Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

SCHOOL OF MECHANICAL ENGINEERING

M.Tech Applied Computational Fluid Dynamics

Curriculum & Syllabi

(2022-2023 batch onwards)

VIT®
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

VISION STATEMENT OF VELLORE INSTITUTE OF TECHNOLOGY

- Transforming life through excellence in education and research.

MISSION STATEMENT OF VELLORE INSTITUTE OF TECHNOLOGY

- **World class Education:** Excellence in education, grounded in ethics and critical thinking, for improvement of life.
- **Cutting edge Research:** An innovation ecosystem to extend knowledge and solve critical problems.
- **Impactful People:** Happy, accountable, caring and effective workforce and students.
- **Rewarding Co-creations:** Active collaboration with national & international industries & universities for productivity and economic development.
- **Service to Society:** Service to the region and world through knowledge and compassion.

VISION STATEMENT OF THE SCHOOL OF MECHANICAL ENGINEERING

- To be a leader in imparting world class education in Mechanical Engineering, leading to nurturing of scientists and technologists of highest caliber who would engage in sustainable development of the globe.

MISSION STATEMENT OF THE SCHOOL OF MECHANICAL ENGINEERING

- To create and maintain an environment fostering excellence in instruction & learning, Research and Innovation in Mechanical Engineering and Allied Disciplines.

- To equip students with the required knowledge and skills to engage seamlessly in higher educational and employment sectors ensuring that societal demands are met.

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M. Tech Applied Computational Fluid Dynamics

PROGRAMME OUTCOMES (POs)

PO_1: Having an ability to apply mathematics and science in engineering applications.

PO_2: Having an ability to design a component or a product applying all the relevant standards and with realistic constraints, including public health, safety, culture, society and environment.

PO_3: Having an ability to design and conduct experiments, as well as to analyse and interpret data, and synthesis of information.

PO_4: Having an ability to use techniques, skills, resources and modern engineering and IT tools necessary for engineering practice.

PO_5: Having problem solving ability- to assess social issues (societal, health, safety, legal and cultural) and engineering problems.

PO_6: Having adaptive thinking and adaptability in relation to environmental context and sustainable development.

PO_7: Having a clear understanding of professional and ethical responsibility.

PO_8: Having a good cognitive load management skills related to project management and finance.

M. Tech Applied Computational Fluid Dynamics

PROGRAMME SPECIFIC OUTCOMES (PSOs)

On completion of M. Tech. (Applied Computational Fluid Dynamics) programme, graduates will be able to

PSO1: Compute, Design, Model, Simulate and Analyse various fluid flow and heat transfer problems using numerical techniques for applications in Aerospace, Automotive, Biomedical, Chemical, Environmental and Energy Engineering.

PSO2: Adopt a multidisciplinary approach to solve real-world industrial problems involving Mass, Momentum and Energy transport processes.

PSO3: Independently carry out research / investigation to solve practical problems and write / present a substantial technical report/dissertation.

M. Tech Applied Computational Fluid Dynamics

PROGRAMME EDUCATIONAL OBJECTIVES (PEOs)

1. Graduates will be engineering practitioners and leaders, who would help solve industry's technological problems.

2. Graduates will be engineering professionals, innovators or entrepreneurs engaged in technology development, technology deployment, or engineering system implementation in industry.

3. Graduates will function in their profession with social awareness and responsibility.

4. Graduates will interact with their peers in other disciplines in industry and society and contribute to the economic growth of the country.

5. Graduates will be successful in pursuing higher studies in engineering or management.

6. Graduates will pursue career paths in teaching or research.

Master of Technology in Applied Computational Fluid Dynamics
School of Mechanical Engineering

Programme Credit Structure	Credits
Discipline Core Courses	24
Skill Enhancement Courses	05
Discipline Elective Courses	12
Open Elective Courses	03
Project/ Internship	26
Total Graded Credit Requirement	70

Discipline Core Courses **24**

		L	T	P	C
MCFD501L	Transport Phenomena	3	0	0	3
MCFD502L	Advanced Fluid Dynamics	3	0	0	3
MCFD503L	Advanced Heat Transfer	3	0	0	3
MCFD504L	Numerical Methods for Partial Differential Equations	3	0	0	3
MCFD504P	Numerical Methods for Partial Differential Equations Lab	0	0	2	1
MCFD505P	Computational Fluid Dynamics Lab	0	0	4	2
MCFD506L	Numerical Solution of the Navier-Stokes equations	3	0	0	3
MCFD506P	Numerical Solution of the Navier-Stokes equations Lab	0	0	2	1
MCFD507P	Advanced Computational Fluid Dynamics Lab	0	0	4	2
MCFD508L	Turbulence Modelling	3	0	0	3

Skill Enhancement Courses **05**

MENG501P	Technical Report Writing	0	0	4	2
MSTS501P	Qualitative Skills Practice	0	0	3	1.5
MSTS502P	Quantitative Skills Practice	0	0	3	1.5

Discipline Elective Courses **12**

MCFD601L	Computational Aerodynamics	3	0	0	3
MCFD602L	Chemically Reacting Flows - Combustion	2	0	0	2
MCFD602P	Chemically Reacting Flows - Combustion Lab	0	0	2	1
MCFD603L	Fluid Structure Interaction	3	0	0	3
MCFD604L	Experimental methods for Fluid Flow	2	0	0	2
MCFD604P	Experimental methods for Fluid Flow Lab	0	0	2	1
MCFD605L	Multiphase flows	3	0	0	3
MCFD606L	Finite Element Analysis of Solids and Fluids	3	0	0	3
MCFD607L	High Performance Computing	2	0	0	2
MCFD607P	High Performance Computing Lab	0	0	2	1
MCFD608L	Numerical Simulation of Environmental and Atmospheric Flows	3	0	0	3
MCFD609L	Modeling and Simulation of Energy Systems	3	0	0	3

Open Elective Courses **03**

Engineering Disciplines | Social Sciences

Project and Internship **26**

MCFD696J	Study Oriented Project	02
MCFD697J	Design Project	02
MCFD698J	Internship I/ Dissertation I	10
MCFD699J	Internship II/ Dissertation II	12

Discipline Core Courses

Course Code	Course Title		L	T	P	C
MCFD501L	**Transport Phenomena**		**3**	**0**	**0**	**3**
Pre-requisite	**NIL**	**Syllabus version**				
		1.0				

Course Objectives

1. To teach the basic concepts of transport phenomena, similarities of the governing equations of mass, momentum, and heat transfer
2. To illustrate the common mathematical structure of transport problems.
3. To formulate appropriate differential equations to obtain velocity, temperature, and concentration profiles of transport processes.

Course Outcome

Upon successful completion of the course the students will be able to

1. Understand the transport properties of molecular transfer of mass, momentum and energy
2. Relate simultaneous mass, momentum and heat transfer analysis
3. Solve one-dimensional steady state momentum, heat and mass transfer problems.
4. Apply Navier-Stokes equation to examine the problems related to fluid, heat, and mass transfer.
5. Analyse industrial transport problems with appropriate approximations and boundary conditions

Module:1	Mechanisms of Momentum, Energy and Mass transport	7 hours

Coordinate systems and its rotation of axes- Vector and tensor differential operations - Vector and tensor integral theorems. momentum transport, energy transport and mass transport - level of analysis - molecular transport properties of gases and liquids - effect of pressure and temperature.

Module:2	Equations of Change	6 hours

Equations of change for isothermal systems - equations of change for non-isothermal systems - equations of change for multicomponent systems

Module:3	Interphase Transport and Macroscopic Balances for Isothermal Flow Systems	6 hours

Friction factors for flow in tubes, Friction factors for flow around a bluff body, Estimation of the viscous loss, Use of the macroscopic balances for steady-state and unsteady-state problems.

Module:4	Transport phenomena in polymeric Liquids	5 hours

Behaviour of polymeric liquids, non-Newtonian viscosity and the generalized Newtonian models, Elasticity and the linear viscoelastic models, nonlinear viscoelastic models.

Module:5	Temperature distributions in Turbulent Flows	7 hours

Time-averaged equations of change for incompressible non-isothermal flow, the time-averaged temperature profile near a wall, temperature distribution for turbulent flow in tubes and jets.

Module:6	Concentration Distributions in Laminar Flows	6 hours

Shell mass balances, boundary conditions; Diffusion through a stagnant gas film; Diffusion with a heterogeneous and a homogeneous chemical reaction; Diffusion into a falling liquid film-gas absorption - solid dissolution.

Module:7	**Concentration Distributions with Multiple Independent Variables**			**6 hours**
Time-dependent diffusion; Steady-state transport in binary boundary layers; Steady-state boundary layer theory for flow around objects; Boundary layer mass transport with complex interfacial motion				
Module:8	**Contemporary Issues**			**2 hours**
	Total Lecture hours:			**45 hours**
Text Book(s)				
1.	Bird R. B., Stewart W. E., Lightfoot E. N., Transport Phenomena, 2012, Second Edition, John Wiley & Sons Inc., Wiley Student Edition, India.			
Reference Books				
1	Geankoplis C.J., Transport Processes and Separation Process Principles, 2018, Fifth Edition, Pearson Education India.			
2.	Plawsky Joel L, Transport Phenomena fundamentals, 2020, Fourth Edition., CRC Press, USA.			
3.	William M. Dean, Analysis of Transport Phenomena, 2013, Second Edition, Oxford University Press, India.			
Mode of Evaluation: Continuous assessment test, written assignment, Quiz and Final assessment test				
Recommended by Board of Studies	27-05-2022			
Approved by Academic Council	No. 66	Date	16-06-2022	

Course Code	Course Title	L	T	P	C
MCFD502L	**Advanced Fluid Dynamics**	**3**	**0**	**0**	**3**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To apply fundamentals of fluid mechanics and governing equations for solving real time engineering applications.
2. To provide in-depth knowledge of potential flow and boundary layers.
3. To understand complex phenomena underlying turbulent and compressible flows.
4. To familiarize students with experimental techniques related to fluid mechanics.

Course Outcome

Upon completion of the course the students will be able to

1. Deduce governing equations for particular flow fields with applications.
2. Analyse potential flows and execute concept of conformal transformation for flow over bodies.
3. Apply boundary layer concepts for real fluids for solving fluid flow and heat transfer problems.
4. Analyse turbulent flows through various techniques for wall bounded and free shear flows.
5. Examine compressible flows through various systems involving shock waves.
6. Apply various intrusive and non-intrusive techniques to measure flow and fluid properties.

Module:1	Overview of fluid motion	5 hours

Introduction- Newtonian and non-Newtonian fluids. Description of fluid motion – Lagrangian and Eulerian approaches. Motion of fluid element translation, rotation and deformation; vorticity and strain-rate tensors; Streamlines, Path lines, Streak lines and Time lines, Stream function and Velocity Potential Functions, Rotational and irrorational flows - circulation – vorticity.

Module:2	Governing Equations of Fluid Flow	8 hours

Reynolds transport theorem. Three dimensional continuity equation - differential and integral forms – equations of motion momentum, energy, and their engineering applications. Derivation of Navier-Stokes Equations for viscous compressible flows – Exact solutions to certain simple cases: Coutte flow – Hagen Poisoulle flow – flow between two concentric rotating cylinders.

Module:3	Potential Flow Theory	5 hours

Pressure distribution over stationery and rotating cylinders in a uniform flow - Magnus effect - Kutta – Zhukovsky theorem. Complex potential functions. Conformal transformation to analyze flow over a flat plate, cylinder, spherical body and airfoils. Thin airfoil theory – generalized airfoil theory for cambered and flapped airfoils.

Module:4	Boundary layer Theory	7 hours

Boundary Layer thickness - laminar and turbulent boundary layer formulation, governing equations, order-of-magnitude analysis, von Karmann Momentum integral equation. Flow separation and recirculation.

Module:5	Turbulent Flow	7 hours

Introduction to Theory of Hydrodynamic Stability, factors affecting transition and its control. RANS equation, Prandtl's Mixing Length and Eddy Viscosity concepts, Universal Velocity distribution, Laws of the wall and free shear flows.

