Course-Plan

School : ENGINEERING
Department : Mechanical Engineering
Course Code : ME 542
Course Name : Computational Fluid Dynamics

Instructor: Paragmoni Kalita

1. Abstract:

ME 542 is an elective course offered for the M.Tech. programme in Mechanical Engineering (Specializations: Thermal and Fluid Engineering). The course starts with a review of the governing equations of fluid dynamics followed by the mathematical classification of these equations. It then covers different techniques to discretize the governing equations for their numerical solutions, the issues of consistency, stability and convergence and some special numerical methods to solve the inviscid and viscous fluid flow equations.

2. Objectives:

The course shall be taught with the following objectives:

i. To revise the governing equations of fluid dynamics.
ii. To train the students on the discretization techniques for the numerical solution of the governing equations.
iii. To familiarize with the critical issues of numerical consistency, stability, convergence and discretization errors.
iv. To introduce the finite difference and finite volume techniques for numerical solutions of the fluid flow problems.
v. To train the students to numerically solve the fluid flow problems with the help of computer programming.
vi. To acquaint the students with the research scopes in the field of computational fluid dynamics.

3. Prerequisites of the course:

Elementary knowledge of Fluid Mechanics and Mathematics will be helpful for this course.

4. Course outline:

General form of a conservation law; The Navier-Stokes (NS) equation; The inviscid flow model: Euler equations; Steady inviscid rotational flow; Mathematical nature of PDE's and flow equations. Basic Discretization techniques in Finite Difference Method (FDM), Consistency; Stability; Convergence; Fourier or von Neumann stability analysis; Modified equation; Application of FDM to wave, Heat, Laplace and Burgers equations, Integration methods for systems of ODE's, Linear Solver, Introduction to Finite Volume Methods, Numerical solution of the Euler equations, Mathematical formulation of the system of Euler equations; Numerical solution of the incompressible Navier-Stokes equations,

5. (a) Time-Plan

Topic	Content	Book	Class Hours L	Class Hours T
The basic equations of Fluid Dynamics:	General form of a conservation law; Equation of mass conservation	[AJ]	2	1
	Conservation laws of momentum; Conservation equation of energy			
The dynamic levels of approximation	The Navier-Stokes (NS) equation, The Reynolds-averaged NS equations	[TAP]	1	1
	The thin layer NS approximation; The parabolised NS approximation		1	
	The inviscid flow model: Euler equations; Steady inviscid rotational flow		1	1
	Mathematical nature of PDEs and flow equations		2	
Basic discretization techniques in Finite Difference Method (FDM)	Explicit and Compact Schemes for spatial discretization	[AJ}	2	1
	Central and Upwind Schemes		1	1
Analysis and applications of numerical schemes	Consistency; Stability; Convergence	[TAP]	2	1
	Modified equation		1	
	Fourier or von Neumann stability analysis		1	
	Application of von Neumann stability analysis to wave, Heat, Laplace and Burgers equations		2	1
Integration methods for systems of ODE’s	Explicit and Implicit Methods	[TAP]	1	1
	Multi-step methods		1	
	Predictor-corrector schemes		1	
	ADI methods		1	1
	The Runge-Kutta schemes		1	
Introduction to Finite Volume Methods	Finite Volume Discretization of Time Derivative		1	1
	Finite Volume Discretization of the Convective Term		1	
	Finite Volume Discretization of the Dissipative Term		1	
Numerical solutions of the Euler equations	Space-centred schemes	[TAP]	1	1
	Upwind schemes for the Euler equations – Steger and Warming Flux-Vector Splitting (FVS), van Leer’s FVS and Roe’s Flux-Difference Splitting		3	
	Shock tube problem		1	
Numerical solutions of the incompressible Navier Stokes equations	Stream function-vorticity formulation	[TAP]	1	1
	Primitive variable formulation		1	
	staggered and collocated grids		2	
	MAC, SMAC, SIMPLE, SIMPLER and SIMPLEC algorithms		5	1
	Lid-driven cavity flow.		1	
	Total Classes	**39L + 13 T = 52**		

Text Books:

[TAP] Computational Fluid Mechanics and Heat Transfer 2e- Tannehill, Anderson and Pletcher, Taylor and Francis, 1997.

[AJ] Computational Fluid Dynamics – J.D.Anderson, Jr., McGraw-Hill International Edition, 1995.

Reference:

[VM] An introduction to computational fluid dynamics: The finite volume method - H.K. Versteeg and W. Malalasekera, Longman, 1995

[SVP] Numerical Heat Transfer and Fluid Flow - S.V. Patankar, Hemisphere, 1980.

[CH1] Numerical Computation of Internal and External Flows, Vol.1 (1988) – Charles Hirsch, John Wiley & Sons

[CH2]Numerical Computation of Internal and External Flows, Vol.2 (1990) – Charles Hirsch, John Wiley & Sons

[FP] Computational Methods for Fluid Dynamics- J. H. Ferziger, M. Peric, Springer, 2002

5. (b) Evaluation Plan:

Test No.	Marks	Type	Duration (minutes)	To be completed within
Sessional Test I	10	Assignments	-	18.02.2025
Mid-Semester examination)	30	Written	90	29.03.2025
Sessional Test II	10	Seminar	-	30.04.2025
End-Semester Examination	50	Written	120	31.05.2024
Total Marks	**100**			

All the examinations/tests will be held as per the University Academic Calendar.

6. Pedagogy:

Teaching-learning methods to be used:
Lecture and Discussion
Hands-on sessions
Assignment problems,
Class Tests/Quiz

7. Course Outcomes:

CO1: Obtain the finite difference approximations of partial derivatives to specified orders of accuracy.

CO2: Discretize the governing equations of fluid mechanics and heat transfer on finite difference and finite volume frameworks.

CO3: Carry out linear stability analysis of various numerical schemes for solving PDEs governing fluid flow and heat transfer.

CO4: Solve a system of discrete linear algebraic equations using iterative solvers.

CO5: Write computer codes to solve basic fluid flow and heat transfer problems using numerical methods and use appropriate post-processing methods for analyzing the solutions.

CO6: Identify the challenges and scopes of further research in the field of computational fluid dynamics.