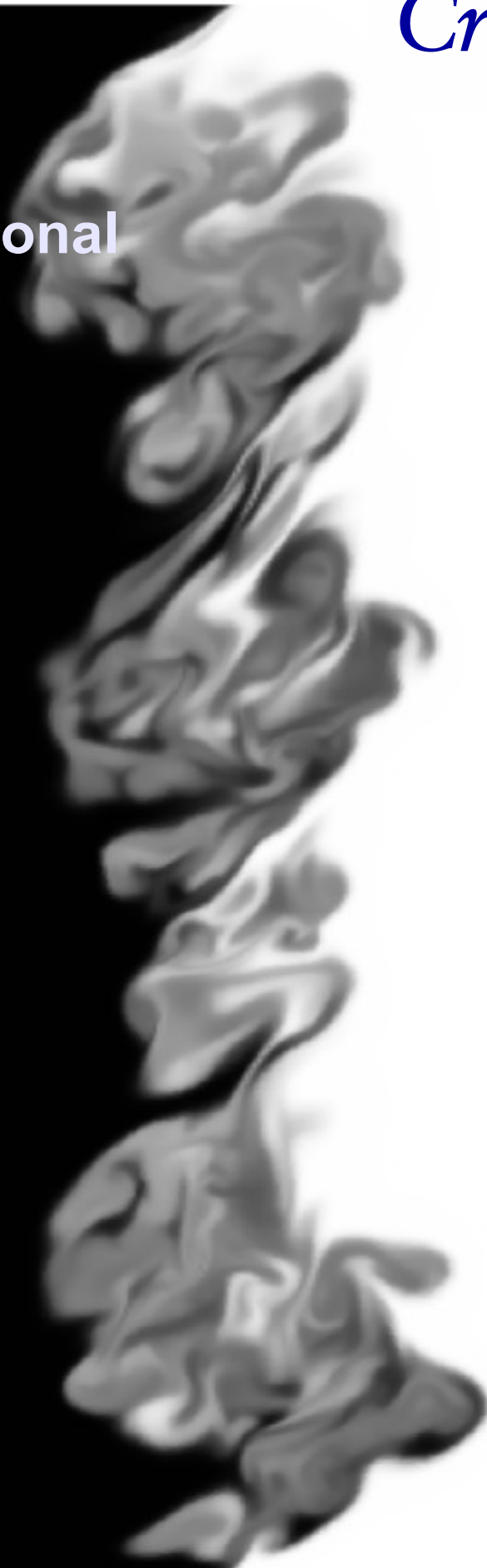


**Computational  
Fluid  
Dynamics**

MSc/PGCert/PGDip

2008-2009



# Computational Fluid Dynamics

**Qualification**        MSc (with PG Certificate / PG Diploma)

**School**                School of Engineering

**Course Director:**    Dr Evgeniy Shapiro

The aim of this course is to offer a programme of study which will enhance the skills of the graduate student providing a detailed introduction to the fundamentals of Computational Fluid Dynamics (CFD) together with an insight into the applications of CFD across the breadth of the subject.

**For more details of this course please contact**

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**"The course is designed to meet the educational needs of graduates planning to make CFD one of their professional skills. It sets out to bridge the gap between the introductory level of undergraduate courses and the applied expertise acquired by engineers using CFD in industry. Students will gain the knowledge and appreciation of CFD methods necessary for strong foundations to a career in this exciting engineering discipline."**

*Chris Carey, Fluent Europe's Technical Services Manager*

**"As well as providing solid foundation knowledge, this MSc course allows students to discover the latest research in CFD within an efficient and friendly environment."**

*Pierre-Yves Passaggia (MSc CFD 2006-07)*

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## **Introduction**

Computational Fluid Dynamics (CFD) is the science of determining a numerical solution to the governing equations of fluid flow whilst advancing the solution through space and time to obtain a numerical description of the complete flow field of interest.

As a developing science, CFD has received extensive attention throughout the international community since the advent of the digital computer. The attraction of the subject is twofold. Firstly, the desire to be able to model physical fluid phenomena that cannot be easily simulated or measured with a physical experiment, for example weather systems or hypersonic aerospace vehicles. Secondly, the desire to be able to investigate physical fluid systems more cost effectively and more rapidly than with experimental procedures.

There has been considerable growth in the development and application of CFD to all aspects of fluid dynamics. In design and development, CFD programs are now considered to be standard numerical tools, widely utilised within industry. As a consequence there is a considerable demand for specialists in the subject, to apply and develop CFD methods throughout engineering companies and research organisations.

The current status of CFD within industry may be likened to that of structural analysis a decade ago, when it too was rapidly maturing. At that time the typical company marketing Finite Element structural analysis programs had a turnover an order of magnitude greater than the largest CFD vendor. Finite Element programs are now considered to be part of the routine design and analysis cycle within industry and are available on almost every computing platform. In a similar manner Computational Fluid Dynamics has become a standard industry tool and is now finding its place alongside CAD and FE packages.