Module:6	**Compressible Flow**	**6 hours**
One dimensional compressible fluid flow – flow through variable area passage – nozzles and diffusers, fundamentals of supersonics – normal and oblique shock waves and calculation of flow and fluid properties over solid bodies - flat plate, wedge and diamond.		
Module:7	**Experimental Techniques**	**5 hours**
Introduction: Design of fluid flow experiments; uncertainty analysis - types of error; flow measurement - hot wire and hot film anemometers; flow visualization techniques - Laser - Doppler anemometry (LDA) and Particle Image Velocimetry (PIV), pressure and temperature measurements, methods of measuring turbulence.		
Module:8	**Contemporary issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)	
1.	Muralidhar, Gautam Biswas, Advanced engineering fluid mechanics, 2015, 3rd Edition, Narosa Publications.
2.	White, Frank M. Fluid Mechanics. McGraw-Hill Education, 9th Edition, 2021.
Reference Books	
1.	S K Som, Gautam Biswas, S Chakraborty, Introduction to Fluid Mechanics and Fluid Machines, 2017, McGraw Hill
2.	Kundu, Pijush K., Ira M. Cohen, and David R. Dowling. *Fluid mechanics*. Academic press, 2015.
3	Schlichting, H and K. Gersten. Boundary Layer Theory. Springer, 2017

Mode of Evaluation: CAT, written assignment, Quiz and FAT			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD503L	**Advanced Heat Transfer**	**3**	**0**	**0**	**3**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To impart knowledge of governing laws of different modes of heat transfer.
2. To formulate and reduce mass, momentum and energy conservation equations situationally.
3. To obtain the exact and approximate solutions of external and internal heat transfer equations.
4. To determine radiative heat flux between the two surfaces with participating/non-participating mediums.

Course Outcome

Upon successful completion of the course the students will be able to

1. Formulate governing equations for real time problems.
2. Solve problems of steady state heat conduction.
3. Analyze problems of transient heat conduction.
4. Solve forced convective heat transfer problems
5. Solve natural convective heat transfer processes.
6. Solve radiative heat transfer problems.

Module:1	**Governing laws of Heat Transfer**	**5 hours**

A review of heat conduction, convection, thermal radiation, and viscous flow; the derivation of mass, momentum, and energy equation in dimensional and non-dimensional forms. Various non-dimensional numbers in heat transfer.

Module:2	**Steady State Conduction**	**6 hours**

Derivation of three-dimensional heat conduction equations for anisotropic inhomogeneous mediums, conductive tensor. Steady state conduction in isotropic and homogeneous mediums. Solution methods - analytical and numerical;

Module:3	**Transient Conduction**	**6 hours**

Transient conduction: Recapitulation of transient conduction for simple systems. Analysis of transient heat conduction with complex boundary conditions. Solution methods - analytical and numerical.

Module:4	**External Forced Convection**	**6 hours**

Convective heat transfer in external flows and their solution methods: Analogy between momentum and heat transfer, Boundary layer approximations to momentum and energy equations, Similarity solution techniques, Momentum and energy integral methods and their applications in flow over flat plates with low and high Prandtl number approximations.

Module:5	**Internal Forced Convection**	**7 hours**

Convective heat transfer in internal flows and solution methods: Flow through channels and circular pipes, Fully developed forced convection in ducts with constant heat flux and constant wall temperature boundary conditions, Forced convection in the thermal entrance region of ducts, Heat transfer in combined entrance region, Integral method for internal flows with different wall boundary conditions.

Module:6	**Natural Convection**	**7 hours**

Introduction to natural convection; Boussinesq approximation and scale analysis; Natural convection from a vertical plate using similarity and integral solution, Natural convection in enclosed spaces. Combined forced and free convection.

Module:7	**Radiation**	**6 hours**
Laws of Radiation, Intensity of Radiation, Irradiation, Radiosity, Radiative properties of surfaces, Radiation exchange between surfaces, View Factor, Radiation exchange in a black enclosure, Radiative heat transfer in participating media (Gas Radiation), Radiative Transfer Equation. Radiant exchange between surfaces; Radiative heat transfer in non-participating media.		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)	
1.	Yunus A Cengel and Afshin J Ghajar,Heat and Mass Transfer: Fundamentals and Applications, 5 th edition, McGraw-Hill, 2015.
Reference Books	
1	J P Holman and Souvik Bhattacharyya, Heat Transfer, 10 th edition, McGraw-Hill, 2016.
2.	F P Incropera, D P Dewitt, T L Bergman, and A S Lavine, Incropera's Principles of Heat and Mass Transfer, Wiley, 2018.
3.	D W Hahn, and M N Ozisik, Heat Conduction, John Wiley & Sons, 3rd Edition, 2012.
4.	V S Arpaci, Conduction Heat Transfer, Addison-Wesley, Reading, MA, 1966.
5.	M F Modest, Radiative Heat Transfer, Academic Press, 3rd Edition, 2013.
6.	Kays, W.M. and Crawford W., Convective Heat and Mass Transfer, McGraw Hill , 2004
Mode of Evaluation: Continuous assessment test, written assignment, Quiz and Final assessment test	

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title		L	T	P	C
MCFD504L	Numerical Methods for Partial Differential Equations		3	0	0	3
Pre-requisite	NIL	Syllabus version				
		1.0				

Course Objectives

1. To develop a conceptual understanding of numerical methods commonly used for solving partial differential equations
2. To impart working knowledge of numerical methods including experience in implementing them for model problems drawn from fluid flow and heat transfer applications
3. To develop a foundation for theoretical techniques to analyze the behavior of the numerical methods

Course Outcome

Upon successful completion of this course students will be able to

1. Demonstrate the understanding of numerical methods commonly used for solving partial differential equations.
2. Apply different interpolation methods to compute parameters needed as the part of numerical simulation and presentation of results
3. Develop numerical algorithms using finite difference method to solve PDEs
4. Apply direct and iterative techniques to solve system of equations
5. Examine the consistency of a finite differences scheme and define the stability criteria.
6. Apply different boundary conditions and linearization techniques.
7. Apply the finite element method for the solution of PDEs.

Module:1	Partial Differential Equations	6 hours

PDE Definition – Linear, Semi-linear, Quasi-linear, fully non-linear – Some model equations – Applications, Limiting Cases –The existence of characteristics and their physical interpretation. Elliptic, parabolic, and hyperbolic partial differential equations. The convection-diffusion equation. Initial Values and Boundary Conditions-numerical concerns. Machine arithmetic and related matters relevant to computations.

Module:2	Interpolation Methods	6 hours

Operators –finite differences, average, differential, etc., their inter-relations. Difference of polynomials. Difference equation. Interpolation. Lagrange's methods, error terms. Uniqueness of interpolating polynomial. Newton's fundamental interpolation. Forward, backward, and central difference interpolations. Interpolation by iteration. Spline interpolation, comparison with Newton's interpolation. Hermite's interpolation. Bivariate interpolation, Lagrange, and Newton's methods. Inverse interpolation.

Module:3	Solution Mechanisms for linear systems – Elliptic equations	6 hours

Finite difference discretization – Lagrangian interpolation, Taylor's series, truncation error, Application to Poisson equation in one and two dimensions – Solution methods-Direct methods: Gauss-Jourdan elimination, Lower-Upper decomposition, Thomas algorithm for tridiagonal systems. Iterative methods: Jacobi Gauss-Seidel , Successive Over-Relaxation, Successive Line Over-Relaxation, Steepest descent, Conjugate gradient. Convergence analysis for iterative methods. Solution of algebraic system. Solution methods for elliptic equations.

Module:4	Solution Techniques for Parabolic Partial Differential Equations	6 hours

Finite difference discretization of spatial derivatives - Parabolic equation in its semi-discrete

form – Matrix formulation, Initial Boundary Value problems –solution properties – Consistency, Stability, Convergence. Solution methods for the Parabolic Differential equations (1D & 2D): Forward-Time Centered Space (FTCS), Backward-Time Centered Space (BTCS), Crank Nicolson, Alternating Direction Implicit (ADI). Newmann Boundary conditions- Over relaxation – Under relaxation. Multigrid Techniques.		
Module:5	**Solution for Hyperbolic Partial Differential Equations**	**7hours**
Solution properties- Domain of Dependence, General solution –Time and spatial Finite difference discretization schemes - Forward time central difference, Forward time upwind, Lax-Wendroff, Beam and Warming, Predictor/Corrector Algorithm , Semi-discrete form, Method of lines; Consistency , Stability Analysis, Convergence, Truncation Error, Lax Equivalence theorem, CFL condition, Fourier stability Analysis , Von Stability Criterion , Absolute Stability Diagrams, Dispersion and Dissipation behaviour; Application- wave equations, Runge–Kutta Methods.		
Module:6	**The Finite Volume Method**	**6hours**
Finite volume discretization – conservation methods Finite Volume Method (1D), Finite Volume Method (2D): computational cells, cell averages, Cartesian grids, orthogonal non-Cartesian grids, non-orthogonal meshes.		
Module:7	**The Finite Element Method**	**6hours**
Generalization of the finite element concepts. Basic equations and solution procedure: Direct method, Galerkin-weighted residual, variational approaches. The Finite Element Method (1D): Discretization of the domain, Derivation of element matrices and vectors, Assembly of element matrices and vectors and derivation of system equations		
Module:8	**Contemporary Issues**	**2hours**
	Total Lecture hours:	**45hours**

Text Book(s)	
1.	Sandip Mazumder, Numerical Methods for Partial Differential Equations, Finite Difference and Finite Volume Methods, Academic Press, 2016, ISBN: 978-0-12-849894-1.
2	Hoffman, Joe D., and Steven Frankel. Numerical Methods for Engineers and Scientists. CRC press, 2001, ISBN 978-0-82-470443-8
Reference Books	
1.	Morton, K. W., & Mayers, D. F. Numerical Solution of Partial Differential Equations (2nd Ed.). Cambridge University Press, 2005.
2.	Pinder, George F. Numerical methods for solving partial differential equations: a comprehensive introduction for scientists and engineers. John Wiley & Sons, 2018.

Mode of Evaluation: CAT , written assignment , Quiz , FAT

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD504P	**Numerical Methods for Partial Differential Equations Lab**	**0**	**0**	**2**	**1**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To enable the students to develop numerical codes by applying theoretical. knowledge of numerical methods commonly used for solving PDEs.
2. To teach the students to extend the numerical methods of model PDEs to the. solution of fluid flow and heat transfer problems.

Course Outcome

Upon successful completion of this course students will be able to.

1. Develop numerical codes using FDM for solving model partial differential equations.
2. Develop numerical codes using FEM for solving model partial differential equations.

Indicative Experiments

1.	Write a program to solve a 2D Elliptic (Poisson equation) using Jacobi, Gauss-Seidel and SOR methods subjected to Dirichlet or Neumann boundary conditions
2.	Write a program to solve a 1D parabolic (Heat equation) using the FTCS method
3.	Write a program to solve a 2D parabolic (Heat equation), using the FTCS method
4.	Write a program to solve a 1D advection equation, using the Upwind scheme, the Lax-Friedrichs scheme and the Lax-Wendroff scheme and check the unstable FTCS scheme
5.	Write the code to solve a 1D convection-diffusion equation, using the FTCS scheme and the upwind scheme
6.	Write the code to solve a 1D convection-diffusion equation, using finite volume method to implement the FTCS scheme and the upwind scheme.
7.	Write the code to solve a 1D convection-diffusion equation, using finite volume method to implement QUICK scheme
8.	Write the code to solve 1D finite element Poisson eq. using Conjugate gradient method
9.	Write the code to solve Lid-driven cavity using vorticity-stream function formulation
10.	Write the code to solve Sod's shock tube problem using any two upwind schemes
	Total Laboratory Hours: 30 hours

Text Book(s)

1.	Hoffman, Joe D., and Steven Frankel. Numerical methods for engineers and scientists. CRC press, 2018.

Reference Books

1.	Morton, K. W., & Mayers, D. F. Numerical Solution of Partial Differential Equations (2nd Ed.). Cambridge University Press, 2012.
	LeVeque, Randall J. Finite Difference Methods for Ordinary and Partial Differential Equations: Steady-State and Time-Dependent Problems. Philadelphia, PA: Society for Industrial and Applied Mathematics, 2007. ISBN: 9780898716290.

Mode of assessment: Continuous assessment and FAT

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	**Course Title**	**L**	**T**	**P**	**C**
MCFD505P	**Computational Fluid Dynamics Lab**	**0**	**0**	**4**	**2**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To impart skills required for the creation of 2D and 3D geometries for flow modeling.
2. To teach different methods of grid generation for simple fluid flow problems.
3. To enable students to apply the concepts of CFD and perform simulations using flow solvers and visualize the results.

Course Outcome

Upon successful completion of this course students will be able to

1. Perform geometry modeling for simple fluid flow problems.
2. Develop different types of mesh suited for the accurate capturing of flow field.
3. Perform 2D analysis to understand the flow characteristics and forces involved in different internal and external flows.
4. Develop user defined functions to perform customized simulations.
5. Demonstrate simulation-results using different post processing tools.

Indicative Experiments	
1.	2D/3D geometry creation using Design Modeler and/or Space Claim
2.	Unstructured mesh generation for a y-section/ Bifurcating Artery domain
3.	Structured mesh generation for the study of external flow over a NACA aerofoil
4.	Laminar and turbulent flow over an aerofoil at different angles of attack
5.	Simulation of incident shock wave and boundary layer interaction
6.	Investigation of flow patterns in oil-water flows using VOF model
7.	Prediction of wake formation behind tandem cylinders subjected to constant heatflux
8.	Simulation of blood flow through bifurcating artery
9.	Numerical study of tube-in-tube heat exchanger with the incorporation of user defined inlet velocity profiles
10.	Transient study of phase change characteristics of an ice block
	Total Laboratory Hours: 60 hours

Text Book(s)

1. Tu, Jiyuan, Guan Heng Yeoh, and Chaoqun Liu. Computational fluid dynamics: a practical approach. Butterworth-Heinemann, 2018.

