# AE 6040 COMPUTATIONAL FLUID DYNAMICS

Credit Hours: 4-0-4

# CATALOG DESCRIPTION:

Finite-difference, finite-volume methods for solution of Navier-Stokes and Euler Equations. Classification of equations, stability, grids, boundary conditions, implicit and explicit methods, turbulence modeling

# PREREQUISITE COMPETENCE:

* Consent of Instructor
* Proficiency in a computer programming language (e.g. FORTRAN, C++, BASIC, ...)
* Undergraduate knowledge of incompressible and compressible fluid dynamics

# TEXT AT THE LEVEL OF:

* Numerical Computation of Internal and External Flows, Hirsch, Ch., Volumes I and II, Wiley, 1988, 1990
* Computational Fluid Mechanics and Heat Transfer, Anderson, D.A., Tannehill, J.C., Pletcher, R.H., Hemisphere Publishing Corp., 1984.
* Numerical Computation of Internal and External Flows, Hirsch, Ch., Volumes I and II, Wiley, 1988, 1990

# LECTURE TOPICS:

**Week 1: Governing Equations**

Introduction: Euler, Full Potential, Laplace, Navier-Stokes eqns in vector form Turbulence treatment: Direct Simulation, LES, RANS

Navier-Stokes approximations:

Thin-Layer Navier-Stokes (TLNS) Parabolized Navier-Stokes (PNS)

Mathematical Classification of Equations Model Equations and Domains of Dependence

# Week 2: Computational Grids

Generalized transformation

Basic requirements, and terminology

Basic types: algebraic, elliptic, hyperbolic, unstructured

# Week 3: Discrete Modeling

Taylor Series Expansions Consistency

Stability Analysis: von Neumann and Matrix Methods Finite difference vs finite volume approach

# Week 4-5: Numerical Solution of Elliptic Equations

Introduction & Model Equation

1-D Iterative Formulations: Point Jacobi, Gauss-Seidel, Direct Inversion Stability of Iterative Schemes

Multi-dimensional Schemes: Point Jacobi, Gauss-Seidel, SOR, SLOR, ADI Stability of the ADI Scheme

# Week 6-7: Solution of 1-D, Unsteady Parabolic and Hyperbolic Equations

1-D Formulations: FTCS (Explicit), 1st Order Upwind, Lax Modified Equation and Artificial Viscosity

Lax-Wendroff, MacCormack, & Runge-Kutta Schemes

# Week 8-11: Solution of the 2-D, Unsteady Euler and Navier-Stokes Equations

Extension of MacCormack's Method and Runge-Kutta to multi-dimensional problems Steger and Warming flux vector splitting, MUSCL differencing

Van Leer flux vector splitting

Roe’s Approximate Riemann Solver

Total Variation Dimenishing Schemes (TVD) Limiters, explicit and implicit formulations

Implicit upwind schemes:

Alternating Direction Implicit (ADI), Lower-Upper (LU), and Approximate Factorization (AF) methods

# Week 12-13: Boundary Condition Treatment

Characteristic boundary conditions, Inflow/Outflow conditions Compatibility relations

Solid wall boundaries:

Slip and no-slip conditions Adiabatic and isothermal conditions

Discrete modeling of viscous terms

**Week 14-15: RANS Turbulence Modeling** Eddy viscosity and Reynolds stress

Algebraic Models

Prandtl-van Driest, Cebeci-Smith, and Baldwin-Lomax models

One and two-equation **models

Please direct questions/comments to Dr. Stephen M. Ruffin, Professor