CFD is utilised as a design analysis tool within both industry and research organisations. The course provides a solid background for graduates to be able to apply, in an educated manner, CFD as a design tool for engineering applications. For those graduates who prefer to study for a PhD, the course provides an excellent basis from which to further specialise in the development and application of both numerical algorithms and physical models.

This course has been designed to reflect the wide application of CFD within industry, from aerospace applications, combustion and two phase flow, heat transfer, to turbomachinery and environmental flows. The course is organised in a modular fashion and is specifically designed to permit both part time study by industrially supported students and more usually one year, full time, study.

## Intended learning outcomes of the course

On successful completion of the course a student will be able to:

- i. Demonstrate a critical awareness of the governing equations of fluid mechanics, and their mathematical properties, in various formulations for compressible and incompressible inviscid and viscous flows.
- ii. Demonstrate a critical awareness of the underlying principles of numerical analysis, concepts of stability, approximation and convergence and the numerical solution of systems of algebraic equations.
- iii. Demonstrate a critical awareness of different state-of-the-art CFD methods as used in engineering practice and research and development for both incompressible and compressible flows.
- iv. Demonstrate a systematic application of the principles and limitations of alternative techniques for the simulation of turbulent and transitional flows and thus be able to apply these in a critical manner to practical applications.
- v. Recognise the potential sources of, and discriminate between, error and uncertainty in numerical simulations. Be aware of the tools that are available for the quantification of error and uncertainty in computational simulations. Be able to plan and perform credible computational simulations.
- vi. Demonstrate a systematic application of the requirements of grid generation for CFD applications and alternative techniques for the visualisation and interpretation of CFD results.
- vii. Demonstrate a systematic application of the use of CFD to practical scientific and engineering fluid flow problems.
- viii. Demonstrate their acquired skills in applying commercial CFD software packages to practical engineering applications.

Students completing the **PG Certificate** will be able to fulfil outcomes (i)-(v)

Students completing the **PG Diploma** will be able to fulfil outcomes (i)-(v) and a combination of the remaining outcomes depending on the modules selected for study.

# Learning and Teaching

The course is designed to achieve the broad aims of the University's curriculum through:

## *Acquisition of Knowledge*

Computational Fluid Dynamics (CFD) is the science of determining a numerical solution to the governing equations of fluid flow whilst advancing the solution through space and time to obtain a numerical description of the complete flow field of interest. Through the Intended Learning Outcomes the course will provide a sound foundation to the underlying fundamental topics in fluid dynamics and the relevant numerical methods employed in CFD computational codes.

## *Understanding*

Through use of activities such as code development, hands-on experience of commercial CFD codes, practical reports, problem solving, and evaluation of published research, all students will be able to demonstrate systematic application and critical awareness of the underlying theory.

## *Skills acquisition*

All students will be expected to demonstrate the ability to apply commercial Grid Generation, Flow Solver and Visualisation software packages to practical problems. In addition, students will be required to demonstrate the ability to utilise manual and computer-based information retrieval systems, critically evaluate their own and other's work, work independently or as part of a team, and communicate effectively verbally or in writing to suit a range of audiences. Such transferable skills will be developed in a context appropriate to the application of Computational Fluid Dynamics to practical engineering problems.

## *Curriculum Delivery*

The research and teaching facilities within the Department of Aerospace Sciences are ideally suited to teaching this course. The academic staff from the Aerospace Sciences Department collectively holds over 75 years of experience in the application and development of CFD to practical engineering problems. Computational Fluid Dynamics is a major research activity, being actively pursued and applied to practical engineering disciplines throughout the Department of Aerospace Sciences.

## *Group Work*

Many of the more application oriented course modules include a 'hands-on' practical component as computational laboratory/tutorial sessions. During these 'workshops' students will be encouraged to work together as teams, in order to build upon their combined skills, and more efficiently manage their time when considering more complex computational simulations.

## *Knowledge and understanding and their application*

Students will be provided with subject material such that they can demonstrate a systematic application and a critical awareness of the topic. The subject material will be delivered by modules covering the major topic areas in Computational Fluid Dynamics. The modules will reflect the current state of the art at both applied and research level.

The taught material provides the basis for a sound understanding of the fundamental concepts of CFD, enabling students to critically evaluate current practice and the direction of future research innovations.

The course will allow students to demonstrate originality in the application of their acquired knowledge through a research project in a specific topic within the broad field of Computational Fluid Dynamics.

Through the assessment of both the taught components and the research project the students will be able to demonstrate an independent learning ability and interest in advancing their knowledge and understanding of the subject.

#### *Problem solving and communication skills*

Selected modules include group work as part of their computational laboratory sessions. These will provide the opportunity for self-direction and originality in tackling and solving problems, working effectively both individually and in teams.

The students will be expected to present the progress of their research project through the course of the academic programme on a number of occasions to their colleagues, academic staff and project sponsors. These will provide the opportunity to communicate clearly, both orally and in writing, to specialist and non-specialist audiences.