Reference Books

1. Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015.
2. John Matsson, An Introduction to ANSYS Fluent 2020, SDC Publications, 2020
3. Versteeg, Henk Kaarle, and Weeratunge Malalasekera. An introduction to computational fluid dynamics: the finite volume method. Pearson education, 2007.

Mode of assessment: Continuous assessment and FAT			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD506L	Numerical Solution of the Navier-Stokes Equations	3	0	0	3
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To develop a conceptual understanding of different forms of Navier Stokes equations and the solution algorithms used to solve them
2. To develop a foundation for understanding the different finite volume numerical schemes for structured and unstructured grids, boundary and initial conditions, linear algebraic and differential algebraic equations solvers
3. To impart working knowledge implementing the solution algorithms and develop computer programs to solve benchmark incompressible fluid flow and heat transfer problems on simple and complex geometries and evaluate the solver accuracy thorough verification and validation

Course Outcome

Upon successful completion of this course students will be able to

1. Distinguish and apply different forms of Navier Stokes equations.
2. Distinguish and apply different solution algorithms to solve the Navier-Stokes equation
3. Explain the different finite volume schemes to discretize the convection and diffusion terms on structured and unstructured grids
4. Develop computer programs to solve steady and unsteady Navier Stokes equation in primitive variables using finite volume methods for simple and complex geometries
5. Apply linearization techniques, boundary conditions, direct and iterative approaches for the development of flow solvers
6. Demonstrate the accuracy of the developed computer program with thorough verification and validation and generation of quality documentation of results

Module:1	Navier-Stokes equations variants and related mathematical formulations	6 hours

Vorticity-stream function formulation for two-dimensional flow - Governing equations, Flow in a rectangular cavity, Direct computation of a steady flow, Modified dynamics for steady flow, unsteady flow. Velocity-pressure formulation - Pressure Poisson equation (PPE), Alternative systems of governing equations, Boundary conditions for the pressure, Compatibility condition for the PPE, Ensuring compatibility, Explicit evolution equation for the pressure. Implementation of primitive variables - Implementation on a staggered grid, non-staggered grid, Second-order methods.

Module:2	Solution algorithms for Navier Stokes equations	6 hours

Operator splitting, projection, and pressure-correction methods - Solenoidal projection and the role of the pressure - Boundary conditions for intermediate variables - Evolution of the rate of expansion - First-order projection method - Second-order methods. Methods of modified dynamics or false transients - Artificial compressibility method for steady flow. Modified PPE - Penalty-function formulation

Module:3	Finite Volume methods for Convection-Diffusion Equations	7 hours

Steady one-dimensional convection and diffusion, Central differencing scheme, Properties of discretization schemes - Conservativeness - Boundedness – Transportiveness, Upwind differencing scheme, Hybrid differencing scheme , Assessment of the central differencing , upwind differencing and hybrid differencing scheme for convection–diffusion problems, Hybrid differencing scheme for multi-dimensional convection–diffusion, Power-law scheme, Higher-order differencing schemes for convection–diffusion problems- Quadratic upwind differencing scheme: QUICK scheme - Assessment of the QUICK scheme - Stability problems of the QUICK scheme and remedies- General comments on the QUICK

differencing scheme, TVD schemes- Generalization of upwind-biased discretization schemes- Total variation and TVD schemes- Criteria for TVD schemes- Flux limiter functions- Implementation of TVD schemes- Evaluation of TVD schemes		
Module:4	**Finite volume implementation of pressure-correction based incompressible Navier-Stokes Solver for Steady flows**	**6 hours**
The staggered grid, The momentum equations, Discretization of convection, diffusion, pressure gradient and body force terms, The SIMPLE algorithm, Assembly of a complete method, The SIMPLER algorithm, The SIMPLEC algorithm, The PISO algorithm, General comments on SIMPLE, SIMPLER, SIMPLEC and PISO, Worked examples of the SIMPLE algorithm.		
Module:5	**Finite volume implementation of pressure-correction based incompressible Navier-Stokes Solver for Unsteady flows**	**7 hours**
Explicit scheme, Crank–Nicolson scheme, the fully implicit scheme, Implicit method for two- and three-dimensional problems, Solution procedures for unsteady flow calculations - Transient SIMPLE - The transient PISO algorithm, Steady state calculations using the pseudo-transient approach.		
Module:6	**Finite volume Implementation of Boundary conditions**	**4 hours**
Inlet boundary conditions - Outlet boundary conditions - Wall boundary conditions - The constant pressure boundary condition - Symmetry boundary condition - Periodic or cyclic boundary condition - Potential pitfalls		
Module:7	**Finite volume methods for dealing with complex geometries**	**7 hours**
Body-fitted co-ordinate grids for complex geometries, Cartesian vs. curvilinear grids – an example, Curvilinear grids – difficulties, Block-structured grids, Unstructured grids, Discretization in unstructured grids, Discretization of the diffusion term, Discretization of the convective term, Treatment of source terms, Assembly of discretised equations, Example calculations with unstructured grids, Pressure–velocity coupling in unstructured meshes, Staggered vs. co-located grid arrangements, Extension of the face velocity interpolation method to unstructured meshes.		
Module: 8	**Contemporary issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)	
1.	H K Versteeg and W Malalasekera, An Introduction to Computational Fluid Dynamics - The Finite Volume Method, 2nd Edition, Pearson Prentice Hall, 2007, ISBN: 978-0-1312-7498-3
2	Pozrikidis, C. Introduction to theoretical and computational fluid dynamics, Second Edition Oxford University Press, 2011, ISBN 978-0-1997-5207-2
Reference Books	
1.	Joel H. Ferziger, Milovan Perić, Robert L. Street, Computational Methods for Fluid Dynamics, 4th Edition, Springer, 2021, ISBN: 978-3-3199-9691-2
2.	Hirsch. Ch., Numerical computation of internal and external flows, Vol.1 Fundamentals of Numerical discretization, 2nd Edition, Butterworth-Heinemann, Elsevier, 2007, ISBN: 978-0-7506-6594-0.
3.	Jiri Blazek, Computational Fluid Dynamics: Principles and Applications, 3rd Edition, Butterworth-Heinemann, 2015, ISBN 978-0-0809-9995-1
Mode of Evaluation: CAT , written assignment , Quiz , FAT	

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD506P	Numerical Solution of the Navier-Stokes Equations Lab	0	0	2	1
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To develop a conceptual understanding and working knowledge of Finite difference and finite volume discretization techniques and solution algorithms used for solving Navier Stokes equations in velocity/pressure, velocity/vorticity, and vorticity/stream formulation.
2. To impart working knowledge of developing CFD codes for bench mark problems drawn from fluid flow and heat transfer applications

Course Outcome

Upon successful completion of this course students will be able to

1. Demonstrate the understanding of finite difference methods used for solving the incompressible Navier- Stokes equations in velocity/pressure, velocity/vorticity, and vorticity/stream function formulation
2. Demonstrate the understanding of finite volume methods used for solving the incompressible Navier- Stokes equations in velocity/pressure formulation
3. Demonstrate the understanding of different solution algorithms used for solving the incompressible Navier- Stokes equations in velocity/pressure formulation
4. Develop finite difference scheme to simulate benchmark problems for simple geometries by solving the Navier -Stokes equations in vorticity/stream function formulation on Cartesian grids.
5. Develop finite difference scheme to simulate benchmark problems for simple geometries by solving the Navier -Stokes equations in velocity/pressure formulation on staggered and collocated Cartesian grids using operating splitting and projection method
6. Develop finite volume scheme to simulate benchmark problems for simple geometries by solving the two dimensional Navier -Stokes equations in velocity/pressure formulation on staggered and collocated Cartesian grids using SIMPLE, SIMPLEC and projection method

Indicative Experiments	
1.	Write a Explicit finite difference code to compute the velocity profile in a unidirectional channel flow starting from the specified initial condition, subject to the prescribed boundary conditions by solving the governing equation in velocity/pressure formulation
2.	Write a Implicit finite difference code to compute the velocity profile in a unidirectional channel flow starting from the specified initial condition, subject to the prescribed boundary conditions by solving the governing equation in velocity-pressure formulation
3.	Write a Implicit finite difference code to compute the velocity profile in a unidirectional channel flow starting from the specified initial condition and pressure gradient, subject to the prescribed boundary conditions by solving the governing equation in velocity/vorticity formulation
4.	Develop a finite-difference method based on the stream function/vorticity formulation for computing the velocity profile of steady channel flow subject to a specified flow rate.
5.	Develop a finite-difference method based on the stream function/vorticity formulation for computing the two-dimensional flow in a square cavity driven by a sliding lid.
6.	Develop a finite-difference method based on the velocity /pressure formulation

	for computing the two-dimensional flow in a square cavity driven by a sliding lid using the operation splitting and solenoidal projection method on a collocated grid.
7.	Develop a finite-difference method based on the velocity /pressure formulation for computing the two-dimensional flow in a square cavity driven by a sliding lid using the operation splitting and solenoidal projection method on a staggered grid.
8.	Develop a finite-volume method based on the velocity /pressure formulation for computing the two-dimensional flow in a square cavity driven by a sliding lid on a staggered grid using the SIMPLE algorithm
9.	Develop a finite-volume method based on the velocity /pressure formulation for computing the two-dimensional natural convection flow in a square cavity on a staggered grid using Projection method
10.	Develop a finite-volume method based on the velocity /pressure formulation for computing the two-dimensional flow over a backward facing step on a staggered grid using the SIMPLEC algorithm
	Total Laboratory Hours 30 hours
Text Book(s)	
1.	George Qin, Computational Fluid Dynamics for Mechanical Engineering, 1st Edition, CRC press, 2022, ISBN: 978-0-367-68730-4.
2.	C. Pozrikidis, Fluid Dynamics: Theory, Computation and Numerical simulation, 3rd Edition, Springer,2017, ISBN 978-1-4899-7990-2.
Reference Books	
1.	H K Versteeg and W Malalasekera, An Introduction to Computational Fluid Dynamics - The Finite Volume Method, 2nd Edition, Pearson Prentice Hall, 2007, ISBN: 978-0-1312-7498-3.
2.	D. G. Roychowdhury, Computational Fluid Dynamics for Incompressible Flows, 1st Edition, CRC press, ISBN: 978-0-367-40806-0
3.	Joel H. Ferziger, Milovan Perić, Robert L. Street, Computational Methods for Fluid Dynamics, 4th Edition, Springer, 2021, ISBN: 978-3-3199-9691-2
4.	Sreenivas Jayanthi, Computational Fluid Dynamics for Engineers and Scientists, 1st Edition, Springer, 2018, ISBN 978-94-024-1215-4

Mode of assessment: Continuous assessment / FAT / Oral examination and others			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 16	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD507P	**Advanced Computational Fluid Dynamics Lab**	**0**	**0**	**4**	**2**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To impart skills required for the advanced grid generation techniques.
2. To teach different methods of simulation setup for fluid flow problems.
3. To enable the students to apply CFD techniques for the design and analysis of aerospace, automotive and turbo machinery systems.

Course Outcome

Upon successful completion of the course, students will be able to

1. Perform geometry modeling and grid generation for complex fluid flow domains.
2. Perform computational analysis on internal and external flows.
3. Analyze the interaction between fluid and structure.
4. Setup computational framework for the analysis of reacting flows.
5. Perform computational analysis of turbomachines using moving reference frame.
6. Develop user defined functions to perform customized simulations.

Indicative Experiments	
1.	Grid generation for 3D domain using ICEM CFD
2.	Computational analysis of Jet surface interaction
3.	Computational study of supersonic flow over a 3D bump
4.	Computational analysis of shell and tube heat exchanger
5.	Investigation of a hydraulic jump using two phase flow model
6.	Analysis of a moving strip in an air stream using Fluid structure interaction
7.	Simulation of a centrifugal blower using multiple reference frames
8.	Simulation of Species transport and gaseous combustion using methane and air mixture.
9.	Simulation of a porous media in an exhaust system of an IC engine
10	Creating and compile user defined function (UDF) of temperature profile
	Total Laboratory Hours **60 hours**

Text Book(s)

1. Tu, Jiyuan, Guan Heng Yeoh, and Chaoqun Liu. Computational fluid dynamics: a practical approach. Butterworth-Heinemann, 2018.

