Course Type	Course Code	NameofCourse	L	T	P	Credit
DE	NMED528	**Navier-Stokes solvers**	3	0	0	3

CourseObjectives
1. To familiarize the students with the classical approaches of numerically solving the Navier- Stokes (or N-S) equations of motion and aid them develop a solid foundation on the solvers. The students mostly with prior background of dealing with a single ODE/PDE will have detailed flavour of dealing with systems of coupled non-linear PDEs. 2. Step-by-step illustration of the basic algorithms and computer codes for two-dimensional Navier-Stokes solvers using finite volume (for sequential SIMPLE solver) and finite element (for coupled solver) methods.

LearningOutcomes
1. The students will be confident enough to write Navier-Stokes codes on structured mesh in two-dimensions. 2. The students will appreciate the differences between FVM andFEM approaches with respect to a given flow problem in two-dimensions. 3. The students will be enlightened on different advanced linear equation solvers (eg., non- stationary iterative solvers) that are extensively used for solving the asymmetric flow matrix obtained using FEM.

Unit No.	TopicstobeCovered	Lecture Hours	Learningoutcome
1	**MODULEI** The Navier-Stokes equations of motion in primitive variables – various couplings, mathematical behaviour and properties, applicability, derivation of equations, Stokes equations, Streamfunction-vorticityequations, velocity-vorticity equations, pressure Poisson equation	6	The students will learn the method of derivation of differential formof the N-S equations starting from an integral form.This introductory module will also familiarize them with different variants of the N-S equations
2	**MODULEII** Need for methods for approximate solutions of Navier-Stokes equations, strong and weak forms of a differential equation	1	Realization of the importance of numerical methods in solving the N-S equations
3	**MODULEIII** The classification of primitive variable based Navier-Stokes solvers – the sequential and coupled solvers, collocated and staggered arrangement of primitive variables, the first sequential MAC solver of Harlow and Welch using FDM	6	Understanding of the difficulties encounteredwhiledealingwiththe N-S equations numerically. Introduction to the first primitive variable based N-S solver

4	**MODULEIV** Discretization of the convection term via central difference scheme, power-lawscheme,hybridscheme,firstorderupwinding scheme, second order upwinding scheme, QUICK scheme, discretization of the diffusion term, the need for upwinding, the odd-even decoupling of pressure	6	Assessment of various competing discretization schemes for approximatingtheconvection term
5	**MODULEV** The SIMPLE family of sequential Navier- Stokes solvers on staggered structured mesh: complete demonstration of the algorithm using FVM for two-dimensional lid-driven cavity problem on *u*-mesh, *v*-mesh and *p*- mesh	8	Complete understanding of the classical SIMPLE solver on FVM staggered mesh
6	**MODULEVI** LBB compatibility criterion, the coupled Navier-Stokes solver using Galerkin FEM or GFEM: derivation of element level matrices, vectors, implementation of boundary conditions, assemblyof element level matrices and vectors using Q1Q0 elements	8	Generation of the linearized asymmetric global matrix equations for flow problems under the framework of GFEM using Q1Q0 elements
7	**MODULEVII** The limitations of GFEM and need forPetrov-Galerkin (PGFEM) formulation, PGFEM on collocated mesh using Q1Q1 elements, SUPG and PSPG stabilizations, derivation of element level matrices, vectors, implementation of boundary conditions, assemblyof element level matrices and vectors using Q1Q1 elements	7	Need for stabilized FEM formulation for Q1Q1 elements, differences between GFEM and PGFEM

Total 42 hours

TextBooks:

1. H.K.VersteegandW.Malalasekera, *AnIntroductiontoComputationalFluidDynamics*,Pearson Education Limited, 2nd Edition, 2007.

2. J. Doneaand A. Huerta,*FiniteElement Methodfor FlowProblems*, John Wiley& Sons,Ltd., 2003.

References:

1. S.V.Patankar,*NumericalHeatTransferandFluidFlow*,CRCPress,1stEdition,1980.
2. Richard H. Pletcher, John C. Tannehill and Dale A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, 3rd Edition, 2012.
3. JoelH.Ferziger andM.Peric, *ComputationalMethodsforFluidDynamics*,Springer, 3rdEdition, 2002.