RYERSON UNIVERSITY
MECHANICAL AND INDUSTRIAL ENGINEERING GRADUATE PROGRAM
YEATES SCHOOL OF GRADUATE STUDIES

Course Outline

ME8112: Computational Fluid Mechanics and Heat Transfer (Winter 2013)

Instructor: Prof. Seth Dworkin
Office: EPH-324
Email: seth.dworkin@ryerson.ca
Website: www.ryerson.ca/~dworkin
Office hours: posted on office door & website

Antirequisite: AE8112

Calendar Description:
The finite difference discretization method is applied to the solution of the partial differential equations arising from the mathematical modelling of fluid flow, heat transfer and combustion processes. The equations can be parabolic, elliptic or hyperbolic. Items like convergence, stability, consistency, numerical diffusion and turbulence modelling will also be presented.

Compulsory Text(s)/ Reading materials:
There will be no required texts but the following are identified as references:

- Chapra and Canale Numerical Methods for Engineers (2006) or equivalent
- Patankar, Numerical Heat Transfer and Fluid Flow (1980)
- Roache, Fundamentals of Computational Fluid Dynamics (1998)
- Lomax, Pulliam, & Zingg, Fundamentals of Computational Fluid Dynamics (1999)
- Hirsch, Numerical Computation of Internal and External Flows (2007)
- Ferziger, Computational Methods for Fluid Dynamics (2002)

Patankar will be most heavily cited in this course as it remains a classical and important text. However, it is somewhat dated, and therefore it will be supplemented by the others.

Course Content/Objectives:
MIE1210 is an introductory course that will teach Finite Volume (FV) and Finite Difference (FD) approaches to Computational Fluid Mechanica and Heat Transfer, often referred to as CFD (D for Dynamics). Since the advent of commercially available computers, CFD has been an important engineering research domain as it gave researchers the ability to solve analytically intractable problems of industrial relevance. In the last two decades, the immense demand for CFD research and expertise has spawned the commercialization of software packages such as Fluent/CFX, COMSOL and FEMlab. Despite these readily available software

packages, there is a recognized importance to user expertise, fundamental knowledge, and critical understanding of their inner workings. In addition, home spun research codes are still prominent in academia and industry. This is due in large part to the fact that commercial software packages are geared toward a broad range of research topics, and may not function as efficiently as a code designed with a specific problem in mind, and to the fact that developments in CFD are typically achieved in research before they are adopted by software companies.

This course is appropriate both for students who wish to become knowledgeable users of commercial CFD programs, and students who plan to create, develop, or enhance research codes. Therefore, the overreaching goals of this course are threefold: 1. To give you an introduction to fundamental discretization and solution techniques for heat transfer and fluid dynamics problems; 2. To give you an understanding of solution methodologies, advantages, downfalls, considerations (stability, accuracy, efficiency), and the inner workings of CFD software; and 3. To have you gain experience writing programs and solving 1D and 2D problems, and in using these programs to demonstrate and reinforce 1 and 2.

A note about “heat transfer”:
Although the goal of this course is to create proficient computational fluid dynamicists, “heat transfer” is included in the course title and content. This is due in large part to the fact that heat transfer problems are considerably simpler than fluid dynamics problems but still serve to illustrate concepts and techniques that are applicable to CFD. In addition, heat transfer codes constitute both a starting point, and building block for CFD codes.

Course Topics

(i) Introduction and toolkit review
(ii) Model problem (the heat conduction equation)
(iii) 2D problems (the convection/diffusion equations)
(iv) 2D Navier-Stokes equations and Parallel CFD, and
(v) (Supplemental): Future perspectives for research and algorithm development.

Course Organization /Teaching method(s): The course calendar can be found on the course Blackboard page. Lectures will be on Wednesdays from 1:00 PM to 4:00 PM beginning on Jan 16, 2013. Room: EPH441

Course Evaluation: 100% of your course grade will be based on five assignments (worth 20% each), which will cover topics (i) through (iv).

Course Content

Part 1: Introduction and toolkit review

- Conservation equations (mass, momentum, energy, species) (Roache, Patankar)
- Taylor series expansion and manipulation (Roache, Patankar, C&C)
- Solutions methods (Euler's method, Newton's method) (C&C)
- Linear system solution (structured/unstructured, direct/iterative) (C&C)
- Introduction to Finite difference discretization (Roache, LP&Z)
- Introduction to Finite volumes discretization (Patankar, Roache, LP&Z)

Part 2: Model problem (the heat conduction equation) (Patankar, Roache, LP&Z)

- Finite difference and finite volume discretization techniques
- Boundary Conditions
- Linear systems and their solution (sparsity, TDMA, …)
- Taylor series analysis and order of error
- Mesh Adaptation
- Multigrid extrapolation
- Other considerations

Part 3: 2D problems (the convection/diffusion equations) (Patankar, Roache, LP&Z)

- Elliptic, parabolic, and hyperbolic problem definitions
- Finite difference and finite volume discretization techniques
- Temporal discretization
- Linear systems and their solution (sparsity, bandedness, iterative solution)
- Solution methods (explicit, implicit, semi-implicit)
- Numerical diffusion
- Other considerations (stability, artificial viscosity)

Part 4: 2D Navier-Stokes equations (Patankar, Roache, LP&Z)

- Pressure and velocity coupling and staggered grids
- Difficulties
- Pressure and velocity corrections
- The vorticity transport equation
- Solution techniques (algorithms, multistep, SIMPLE, …)
- Parallel CFD

Part 5 (supplemental): Future perspectives for research and algorithm development

- Turbulent flow approximation models (Hirsch, Ferziger)
- Discretizing equations on unstructured meshes
  Compressible flows (Roache)