Reference Books

1. Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015.
2. John Matsson, An Introduction to ANSYS Fluent 2020, SDC Publications, 2020
3. Versteeg, Henk Kaarle, and Weeratunge Malalasekera. An introduction to computational fluid dynamics: the finite volume method. Pearson education, 2007.
4 Charles Hirsch, Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics, Butterworth-Heinemann, 2007

Mode of assessment: Continuous assessment / Lab FAT / Viva voce			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD508L	Turbulence Modelling	3	0	0	3
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To provide a comprehensive knowledge in the field of turbulence modelling and simulation.
2. To provide the physical insight and the mathematical framework needed to understand the formulations of turbulence models and their essential limitations.
3. To make the students to understand the underlying complex phenomenon in turbulent flows and modelling approaches.

Course Outcome

Upon successful completion of the course, students will be able to

1. Relate the basic characteristics of turbulence in various engineering applications.
2. Analyse the transport of momentum and energy in turbulent flows.
3. Apply Reynolds decomposition principle for the analysis of turbulent mean flow.
4. Analyse the free shear and wall bounded turbulent flow characteristics
5. Apply the advanced turbulence modelling techniques in predicting the small-scale fluctuations.

Module:1	Characteristics of Turbulence	5 hours

Origin of turbulence, irregularity, diffusivity, three dimensional motions, dissipation, wide spectrum, eddy motions and length scales, experimental techniques in turbulent measurements.

Module:2	Statistical Description of Turbulence	7 hours

Random nature of turbulence, distribution function, probability density function (PDF), moments, correlations, Taylor's hypothesis, integral micro scales, homogeneous and isotropic turbulence, Kolmogorov hypothesis, scales of turbulence, energy cascade, turbulence spectra.

Module:3	Turbulent Transport of Momentum and Energy	7 hours

Reynolds decomposition technique, turbulent stresses, vortex stretching, Reynolds equations, mixing-length model, Reynolds' analogy, dynamics of turbulence.

Module:4	Turbulence Modelling	7 hours

Introduction, eddy-viscosity hypothesis, algebraic model, Spalart Allmaras model, k-ε and k-ω models, Reynolds-stress model, near-wall treatment.

Module:5	Free Shear Flows	6 hours

Mixing Layer, Turbulent Wakes – plane and axisymmetric wakes, Jets, self-similarity, Grid Turbulence, Large scale turbulent motion – Vortex stretching.

Module:6	Wall-Bounded Turbulent Flows	6 hours

Channel and pipe flows, Reynolds stresses, turbulent boundary layer equations, logarithmic-law of walls, turbulent structures

Module:7	Advanced Turbulence Modelling Techniques	5 hours

Large Eddy simulation - Smagorinsky–Lilly model, Dynamic Smagorinsky–Lilly model, wall adopting local eddy viscosity (WALE) sub grid scale model; Direct Numerical Simulation

(DNS) model. Detached Eddy Simulation (DES) model.				
Module:8	**Contemporary Issues**			**2 hours**
	Total Lecture hours:			**45 hours**
Text Book(s)				
1.	Pope, S.B., 2003, *Turbulent Flows*, Cambridge University Press. ISBN: 0-521-59886-9.			
2.	Tennekes, H., and Lumley, J.L., 2018, *A First Course in Turbulence*, MIT Press, Cambridge, Massachusetts, USA. ISBN: 9780262536301.			
Reference Books				
1.	Wilcox, D.C., 2006, *Turbulence Modelling for CFD, DCW Industries*, California, USA.			
2.	Ferziger, J.H., and Peric, M., 2002, *Computational Methods for Fluid Dynamics*, Springer.			
3	Sagaut, P., and Germano, M., 2002, *Large Eddy Simulation for Incompressible Flows*, Springer Verlag.			
Mode of Evaluation: CAT, written assignment, Quiz and FAT				
Recommended by Board of Studies	27-05-2022			
Approved by Academic Council	No. 66	Date	16-06-2022	

Skill Enhancement Courses

Course code	Course Title	L	T	P	C
MENG501P	Technical Report Writing	0	0	4	2
Pre-requisite	Nil	Syllabus version			
		1.0			

Course Objectives
1.To develop writing skills for preparing technical reports. 2. To analyze and evaluate general and complex technical information. 3. To enable proficiency in drafting and presenting reports.
Course Outcome
At the end of the course, the student will be able to 1.Construct error free sentences using appropriate grammar, vocabulary and style. 2. Apply the advanced rules of grammar for proofreading reports. 3. Interpret information and concepts in preparing reports. 4. Demonstrate the structure and function of technical reports. 5. Improve the ability of presenting technical reports.

Indicative Experiments	
1.	**Basics of Technical Communication** General and Technical communication, Process of communication, Levels of communication
2.	**Vocabulary& Editing** Word usage: confusing words, Phrasal verbs Punctuation and Proof reading
3.	**Advanced Grammar** Shifts: Voice, Tense, Person, Number Clarity: Pronoun reference, Misplace and unclear modifiers
4.	**Elements of Technical writing** Developing paragraphs, Eliminating unnecessary words, Avoiding clichés and slang Sentence clarity and combining
5.	**The Art of condensation** Steps to effective precis writing, Paraphrasing and summarizing
6.	**Technical Reports:** Meaning, Objectives, Characteristics and Categories
7.	**Formats of reports and Prewriting**: purpose, audience, sources of information, organizing the material
8.	**Data Visualization** Interpreting Data - Graphs - Tables – Charts - Imagery - Info graphics
9.	**Systematization of Information:** Preparing Questionnaire Techniques to Converge Objective-Oriented data in Diverse Technical Reports
10.	**Research and Analyses:** Writing introduction and literature review, Reference styles, Synchronize Technical Details from Magazines, Articles and e-content
11..	**Structure of Reports** Title – Preface – Acknowledgement - Abstract/Summary – Introduction - Materials and Methods – Results – Discussion - Conclusion - Suggestions/Recommendations
12.	**Writing the Report:** First draft, Revising, Thesis statement, Developing unity and coherence
13.	**Writing scientific abstracts:** Parts of the abstract, Revising the abstract Avoiding Plagiarism, Best practices for writers
14.	**Supplementary Texts** Appendix – Index – Glossary – References – Bibliography - Notes
15	**Presentation**

	Presenting Technical Reports Planning, creating anddigital presentation of reports			
			Total Laboratory hours :	**60 hours**
Text Book(s)				
1.	Raman, Meenakshi and Sangeeta Sharma, (2015).Technical Communication: Principles and Practice, Third edition, Oxford University Press, New Delhi.			
Reference Books				
1.	Aruna, Koneru, (2020). English Language Skills for Engineers. McGraw Hill Education, Noida.			
2.	Rizvi,M. Ashraf (2018)Effective Technical Communication Second Edition. McGraw Hill Education, Chennai.			
3.	Kumar, Sanjay and Pushpalatha, (2018). English Language and Communication Skills for Engineers, Oxford University Press.			
4.	Elizabeth Tebeaux and Sam Dragga, (2020).The Essentials of Technical Communication, Fifth Edition, Oxford University Press.			
Mode of Evaluation **:** Continuous Assessment Tests, Quizzes, Assignment, Final Assessment Test				
Recommended by Board of Studies	19-05-2022			
Approved by Academic Council	No. 66	Date	16-06-2022	

Course Code	Course Title	L	T	P	C
MSTS501P	**Qualitative Skills Practice**	**0**	**0**	**3**	**1.5**
Pre-requisite	**Nil**	**Syllabus version**			
		1.0			

Course Objectives:

1. To develop the quantitative ability for solving basic level problems.
2. To improve the verbal and professional communication skills.

Course Outcome:

At the end of the course, the student will be able to

1. Execute appropriate analytical skills.
2. Solve problems pertaining to quantitative and reasoning ability.
3. Learn better vocabulary for workplace communication.
4. Demonstrate appropriate behavior in an organized environment.

Module:1	**Business Etiquette: Social and Cultural Etiquette; Writing Company Blogs; Internal Communications and Planning: Writing press release and meeting notes**	**9 hours**

Value, Manners- Netiquette, Customs, Language, Tradition, Building a blog, Developing brand message, FAQs', Assessing Competition, Open and objective Communication, Two way dialogue, Understanding the audience, Identifying, Gathering Information,. Analysis, Determining, Selecting plan, Progress check, Types of planning, Write a short, catchy headline, Get to the Point –summarize your subject in the first paragraph., Body– Make it relevant to your audience.

Module:2	**Time management skills**	**3 hours**

Prioritization, Procrastination, Scheduling, Multitasking, Monitoring, Working under pressure and adhering to deadlines

Module:3	**Presentation skills – Preparing presentation; Organizing materials; Maintaining and preparing visual aids; Dealing with questions**	**7 hours**

10 Tips to prepare PowerPoint presentation, Outlining the content, Passing the Elevator Test, Blue sky thinking, Introduction , body and conclusion, Use of Font, Use of Color, Strategic presentation, Importance and types of visual aids, Animation to captivate your audience, Design of posters, Setting out the ground rules, Dealing with interruptions, Staying in control of the questions, Handling difficult questions.

Module:4	**QuantitativeAbility-L1–Numberproperties; Averages; Progressions; Percentages; Ratios**	**11 hours**

Number of factors, Factorials, Remainder Theorem, Unit digit position, Tens digit position, Averages, Weighted Average, Arithmetic Progression, Geometric Progression, Harmonic Progression, increase and Decrease or Successive increase, Types of ratios and proportions.

Module:5	**Reasoning Ability - L1 – Analytical Reasoning**	**8 hours**

Data Arrangement (Linear and circular & Cross Variable Relationship), Blood Relations, Ordering / ranking / grouping, Puzzle test, Selection Decision table.

Module:6	**Verbal Ability -L1 – Vocabulary Building**	**7 hours**

Synonyms & Antonyms, One word substitutes, Word Pairs, Spellings, Idioms, Sentence completion, Analogies.				
			Total Lecture hours:	**45 hours**
Reference Books				
1.	Kerry Patterson, Joseph Grenny, Ron McMillan and Al Switzler, (2017).2nd Edition, Crucial Conversations: Tools for Talking when Stakesare High .McGraw-Hill Contemporary, Bangalore.			
2.	Dale Carnegie,(2016).How to Win Friends and Influence People. Gallery Books, New York.			
3.	Scott Peck. M, (2003). Road Less Travelled. Bantam Press, New York City.			
4.	SMART, (2018). Place Mentor, 1st edition. Oxford University Press, Chennai.			
5.	FACE, (2016). Aptipedia Aptitude Encyclopedia. Wiley publications, Delhi.			
6.	ETHNUS, (2013). Aptimithra. McGraw – Hill Education Pvt .Ltd, Bangalore.			
Websites:				
1.	**www.chalkstreet.com**			
2.	**www.skillsyouneed.com**			
3.	**www.mindtools.com**			
4.	**www.thebalance.com**			
5.	**www.eguru.ooo**			
Mode of Evaluation: Continuous Assessment Tests, Quizzes, Assignment, Final Assessment Test				
Recommended by Board of Studies	19-05-2022			
Approved by Academic Council	No.66	Date	16-06-2022	

Course Code	Course Title	L	T	P	C
MSTS502P	**Quantitative Skills Practice**	**0**	**0**	**3**	**1.5**
Pre-requisite	**Nil**	**Syllabus version**			
		1.0			

Course Objectives:

1. To develop the students' advanced problem solving skills.
2. To enhance critical thinking and innovative skills.

Course Outcome:

At the end of the course, the student will be able to

1. Create positive impression during official conversations and interviews.
2. Demonstrate comprehending skills of various texts.
3. Improve advanced level thinking ability in general aptitude.
4. Develop emotional stability to tackle difficult circumstances.

Module:1	**Resume skills – Resume Template; Use of power verbs; Types of resume; Customizing resume**	**2 hours**

Structure of a standard resume, Content, color, font, Introduction to Power verbs and Write up, Quiz on types of resume, Frequent mistakes in customizing resume, Layout-Understanding different company's requirement, Digitizing career portfolio.

Module:2	**Interview skills – Types of interview; Techniques to face remote interviews and Mock Interview**	**3 hours**

Structured and unstructured interview orientation, Closed questions and hypothetical questions, Interviewers' perspective, Questions to ask/not ask during an interview, Video interview, Recorded feedback, Phone interview preparation, Tips to customize preparation for personal interview, Practice rounds.

Module:3	**Emotional Intelligence - L1 – Transactional Analysis; Brain storming; Psychometric Analysis; SWOT analysis**	**12 hours**

Introduction, Contracting, ego states, Life positions, Individual Brainstorming, Group Brainstorming, Stepladder Technique, Brain writing, Crawford's Slip writing approach, Reverse brainstorming, Star bursting, Charlette procedure ,Round robin brainstorming, Skill Test, Personality Test, More than one answer, Unique ways, SWOT analysis.

Module:4	**Quantitative Ability - L3–Permutation - Combinations; Probability; Geometry and menstruation; Trigonometry; Logarithms; Functions; Quadratic Equations; Set Theory**	**14 hours**

Counting, Grouping, Linear Arrangement, Circular Arrangements, Conditional Probability, Independent and Dependent Events, Properties of Polygon, 2D & 3D Figures, Area & Volumes, Heights and distances, Simple trigonometric functions, Introduction to logarithms, Basic rules of logarithms, Introduction to functions, Basic rules of functions, Understanding Quadratic Equations, Rules & probabilities of Quadratic Equations, Basic concepts of Venn Diagram.

