Engineering Tripos Part IIB, 4A2: Computational Fluid Dynamics, 2020-21

Module Leader

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Lecturer

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Lab Leader

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Timing and Structure

Michaelmas term. Online lectures and demonstrations. Coursework with integrated lectures. Assessment: 100% coursework.

Prerequisites

3A1 and 3A3 assumed. Pre-module reading about Fortran helpful

Aims

The aims of the course are to:

- provide an introduction to the field of computational fluid mechanics.
- help students develop an understanding of how numerical techniques are devised.
- implement these techniques in practical computer codes.
- overview the nature of simulation in the future and advanced methods.

Objectives

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

- formulate numerical approximations to partial differential equations.
- write computer programs for solving the resulting difference equations.
- learn modern TVD shock-capturing methods.
- appreciate the power of numerical solutions to predict complex flows, including shock waves.
- develop the critical skills necessary to respond to and audit simulations produced by CFD for complex flow problems.

Content

This is a course work based project. The students have to write a Computational Fluid Dynamics (CFD) program - in Euler mode with time marching. There is also some basic mesh generation, preprocessing and post processing tasks. The assessment is through two reports. The first report demonstrates the performance of a basic CFD program and studies basic properties of finite difference methods. This needs to be handed in week 6 of the

Michaelmas term. The 2nd report demonstrates the coding and performance of more advanced CFD algorithms with discussion on a selected advanced CFD topic. The performance and traits of the extended CFD code are contrasted with expected traits for a range of subsonic and transonic flows. The final report is handed in at the end of the Michaelmas term.

Introduction and Basic Numerical Concepts (2L)

- The proper use of CFD and the equations used
- Finite difference, finite volume, finite element approaches
- Difference scheme and molecules
- Stability, Dispersion and Diffusion errors, Cell Re
- Compressible Flows vs Incompressible Flows
- Single Phase Flows vs Multiphase Flows
- Turbulence Modelling, Adaptive Methods and Parallel Computing

Modern Shock-Capturing Methods for Time-Dependent Compressible Flows (6L)

- Euler Equations and Hyperbolicity
- The Upwinding Method for Advection
- Godunov's Method for Linear System
- Total Variation Diminishing (TVD) Methods
- High-Resolution Methods and Limiters
- Approximate Riemann Solvers
- Roe Solver for Euler Equations

Coursework

Progress Check/Brief Report/Week 6 of Michaelmas term [25%]
Coursework/Report/1 Week after end of Michaelmas term [75%]

Mesh Generation and Preprocessing (Coursework: approx 2 hours)

- Conversion to Fortran; examples of Fortran programs
- Mesh generation for simplified geometries (eg bend, nozzle, hump, airfoil)
- Preprocessing

2-D Euler, Time Marching CFD Program

(Coursework: 5 mini-exercises of about 2-4 hours each, forming a 16 hour mini-project)

1. Finite volume discretisation, evaluation of fluxes. (4h)
2. Application of boundary conditions. (2h)
3. Time Iteration, simple LAX method. (2h)
4. Convergence & accuracy testing. (4h)
5. Enhancements, e.g. deferred corrections, Adams - Bashforth RK integration, use of energy equation. (4h)
6. Exploration of post-processing

Coursework	Format	Due date & marks
[Coursework activity #1 title / Interim] Coursework 1 brief description	Individual Report anonymously marked	day during te Thu week 6

Coursework	Format	Due date & marks
Learning objective: • study basic properties of finite difference methods. • learn to use Linux system and Fortran 90 • Complete and validate a basic Euler code		[25%]
[Coursework activity #2 title / Final] Coursework 2 brief description Learning objective: • Extend and improve the Euler code • Use it to investigate challenging flows	Individual Report anonymously marked	Fri week 10 [75%]

Booklists

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

Main course text is:

LeVeque R. J. 2002. Finite Volume Methods for Hyperbolic Problems, *Cambridge University Press.*

Also, useful material can be found in these texts.

Ferziger J. H. and Peric M. 2002. Computational Methods for Fluid Dynamics, *Springer.*

Toro E. F. 2009. Riemann Solvers and Numerical Methods for Fluid Dynamics: A Practical Introduction, Springer

Hirsch C. 1988-1990 Numerical Computation of Internal and External Flows, Volumes 1 and 2, Wiley

Davies R., Rea A. and Tsaptsinos D. Introduction to FORTRAN 90, Student Notes, Queen's University, Belfast

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.

IA2

Demonstrate creative and innovative ability in the synthesis of solutions and in formulating designs.

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.

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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