Engineering Tripos Part IIA, 3A1: Fluid Mechanics I (double module), 2021-22

Module Leader

Dr A Agarwal [1]

Lecturers

Prof H Babinsky, Dr J Lie, Prof M Juniper

Lab Leaders

Dr A Anurag, Prof P Davidson

Timing and Structure

Michaelmas and Lent. 32 lectures.

Aims

The aims of the course are to:

- Develop an understanding of when and where fluid flows can be modelled as incompressible and inviscid.
- Develop simple analytical and computational methods to solve incompressible and inviscid flows, and build up physical understanding through a range of practical examples.
- Introduce the effects of viscosity, and discuss boundary layer flows in some detail.
- Bring the ideas developed together in two applications sections, which consider the aerodynamics of aircraft wings and road vehicles.

Objectives

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

- Know when and where incompressible fluid flows can be modelled as irrotational.
- For two-dimensional incompressible flow, use the complex potential to determine the velocity and pressure distribution in simple geometries eg. corner flow.
- For two-dimensional incompressible flow, superimpose elementary solutions to calculate velocity and pressure distributions in a range of practical flows.
- For two-dimensional incompressible flow, know that the panel method leads to an efficient computational scheme.
- For two-dimensional incompressible flow, understand the relationship between circulation and lift.
- Use images to investigate ground effects and the influence of wind-tunnel walls.
- Use elementary solutions to calculate velocity and pressure in some simple three-dimensional flows.
- Use vortex dynamics to explain the development of simple three-dimensional flows.
- For boundary layer flows, understand the coupling between the viscous-dominated near-field flow and the inviscid far-field.
- Understand classical and integral solution techniques.
- Understand the difference between laminar and turbulent flows and transition.
- Understand the nature of flow around an aircraft.

- Understand the interaction between lift and induced velocity.
- Estimate the lift and drag of aircraft wings
- Qualitatively understand the effects of viscosity on the flow around airfoils and wings
- Describe the physical features of the flow around a road vehicle.
- Understand the origins of the aerodynamic forces on a road vehicle
- Explain how the aerodynamic forces are affected by road vehicle shape.

Content

Incompressible Flow (10L); 2 lectures/week, weeks 1-5 Michaelmas term (Prof S Hochgreb)

- Irrotational flow and the velocity potential.
- *Two-dimensional flow:*stream function and streamline; complex potential; sources, sinks and vortices; superposition of elementary sources to determine real flows; panel method; circulation and lift; use of images.
- *Three-dimensional flow:*sources and sinks; vorticity in 3D, Kelvin's circulation theorem.
- *Viscous effects*: Navier Stokes equation, vorticity equation.

Boundary Layer Flows (10L); 2 lectures/week, weeks 6-8 Michaelmas term and 1-2 Lent (Dr J Li)

- The boundary layer equations.
- Laminar boundary layers, similarity solutions
- Thwaites method, numerical methods.
- Turbulent boundary layers, the log law.
- Turbulent boundary layers with roughness
- Pipe flows

Applications I - Aerofoils and Wings (8L); 2 lectures/week, weeks 3-6 Lent term (Prof H Babinsky)

Two-dimensional aerofoil flows:

- modelling assumptions;
- vortex sheet panel method;
- thin aerofoil theory;
- lumped parameter modelling;
- viscous effects and stall.

Three dimensional wing flows:

- general features;
- panel methods in 3D;
- lifting line theory;
- lumped parameter modelling;
- wing stall;

Applications II - Aerodynamics of Road Vehicles (4L); 2 lectures/week, weeks 7-8 Lent term (tbc)

- Review of fundamental concepts : bluff-body aerodynamics, friction vs pressure drag, 2 and 3 dimensional bodies, ground effect
- Drag of passenger cars ; boat-tailing, tail shapes, skirts
- Lift/downforce: spoilers, wings, diffusers
- Drag of haulage vehicles: tractor/trailer junction, trailer shape effects, cross-wind stability .

Coursework

Flow Around Bodies of Revolution

Learning objectives:

- To measure the drag forces on three bodies of revolution over a range of flow speeds.
- To observe some aspects of the flow structures with oil flow and a tuft mast.
- To obtain curves of drag coefficient versus Reynolds number.
- To find the critical Reynolds Number at which the flow pattern on a sphere changes from a high drag regime to a low drag one.

Practical information:

- Due to COVID-19 restrictions, data normally obtained in the laboratory may be provided by other means.
- Any practical sessions will take place in the 3rd-floor Aerodynamics Laboratory, during Michaelmas week(s) 1-4 (approx).
- This activity does not involve preliminary work.

Full Technical Report:

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

Turbulent Boundary Layer

Learning objectives:

- To observe with the aid of a hot-wire anemometer and a stethoscope the transition from a laminar to a turbulent boundary layer on a flat plate under various conditions.
- To obtain the transition Reynolds numbers.
- To measure the angle of the turbulent wedge that is formed downstream of a roughness element.
- To measure the mean and turbulence profiles of the boundary layer when it is fully turbulent.
- To use the mean flow velocity profile to estimate the skin friction coefficient.

Practical information:

- Due to COVID-19 restrictions, data normally obtained in the laboratory may be provided by other means.
- Any practical sessions will take place in the 2nd-floor Aerodynamics Laboratory, during a limited period in the Lent term.
- This activity does not 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).

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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