Module:5	**Reasoning ability - L3 – Logical reasoning; Data Analysis and Interpretation**	**7 hours**

Syllogisms, Binary logic, Sequential output tracing, Crypto arithmetic, Data Sufficiency, Data Interpretation-Advanced, Interpretation tables, pie charts & bar chats.		
Module:6	**Verbal Ability - L3 – Comprehension and Critical reasoning**	**7 hours**
Reading comprehension, Para Jumbles, Critical Reasoning (a) Premise and Conclusion, (b) Assumption & Inference, (c) Strengthening & Weakening an Argument.		
	Total Lecture hours:	**45 hours**

Reference Books

1.	Michael Farra and JIST Editors,(2011).Quick Resume & Cover Letter Book: Write and Use an Effective Resume in Just One Day. Jist Works, Saint Paul, Minnesota.
2.	Flage Daniel E, (2003).The Art of Questioning: An Introduction to Critical Thinking. Pearson, London.
3.	David Allen, (2015).Getting Things done: The Art of Stress-Free productivity. Penguin Books, New York City.
4.	SMART, (2018). Place Mentor 1st edition. Oxford University Press, Chennai.
5.	FACE, (2016).Aptipedia Aptitude Encyclopedia. Wileypublications, Delhi.
6.	ETHNUS, (2013).Aptimithra. McGraw-Hill Education Pvt Ltd, Bangalore.

Websites:

1.	www.chalkstreet.com
2.	www.skillsyouneed.com
3.	www.mindtools.com
4.	www.thebalance.com
5.	www.eguru.ooo

Mode of Evaluation: Continuous Assessment Tests, Quizzes, Assignment, Final Assessment Test

Recommended by Board of Studies	19-05- 2022		
Approved by Academic Council	No.66	Date	16-06-2022

Discipline Elective Courses

Course Code	Course Title	L	T	P	C
MCFD601L	**Computational Aerodynamics**	**3**	**0**	**0**	**3**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To develop a conceptual understanding of numerical methods suitable for the compressible flows.
2. To impart knowledge of spatial and temporal discretization schemes applicable for unstructured finite volume framework.
3. To teach the turbulence modelling techniques and boundary conditions implementation strategies applicable for the compressible flows.

Course Outcome

Upon successful completion of this course students will be able to

1. Demonstrate the knowledge of complex flow structures of different regimes of compressible flows.
2. Formulate governing equations of compressible flows by considering different flow features involved.
3. Develop numerical algorithms for steady and unsteady Euler equations.
4. Apply schemes suitable for the discretization of convective and viscous fluxes for the development N-S solvers.
5. Develop compressible unsteady flow solvers using different time marching strategies
6. Select suitable turbulent flow model for the study of internal/external flow aerodynamics.
7. Implement appropriate boundary condition for a chosen flow domain.

Module:1	**Computational Aerodynamics: Aerodynamics/Gas dynamics Concepts: Overview and Preparation**	**8 hours**
Wing Aerodynamics- Wing Terminology, Prandtl's Lifting Line Theory, Subsonic Compressibility Effects, Transonic Aerodynamics- Wing Sweep. Supersonic Aerodynamics- Oblique shock waves, shock reflections, shock/shock interactions, Prandtl-Meyer expansion waves, under/over-expanded flow. Hypersonic Aerodynamics- Importance of Temperature in Hypersonic Flow, Aerodynamic Heating.		
Module:2	**Principles of Computational Gas dynamics**	**4 hours**
Compressible flow governing equations in integral form, conservative finite volume method - The Euler Equations, introduction to flux averaging, introduction to flux splitting. Introduction to flux reconstruction. Artificial viscosity		
Module:3	**Basic numerical methods for Euler Equations**	**6 hours**
Flux Approach-Lax-Friedrichs method, Lax-Wendroff Methods. Wave Approach-I: Flux vector Splitting-Steger-Warming Flux vector splitting, Van Leer Flux Vector Splitting, Wave Approach-II: Reconstruction-Evolution- Roe's First-Order Upwind Method		
Module:4	**Finite Volume Method for compressible flow- Spatial discretization**	**7 hours**
Structured Finite-Volume Schemes, Geometrical Quantities of a Control Volume, General Discretization Methodologies, Discretization of the Convective Fluxes. Discretization of the Convective Fluxes-Geometrical Quantities of a Control Volume, Cell-centered scheme, Median-Dual Cell-vertex scheme, Discretization of the Convective Fluxes-central scheme with artificial dissipation, upwind schemes, Solution reconstruction, gradients and limiter functions, Discretization of the Viscous Fluxes.		
Module:5	**Finite Volume Method for compressible flow- Temporal Discretization**	**6 hours**
Explicit Time-Stepping Schemes - First-Order Time Accuracy, Second-Order Time Accuracy, General Form of Backward Time Difference, Multistage Schemes (Runge-Kutta), Hybrid		

Multistage Schemes, Determination of the Maximum Time Step, Implicit Time-Stepping Schemes		
Module:6	**Turbulence Modelling for compressible flows**	**6 hours**
Turbulence Modeling Approaches- Basic Equations of Turbulence, Favre (Mass) Averaging, Eddy, Viscosity Hypothesis, First-Order Closures- Spalart-Allmaras One-Equation Model, k-ε-Two-Equation Model, Wall functions, SST Two-Equation Model		
Module:7	**Boundary Conditions and their implementations**	**6 hours**
Solid wall boundary, farfield in external flows, Inlet/Outlet boundary in internal flows, symmetry, coordinate cut and periodic boundary, interface between grid blocks-physical significances and implementation strategies for structured and unstructured domains.		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)

1.	Cummings, Russell M., et al. Applied computational aerodynamics: A modern engineering approach. Vol. 53. Cambridge University Press, 2015.
2	Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015.

Reference Books

1.	Laney, Culbert B. Computational gasdynamics. Cambridge university press, 1998.
2.	Moran, Jack. An introduction to theoretical and computational aerodynamics. Courier Corporation, 2003.

Mode of Evaluation: CAT , written assignment , Quiz , FAT			
Mode of assessment: Continuous assessment and FAT			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course code	Course Title	L	T	P	C
MCFD602L	Chemically Reacting Flows-Combustion	2	0	0	2
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To introduce theory and methodology to simulate reacting flows with CFD.
2. To impart skills required for incorporating species transport and coupling the interaction between turbulence and chemistry.
3. To enable students to perform combustion simulations using commercial CFD tools.
4. To familiarize the students with the multi-phase spray modeling.

Course Outcome

Upon completion of the course the students will be able to

1. Explain the knowledge of different types of flames.
2. Apply the knowledge of different turbulence-chemistry interaction models for the simulation of reacting flows.
3. Perform gas turbine engine's combustion analysis.
4. Understand basic theory of Lagrangian models for spray and its application for fuel injection.
5. Perform fuel injection simulation and analyse key fuel droplet characteristics.
6. Perform liquid fuel atomization and combustion simulation within a typical gas turbine combustor.

Module:1	Combustion and thermochemistry	3 hours

Introduction to flame types, lean and rich combustion, and their corresponding applications. Property relations, Reactant and Product mixtures, Standard Enthalpies of formation. Chemical Equilibrium. Equilibrium products for combustion. Determination of adiabatic flame temperature. Introduction to the physics of turbulence-chemistry interaction and different flame regimes.

Module:2	Chemical Kinetics	5 hours

Introduction to Chemical Kinetics. Global versus elementary reactions. Elementary reaction rates. Rates of reaction for multistep mechanisms. Analysis of reaction mechanisms. Some important chemical mechanisms- The H2-O2 system. CO oxidation. Oxidation of hydrocarbons, Methane combustion. Oxides of Nitrogen formation.

Module:3	Conservation Equations for Reacting flows	4 hours

Conservation of mass in reacting flows, Species mass conservation (species continuity), multicomponent diffusion, Conservation of momentum in reacting flows. Conservation of energy in reacting flows. The concept of conserved scalar.

Module:4	Laminar flames	5 hours

Laminar premixed flames. Zeldovich's analysis of flame propagation. Structure of CH4-air flame. Flame velocity and flame thickness in laminar premixed flames. Quenching, flammability, and ignition in laminar premixed flames. Flame stabilization.

Laminar diffusion flames. Mixing in non-reacting jets. Jet-flame physical description. Simplified model for laminar jet non-premixed flames. Laminar diffusion jet flames: flame length for circular port and slot burners.

Module:5	Droplet evaporation and burning	4 hours

Applications. Simple model for droplet evaporation-Gas-phase analysis, Droplet lifetimes. Simple model of droplet burning- Problem setup and conservation equations, burning rate constant and droplet lifetimes.

Module:6	Turbulent premixed and nonpremixed flames	4 hours

Practical applications. Turbulent flame speed. Structure of turbulent premixed flames. Wrinkled laminar flame regime. Distributed Reaction regime. Flamelet model. Flame stabilization. Turbulent nonpremixed flames- Jet flame, Flame length, Flame radiation, Lift off and blowout		
Module:7	**Burning of solids**	**3 hours**
Practical applications. Heterogeneous reactions. Burning of carbon-overview, one-film model, two-film model, particle burning times. Coal combustion.		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**30 hours**

Text Book(s)	
1.	Turns, Stephen R., An Introduction to Combustion: Concepts and Applications, 2018, 3rd edition, McGraw-Hill Companies, New York, NY, USA
2	Poinsot, Thierry, and Denis Veynante. Theoretical and numerical combustion, 2005, 2nd edition, RT Edwards, Inc.
Reference Books	
1.	Lefebvre, Arthur H., and Dilip R. Ballal. Gas turbine combustion: alternative fuels and emissions. CRC press, 2010.
Mode of Evaluation: CAT, written assignment, Quiz. FAT	

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course code	**Course Title**		**L**	**T**	**P**	**C**
MCFD602P	**Chemically Reacting Flows - Combustion Lab**		**0**	**0**	**2**	**1**
Pre-requisite	**NIL**	**Syllabus version**				
		1.0				

Course Objectives

1. To provide hands on experience required to simulate reacting flows by choosing adequate combustion models.
2. To enable students to perform combustion simulations using commercial CFD tools.
3. To train students to carry out the multi-phase spray modelling studies.

Course Outcome

Upon successful completion of the course, students will be able to

1. Perform combustion simulation of an IC engine.
2. Perform simulations of flow combustion.
3. Perform spray modelling studies.

Indicative Experiments	
1.	Simulation of combustion of Methane in the presence of air.
2.	Simulation of combustion in a rocket engine's combustion section
3.	Simulation of gas burner with air swirler
4.	Simulation of a Non-Premixed combustion
5.	Spray simulation by using DPM model
Total Laboratory Hours	**30 hours**

Text Book(s)

1. Poinsot, Thierry, and Denis Veynante. Theoretical and numerical combustion, 2005, 2nd edition, RT Edwards, Inc.

Reference Books

1. Ansys Fluent 2020 R1-Theory Guide

Mode of assessment: Continuous assessment / Lab FAT / Viva voce

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD603L	**Fluid Structure Interaction**	**3**	**0**	**0**	**3**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives

1. To develop a conceptual understanding of governing equations of fluid and structural Mechanics.
2. To develop a foundation for understanding of the coupling conditions involved in fluid structure interactions.
3. To develop an understanding of FEM methods to solve the governing equations of Fluid structure interactions.
4. To impart an understanding of linear equations solvers for FSI.

Course Outcome

Upon successful completion of this course students will be able to

1. Apply the governing equation of fluid and structural mechanics.
2. Apply the different coupling conditions involved in fluid structure interaction.
3. Formulate the FSI governing equations in ALE and Fully Eulerian approaches.
4. Explain the different finite element schemes to discretize the FSI governing equations.
5. Apply linearization techniques and linear algebraic equation solvers for solving FSI problems.
6. Perform numerical simulation of Fluid structure Interaction problems.