#### *Other qualities and transferable skills*

The course will provide an opportunity to use some of the leading commercial software in the field of Computational Fluid Dynamics. This will provide practical hands-on experience of the software tools that students will be expected to use within industry. In addition, students will be required to demonstrate the ability to utilise manual and computer-based information retrieval systems, critically evaluate their own and other's work, work independently or as part of a team, and communicate effectively verbally or in writing to suit a range of audiences.

Development of generic skills such as communication, presentation, project management and team working skills will be encouraged throughout the course. This will be achieved by delivery of sessions offering guidance in such activities, which will then be central to many of the assessment methods as already indicated, allowing the students both to practice these skills and reflect on feedback given as part of the assessment process. In addition, Personal Development Planning initiative will be offered to all students in line with Faculty Board policy.

## Assessment Strategy and Methods

The assessment methods on the course will include the following and are designed to enable students to achieve the learning outcomes for the course in the following ways:

### *Written Coursework Assignments*

Such assignments will take a variety of formats, from traditional style essays and (computational) laboratory reports to presentation in the style of a poster or academic journal style paper. Such assignments will demonstrate skills in information retrieval, literature citation, critical evaluation, and written presentation skills to suit a variety of formats and audiences. Problem solving activities will also be incorporated in such assignments.

### *Oral Presentations*

In addition to an assessed oral presentation of the MSc thesis, some modules will include oral presentation. Development of oral presentation skills throughout the course is seen as essential preparation for a research career that frequently involves oral dissemination of results.

### *Group work*

Team working is seen as an essential component of the learning process, providing the opportunity for students to demonstrate their ability to work and communicate within group environments, further developing their own interpersonal skills. Where appropriate this will be incorporated into the assessment for the individual modules.

### *Written Examination*

Most modules will retain a component of written examination where appropriate. This will demonstrate the ability of the students to retain important information, and apply it to a given scenario on demand and in an appropriate context.

### *Dissertation (PgDip)*

The Dissertation will allow students to demonstrate their knowledge of specific aspects of Computational Fluid Dynamics and will provide an opportunity for the further development of the skills developed during coursework assignments in a manner that demonstrates independent advancement of knowledge and understanding of the subject.

### *Research Project and Presentation by Thesis and Oral Examination (MSc)*

The Research Project and the production of a thesis and oral presentation will extend those skills developed during coursework assignments in a manner that will be directly applicable to the way in which research is presented in industry and academia. The research project will provide graduates with experience of planning and conducting a post graduate M level research project, including the ability to critically evaluate the existing research literature, to place the proposed research into a theoretical and practical context and to demonstrate their knowledge and understanding of Computational Fluid Dynamics through an individual research project.

In all instances, assessment will be based on the demonstration of appropriate knowledge, an appropriate mode of presentation, interpretation within the correct context, critical discussion, and the use and citation of appropriate sources of information.

# Syllabus

## Core Modules

The core part of the course consists of eleven subject modules. These are considered to represent the necessary foundation subject material. The first 8 modules form the Postgraduate Certificate qualification.

- Introduction to Fluid Mechanics & Heat Transfer
- Numerical Methods for PDE's
- Numerical Modelling for Steady & Unsteady Incompressible Flows
- Numerical Modelling for Steady & Unsteady Compressible Flows
- Classical Turbulence Modelling
- Advanced Turbulence Modelling and Simulation: LES & DNS
- High Performance Computing for CFD
- Managing Uncertainty in Simulations: Validation & Verification
- Grid Generation / CAD
- Data Analysis, Data Fusion & Post Processing
- The Role of Experimental Data in CFD

## Optional Modules

Computational Fluid Dynamics is now commonly accepted as a standard numerical tool to be applied in a broad range of application areas wherever fluid flow occurs. The course is designed to reflect this broad application by providing a range of optional modules to address specific application areas:

- CFD for Aerospace Applications
- CFD for Micro and Nano Flows
- CFD for Rotating Wings
- CFD for Automotive Flows
- CFD for Multiphase Flows and Combustion
- CFD for Environmental Flows
- CFD for Fluid-Structure Interaction

# **Introduction to Fluid Mechanics & Heat Transfer**

**Class contact hours:** 20

**Private study hours:** 80

**Total Notional Learning Hours:** 100

**Credit Rating:** 10

**Assessment method:** Assignment (1/3) & Examination (2/3)

**Status:** Compulsory

**Aim:** To introduce the foundations of fluid mechanics, various formulations of governing equations and their mathematical properties in order to establish a firm basis for other modules.

## **Syllabus:**

- Introduction to thermodynamics of gases and liquids
- Introduction to heat transfer
- Compressible flows
- Incompressible flows
- Dimensional analysis and similarity parameters
- Mathematics of governing equations, classification of PDEs
- Model equations for fluid dynamics
- Introduction to unstable and turbulent flows

## **Intended Learning Outcomes:**

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of the governing equations of fluid mechanics & Heat transfer in various formulations for compressible and incompressible viscous and inviscid flows.
- Estimate the impact of different physical phenomena based on dimensional analysis.
- Understand mathematical properties of governing equations and be able to critically evaluate correct boundary/initial value problems for various flows.
- Demonstrate the systematic application of the model equations and problems used in CFD.
- Demonstrate a critical awareness of the concepts of stability and turbulence.

