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

Module Leader
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Lecturer
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Lab Leader
Dr J Li

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

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<thead>
<tr>
<th>Coursework</th>
<th>Format</th>
<th>Due date &amp; marks</th>
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<tbody>
<tr>
<td>[Coursework activity #1 title / Interim]</td>
<td>Individual Report</td>
<td>day during term</td>
</tr>
<tr>
<td>Coursework 1 brief description</td>
<td>anonymously marked</td>
<td>Thu week 6</td>
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</tbody>
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Coursework

<table>
<thead>
<tr>
<th>Learning objective:</th>
<th>Format</th>
<th>Due date &amp; marks</th>
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<tbody>
<tr>
<td>• study basic properties of finite difference methods.</td>
<td>Individual Report</td>
<td>Fri week 10</td>
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<tr>
<td>• learn to use Linux system and Fortran 90</td>
<td>anonymously marked</td>
<td>[75%]</td>
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<tr>
<td>• Complete and validate a basic Euler code</td>
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[Coursework activity #2 title / Final]

Coursework 2 brief description

Learning objective:

• Extend and improve the Euler code
• Use it to investigate challenging flows

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:


Also, useful material can be found in these texts.


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

The *UK Standard for Professional Engineering Competence (UK-SPEC)* [3] describes the requirements that have to be met in order to become a Chartered Engineer, and gives examples of ways of doing this.

UK-SPEC is published by the Engineering Council on behalf of the UK engineering profession. The standard has
been developed, and is regularly updated, by panels representing professional engineering institutions, employers and engineering educators. Of particular relevance here is the 'Accreditation of Higher Education Programmes' (AHEP) document [4] which sets out the standard for degree accreditation.

The Output Standards Matrices [5] indicate where each of the Output Criteria as specified in the AHEP 3rd edition document is addressed within the Engineering and Manufacturing Engineering Triposes.

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Links
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