Module	Title	Hours
Module:1	**Models : Governing Equations of Fluid and Structural Mechanics**	**6 hours**

Continuum Mechanics - Coordinate Systems - Deformation Gradient - Strain - Rate of Deformation and Strain Rate - Stress - Conservation Principles in Different Coordinate Systems, Material Laws - Hyperelastic and Incompressible Materials, The Solid Problem - The Navier-Lamé Equations - Steady and unsteady incompressible Navier-Lamé Equations. The Fluid Problem- Boundary and Initial Conditions-The Linear Stokes Equations- Theory of Incompressible Flows- Flow Problems on Moving Domains- Eulerian Techniques for Flow Problems on Moving Domains - The Arbitrary Lagrangian Eulerian (ALE) Formulation for Moving Domain Problems

Module	Title	Hours
Module:2	**Coupled Fluid Structure Interactions**	**6 hours**

Coupling Conditions - Kinematic, Dynamic and Geometric Conditions- Interface Regularity and Boundary Conditions - Coupled Fluid-structure Interaction - The Added Mass Effect - Variational Coupling Techniques - Fluid-structure Interactions in ALE Coordinates - Definition of the ALE Map - Coupled ALE Formulation - Fully Eulerian Formulation - Elastic Structures in Eulerian Coordinates - Fluid-structure Interaction in Eulerian Coordinates

Module	Title	Hours
Module:3	**Discretization techniques for FSI governing equations**	**6 hours**

Time Discretization - Numerical Stability- Numerical Dissipation- Shifted Crank-Nicolson Methods- The Fractional-Step-Method -Galerkin and Discontinuous Galerkin Methods- Time Discretization of the Stokes and N-S Equations. Spatial Discretization - Interpolation with Finite Elements - Elliptic Problems - Finite Elements on Curved Domains - Saddle-Point Problems. Methods for Navier-Stokes equations- Oseen Fixed Point Linearization -Newton Iteration -Discretization of Transport Dominant Flows-Discretization of Interface-Problems - Discretization of Moving Interfaces

Module	Title	Hours
Module:4	**ALE Formulation for Fluid-structure Interactions**	**7 hours**

Time-Discretization for the FSI Problem in ALE-Formulation - Non-stationary Dynamics of Fluid-structure Interactions- Time Stepping Schemes for Fluid-structure Interactions- Derivation of Second Order Time Stepping Schemes - Temporal Stability - Stable Time-Discretization and Damping, Linearization of Fluid-structure Interactions in the ALE Framework - Linearization by Fixed Point-Iterations- Newton Linearization for Fluid-structure

Interactions in Arbitrary Lagrangian Eulerian Formulation - Numerical Study on Linearizations		
Module: 5	**Finite Elements for Fluid-structure Interactions in ALE Formulation**	**6 hours**
Finite Element Triangulations for Fluid-structure Interactions in ALE Formulation - Inf-Sup Stable FE-Spaces for Fluid-structure Interactions in ALE Formulation - Stabilized Finite Elements for Fluid-structure Interactions- Matrix Formulation of the Linear Systems - Construction of the ALE Map - Harmonic Extension - Harmonic Extension with Stiffening - Extension by Pseudo-Elasticity- Biharmonic Extension		
Module:6	**Fully Eulerian Formulation for Fluid-structure Interactions**	**6 hours**
Eulerian Models for Fluid-structure Interactions - Elastic Structures in Eulerian Coordinates - Fluid-structure Interaction in Eulerian Coordinates- Interface Capturing and the Initial Point Set Method-Time-Discretization of the Fully Eulerian Framework - Linearization of the Fully Eulerian Coordinates - Finite Elements for the Fully Eulerian Framework - Numerical Study- Stationary Structure Benchmark Problem - Stationary Fluid-structure Interaction Problem - Contact Problem.		
Module:7	**Linear Solvers for Fluid-structure Interactions**	**6 hours**
Partitioned Solvers - Direct Solution of Linear Systems - Condition Number Analysis of the System Matrices -Krylov Space Solvers for Fluid-structure Interactions - Multigrid Solvers for the Arbitrary Lagrangian Eulerian Formulation - GMRES Multigrid Iteration- Partitioned Multigrid Smoother.		
Module: 8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**45 hours**
Text Book(s)		
1.	Thomas Richter, Fluid Structure Interactions: Models, Analysis and finite elements, Second Edition Springer, 2017, ISBN 978-3-319-63969-7	
Reference Books		
1.	Yuri Bazilevs, Kenji Takizawa, Tayfun E. Tezduyar, Computational Fluid Structure Interaction: Methods and Application, 1st Edition, John-Wiley, 2013, ISBN: 978-0-4709-7877-1	
2.	Rajeev Kumar Jaiman, Vaibhav Joshi, Computational Mechanics of Fluid Structure Interaction: Computational methods for coupled fluid structure analysis, 1st Edition, Springer, 2021, ISBN 978-981-16-5354-4	
3.	Jean-François Sigrist, Fluid Structure Interaction: An introduction to finite element coupling, 1st Edition, John Wiley, 2015, ISBN 978-1-119-95227-5	
Mode of Evaluation: CAT, written assignment, Quiz, FAT		
Mode of assessment: Continuous assessment and FAT		

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course code	Course Title		L	T	P	C
MCFD604L	**Experimental methods for fluid flow**		**2**	**0**	**0**	**2**
Pre-requisite	**NIL**	**Syllabus version**				
		1.0				

Course Objectives

1. To teach various measuring techniques suited for thermal, flow and force measurements.
2. To impart knowledge on how to interpret and analyse the experimental data and its error estimation.
3. To teach the verification and validation methods of numerical models in comparison with experimental data.

Course Outcome

Upon successful completion of the course the students will be able to

1. Understand the measuring techniques of temperature, heat flux and species concentration.
2. Understand the measuring techniques of pressure, velocity, and flow rate.
3. Understand the measuring techniques of force.
4. Verify and validate the numerical model with experiments.
5. Demonstrate the knowledge of experimental fluid dynamics and analyse the experimental data and uncertainties.
6. Validate CFD solvers by comparing with experimental data

Module:1	**Measurements**	**5 hours**

Thermal and Flow Measurements, Characteristics of Measurement Systems, Time Response of Measurement Systems, Time-Series Analysis and Signal Processing, Statistical Principles, Error Estimates, Cramer–Rao Lower Bound (CRLB), Propagation of Errors. Data Regression, Uncertainty Analysis, Dimensional Analysis and Similitude.

Module:2	**Measurements of Pressure**	**4 hours**

Manometers, Measurement of Pressure with Wall Tapping - Static Tubes, Pressure Transducers Based on Elastic Strain, Piezoelectric Transducers, Pressure-Sensitive Paint (PSP)

Module:3	**Measurements of Temperature, Heat flux and Species Concentrations**	**5 hours**

Temperature Measurements based on Thermal Expansion of Materials, Thermocouples, Resistance-Based Temperature Sensors, Pyrometer Measurements of Temperature. Thermochromic Liquid Crystals, Measurements of Surface Heat Transfer Characteristics, Temperature-Sensitive Paint, Infrared Imaging.

Molecular Energy and Spectroscopy, Rayleigh Scattering, Mie Scattering, Raman Scattering, Light Scattering and Laser-Induced Fluorescence

Module:4	**Measurement of Flow Rates**	**3 hours**

Fundamentals, Obstruction Flowmeters., Rotameters, Turbine Flowmeters, Thermal Mass Flowmeters

Module:5	**Measurements of Flow Velocity**	**5 hours**

Pressure-based Velocity Measurements- Pitot-Static tube; Particle-based techniques- Laser Doppler Anemometry/Velocimetry (LDA/LDV), Particle Image Velocimetry (PIV), Doppler Global Velocimetry (DGV), and Laser Transit Velocimetry (LTV); Density-based Techniques- Shadowgraph, Schlieren Method, Interferometry, Optical Tomography.

Module:6	**Measurements of Force and Moment**	**3 hours**

Basics, Basic Terms of Balance Metrology, Mounting Variations, Strain Gauges- Wiring of Wheatstone Bridges, Strain Gauge Selection, Strain Gauge Application, Materials, Single-Force Load Cells, Multicomponent Load Measurement- Internal Balances - External Balances.

Module:7	**Experimental Synergy**	**3 hours**

Computer program verification and validation, Fundamentals of verification, Role of computational error estimation in verification testing, Fundamentals of validation, Construction of a validation experiment hierarchy, Statistical estimation of experimental error, Uncertainty quantification in computations, Validation metrics.		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**30 hours**

Text Book(s)	
1.	Taewoo Lee., Thermal and flow measurements, 2008, CRC Press.
2.	Roache, P.J., Verification and Validation in Computational Science and Engineering, 1998, Hermosa publishers, Albuquerque, NM.
Reference Books	
1.	Cameron Tropea, Alexander L. Yarin, John F. Foss (Eds.) - Handbook of Experimental Fluid Mechanics, 2007, Springer.
2.	Robert P. Benedict (auth.) - Fundamentals of Temperature, Pressure, and Flow Measurements, 1984, Third Edition, John Wiley & Sons.
Mode of Evaluation: Continuous assessment test, written assignment, Quiz and Final assessment test	

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course code	Course Title	L	T	P	C
MCFD604P	Experimental methods for Fluid Flow Lab	0	0	2	1
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To teach various measuring techniques suited for thermal, flow and force measurements.
2. To impart knowledge on how to interpret and analyse the experimental data and its error estimation.
3. To teach the verification and validation methods of numerical models in comparison with experimental data.

Course Outcome

Upon successful completion of the course, students will be able to

1. Perform temperature, heat flux and species concentration measurements using standard instruments
2. Carry out pressure, velocity, and flow rate measurements in a given flowfield
3. Perform flow visualization using high speed imaging
4. Conduct the experiments and analyse the experimental data and uncertainties.

Indicative Experiments	
1.	Wind Tunnel study of flow over an airfoil at different angles of attack-Surface pressure measurements
2.	Measurements of lift and drag forces of a symmetric aerofoil in a low speed flow
3.	Smoke visualization of flow over a cylinder
4.	Shadowgraph visualization of a flame
5.	Visualization of an under expanded jet using Schlieren technique
6.	Measurement of open flame temperature using a IR thermal imaging camera
7.	Measurement of temperature in different mediums using thermocouples
8.	Visualization of flow over a bluff body using tuft/oil flow
9.	Flow rate measurements using venturi and orifice meters
10.	Comparison of experimental and numerical results of flow over a NACA0012 airfoil
11.	Non-intrusive velocity measurements using advanced flow diagnostic techniques
	Total Laboratory Hours: 30 hours

Text Book(s)

1. Taewoo Lee., Thermal and flow measurements, 2008, CRC Press.

Reference Books

1. Cameron Tropea, Alexander L. Yarin, John F. Foss (Eds.) - Handbook of Experimental Fluid Mechanics, 2007, Springer.
2. Robert P. Benedict (auth.) - Fundamentals of Temperature, Pressure, and Flow Measurements, 1984, Third Edition, John Wiley & Sons.

Mode of assessment: Continuous assessment / Lab FAT / Viva voce

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD605L	Multiphase flows	3	0	0	3
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To provide a comprehensive knowledge of various flow patterns in multiphase flows
2. To provide the physical insight and the mathematical aspects of multiphase flow pressure drop and its different model/correlations.
3. To understand the complex phenomenon underlying in multiphase flows for various industrial problems.

Course Outcome

Upon successful completion of this course students will be able to

1. Apply the concepts and quantitative description of multiphase flows in engineering problems.
2. Analyse the different flow patterns in liquid-gas two-phase flows and examine the flow regime maps.
3. Analyse the particles motion in multiphase flows problems.
4. Understand phenomenon of growth of bubbles and collapses.
5. Analyse the various forces acting on the fluid particles that are applied in industrial needs.
6. Demonstrate the knowledge of pool, flow boiling, and condensation.

Module:1	Overview of Multiphase Flows	7 hours

Basic definitions, Importance of dimensionless numbers, Classification of multiphase flows, Flow patterns and regimes, Horizontal and vertical two-phase flows, Eulerian and Lagrangian description of fluid motion, Mass, momentum and energy conservation equations for single and multi-phase flows, Mixture model equations, Two-fluid model equations, Boundary conditions in two-phase flow.

Module:2	Liquid-Gas Two-Phase Flows	8 hours

Flow pattern classification, Flow regime maps for vertical and horizontal flow - Bubble flow, Slug flow, Churn flow, Annular flow, Dispersed flow, Flow regimes limits, Separated flow instabilities. Frictional pressure drop in disperse, homogenous and separated flows, Darcy–Weisbach equation. Pressure drop models by Lockhart-Martinelli, Baroczy-Chisholm, Beggs-Brill, Friedel, Gas/bubble dynamics flows.

Module:3	Particle Motion	6 hours

Single particle motion, Flow around a sphere, Free flow velocity, Grain’s size and concentration effect on free flow drag, Schiller-Naumann drag model, Hydraulic transport of solids, Particle flow motion.

Module:4	Bubble/Droplets dynamics	5 hours

Bubble shape, Marangoni effects and Bjerkes forces, Rayleigh-Plesset equation, Thermal and non-thermal bubble growth and collapse.

Module:5	Euler-Lagrangian Model	6 hours

Newton’s second law for single particle’s motion, Lagrangian particle tracking, Force balance, Drag, lift, buoyancy, gravitational and Brownian forces, Particle’s relaxation time, Visualization of particle’s trajectory.