# Numerical Methods for PDEs

**Class contact hours:** 20

**Private study hours:** 80

**Total Notional Learning Hours:** 100

**Credit Rating:** 10

**Assessment method:** Examination (2/3) + Assignment (1/3)

**Status:** Compulsory

**Aim:** To introduce the basics of numerical analysis and numerical methods for partial differential and algebraic equations.

## Syllabus:

- Introduction to numerical analysis
- Discretisation approaches: finite difference, finite volume, finite element and spectral methods
- Numerical methods for algebraic equations/systems of equations

## Intended Learning Outcomes:

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of the principles of numerical analysis and concepts of stability, approximation and convergence.
- Demonstrate the systematic application of the principles of finite difference/volume/element and functional decomposition methods and be able to critically evaluate these in model problems.
- Demonstrate the systematic application of the numerical solution of algebraic equations and systems of equations.

# Numerical Modelling for Steady & Unsteady Incompressible Flows

**Class contact hours:** 20

**Private study hours:** 80

**Total Notional Learning Hours:** 100

**Credit Rating:** 10

**Assessment method:** Assignment (1/3) & Examination (2/3)

**Status:** Compulsory

**Aim:** To understand the state-of-the-art CFD methods used for computing incompressible flows in science and engineering.

## Syllabus:

- Overview of various formulations of the governing equations and numerical methods for incompressible flows (linear & high-resolution methods)
- Solution approaches: pressure Poisson, projection (approximate and exact), artificial compressibility
- Centred schemes
- TVD and Riemann solvers for incompressible methods
- Second and high-order methods (time and spatial discretisation)

## Intended Learning Outcomes:

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of alternative spatial and time discretisation methods for solving fluid mechanics problems governed by the incompressible Navier-Stokes/Euler equations.
- Demonstrate the systematic application of the mathematical and numerical classification and properties of different state-of-the-art CFD incompressible methods as used in engineering practice as well as in research and development.
- Demonstrate a critical awareness of uncertainties and limitations associated with each method.

# **Numerical Modelling for Steady & Unsteady Compressible Flows**

**Class contact hours:** 20

**Private Study Hours:** 80

**Total Notional Learning Hours:** 100

**Credit Rating:** 10

**Assessment Method:** Assignment (1/3) & Examination (2/3)

**Status:** Compulsory

**Aim:** To introduce basic concepts in the discretisation and numerical solution of the hyperbolic systems of partial differential equations describing the flow of compressible fluids.

## **Syllabus:**

- Mathematical properties of hyperbolic systems
- Conservation Laws
- Non-linearities and shock formation
- The concept of weak solutions
- Artificial viscosity
- Introduction to the Riemann problem
- Lax-Wendroff scheme
- McCormack's scheme
- Method of Lines and Jameson's scheme
- Introduction to Godunov's method
- Flux vector splitting methods
- Approximate Riemann solvers
- High-order and TVD methods

## **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a critical awareness of the mathematical properties of hyperbolic partial differential equations
- Recognise the importance of non-linearities in the formation of shock waves
- Demonstrate a critical awareness of the application and limitations of finite difference methods for hyperbolic systems of partial differential equations
- Demonstrate a critical awareness of the characteristics of high-resolution shock capturing schemes
- Demonstrate the systematic application of approximate Riemann solvers within simple one-dimensional problems

# Classical Turbulence Modelling

**Class contact hours:** 10

**Private study hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment method:** Assignment

**Status:** Compulsory

**Aim:** To introduce students to closure methods for the Navier-Stokes equations as applied to turbulent and transitional flows, and the classical physical modelling approximations required to achieve this.

## Syllabus:

- Introduction to Reynolds Averaged Navier Stokes Modelling
- Mixing Length Approaches
- Turbulent Transport
- Two Equation Models
- Non-Linear Models
- Non-equilibrium Models
- Reynolds Stress Transport Schemes
- Low-Re Modelling
- Transition Modelling Extensions
- Best Practice Guidelines
- Limits of Current Approximations

## Intended Learning Outcomes:

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of the basic principles of turbulence modelling approximations required to close RANS equations
- Discriminate between different levels of closure and their limitations
- Appreciate how modelling methods may be extended to transition prediction
- Critically select between the different types of model available in current codes

# **Advanced Turbulence Modelling and Simulation: LES and DNS**

**Class contact hours:** 10

**Private study hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment method:** Examination

**Status:** Compulsory

**Aim:** To understand the principles of Large Eddy Simulation (LES) and Direct Numerical Simulation (DNS).

## **Syllabus:**

- Overview of the basic equations used in LES, including filtered and unfiltered formulations.
- Classical LES and subgrid scale models
- Implicit LES (numerical and physical principles)
- Numerical and physical principles of DNS
- Applications and challenges for LES and DNS

## **Intended Learning Outcomes:**

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of the numerical and physical principles of LES and DNS in the simulation of transitional and turbulent flow simulations.
- Demonstrate the systematic application of the key computational methods used in LES & DNS, and subgrid scale models used in LES.
- Critically evaluate the challenges in the implementation of LES and DNS in science and engineering.

