/watch?v=d97Yr-03d4M

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Lesson 4: Viscosity of flowing fluids and dimensional analysis

Suggested Teaching Time: 8 hours

Learning Outcome: Understand principles of flowing fluids

Topic	Suggested Teaching	Suggested Resources
Explain **viscosity** of flowing fluids (AC 1.3) Apply dimensional analysis to flowing fluids (AC1.4)	• The tutor must explain the principle of viscosity as it applies to both Newtonian and non-Newtonian fluids in terms of fluid motion, friction, shear forces and streamlines. • Laboratory demonstrations could be used to show simple flows resulting from a combination of uniform stream, source, sink, doublets and point vortices. This should be clearly linked to the concept of viscosity in the fluid. • The tutor should provide diagrams of how fluids flow around a circular cylinder, with graphs and calculations to show what this implies for circulation, pressure distribution and lift force. • A whole-class, teacher-led discussion will help to embed the use of geometric, kinematic and dynamic similarities in fluid flow to test engineering models. This can be supported by the use of dimensional analysis. • The tutor should introduce the Buckingham π theorem and demonstrate how this is related to Rayleigh's method. • The tutor should demonstrate their purpose and use to derive the principal dimensionless numbers shown below. • Small groups should be given a different number to determine. These should include Reynolds, Euler, Froude, Mach numbers; coefficients for pressure, lift and drag, and roughness ratios.	**Books:** Douglas, John F., Gasiorek, Janusz M., Swaffield, John A., and Jack, Lynne B., *Fluid Mechanics*, 6th edition, Pearson 2011, 978-0-13-129293-2, ISBN-10: 0273717723, ISBN-13: 978-0273717720 **Websites:** https://ecourses.ou.edu/cgi-bin/ebook.cgi?doc=andtopic=flandchap_sec=07.3andpage=theory http://www.ukessays.com/essays/biology/pressure-distribution-around-circular-cylinder-lab-report-biology-essay.php http://imechanica.org/files/Sato_MDAC_final_2232012.pdf

Lesson 5: Inviscid fluid flows **Suggested Teaching Time:** 8 hours

Learning Outcome: Understand the mechanics of flowing fluids

Topic	Suggested Teaching	Suggested Resources
Analyse inviscid fluid flows (AC 2.1) Evaluate the effects of viscosity in fluid flows (AC 2.2)	• The tutor must define the terms viscosity, viscid and inviscid and explain what each means in terms of laminar and turbulent flow and Reynold's number. • The learners should use independent research to determine what the above implies for the effects of viscosity, including the drag force (frictional force) as predicted by Stokes' law and the relevance and practice of the Boundary Layer theory. • This should be reinforced by a targeted question and answer session designed to embed the concepts in the learners' understanding. • The learners should access the website relating to vortices as indicated on the right. This should be followed by a whole-class discussion of how vortices comprise fluids spinning about an axis, that they are a major component of turbulent flow, and the part played by viscous friction in their formation.	**Books:** Massey, Bernard S., and Ward-Smith, John, *Mechanics of Fluids* 9th edition, Taylor and Francis Ltd (2011), ISBN-10: 0415602599, ISBN-13: 978-0415602594 **Websites:** Viscosity http://alevelnotes.com/Upthrust-and-Viscosity/113?tree= Boundary layer principles https://www.math.ucdavis.edu/~hunter/m204/boundary.pdf Vortices http://www.whoi.edu/fileserver.do?id=9349andpt=2andp=12248 Laminar and turbulent flows http://www.efm.leeds.ac.uk/CIVE/CIVE1400/Section4/laminar_turbulent.htm Drag forces http://www.ce.utexas.edu/prof/kinnas/319LAB/Applets/Viscous/viscous.html

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Lesson 6: Laminar flow of incompressible fluids using boundary layer theory **Suggested Teaching Time:** 7 hours

Learning Outcome: Understand the mechanics of flowing fluids

Topic	Suggested Teaching	Suggested Resources
Laminar flow of incompressible fluids using boundary layer theory (AC 2.3) Boundary layer transition (AC 2.4)	• The tutor should extend the learning in the previous lesson to develop an understanding of how the boundary layer concept, vortices, laminar and turbulent flows, wakes and viscous drag interact. • Learners should work in small groups to research any one of the following: displacement and momentum thicknesses, skin-friction coefficients, the drag on a flat plate. They should provide copies of their research for the rest of the class. • In particular, for steady, two-dimensional laminar flows, the learners should research the importance of the Euler and Bernoulli equations of motion, the stream function and the velocity potential function. • Worked examples should be provided by the tutor and the learners should practise using the equations. • Laminar flow should be practically demonstrated for simple combinations of a uniform stream, source, sink, doublet and point vortex, and for flow around a circular cylinder. • The effects of circulation, pressure distribution and lift force on the latter should be discussed after consideration of the practical demonstrations.	**Books:** Massey, Bernard S., and Ward-Smith, John, *Mechanics of Fluids* 9th edition, Taylor and Francis Ltd (2011), ISBN-10: 0415602599, ISBN-13: 978-0415602594 **Websites:** Boundary layer theory http://user.engineering.uiowa.edu/~me_160/lecture_notes/ch7fall2010-2.pdf Boundary layer tutorial http://www.freestudy.co.uk/fluid%20mechanics/t3203.pdf Boundary layer transition http://www.efm.leeds.ac.uk/CIVE/FluidsLevel1/Unit04/T2.html