Module:6	Euler-Euler Model	6 hours

Euler-Euler model for multiphase flows, Link momentum equation for each phase, Liquid-

liquid / liquid-solid mixing, Complex multiphase flows with turbulence, compressibility and heat transfer effects.		
Module:7	**Boiling and Condensation**	**5 hours**
Horizontal surfaces – Pool boiling, Nucleate boiling, Film boiling, Critical heat flux (CHF) and post CHF heat transfer in flow boiling, Flow boiling and CHF in mini and micro channels; Vertical surfaces – Film boiling; Condensation, Choking in two-phase flow		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)	
1.	Brennen, C. (2005). Fundamentals of Multiphase Flow. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511807169
Reference Books	
1.	Guan Heng Yeoh, Jiyuan Tu. (2019). Computational Techniques for Multiphase Flows (Second Edition). Butterworth-Heinemann. ISBN 9780081024539. https://doi.org/10.1016/B978-0-08-102453-9.12001-X.
2.	S. Mostafa Ghiaasiaan (2014). Two-Phase Flow, Boiling, and Condensation, Georgia Institute of Technology, ISBN: 9781107431638.

Mode of Evaluation: CAT, written assignment, Quiz and FAT			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title		L	T	P	C
MCFD606L	**Finite Element Analysis of Solids and Fluids**		**3**	**0**	**0**	**3**
Pre-requisite	**Nil**	**Syllabus version**				
		1.0				

Course Objectives

1. To provide students with an introduction to Finite Element Analysis and help them use this method to solve problems in solid mechanics, heat transfer, fluid flow and machine design.
2. To teach how to convert the physical problem into an engineering problem through geometrical and numerical modelling capabilities.
3. To introduce students to various field problems and the discretization of the problem.
4. To make the students drive finite element equations for simple and complex elements and establish the computational model of the given problem.

Course Outcome

On completion the student will be able to

1. Apply suitable product data exchange techniques to convert geometric model into numerical model
2. Apply the knowledge of mathematics and engineering to solve problems in structural, fluid and thermal engineering by approximate and numerical methods
3. Formulate 1D and 2D finite element equations at element and assembly level for various applications
4. Apply finite element formulations using linear and quadratic shape functions to compute desired results.
5. Simplify a complex engineering problem, design engineering components and solve real life problems using commercial FEM tools or develop FE codes.

Module:1	**Introduction to Approximation Methods**	**6 hours**

Basic Steps in the Finite Element Method-Material models-Direct formulation-Minimum total potential energy formulation-weighted residual formulation-variational approach.

Module:2	**Higher Order and Isoparametric Elements**	**6 hours**

Polynomial form of interpolation functions- linear, quadratic and cubic, Simplex, Complex, Multiplex elements, Convergence requirements, Linear interpolation polynomials in terms of global coordinates and local coordinates of bar, triangular elements, CST element.
Lagrangian interpolation, Higher order one dimensional elements- quadratic, Cubic element and their shape functions, properties of shape functions, Truss element, Shape functions of 2D quadratic triangular element in natural coordinates, 2D quadrilateral element shape functions – linear, quadratic element, Shape function of beam element. Hermite shape function of beam element.

Module:3	**Application to Solid Mechanics- One Dimensional Analysis**	**6 hours**

Generic form of 1D finite element equations –Truss, Beam -1D thermal problem – Linear elements-Quadratic elements- Natural coordinates - Isoparametric elements-Numerical Integration.

Module:4	**Application to Solid Mechanics – Multi-dimensional Problems**	**6 hours**

Generic form of 2D finite element equations - Triangular element - Rectangular elements-Axisymmetric elements- Vector variable problems such as plane stress, plane strain and axi-symmetric problems; Shell structures -Applications in structural and thermal problems.

Module:5	**Fluid Mechanical Applications**	**7 hours**

Discrete and semi-discrete FEM for fluid flow -Split method and penalty method - Discrete mass conservation and energy conservation; Isothermal fluid flow problems; Non-isothermal benchmark flow problem;

Module:6	**Steady State Heat Conduction with Applications**	**6 hours**
Heat Transfer through Plane and Composite walls- Radial Heat Flow in a cylinder- Conduction and Convections Systems; Two-dimensional plane problems- Three dimensional and axisymmetric problems- Finite element solution to convection–diffusion equation.		
Module:7	**Transient Heat Conduction Analysis with Applications**	**6 hours**
Lumped Heat Capacity System- Numerical Solution- Transient governing equations and boundary and initial conditions -The Galerkin method -One-dimensional Transient State Problem - Multi-dimensional Transient Heat Conduction - Phase Change Problems—Solidification and Melting.		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Text Book(s)	
1.	Rao S. S., Finite Elements Method in Engineering, 5th Edition, Elsevier, 2010.
2	Ronald W Lewis, P. Nithiyaarasu and K.N.Seetharamu, Fundamentals of Finite Element Method for Heat and Fluid Flow, John Wiley & sons, 2004.
Reference Books	
1.	J.N.Reddy, Introduction to Finite Element Method, McGraw -Hill International Edition, 2019.
2	Tirupathi R. Chandrupatla and Ashok D. Belugundu, Introduction to Finite Elements in Engineering, 4th Edition, Prentice Hall, 2011.
3	Seshu. P, Finite Element Analysis, Prentice Hall of India, 2013
4	Saeed Moaveni, Finite Element Analysis, Theory and Application with ANSYS, Pearson Fifth Edition, 2021

Mode of Evaluation: CAT, written assignment , Quiz, FAT

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

<table>
<tr><td>Course code</td><td>Course Title</td><td>L</td><td>T</td><td>P</td><td>C</td></tr>
<tr><td>MCFD607L</td><td>High Performance Computing</td><td>2</td><td>0</td><td>0</td><td>2</td></tr>
<tr><td>Pre-requisite</td><td>NIL</td><td colspan="4">Syllabus version</td></tr>
<tr><td></td><td></td><td colspan="4">1.0</td></tr>
<tr><td colspan="6">Course Objectives</td></tr>
<tr><td colspan="6">1. To develop understanding of programming best practices, productivity tools and linux operating system in general.
2. To improve the knowledge on working of modern computers and program execution, program efficiency and optimization procedures.
3. To familiarize our students with debugging, performance evaluation techniques, profiling and instrumentation to identify bottlenecks and opportunities of parallelization in programs.
4. To impart basic knowledge of OpenMP in the context of shared memory architecture.
5. To demonstrate the basics of MPI in the context of distributed memory architecture.
6. To familiarize with GPGPU device architecture and accelerated code using CUDA.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Course Outcome</td></tr>
<tr><td colspan="6">Upon successful completion of the course the students will be able to
1. Demonstrate basic familiarity with linux operating system and programming tools.
2. Analyze time, profile, benchmark and optimize serial codes.
3. Demonstrate ability to use documentation system, debugging system, build system, version control system, profiler, program analyzer, etc.
4. Understand parallelizing mechanisms in modern computer and be able to use cache, data-locality, branch-prediction, virtual memory etc and shall be able to exploit them to write better performing programs.
5. Develop parallel program on a shared memory architecture using OpenMP.
6. Write parallel program for a distributed memory architecture using MPI.
7. Use GPGPU to accelerate program performance using SIMD architecture.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>Module:1</td><td>HPC and Linux Environment</td><td colspan="4">4 hours</td></tr>
<tr><td colspan="6">History of computing and computers, Moore's law and saturation, Multicore-nature of the computers and super-computers, Amdahl's law, top500.org, Challenging problems that need high-performance. How to get Linux? Linux on a USB stick, dual boot system. Basic linux literacy - ls, cp, mv, cd, mkdir, cut, curl, indirection, tee, pipe, top, head, tail, grep, sed, ssh, scp, .bashrc, .bash_profile, .bash_history.</td></tr>
<tr><td>Module:2</td><td>Professional Code Development Practices</td><td colspan="4">6 hours</td></tr>
<tr><td colspan="6">Editors: vim, emacs, compilers: gcc, g++, gfortran, nvcc, debugging: gdb, ddd, IDEs: eclipse (,netbeans, Visual Studio), version control system: git (,svn), build system: make, cmake, documentaion : doxygen (,sphinx), scripting: shell scripting, awk scripting, using HPC machine: PBS scripts, job scheduling, environment modules, best practices for reproducible research</td></tr>
<tr><td>Module:3</td><td>Modern Computers and Program Optimization</td><td colspan="4">4 hours</td></tr>
<tr><td colspan="6">Clock cycle, Memory types (Registers, L1 cache, L2 cache, L3 cache, RAM, SSD, HDD, intranet, internet) and its significance in latency, virtual memory, paging, pipelining, branch prediction, architecture based optimization.
Compiler Flags: inlining, loop-unrolling, data-contiguity, improving latency by data locality, gdb- debugging the code, .gdbinit, preprocessor directives, Appropriate selection of data structures and algorithms, timing and profiling: time, gprof.</td></tr>
<tr><td>Module:4</td><td>Analysis Tools and Optimization of Serial Code</td><td colspan="4">4 hours</td></tr>
<tr><td colspan="6">Instrumentation of the code: google-tools, scorep, TAU, Use of Libraries - LAPACK, SCALAPACK, netlib, Benchmarking and its importance, Interoperability between languages C-Fortran, creating library: sharing developed features without sharing full code.</td></tr>
<tr><td>Module:5</td><td>Shared Memory Architecture (Open MP)</td><td colspan="4">4 hours</td></tr>
</table>

Directive driven parallelisation, OpenMP directives (OpenMP 4.0) though OpenMP 5.2 is out, most compliers lack the implementation, data dependancies: flow dependency, anti-dependency, output dependency, Granularity of parallelism: fine vs coarse, Synchronization, Atomic operations,omp_set_num_threads, omp_get_num_threads, omp_get_max_threads, omp_get_wtime, omp_get_wtick, omp_set_nested, OMP parallel, parallel loop, parallel sections for, private, firstprivate, lastprivate, reduction, schedule, collapse, ordered, nowait, OMP section, single, master, critical, task, barrier, taskwait, flush, cancel, cancellation point, Accelerator off-loading (simd, declare simd, loop simd, target data, declare target, target update, teams, distribute simd, distribute parallel), Debugging, Profiling and selection of code to be parallelized. Performance evaluation: speedup, latency.		
Module:6	**Distributed Memory Architecture (MPI)**	**3 hours**
Open MPI library and how to build it. basic MPI - Message Passing Interface program, Blocking and non-blocking communication, Importance of minimizing communication, MPI_Init, MPI_Finalize, MPI_Comm_rank, MPI_Comm_size, MPI_COMM_WORLD, MPI_Get_processor_name, MPI_Send, MPI_Recv, MPI_Bcast,MPI_Reduce,MPI_Allreduce		
Module:7	**Hybrid Computing**	**3 hours**
GPU architecture, SIMD instruction, NVidia and CUDA, (OpenCL - much broader applicability but complex), thread, block, grid, warp concepts, Nsight IDE, GPU kernels and host code, local data, shared data, global data, data transfers, synchronization, parallel algorithms and design patterns		
Module:8	**Contemporary Issues**	**2 hours**
	Total Lecture hours	**30 hours**

Text Book(s)	
1.	George Hager, Gerhard Wellein - Introduction to High Performance Computing for Scientists and Engineers, CRC Press, Taylor & Francis Group, 2010.
Reference Books	
1.	Jason Sanders, Edward Kandrot - CUDA by Example: An Introduction to General-Purpose GPU Programming 1st Edition.

Mode of Evaluation: Continuous assessment test, Programming assignments, Quiz and Final assessment test			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course code	Course Title	L	T	P	C
MCFD607P	High Performance Computing Lab	0	0	2	1
Pre-requisite	NIL	Syllabus version			
		1.0			

Course Objectives

1. To develop understanding of programming best practices, productivity tools and linux operating system in general.
2. To impart knowledge on working of modern computers and program execution, program efficiency and optimization procedures.
3. To teach parallel code development using OpenMP, MPI and GPGPU.

Course Outcome

Upon successful completion of the course, students will be able to

1. Analyze time, profile, benchmark and optimize serial codes.
2. Apply parallelizing mechanisms in modern computer and be able to use cache, data-locality, branch-prediction, virtual memory to write better performing programs.
3. Develop parallel program on a shared memory architecture using OpenMP.
4. Write parallel program for a distributed memory architecture using MPI.

Indicative Experiments

1.	Setup linux development environment. Install compiler, eclipse, doxygen, graphviz, gnuplot, git, gdb, cmake, nvidia-nsight, metis, open MPI, TAU.
2.	Write a complete program for 1D Heat Diffusion problem using Finite Difference Method with unit test cases. demonstrate build system and git version control
3.	Using gdb debug and fix issues in provided programs.
4.	Time and profile provided serial codes and identify the bottlenecks – opportunities of parallelization.
5.	For a given Poisson's equation program, experiment with optimization flags. Compare timings of different solver algorithms. (Jacobi, GS, GS-SOR, ADI). Profile these codes.
6.	For a given unsteady LDC problem, time and instrument the code and analyse it with scorep /TAU.
7.	Parallelize a SIMPLE program using OpenMP. Compare timing and compute speedup. Instrument and Analyze the code.
8.	Improve data locality using METIS graph-partitioning library. Compare performance of a given Unstructured FE code.
9.	Compute mesh-partition using METIS and implement MPI parallelization. Compare performance.
10	Convert the IO operations in a given program to use binary read-write to improve IO performance. Comment on the improvement.
	Total Laboratory Hours **30 hours**

Text Book(s)

1. Georg Hager, Gerhard Wellein - Introduction to High Performance Computing for Scientists and Engineers, CRC Press, Taylor & Francis Group, 2010.