# High Performance Computing for CFD

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Compulsory

**Aim:** To introduce students to the most advanced current computing capabilities and what these offer over desktop environments

## Syllabus:

- Desktop versus supercomputing
- Parallel computing issues
- Parallellisation approaches for distributed and shared memory systems. MPI & OpenMP
- Current CFD Process Bottlenecks
- Whole Product Applications

## Intended Learning Outcomes:

On successful completion of this course the student will be able to:

- Demonstrate a critical awareness of the range of high performance computing (hardware) platforms available for computational fluid dynamics simulations
- Demonstrate the systematic application of the essential software extensions required for parallel computing
- Recognise what application of high performance computing can achieve

# **Managing Uncertainty in CFD: Validation and Verification**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Compulsory

**Aim:** To introduce the concepts of error and uncertainty and how they relate to the credible numerical solution of the partial differential equations encountered in computational fluid mechanics.

## **Syllabus:**

- The right answer: consistency, stability and convergence revisited
- Taxonomies of error and uncertainty
- Principles of code verification
- Introduction to the method of manufactured solutions
- Principles of solution verification
- Role of systematic iterative and space-time grid convergence studies
- Richardson extrapolation
- Principles of validation
- Statistical approaches to epistemic uncertainty
- Construction of validation hierarchies

## **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Discriminate between error and uncertainty in computational simulations
- Recognise the potential sources of error and uncertainty in computational simulations
- Critically evaluate the tools that are available for the quantification of error and uncertainty in computational simulations
- Be able to plan and perform credible computational simulations

## **Grid Generation / CAD**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Compulsory

**Aim:** To introduce the concepts of grid generation, including structured and unstructured approaches. To provide hands-on experience using commercial CAD and grid generation packages.

### **Syllabus:**

- Geometry Modelling and Surface Grids
- Algebraic Mesh Generation
- Structured Meshes from Partial Differential Equations
- Automatic generation of Unstructured Meshes
- Multiblock Mesh Generation
- Unstructured grids by Delaunay Triangulation
- Mesh Adaptation on Unstructured Grids
- Unstructured Grids for Viscous Flows

### **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a systematic understanding of the requirements of grid generation for CFD applications
- Critically evaluate alternative methods for efficiently generating computational grids
- Demonstrate the systematic application of grid generation through structured single and multiblock grids with controlled grid quality by employing commercial grid generation packages
- Demonstrate a systematic application of the generation of unstructured grids with controlled grid quality within commercial meshing packages

# **Data Analysis, Data Fusion and Post Processing in CFD**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Compulsory

**Aim:** To provide an introduction into the use of visualisation, data mining, and interactive human-computer interfaces for the analysis and interpretation of CFD simulations. Visualisation can be a critical component in helping an engineer gain insight into the typically complex optimization problems that arise in design. Through the combination of visualisation and user interaction in computer tools, the engineer's insight can help guide the computer in the process of identifying better, more effective designs. Visualisation can also be combined with automated data mining techniques to improve optimization procedures.

To provide hands-on experience using both commercial and community developed visualisation packages.

## **Syllabus:**

- Data interchange formats
- Interpretation of data
- Graphical representation of data
- Parallel data visualisation
- Data mining, reduced order modelling, model identification and surrogate models
- Data fusion
- Virtual reality visualisation

## **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a systematic understanding of the alternative techniques for the visualisation and interpretation of CFD results
- Apply commercial and community developed visualisation software packages to real CFD data
- Critically evaluate the use of limited simulation data when making engineering decisions

## **The Role of Experimental Data in CFD**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Compulsory

**Aim:** To provide an introduction into practical techniques for experimental data collection and its subsequent post-processing. To contrast the resultant data representation with that obtained through CFD simulation.

### **Syllabus:**

- Introduction to the measurement of turbulent flows
- Velocity and pressure measurement by aerodynamic probes
- Velocity measurement by hot-wires/hot-film
- Velocity measurement by optical techniques
- Temperature measurement
- Simple optical visualisation, Shadowgraph, Schlieren
- Laser-based temperature and species measurements
- Laser Induced Fluorescence
- Skin friction, convective and radiative heat transfer
- Error analysis

### **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a critical awareness of the alternative experimental methods available for the investigation of turbulent fluid flow
- Demonstrate the ability to analyse and interpret quantitative and qualitative observations
- Demonstrate a critical awareness of the relationship between the observations and the underlying theory
- Critically interpret experimental data and contrast with that obtained from CFD simulations

# **CFD for Aerospace Applications**

**Class contact hours:** 10

**Private study hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment method:** Assignment

**Status:** Optional

**Aim:** To understand the key features of CFD methods used for simulating external flows in aeronautical and aerospace applications.

