ENAE 684 - Computational Fluid Dynamics I
Fall 2008

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Classroom:	ITV 1100	Class time:	Tu. / Th. 12:30-1:45 pm

Grading:

Homework (and Computer Assignments)	40%
Midterm Exam	25%
Final Exam and/or Project	35%

Homework will be due at *beginning* of class of the due date, unless stated otherwise.
Any homework handed in less than 2 days late will automatically receive 75% of normal grade.
Any poorly done homework will be returned with a request for the homework to be redone.
Always write out the homework in the following format, include conclusions when appropriate:

GIVEN:
REQUIRED:
SOLUTION:

Always liberally comment computer problems and isolate the important algorithms in their own subroutines. Thus, the main program should primarily only call other subroutines, as follows (unless it is a fairly simple program):

```
C Output: Q(X,Y)
C Method: Explicit Euler and Upwinding of Linear Convection
C
      PARAMETER(IDIM=41,JDIM=21)
      COMMON X(IDIM,JDIM),Y(IDIM,JDIM),Q(IDIM,JDIM),
     <       IMAX,JMAX,ITMAX
C
C  Get input
      CALL INPUT
C..Initialize arrays and starting values
      CALL INITIALIZE
C..Perform for requested number of iterations
      DO IT=1,ITMAX
C..Call the step routine to update values to next time step
        CALL STEP
      ENDDO
C...All Done, write final output
      CALL OUTPUT
         STOP
      END
```

Background Assumed:

Math - linear algebra, calculus, complex variables, ODE, and some PDE
Physics - some *basic* understanding of incompressible and compressible fluid flow
Computing - MATLAB, editors, plotting, programming skills
Numerical methods - nothing (or very little)

Textbook (*not required*)**:**

Fundamentals of Computational Fluid Dynamics by Lomax, Pulliam and Zingg

What is Computational Fluid Dynamics (CFD)?

CFD is the numerical solving of partial differential equations on a discretized system that given the available computer resources best approximates the real geometry and fluid flow phenomena of interest.

In other words CFD is a tool, similar to experimental tools, used to gain greater physical insight into problems of interest. Thus, based on

- geometry
- fluid flow physics
- computer

we then select the appropriate:

- governing equations
- numerical method
- grid system

and then examine the results in order to gain physical insight and understanding.

Planned Topics

This semester (ENAE684) will *emphasize the theoretical foundation for the numerical methods* used in CFD with applications to representative problems, both unsteady 1-D and steady 2-D. The extension to systems, multi-dimensions and nonlinear problems will be discussed. By the end of the semester you should understand the limitations of CFD and how to interpret results. The second semester (ENAE685) will emphasize the development of methods for solving systems of nonlinear equations and the generation of curvilinear grids with advanced aerospace applications, from the transonic small disturbance equation to the Euler and Navier-Stokes equations.

Basic Fluid Equations, Control Volume formulation
Model Equations, Exact Solutions
Notation, Space Differencing, Taylor Series, Space Differencing Schemes
Point Operators, Matrix Operators, Boundary Conditions
Taylor Tables, High Order Schemes
Banded Matrices, Inversion of Banded Matrices
Fourier Error Analysis
Difference Operators at Boundaries
Conversion of PDE to ODE (Semi-discrete approach)
Exact Solution of Linear Differential Equations with Constant Coefficients
Real Space and Eigenspace
Analysis of Time March Methods for ODE, Representative Equation
Exact Solution of Linear Difference Equations with Constant Coefficients
Principle and Spurious Roots, Accuracy Measures
Linear Multistep Methods, Predictor-Corrector Methods, Runge-Kutta Methods
Implementation of Implicit Methods for Linear Equations and Nonlinear Equations
Stability of Numerical Methods for ODE
Time-Space Stability and Convergence of Ordinary Difference Equations
Numerical Stability Concepts
Effects of Boundary Conditions, Fourier Stability Analysis
Matrix Norms and Convergence of Time-Accurate Methods
Mixed Time and Space Differencing, Consistency
Choosing Time-Marching Methods, Stiffness, Efficiency
The Modified Partial Differential Equation
Upwind and Central Differencing, Artificial Dissipation

Factored Forms, Analysis of 2-D and 3-D including Stability and Steady-State Accuracy
Finite Volume Methods, Higher order methods and TVD concepts
Nonlinear Stability
Interpolation Point of View for Hyperbolic Problems
Essentially Non-Oscillatory (ENO) methods and weighted ENO (WENO) Methods
Classical Relaxation, SOR, Multi-grid, Iterative Methods
Methods for solving the Euler Equations
Time and Space Metrics
Others, as time permits

Learning Outcomes

1. Students will have a basic knowledge of the essential elements (governing equations, meshing, discretization schemes, etc.) involved in computational fluid dynamics.
2. Students will be able to confidently evaluate the coefficients for numerical approximations to elements of partial differential equations and determine the accuracy of these approximations in terms of Taylor series error and spectral resolution.
3. Students will be able to understand and apply the basic concepts of stability, consistency and convergence as they apply to the numerical solutions of partial differential equations.
4. Students will have a thorough ability to apply Fourier Stability Analysis to numerical schemes common in fluid dynamic applications, as well as determine the influence of various boundary conditions on stability. Furthermore, they will be able to determine how to modify their differencing scheme in order to obtain the desired stability and accuracy properties.
5. Students will be able to program various schemes and analyze their accuracy as compared to exact solutions for simplified model problems. They will be able to give a physical interpretation to the sources of error.
6. Students will understand the potential benefits / liabilities of implicit time marching methods and be able to apply them to linear and nonlinear problems.
7. Students will have a basic understanding of concepts used in the construction of finite-volume, high-order, and upwind methods.
8. Students will have a basic knowledge of multi-dimensional effects as regards stability, accuracy and implementation.
9. Students will have an introductory knowledge of methods used to solve nonlinear system of equations iteratively.
10. Students will have a desire to understand further concepts in computational fluid dynamics, especially as concerns the modeling of systems of equations typical in aerodynamics: the Euler and Navier-Stokes equations in multi-dimensional space on arbitrary mesh systems.

Code of Academic Integrity

The University of Maryland, College Park has a nationally recognized Code of Academic Integrity, administered by the Student Honor Council. This code sets standards for academic integrity at Maryland for all undergraduate and graduate students, As a student you are responsible for upholding these standards for this course. It is very important for you to be aware of the consequences of cheating, fabrication, facilitation, and plagiarism. For more information on the Code of Academic Integrity or the Student Honor Council, please visit http://www.shc.umd.edu.
To further exhibit your commitment to academic integrity, remember to sign the Honor Pledge on all examinations and assignments: "I pledge on my honor that I have not given or received any unauthorized assistance on this examination (assignment)."