Reference Books

1. Jason Sanders, Edward Kandrot - CUDA by Example: An Introduction to General-Purpose GPU Programming 1st Edition.

Mode of assessment: Continuous assessment / Lab FAT / Viva voce			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title		L	T	P	C
MCFD608L	Numerical Simulation of Environmental and Atmospheric Flows		3	0	0	3
Pre-requisite	NIL	Syllabus version				
		1.0				

Course Objectives

1. To provide students with sufficient background to understand the mathematical representation of the governing equations of Environmental and Atmospheric Flows.
2. To enable students to understand cutting edge global issues in a warming planet.
3. To help students learn research trends through a research component within the remit of environmental and atmospheric flows.

Course Outcome

Upon completion of the course the students will be able to

1. Possess knowledge of heat and mass transfer applications in environmental and atmospheric flows.
2. Understand the principles of environmental and atmospheric flows.
3. Interpret energy climate data pools sourced globally and write research papers.
4. Demonstrate how atmospheric processes are linked to the dynamics and gain an insightful understanding of the physico-chemical processes leading to climate change.

Module:1	Overview	5 hours

Foundation of anthropogenic climate change and an introduction to climate models. Overview of fundamental physical processes that shape climate. Solar variability, orbital mechanics, greenhouse gases, Scales of motion, atmospheric and oceanic circulation, and volcanic and soil aerosols.

Module:2	Fundamentals of Atmospheric Processes	5 hours

N-S equations. Coriolis force. Rossby number. Equations of motion in Cartesian coordinates. The f -plane, the β-plane. Geostrophic flows. Vorticity and potential vorticity.

Module:3	Energy Climate Dynamics	6 hours

Hydrostatic balance. Derivation of the Potential Temperature. States of stability. Stratification and diffusion problems. Parcel Concepts. Thermal wind equation. General Circulation. Simulation techniques in large-scale flows.

Module:4	Thermodynamical Processes	8 hours

Principles of Energy, Entropy and Enthalpy. The First and Second law of Thermodynamics. Thermodynamic Energy Equations. Vertical structure and change of state due to vertical motions. Moist and Pseudo-adiabatic processes.

Module:5	Boundary Layer Processes	5 hours

Expanded continuity equations. Cloud-fog physics. Boundary layer physics. Applications of the momentum equation in urban boundary layer.

Module:6	Shallow Water model theory	7 hours

Approximations to N-S equations: Shallow Water (SW) equations, Boussinesq and Anelastic approximations. Potential vorticity and conservation properties.

Module:7	Numerical methods in Boundary layer Processes including large scale flows	7 hours

Coriolis acceleration configuration. Mass conservation equation implementation. Boundary conditions. Introduction of zonal jets and currents. Large scale perturbations and geostrophic

equilibrium.		
Module:8	**Contemporary issues**	**2 hours**
	Total Lecture hours:	**45 hours**

Textbook(s)	
1.	Fundamentals of Atmospheric Modelling. Mark Jacobson. 2nd Edition (2005). Publisher: Cambridge University Press. U.K. ISBN-10: 0521548659 ISBN-13: 978-0521548656.
2.	Ocean Modelling for Beginners. Jochen Kämpf. 1st Edition (2009). Publisher: Springer, Berlin, Heidelberg. ISBN 978-3-642-00819-1
Reference Books	
1.	Geophysical Fluid Dynamics. Joseph Pedlosky. 2nd Edition (1987). Publisher: Springer, New York. ISBN 978-0-387-96388-4
2.	Introduction to Geophysical Fluid Dynamics, Physical and Numerical Aspects. Benoit Cushman-Roisin & Jean-Marie Beckers (2011). Publisher: Academic Press, Cambridge, Massachusetts. Hardcover ISBN: 9780120887590
3.	Computational Methods in Environmental Fluid Mechanics. Kolditz Olaf. 1st Edition (2002). Publisher: Springer, Berlin, Heidelberg. ISBN 978-3-540-42895-4.
4.	Atmosphere, Ocean, and Climate Dynamics. John Marshall and Alan Plumb. 1st Edition (2007). Elsevier Academic Press. USA. ISBN-10: 0125586914 | ISBN-13: 978-0125586917

Mode of Evaluation: CAT, written assignment, Quiz and FAT			
Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title		L	T	P	C
MCFD609L	Modeling and Simulation of Energy Systems		3	0	0	3
Pre-requisite	NIL	Syllabus version				
		1.0				

Course Objectives

1. To impart knowledge on various energy conversion technologies.
2. To apply the dynamic, linear and geometric programming for solving problems related to energy systems.
3. To provide the mathematical aspects and optimization of various thermodynamic systems.

Course Outcome

Upon successful completion of this course students will be able to

1. Analyse the various parameters for optimization in workable systems.
2. Apply the mathematical concepts to carry out the system simulation.
3. Optimize energy systems and their related components.
4. Understand the relations between thermodynamic properties involved in energy systems.
5. Develop mathematical models for various energy systems and components.

Module:1	Overview of Energy Systems	6 hours

Overview of various technologies and energy conversion, Workable and Optimum systems, Economics of Energy Systems, Polynomial representations, Lagrange interpolation, Exponential Forms, Equation fitting.

Module:2	System Simulation	4 hours

Classes of simulation, Sequential and simultaneous calculations, Successive substation, Taylor's series and Newton Raphson methods.

Module:3	Optimization	7 hours

Mathematical representation of optimization problems, Optimization procedure, Lagrange multipliers, Unconstrained and constrained optimization, Sensitivity Coefficients, Search Methods - Dichotomous search, Fibonacci search, Lattice search, Univariate search.

Module:4	Thermal System Analysis	7 hours

Pattern and Characteristics of Dynamic programming solutions, Apparently constrained problems, Geometric programming, Mechanics of Solutions for one independent variable, Linear Programming, Mathematical statement and Geometric Visualization of Linear programming problem, Simplex algorithm.

Module:5	Modeling of Thermodynamic Properties	6 hours

Need for mathematical Modeling, Linear and non-linear Regression analysis, Thermodynamic properties, Internal energy and entropy, pressure-temperature relationship at saturated conditions, Maxwell relations.

Module:6	Design of Heat Exchangers	6 hours

Design of Heat exchangers – parallel flow, counter flow, Evaporators and Condensers, Effectiveness, NTU, Pressure drop and Pumping power.

Module:7	Numerical analysis of thermodynamic systems	7 hours

Simulation and optimization of thermal power plant components, Solar collector, Wind turbine, hydraulic turbine and draft tubes, Gas turbine and compressors.

Module:8	Contemporary Issues	2 hours

	Total Lecture hours:	45 hours

Text Book(s)

1. W.F. Stoecker, Design of Thermal Systems, 4th Edition, McGraw-Hill Book Company,

	2003, ISBN 9780072373431			
2.	Y, Jaluria, Design and Optimization of Thermal Systems, 2nd Edition, McGraw Hill, 2007			
Reference Books				
1.	Hoseyn Sayyaadi, Modeling, Assessment, and Optimization of Energy Systems, Academic Press, 2021, ISBN 978-0-12-816656-7.			
Mode of Evaluation: CAT / written assignment / Quiz / FAT / Project				
Mode of assessment: Continuous assessment / FAT / Oral examination and others				
Recommended by Board of Studies		27-05-2022		
Approved by Academic Council		No. 66	Date	16-06-2022

Project and Internship

<table>
<tr><td>Course Code</td><td>Course Title</td><td>L</td><td>T</td><td>P</td><td>C</td></tr>
<tr><td>MCFD696J</td><td>Study Oriented Project</td><td></td><td></td><td></td><td>02</td></tr>
<tr><td>Pre-requisite</td><td>NIL</td><td colspan="4">Syllabus version</td></tr>
<tr><td></td><td></td><td colspan="4">1.0</td></tr>
<tr><td colspan="6">Course Objectives:</td></tr>
<tr><td colspan="6">1. The student will be able to analyse and interpret published literature for information pertaining to niche areas.
2. Scrutinize technical literature and arrive at conclusions.
3. Use insight and creativity for a better understanding of the domain of interest.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Course Outcome:</td></tr>
<tr><td colspan="6">1. Retrieve, analyse, and interpret published literature/books providing information related to niche areas/focused domains.
2. Examine technical literature, resolve ambiguity, and develop conclusions.
3. Synthesize knowledge and use insight and creativity to better understand the domain of interest.
4. Publish the findings in the peer reviewed journals / National / International Conferences.</td></tr>
<tr><td>Module Content</td><td colspan="5">(Project duration: One semester)</td></tr>
<tr><td colspan="6">This is oriented towards reading published literature or books related to niche areas or focussed domains under the guidance of a faculty.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Mode of Evaluation: Evaluation involves periodic reviews by the faculty with whom the student has registered. Assessment on the project – Report to be submitted, presentation and project reviews – Presentation in the National / International Conference on Science, Engineering Technology.</td></tr>
</table>

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD697J	**Design Project**				**02**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives:

1. Students will be able to design a prototype or process or experiments.
2. Describe and demonstrate the techniques and skills necessary for the project.
3. Acquire knowledge and better understanding of design systems.

Course Outcome:

1. Develop new skills and demonstrate the ability to upgrade a prototype to a design prototype or working model or process or experiments.
2. Utilize the techniques, skills, and modern tools necessary for the project.
3. Synthesize knowledge and use insight and creativity to better understand and improve design systems.
4. Publish the findings in the peer reviewed journals / National / International Conferences.

Module Content **(Project duration: One semester)**

Students are expected to develop new skills and demonstrate the ability to develop prototypes to design prototype or working models related to an engineering product or a process.

Mode of Evaluation: Evaluation involves periodic reviews by the faculty with whom the student has registered. Assessment on the project – Report to be submitted, presentation and project reviews – Presentation in the National / International Conference on Science, Engineering Technology.

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	**Course Title**	**L**	**T**	**P**	**C**
MCFD698J	**Internship I/ Dissertation I**				**10**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives:

To provide sufficient hands-on learning experience related to the design, development and analysis of suitable product / process so as to enhance the technical skill sets in the chosen field and also to give research orientation.

Course Outcome:

1. Considerably more in-depth knowledge of the major subject/field of study, including deeper insight into current research and development work.
2. The capability to use a holistic view to critically, independently and creatively identify, formulate and deal with complex issues.
3. A consciousness of the ethical aspects of research and development work.
4. Publications in the peer reviewed journals / International Conferences will be an added advantage.

Module Content **(Project duration: one semester)**

1. Dissertation may be a theoretical analysis, modeling & simulation, experimentation & analysis, prototype design, fabrication of new equipment, correlation and analysis of data, software development, applied research and any other related activities.
2. Dissertation should be individual work.
3. Carried out inside or outside the university, in any relevant industry or research institution.
4. Publications in the peer reviewed journals / International Conferences will be an added advantage.

Mode of Evaluation: Assessment on the project - Dissertation report to be submitted, presentation, project reviews and Final Oral Viva Examination.

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022

Course Code	Course Title	L	T	P	C
MCFD699J	**Internship II/ Dissertation II**				**12**
Pre-requisite	**NIL**	**Syllabus version**			
		1.0			

Course Objectives:

To provide sufficient hands-on learning experience related to the design, development and analysis of suitable product / process so as to enhance the technical skill sets in the chosen field.

Course Outcome:

Upon successful completion of this course students will be able to

1. Formulate specific problem statements for ill-defined real life problems with reasonable assumptions and constraints.
2. Perform literature search and / or patent search in the area of interest.
3. Conduct experiments / Design and Analysis / solution iterations and document the results.
4. Perform error analysis / benchmarking / costing.
5. Synthesize the results and arrive at scientific conclusions / products / solution.
6. Document the results in the form of technical report / presentation.

Module Content **(Project duration: one semester)**

1. Dissertation may be a theoretical analysis, modeling & simulation, experimentation & analysis, prototype design, fabrication of new equipment, correlation and analysis of data, software development, applied research and any other related activities.
2. Dissertation should be individual work.
3. Carried out inside or outside the university, in any relevant industry or research institution.
4. Publications in the peer reviewed journals / International Conferences will be an added advantage.

Mode of Evaluation: Assessment on the project - Dissertation report to be submitted, presentation, project reviews and Final Oral Viva Examination.

Recommended by Board of Studies	27-05-2022		
Approved by Academic Council	No. 66	Date	16-06-2022