## **Syllabus:**

- Overview of external flow problems in aeronautical and aerospace applications.
- CFD methods for subsonic, supersonic and hypersonic regimes
- CFD methods for design
- Application examples.

## **Intended Learning Outcomes:**

On successful completion of the module the student will be able to:

- Demonstrate a critical awareness of the range of external flow problems in aeronautical and aerospace applications in which CFD methods can be used
- Demonstrate the systematic application of the key characteristics of CFD methods used in these sectors
- Critically evaluate the limitations of these methods
- Demonstrate a critical awareness of the current efforts made by industry and academia for improving the state-of-the-art methods in the above applications

## **CFD for Micro and Nano Flows**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To introduce micro- and nanoscale phenomena and CFD methods used for micro and nanoscale applications.

### **Syllabus:**

- Introduction to micro- and nanoscale phenomena
- Areas of CFD application in micro- and nanoscience
- Borderline continuum/molecular models and their domains of applicability
- Multiscale modelling

### **Intended Learning Outcomes:**

On successful completion of this module, students will be able to:

- Demonstrate a critical awareness of the physical phenomena specific to flows at micro- and nano-scale
- Critically evaluate applicability of continuum CFD to a particular problem
- Demonstrate a critical awareness of the techniques that can be used at the borderline between continuum and molecular levels.
- Demonstrate the systematic application of the concepts and current state-of-the-art methods involved in solving multiscale problems

## **CFD for Rotating Wings**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To introduce the numerical approaches required to meet the challenges of flows associated with rotating wings, including rotorcraft, propellers, wind turbines and turbomachinery.

### **Syllabus:**

- Introduction to rotary wing aerodynamics
- Formulation of the governing equations in a rotating inertial frame of reference
- Numerical approaches to vortex capturing
- Blade dynamics as an example of fluid-structure interaction
- Formulation of the governing equations for moving/deforming grids
- Numerical modelling of dynamic stall

### **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a critical awareness of the modelling challenges faced in the numerical analysis of rotating wings
- Demonstrate the systematic application of the Navier-Stokes equations in an appropriate rotating/moving frame of reference
- Critically evaluate the different modelling approaches that can be taken for vortex dominated flows

# **CFD for Multiphase Flows and Combustion**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To introduce physics of multiphase flows and combustion as well as numerical methods for the simulation of multiphase and reacting flows. To provide examples of applications.

## **Syllabus:**

- Physical insight into multiphase and reacting flows
- Governing equations and models for multiphase flows & combustion
- Numerical methods for multiphase and reacting flows.
- Particle tracking methods
- Examples of applications

## **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Demonstrate a critical awareness of the basic principles of multiphase flows and combustion modelling
- Critically assess achievements and limitations of current modelling and simulation approaches for multiphase flows and combustion
- Demonstrate a systematic application of the models within commercial or in-house CFD packages

## **CFD for Automotive Flows**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To show students how CFD may best be applied to a range of automotive flows

### **Syllabus:**

- Application Areas for CFD in automotive engineering
- Choice of CFD technique appropriate to the problem
- CFD as a Complement to Experiment
- High Performance Computing & Design Optimisation
- Analysing Results

### **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Critically evaluate appropriate CFD methods for application to different automotive flow regimes
- Demonstrate a critical awareness of how CFD can complement wind tunnel evaluation of vehicle models
- Assess the value and limitations of applying CFD to vehicle designs

## **CFD for Environmental Flows**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To introduce the application of CFD to environmental flows in urban, inland and coastal environments

### **Syllabus:**

- Atmospheric boundary layer
- Pollution dispersion in the atmosphere
- Rivers, estuaries and tidal flows
- Sediment transport
- Building and urban aerodynamics
- Free-surface and shallow-water flows

### **Intended Learning Outcomes:**

On successful completion of this course the student will be able to:

- Critically assess the physical phenomena of environmental flows
- Demonstrate a critical awareness of the choices to made when selecting the appropriate CFD model for different flow regimes
- Demonstrate a systematic application of the models within commercial CFD packages

## **CFD for Fluid-Structure Interaction**

**Class contact hours:** 10

**Private Study Hours:** 40

**Total Notional Learning Hours:** 50

**Credit Rating:** 5

**Assessment Method:** Assignment

**Status:** Optional

**Aim:** To introduce Fluid Structure Interaction (FSI) models and associated computational challenges. To provide examples of FSI problems arising in engineering applications.

### **Syllabus:**

- Introduction to FSI
- Physical models (Classical models, Distinction between linear and nonlinear models), Time-linearised models, Nonlinear dynamical models, Reduced-order models
- Computational challenges of FSI modelling
- Examples of applications

### **Intended Learning Outcomes:**

On successful completion of the module the students will be able to:

- Demonstrate a critical awareness of the range of FSI problems in engineering applications where CFD methods can be applied.
- Demonstrate the knowledge of mathematical and numerical classification and properties of various numerical models used in FSI computations.
- Critically assess achievements and limitations of current modelling and simulation approaches by reference to practical examples.