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Lesson 7: Turbulent flow of incompressible fluids and boundary layer separation **Suggested Teaching Time:** 6 hours

Learning Outcome: Understand the mechanics of flowing fluids

Topic	Suggested Teaching	Suggested Resources
Turbulent flow of incompressible fluids and boundary layer separation (AC 2.5, 2.6 and 2.7)	• The tutor should introduce the concept of turbulent flow in terms of displacement and momentum thickness in laminar flow, and explain the relevance of skin friction (and the consequent drag on a flat plate), laminar sub-layers and surface roughness effects. • Learners should conduct individual research into the power law and logarithmic velocity distribution in turbulent flows. The websites to the right will be useful here. • There should follow a whole-class discussion of the purpose of Moody's diagram and its applications in the relationship between friction factors, Reynolds number and relative roughness. • The tutor should provide annotated examples of Moody's diagram/chart in use, to support the above discussion, and learners should then be given the opportunity to use the diagram to inform their understanding of turbulent flow. • This should be developed into an understanding of how a non-streamlined object in the flow can cause the boundary layer to separate and create a vortex-filled wake. This can be demonstrated practically, to good effect.	**Website:** Incompressible flow http://www.engr.uconn.edu/~wchiu/ME3250FluidDynamicsI/lecture%20notes/ch09.pdf Basics of turbulent flows http://www.mit.edu/course/1/1.061/OldFiles/www/dream/SEVEN/SEVENTHEORY.PDF Logarithmic velocity profile http://www.engr.colostate.edu/~pierre/ce_old/classes/CE413/CIVE413%20Turbulence.pdf Moody's diagram http://www.engineeringtoolbox.com/moody-diagram-d_618.html Moody's diagram http://faculty.kfupm.edu.sa/CHE/alshami/teaching/Che%20204/Lecture%20Notes/Chapter%203_Lect%20Notes_Turbulent%20Flow%20and%20Moody%20Diagram.htm Flow classification http://www.efm.leeds.ac.uk/CIVE/CIVE1400/PDF/Notes/section3.pdf

Lesson 8: Steady compressible fluid flow

Suggested Teaching Time: 6 hours

Learning Outcome: Understand the mechanics of flowing fluids

Topic	Suggested Teaching	Suggested Resources
Steady compressible fluid flow (AC 2.8)	• The tutor should define the important terms and provide supporting diagrams and charts. • Learners should work in small groups to research one of the following: stagnation pressure, effects of temperature and density, subsonic flow, isentropic flow of a perfect gas in ducts of varying cross-sectional area in terms of Mach number, choked flow; supersonic flow and the formation of normal shocks in a convergent-divergent nozzle. The websites on the right will prove helpful. • Each group should make a short presentation to the rest of the class, supported by hard copies for circulation to all. They should expect to answer questions from the other groups and from the tutor.	**Websites:** Steady compressible flow http://www.efm.leeds.ac.uk/CIVE/CIVE1400/Section3/dynamics.htm Stagnation Pressure http://nptel.ac.in/courses/Webcourse-contents/IIT-KANPUR/FLUID-MECHANICS/lecture-16/16-2_stagnetion_pressure.htm Isentropic flow http://www.potto.org/gasDynamics/node79.html Isentropic flow examples http://www.potto.org/gasDynamics/node83.html Chocked clow http://www.mycheme.com/choked-flow-in-gases/ Supersonic flow http://www.answers.com/topic/supersonic-flow Converging nozzle http://www.engapplets.vt.edu/fluids/CDnozzle/cdinfo.html

Lesson 9: Performance and operating conditions for incompressible fluid turbo-machines **Suggested Teaching Time:** 6 Hours

Learning Outcome: Understand available performance of incompressible fluid turbo-machines

Topic	Suggested Teaching	Suggested Resources
Design performance of Incompressible fluid turbo-machines (AC 3.1) Turbo-machine operating conditions (AC 3.2)	• Learners should have the opportunity to see turbo-machines in operation. Their mode of operation can be explained using cut-away models, diagrams and the website shown on the right. • The tutor should provide worked examples of the use of one-dimensional analysis to evaluate design performance and the learners must then practice such analyses. • Learners should work in small groups to research any one of the following per group: centrifugal, axial and mixed-flow machines; the concept of NPSH (net positive-suction head; flow, head and power coefficients; specific speed and optimum pump operation. • Each group must provide concise texts, diagrams and charts as appropriate, for circulation to the rest of the class.	**Books:** Featherstone, R. E., and Nalluri, C., *Civil Engineering Hydraulics*, 4th edition, Wiley-Blackwell 2001, ISBN: 0632055146 Hamill, Lee, *Understanding Hydraulics*, 3rd edition, Palgrave Macmillan 2011, ISBN: 0231242758 **Website:** Flow in turbo-machinery http://authors.library.caltech.edu/25019/1/chap1.htm