MATH-492 Computational Fluid Dynamics

Credit Hours: 3-0

Prerequisite: MATH-491 Fluid Mechanics

Course Objectives: This course provides an in depth introduction to the method and analysis techniques used in computational solutions of fluid mechanics problems. Modeled problems are used to study the interaction of physical processes and numerical techniques. Contemporary methods for boundary layers, incompressible viscous flows and inviscid compressible flows are studied. Finite difference and finite volume techniques are emphasized.

Core Contents: Discretization methods; Numerical methods for some modeled equations; Approximations to the governing equations in fluid dynamics; Numerical methods for inviscid and viscous flow problems; Numerical solutions of the Navier-Stokes equations.

Detailed Course Contents: Basics of Discretization Methods: Finite volume method, Introduction to the use of irregular meshes, Stability considerations.

Application of Numerical Methods to Selected Model Equations: Burgers equation (inviscid), Burgers equation (viscous).

Governing Equations of Fluid Mechanics: Averaged equations for turbulent flows, Boundary layer equations, Introduction to turbulence modeling, Euler equation, Transformation of the governing equations, Finite-volume formulation.

Numerical Methods for Inviscid Flow Equations: Introduction to numerical methods for inviscid flow equations, Method of characteristics, Classical shock capturing methods, Flux-splitting schemes, Flux-difference splitting schemes, Multi-dimensional case in a general coordinate system, Boundary conditions for the Euler equations, Methods for solving the potential equation, Transonic small disturbance equations, Methods for solving Laplace equation.

Numerical Methods for Boundary-Layer Type Equations: Introduction, Brief comparison of prediction methods, Finite difference method for two-dimensional or axisymmetric external flows, Inverse method, Separated flows and viscous-inviscid interactions, Methods for internal flows, Application to free-shear flows, Three-dimensional boundary layers, Unsteady boundary layers.

Numerical Methods for the Parabolized Navier-Stokes Equations: Introduction, Thin layer Navier-Stokes equations, Parabolized Navier-Stokes equation, Parabolized and partial parabolized Navier-Stokes procedures for subsonic flows, viscous shock layer equations, “Conical” Navier-Stokes equations.

Numerical Methods for the Navier-Stokes Equations: Introduction, Compressible Navier-Stokes equations, Incompressible Navier-Stokes equations.

Course Outcomes:

- To develop an understanding for: the major approaches and methodologies used in CFD, the interplay of physics and numeric, the methods and results of numerical analysis
- To gain experience in: the actual implementation of methods, the little stuff that is not always clear from theory (e.g. boundary conditions, etc.)
- Increase skills in: implementing and using basic CFD methods computer use and programming.

Text Book: R. H. Pletcher, J. C. Tennehill and D. Andersson, Computational Fluid Mechanicsand Heat Transfer, 3rd Edition, Taylor & Francis, ISBN-10: 1591690374

Reference Books:

1. S. Chapra and R. Canale, Numerical Methods for Engineers, (6th Ed.) McGraw-Hill Higher Education, 2009.
2. J. Ferziger and M. Peric, Computational Methods for Fluid Dynamics. (3rd Ed.) Springer, 2001.

Weekly Breakdown		
Week	***Section***	***Topics***
1	3.5, 3.6,3.7	Finite volume method, Introduction to the use of irregular meshes, Stability considerations.
2	4.4, 4.5	Burgers equation (inviscid), Burgers equation (viscous).
3	5.2, 5.3	Averaged equations for turbulent flows, boundary layer equations.
4	5.4, 5.5	Introduction to turbulence modeling, Euler equation.
5	5.6, 5.7	Transformation of governing equations, Finite-volume formulation.
6	6.1, 6.2, 6,3	Introduction to numerical methods for inviscid flow equations, Method of characteristics, Classical shock capturing methods.
7	6.4, 6.5, 6.6, 6.7	Flux-splitting schemes, Flux-difference splitting schemes, Multi-dimensional case in a general coordinate system, Boundary conditions for the Euler equations.
8	6.8, 6.9, 6.10	Methods for solving the potential equation, Transonic small disturbance equations, Methods for solving Laplace equation.
9	**Mid Semester Exam**	
10	7.1, 7.2, 7.3	Introduction to numerical methods for boundary layer type equations, Brief comparison of prediction methods, Finite difference method for two- dimensional or axisymmetric external flows.
11	7.4, 7.5	Inverse method, Separated flows and viscous-inviscid interactions, Methods for internal flows.
12	7.6, 7.7, 7.8	Application to free-shear flows, Three-dimensional boundary layers, Unsteady boundary layers.
13	8.1, 8.2,	Introduction to numerical methods for “parabolized” Navier-Stokes equation, Thin layer Navier-Stokes equations, Parabolized Navier-Stokes equations
14	8.4, 8.5	Parabolized and partial parabolized Navier-Stokes procedures for

		subsonic flows, viscous shock layer equations, “Conical” Navier-Stokes equations.
15	9.1, 9.2	Introduction to Numerical methods for the Navier-Stokes equations, Compressible Navier-Stokes equations.
16	9.3, 10.1	Incompressible Navier-Stokes equations, Introduction to grid generation.
17		Revision
18	**End Semester Exam**	