## **Research Project (MSc)**

**Class contact hours:** 10

**Private Study Hours:** 990

**Total Notional Learning Hours:** 1000

**Credit Rating:** 100

**Assessment Method:** Thesis (85%) Oral presentation (15%)

**Status:** Compulsory

### **Aim:**

To plan, conduct and report a programme of research into one or more aspects of Computational Fluid Dynamics.

Through the Research Project the students will be able to apply and demonstrate their skills in Computational Fluid Dynamics. The production of a thesis and oral presentation will extend those skills developed during coursework assignments in a manner that will be directly applicable to the way in which research is presented in industry and academia.

### **Syllabus:**

The research topic will be defined in collaboration with an allocated research project supervisor from the academic teaching team.

### **Intended Learning Outcomes:**

On successful completion of the research project the student will be able to:

- Prepare a research project plan, with aims, objectives, risk assessment and time line.
- Demonstrate their knowledge and understanding of Computational Fluid Dynamics, either to an applied engineering flow problem or to the further development and refinement of the underlying numerical and computational techniques.
- Acquire, use and correctly reference information from a variety of sources, including books, journals and computer-based information retrieval systems.
- Critically evaluate current research and/or methodologies.
- Work independently on an extended research project.
- Effectively communicate technical information in writing and in an oral presentation.

## **Dissertation (PG Diploma)**

**Class contact hours:** 5

**Private Study Hours:** 195

**Total Notional Learning Hours:** 200

**Credit Rating:** 20

**Assessment Method:** Thesis (85%) Oral presentation (15%)

**Status:** Compulsory

### **Aim:**

To plan, conduct and report upon a critical analysis of one or more aspects of Computational Fluid Dynamics.

The production of the dissertation and oral presentation will extend those skills developed during coursework assignments in a manner that will be directly applicable to the way in which research is presented in industry and academia.

### **Syllabus:**

The dissertation topic will be defined in collaboration with an allocated supervisor from the academic teaching team.

### **Intended Learning Outcomes:**

On successful completion of the dissertation the student will be able to:

- Critically evaluate current research and/or methodologies.
- Acquire, use and correctly reference information from a variety of sources, including books, journals and computer-based information retrieval systems.
- Work independently on the critical analysis of a research topic
- Demonstrate their knowledge of specific aspects of Computational Fluid Dynamics through a written dissertation
- Effectively communicate technical information in writing and in an oral presentation.



# Credit Tariff

School.....**School of Engineering**

Qualification and Course Title.....**MSc in Computational Fluid Dynamics 2008/9**

Course Director.....**Dr. E. Shapiro** Deputy Director..... **Prof. D. Drikakis**

The course consists of a core of 11 compulsory modules (75 credits), selected optional modules (25 credits) and an independent research project. Assessment of the modules will be by combination of assignments and examinations, and by thesis and oral examination for the research project. In line with Faculty policy, the pass mark for each component will be 50%

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Module Title	(a) Class Contact Hours	(b) Private Study Hours	Total Notional Learning Hours (a) & (b)	Assess. Method Exam Assign	Weighting %	Credits
<b>Core Modules</b>						
Introduction to Fluid Mechanics	20	80	100	A1/3 +E2/3	5	10
Numerical Methods for PDE's	20	80	100	A1/3 +E2/3	5	10
Numerical Modelling for Steady & Unsteady Incompressible Flows	20	80	100	A1/3 +E2/3	5	10
Numerical Modelling for Steady & Unsteady Compressible Flows	20	80	100	A1/3 +E2/3	5	10
Classical Turbulence Modelling	10	40	50	A100	2.5	5
Advanced Turbulence Modelling and Simulation: LES and DNS	10	40	50	E100	2.5	5
High Performance Computing for CFD	10	40	50	A100	2.5	5
Managing Uncertainty in Simulations: Validation & Verification	10	40	50	A100	2.5	5
Grid Generation / CAD	10	40	50	A100	2.5	5
Data Analysis, Data Fusion & Post Processing	10	40	50	A100	2.5	5
The Role of Experimental Data in CFD	10	40	50	A100	2.5	5
<i>Total</i>	<i>150</i>	<i>600</i>	<i>750</i>		<i>37.5</i>	<i>75</i>
<b>Optional Modules</b>						
CFD for Aerospace Applications	10	40	50	A100	2.5	5
CFD for Rotating Wings	10	40	50	A100	2.5	5
CFD for Automotive Flows	10	40	50	A100	2.5	5
CFD for Multiphase Flows & Combustion	10	40	50	A100	2.5	5
CFD for Environmental Flows	10	40	50	A100	2.5	5
CFD for Micro- and Nano- Flows	10	40	50	A100	2.5	5
CFD for Fluid-Structure Interaction	10	40	50	A100	2.5	5
<i>Total (choice of 5)</i>	<i>50</i>	<i>200</i>	<i>250</i>		<i>12.5</i>	<i>25</i>
<b>Total taught element</b>			<b>1000</b>		<b>50</b>	<b>100</b>
<b>Research Project</b>	<b>10</b>	<b>990</b>	<b>1000</b>	<b>85% Thesis 15% Oral</b>	<b>50</b>	<b>100</b>
<i>Total</i>	<i>200</i>	<i>1800</i>	<i>2000</i>		<i>100</i>	<i>200</i>

