Engineering Tripos Part IB, 2P4: Thermofluid Mechanics, 2017-18

Lecturers

Prof R Miller, Dr R Garcia-Mayoral and Dr S Scott [1]

Timing and Structure

Weeks 1-5 Michaelmas term (Dr R Garcia-Mayoral), week 6-8 Michaelmas and weeks 1-2 Lent term (Dr SA Scott), weeks 3-5 Lent term (Prof RJ Miller), 26 lectures, 2 lectures/week

Aims

The aims of the course are to:

- Review inviscid flow in three dimensions and derive the Euler equation.
- Examine the effects of viscosity on fluid flow.
- Introduce the phenomena of laminar and turbulent flow and of boundary layers.
- Explore the issues associated with scaling fluid flows and conducting model tests.
- Introduce the concept of availability.
- Show how irreversibilities affect the performance of gas power cycles.
- Introduce the properties of working substances other than ideal gases.
- Describe and analyse simple steam power plant, including the effect of irreversibilities
- Introduce and analyse refrigeration and heat pump cycles.
- Describe how to evaluate the properties of gas and gas/vapour mixtures.
- Show how the First Law may be applied to Combustion
- Develop analysis tools for 1D heat condition, and simple transient conduction problems.
- Examine heat transfer by convection.
- Introduce heat transfer by thermal radiation, including radiation in the environment.
- Describe common types of heat exchanger, and perform an elementary analysis of performance

Objectives

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

- Be able to set up the equations governing laminar viscous flow, and solve them for simple problems.
- Understand how irreversibilities arise in fluid flow and be able to make estimates of loss, drag, etc.
- Describe qualitatively the basic characteristics of boundary layers in internal and external flows.
- Understand the relevance of non-dimensional groups in determining the qualitative nature of fluid flow and how to apply this to model testing.
- Understand the effects of irreversibilities in gas, steam power cycles, and heat pump/refrigeration cycles.
- Understand and be able to use tables of properties for common working substances.
- Understand how to evaluate the properties of arbitrary mixtures of perfect gases, and gas/vapour mixtures, and apply this understanding to problems in psychrometry and combustion.
- Be able to analyse simple problems in conduction, convection and radiation heat exchange.
- Understand the physical principles underlying heat transfer correlations and be able to use these to estimate heat transfer coefficients.

Content

Fluid Mechanics: lectures 1-10

Properties of a fluid (1L)

- Molecular picture vs. continuum picture
- Partial derivatives
- Law of conservation of mass
- Incompressible flow

Incompressible inviscid flow (1L)

- The material derivative, D/Dt
- Euler's equation
- Bernoulli's equation
- Streamline curvature
- Determination of the pressure field from the streamlines of a flow

Incompressible viscous flow and boundary layers (2L)

- Viscosity: momentum transfer through molecular motion
- Couette flow and Poiseuille flow
- The Navier-Stokes equation
- Boundary layers
- Pressure gradients in boundary layers
- Boundary layer separation

Turbulence and the Pipe Flow Experiment (1L)

- Laminar flow in a pipe with circular cross-section
- Turbulent flow
- Mixing, momentum transport and eddy viscosity
- Roughness

Network analysis (1L)

- Static pressure and stagnation pressure
- Stagnation pressure losses across pipe components
- Stagnation pressure changes across pumps and compressors
- Network analysis

The Boundary Layer Experiment (1L)

- Reynolds number in a boundary layer
- Transition to turbulence in a boundary layer
- Effect of turbulence on a boundary layer
- Comparison of transition and separation
- Boundary layer re-attachment

The External Flow and Drag Experiment (1L)

- Lift and drag
- Flows at very low Reynolds number (creeping flow)
- Flows at low Reynolds number
- Flows at high Reyholds number
- Mechanisms of drag reduction
- Vortex shedding
- Inviscid flow and Hele-Shaw cells

Dimensional analysis, scaling and model testing (1.5L)

- Dimensional analysis: the philosopher's, Mathematician's and engineer's approach

- Orific plate example
- Aeroplane example
- Ship example

Introduction to Compressible Flow (0.5L)

- The Steady Flow Energy Equation
- Stagnation enthalpy and stagnation termperature
- Viscous dissipation and irreversibility
- Transfer form thermal energy to mechanical energy.
- Incompressible flows and stagnation pressure.

Heat transfer: lectures 11 - 16

Heat Transfer by Conduction (2L)

- Conduction in solids - Fourier's law
- Energy balance in 1D
- Overall resistance to heat transfer
- Dimensional analysis
- Lumped heat capacity model

Heat Exchangers (0.5L)

- Description of major types
- Analysis, effectiveness, LMTD

Heat Transfer by convection (2L)

- Energy considerations for flows with heat transfer
- Forced convection, Reynolds and Prandtl, Nusselt and Stanton numbers
- Reynolds analogy
- Natural convection. Grashoff and Rayleigh numbers

Heat Transfer by Radiation (1.5L)

- Energy considerations for flows with heat transfer
- Forced convection, Reynolds and Prandtl, Nusselt and Stanton numbers
- Reynolds analogy
- Natural convection. Grashoff and Rayleigh numbers

Heat Transfer by Radiation (1.5L)

- Radiation from black bodies
- Emissivity and radiation from grey bodies
- View factors
- Radiation networks.

Thermodynamics: lectures 17 - 26

Introduction, review of previous material (1L)

- 1st & 2nd laws applied to steady flow device
- The ‘quantity’ and ‘quality’ of energy
- Irreversible entropy creation
- Examples of steady-flow devices

Maximum available power(1L)

- The different value of work and heat

- The maximum available power in a steady flow device
- The dead state
- How to apply availability to a steady flow device
- Lost power potential due to irreversible

Gas turbines(1L)

- Compressor and turbine irreversibilities
- Combustion changes in gas composition
- First law analysis of gas turbines
- Land based gas turbines and aeroengines
- Second law analysis of gas turbines:Availability

Working fluids(2L)

- p-v-T data for water and normal fluids
- Saturation lines, the triple point, the critical point
- Evaluating properties, dryness fraction
- Working with tabulated data

Power Generation (2L)

- Vapour power plant
- The Rankine cycle
- Reheating and superheating
- Isentropic efficiency
- Combined gas-vapour power cycles
- 1st law analysis of Rankine cycles
- 2nd law analysis of Rankine cycles
- HRSG analysis

Refrigeration cycles (1L)

- Refrigerators and heat pumps
- Coefficient of performance
- Real refrigeration cycles
- The T-s and p-h diagram
- Choice of refrigerants
- Practical cycles

Properties of Mixtures (1L)

- Describing mixture composition
- Dalton's law
- Amagat's law
- p,v,T relations for a mixture of ideal gases
- Evaluations of U,H & S for a mixture of ideal gases
- Analysis of gas,vapour mixtures
- Saturated mixtures
- Specific humidity & relative humidity
- Dew point
- Air conditioning

Combustion (1L)

- Chemical equations
- Lambda and equivalence ratio
- First law applied to combustion
- Phase change of reactants

Booklists

Please see the Booklist for Part IB Courses [2] for references for this module.

Examination Guidelines

Please refer to Form & conduct of the examinations [3].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [4] 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.

IA3

Comprehend the broad picture and thus work with an appropriate level of detail.

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.

US3

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

US4

An awareness of developing technologies related to own specialisation.

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