Engineering Tripos Part IIA, 3A3: Fluid Mechanics II (double module), 2020-21

Module Leader

Dr Luca Magri [1]

Lecturers

Luca Magri, Dr S Scott, Dr J Jarrett and Dr J Longley

Lab Leaders

Prof H Babinsky and Dr L Xu

Timing and Structure

Michaelmas and Lent. 32 lectures.

Aims

The aims of the course are to:

- To understand fluid flows to a level such that the pressures and resultant forces acting can be estimated in situations involving complex geometries of industrial interest at both subsonic and supersonic speed.
- To understand the effects of viscosity and heat transfer, where relevant

Objectives

As specific objectives, by the end of the course students should be able to:

- Know the concepts of stagnation temperature and stagnation pressure and be able to determine their values from a knowledge of static temperature, static pressure and Mach number.
- Know how conservation principles determine the behaviour of normal shock waves and be able to use tables to quantify that behaviour.
- Evaluate Mach number of a flow from measurements of Pitot and static pressures.
- Determine flow patterns in nozzles under the assumption of one dimensionality, using tables.
- Know how Mach number and other flow properties change under the influence of friction or heat exchange, and be able to quantify this using tables.
- Know how to construct and interpret x-t diagrams for unsteady ID flow.
- Quantify the behaviour of hydraulic jumps and infinitesimal waves in shallow water.
- Understand the influence of the speed of sound on two-dimensional compressible flow behaviour.
- Apply the two-dimensional method of characteristics for simple flows and flows involving reflection/cancellation.
- Understand the origin of oblique shock waves and their reflection.
- Apply the preceding ideas to practical flows via shock-expansion theory, linearised method of characteristics and linearised potential theory.
- Know how to construct and use numerical solution methods for the equations of fluid flow using finite difference and finite volume approximations
- Know how to estimate the accuracy and analyse the stability of numerical schemes

- Identify and understand the operation of different types of turbomachinery.
- Analyse turbomachinery performance.
- Understand the causes of irreversibilities within the blade passages and their affects on the overall efficiency.
- Analyse compressible flow through turbomachines.

Content

One-dimensional Compressible Flow (12L): 2 lectures/week, weeks 1-6 Michaelmas term (Luca Magri)

- Steady, adiabatic and inviscid flow; speed of sound; reversibility; the stagnation state; the effect of area variation on subsonic/supersonic flow, choking; normal shock waves; flow patterns in nozzles; use of table for isentropic flow and for shock waves.
- Fanno and Rayleigh line processes for the effects of friction and heat exchange.
- Introduction to unsteady flow. Hydraulic analogy for steady compressible flow; speed of waves in shallow water; the hydraulic jump; the venturi flume; weirs.

Two-dimensional Compressible Flow (8L): 2 lectures/week, weeks 7-8 Michaelmas term and weeks 1-2 Lent term (Dr JP Jarrett)

- Method of characteristics, expansion fan and compression ramp.
- Oblique shock waves, strong and weak solutions.
- Shock-expansion theory
- Potential equation and linearisation.

Equations of Fluid Flow and their Numerical Solution (6L): 2 lectures/week, weeks 3-5 Lent term (Dr S Scott)

- Numerical solution techniques; finite difference approximations; finite volume approximations; order of accuracy, diffusion and dispersion errors; stability considerations for time iterative techniques
- Classification of equations; numerical solution of the Euler equations, nonlinearity and shock waves

Turbomachinery (6L): 2 lectures/week, weeks 6-8 Lent term (Dr JP Longley)

- Identify and understand the operation of different types of turbomachinery.
- Analyse turbomachinery performance.
- Understand the causes of irreversibilities within the blade passages and their affects on the overall efficiency.
- Analyse compressible flow through turbomachines.

Coursework

There are 2 parts of coursework, one in Michaelmas and one in Lent (and in these terms only).

The Michaelmas lab will be done live in the lab. Instructions and preparatory material will be on moodle.

You need to book the slots on Moodle early in term.

If future COVID-19-related policies affect the way that labs are being delivered, the updates will be communicated through Moodle.

Turbomachinery

Learning objectives:

- to study the characteristics of a typical centrifugal pump;
- to study the role of the velocity triangles play in the pump characteristics;
- to understand the key non-dimensional groups used to represent the pump characteristics;
- to study the effect of Reynolds number on the pump performance by varying the pump speeds and the viscosity of the working fluids;
- to observe the phenomenon of cavitation in a pump;
- to appreciate the validity and limitations of the simple dimensional analysis for the pump performance;
- to learn different ways of measuring mass flow rate;
- to appreciate the advantage and limitation of using a venturi nozzle to measure mass flow rate.

Practical information:

- Sessions will take place in the Hopkinson Laboratory in the Lent Term;
- This activity does not involve preliminary work, but a preview of the relevant lecture notes as well as the labsheets before the lab would be helpful.

Full Technical Report:

Students will have the option to submit a Full Technical Report based on the lab and research on further reading.

Nozzle and supersonic tunnel

Learning objectives:

- to study the pressure distribution in convergent-divergent nozzles for various pressure ratios;
- to observe the phenomenon of choking;
- to become familiar with the essential features of a supersonic wind tunnel;
- to understand the basic principles of a schlieren system for flow visualisation;
- to observe fundamental flow changes through a normal shock-wave;
- to appreciate the validity and limitations of one-dimensional, adiabatic, inviscid theory.

Practical information:

- Sessions will take place in the Aerolab;
- This activity doesn't involve preliminary work.

Full Technical Report:

Students will have the option to submit a Full Technical Report.

Booklists

Please refer to the Booklist for Part IIA Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [3] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

P4

Understanding use of technical literature and other information sources.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

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