School.....**School of Engineering**

Qualification and Course Title.....**PG Diploma in Computational Fluid Dynamics 2008/9**

Course Director.....**Dr. E. Shapiro** Deputy Director..... **Prof. D. Drikakis**

The course consists of a core of eleven compulsory modules (75 credits), selected optional modules (25 credits) and an independent dissertation (20 credits). Assessment of the modules will be by combination of assignments and examinations, and by thesis and oral examination for the research project. In line with Faculty policy, the pass mark for each component will be 50%

Module Title	(a) Class Contact Hours	(b) Private Study Hours	Total Notional Learning Hours (a) & (b)	Assess. Method Exam Assign	Weighting %	Credits
<b>Core Modules</b>						
Introduction to Fluid Mechanics	20	80	100	A1/3 +E2/3	8.33	10
Numerical Methods for PDE's	20	80	100	A1/3 +E2/3	8.33	10
Numerical Modelling for Steady & Unsteady Incompressible Flows	20	80	100	A1/3 +E2/3	8.33	10
Numerical Modelling for Steady & Unsteady Compressible Flows	20	80	100	A1/3 +E2/3	8.33	10
Classical Turbulence Modelling	10	40	50	A100	4.17	5
Advanced Turbulence Modelling and Simulation: LES and DNS	10	40	50	E100	4.17	5
High Performance Computing for CFD	10	40	50	A100	4.17	5
Managing Uncertainty in Simulations: Validation & Verification	10	40	50	A100	4.17	5
Grid Generation / CAD	10	40	50	A100	4.17	5
Data Analysis, Data Fusion & Post Processing	10	40	50	A100	4.17	5
The Role of Experimental Data in CFD	10	40	50	A100	4.17	5
<i>Total</i>	<i>150</i>	<i>600</i>	<i>750</i>		<i>62.5</i>	<i>75</i>
<b>Optional Modules</b>						
CFD for Aerospace Applications	10	40	50	A100	4.17	5
CFD for Rotating Wings	10	40	50	A100	4.17	5
CFD for Automotive Flows	10	40	50	A100	4.17	5
CFD for Multiphase Flows & Combustion	10	40	50	A100	4.17	5
CFD for Environmental Flows	10	40	50	A100	4.17	5
CFD for Micro- and Nano- Flows	10	40	50	A100	4.17	5
CFD for Fluid-Structure Interaction	10	40	50	A100	2.5	5
<i>Total (choice of 5)</i>	<i>50</i>	<i>200</i>	<i>250</i>		<i>20.83</i>	<i>25</i>
<b>Total taught element</b>			<b>1000</b>			<b>100</b>
<b>Dissertation</b>	<b>5</b>	<b>195</b>	<b>200</b>	<b>85% Thesis 15% Oral</b>	<b>16.67</b>	<b>20</b>
<i>Total</i>	<i>200</i>	<i>1000</i>	<i>1200</i>		<i>100</i>	<i>120</i>

School.....**School of Engineering**

Qualification and Course Title.....**PG Certificate in Computational Fluid Dynamics 2008/9**

Course Director.....**Dr. E. Shapiro** Deputy Director..... **Prof. D. Drikakis**

The course consists of eight compulsory modules (60 credits). Assessment of the modules will be by combination of assignments and examinations. In line with Faculty policy, the pass mark for each component will be 50%

Module Title	(a) Class Contact Hours	(b) Private Study Hours	Total Notional Learning Hours (a) & (b)	Assess. Method Exam Assign	Weighting %	Credits
Introduction to Fluid Mechanics	20	80	100	A1/3 +E2/3	16.67	10
Numerical Methods for PDE's	20	80	100	A1/3 +E2/3	16.67	10
Numerical Modelling for Steady & Unsteady Incompressible Flows	20	80	100	A1/3 +E2/3	16.67	10
Numerical Modelling for Steady & Unsteady Compressible Flows	20	80	100	A1/3 +E2/3	16.67	10
Classical Turbulence Modelling	10	40	50	A100	8.33	5
Advanced Turbulence Modelling and Simulation: LES and DNS	10	40	50	E100	8.33	5
High Performance Computing for CFD	10	40	50	A100	8.33	5
Managing Uncertainty in Simulations: Validation & Verification	10	40	50	A100	8.33	5
<i>Total</i>	<i>120</i>	<i>480</i>	<i>600</i>		<i>100</i>	<i>60</i>