Introduction to Computational Fluid Dynamics

AME 535a, 3 Units

Fall 2011

Lecture 3:30 – 4:50 p.m., TTh, RTH 109

Personnel:

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Course Objectives:

The goal of the course is to provide a description of fundamental and general techniques which are commonly used in solving numerically equations governing fluid flows. Finite difference, finite volume, and finite element methods will be discussed as different means of discretization of the fluid dynamics equations. A necessary theoretical background concerning accuracy, convergence, consistency, and stability of the numerical schemes will be provided. The numerical methods will be implemented on computers and applied to solutions of simple model problems which illustrate a variety of physical phenomena encountered in fluid mechanics: one-dimensional diffusion, multidimensional diffusion, and linear and nonlinear convection-dominated problems. The final project will require combining the developed techniques to solve a realistic fluid dynamics problem. There will be an opportunity of using a commercial CFD package for validating programs designed by students.

Recommended Preparation:

AME 526, "Engineering Analytical Methods" (or an equivalent course in partial differential equations). Although no previous background in numerical methods will be assumed, some knowledge of the elementary techniques (Dahlquist, Bjork, Anderson, ``Numerical Methods"; Press, Flannery, Teukolsky, Vetterling, ``Numerical Recipes"; course AME 404, "Mechanical Engineering Problems") will be helpful. An integral part of the course is the development of numerical programs, which requires knowledge of a high level programming language, e.g., FORTRAN 90, C, or MATLAB. The course materials will include a complete set of computer programs written in FORTRAN 77, which will serve as a starting point for students' own work. A number of these programs, required for homework, will be provided in MATLAB as well.

Lecture Schedule:

Week	**Dates**	**Topics**
1	8/23 8/25	Partial differential equations; finite difference discretization of derivatives; accuracy of discretization; FTCS numerical scheme for diffusion eq. (Program DIFF).
2	8/30 9/01	Definitions of convergence, consistency, and stability; Lax equivalence theorem; stability and consistency of the FTCS scheme.
3	9/06 9/08	Explicit methods for 1-D diffusion equation: FTCS, Richardson, DuFort-Frankel, three-level explicit scheme (Program DIFEX); fully implicit scheme; Crank-Nicolson scheme; stability conditions.
4	9/13 9/15	Weighted residual methods: finite volume, collocation, Galerkin; finite volume method for Poisson eq. in geometrically complex domains (Program FIVOL).
5	9/20 9/22	Galerkin Finite Element Method; linear and quadratic interpolation. Implementation of FEM for a flow in a square duct (Program DUCT).
6	9/27 9/29	Iterative numerical methods for linear systems of algebraic equations: Jacobi, Gauss-Seidel, SOR, conjugate gradient. Midterm.
7	10/04 10/06	Steady Burgers' eq. (Program NEWTBU). Direct numerical solvers for linear systems of algebraic equations: Gaussian elimination with pivoting; LU-decomposition (Programs FACT and SOLVE); tridiagonal and pentadiagonal systems (Programs BANFAC and BANSOL); pseudo-transient method.

8	10/11 10/13	Implicit methods for 1-D diffusion equation (continued): three-level implicit scheme (Program DIFIM); stability conditions. Implementation of boundary and initial conditions. Semi-discretization and time stepping methods: Euler, midpoint, Runge-Kutta, trapezoidal, predictor-corrector, Adams-Bashforth.
9	10/18 10/20	Multidimensional diffusion equation; stability for explicit and implicit schemes; alternating direction implicit method; approximate factorization (Program TWDIF); method of fractional steps.
10	10/25 10/27	Implementation of boundary and initial conditions for 2-D diffusion eq. solvers. 1-D linear advection equation; upwind differencing; CFL number and stability conditions for explicit and implicit methods; Lax-Wendroff scheme; positive definite advection scheme.
11	11/01 11/03	Numerical dispersion and numerical diffusion; modified equation approach. Linear transport (advection-diffusion) equation.
12	11/08 11/10	Implicit and explicit methods; stability conditions (Program TRAN). Numerical schemes for two-dimensional transport equation.
13	11/15 11/17	Nonlinear advection equation; generation of small scales and aliasing errors; explicit and implicit methods; 1-D Burgers' equation.
14	11/22 11/24	Thanksgiving week - no classes.
15	11/29 12/01	Nonuniform grids. Systems of nonlinear equations: 1-D Euler equations.
	12/08	Final Project due.

Course Materials:

Handouts, notes, and programs will be distributed in class.

The following text is available from the USC bookstore and many textbook web sites. Search word `textbooks' in Google.

- C.A.J. Fletcher, Computational Techniques for Fluid Dynamics, Vol. I, 2nd ed., Springer-Verlag, ISBN: 3-540-53058-4.

Additional textbooks in CFD (not required):

- J.H. Ferziger and M. Peric, Computational Methods for Fluid Dynamics, Springer-Verlag.
- R. Peyret and T.D. Taylor, Computational Methods for Fluid Flow, Springer-Verlag.
- J.C. Tannehill, D.A. Anderson, and R.H. Pletcher, Computational Fluid Mechanics and Heat Transfer, Taylor & Francis.
- J. Tu, G.H. Yeoh, and C. Liu, Computational Fluid Dynamics, A Practical Approach, Elsevier.

Grading:

- 10% Homework
- 40% Midterm (theoretical concepts)
- 50% Final (programming project)

Academic integrity

All cases of academic integrity violation will be referred by a written report to the Student Judicial Affairs and Community Standards (http://www.usc.edu/student-affairs/SJACS/). The typical penalty recommended by SJACS is a grade of F for the course.

Page last updated: May 3, 2011.
The contents of this web page are subject to change. Weekly information will be updated without notice. Change in policies, important dates, and project content will be announced in class.