ENAE 684 - Computational Fluid Dynamics I
Fall 2014

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Classroom:	EGR 2116		Class time:	Tu. / Th. 11:00am-12:15 pm
Canvas:	umd.instructure.com		Office Hours:	M/W 1-2 pm; Fr 9-10 am

Grading:

Homework (and Computer Assignments)	40%
Midterm Exam(s)	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
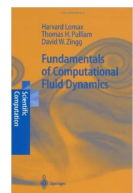> Physics - some *basic* understanding of incompressible and compressible fluid flow
> Computing - MATLAB, editors, plotting, programming skills
> Numerical methods - nothing (or very little)

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.
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.

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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)."

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