DEPARTMENT OF
MECHANICAL ENGINEERING

M.TECH. (TURBOMACHINES)

SARDAR VALLABHBHAI NATIONAL INSTITUTE OF TECHNOLOGY
Ichchhanath, Surat-395007, Gujarat, India
www.svnit.ac.in

MISSION & VISION STATEMENT OF INSTITUTE

Vision Statement

To be one of the leading technical institutes disseminating globally acceptable education, effective industrial training and relevant research output

Mission Statement

To be a globally accepted centre of excellence in technical education catalysing absorption, innovation, diffusion and transfer of high technologies resulting in enhanced quality for all stakeholders

MISSION & VISION STATEMENT OF THE DEPARTMENT

Vision Statement

Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat perceives to be globally accepted centre of quality technical education based on innovation and academic excellence.

Mission Statement

Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat strives to disseminate technical knowledge to its under graduate students, post graduate students and research scholars to meet intellectual, ethical and career challenges for sustainable growth of humanity, nation and global community.

PROGRAM EDUCATIONAL OBJECTIVES (PEO)

The Program of M. Tech. (Turbomachines) will produce graduates who will be able to:

PEO1	Create value to organizations through the analysis, evaluation and improvement of turbomachinery systems using appropriate analytical, experimental and computational tools.
PEO2	Design solutions for complex turbomachinery problems and design system that meet the specified needs like energy and pollution abatement.
PEO3	Apply turbomachinery concepts to address technical and societal problems with creativity, imagination, confidence and ethics
PEO4	Inculcate self-learning skills and communication skills towards overall personality development of the student

PROGRAM ARTICULATION MATRIX

Department Mission	**Mapping of PEO**			
	PEO1	**PEO2**	**PEO3**	**PEO4**
Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat strives to disseminate technical knowledge to its under graduate students, post graduate students and research scholars to meet intellectual, ethical and career challenges for sustainable growth of humanity, nation and global community.	**3**	**3**	**2**	**3**

PROGRAM OUTCOMES (PO)

The graduates of M. Tech. (Manufacturing Engineering) will demonstrate an ability to:

PO1	Carry out independent research /investigation and development work to solve practical problems
PO2	Write and express a substantial technical report/document
PO3	Demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program
PSO1	Apply the mechanical engineering concepts to model, design, analyse and realize turbomachinery systems, components and processes.
PSO2	Assess the performance of turbomachinery systems using computational and experimental techniques.

COURSE STRUCTURE FOR M. TECH. –I (TURBOMACHINES)

SEMESTER – I

Sr. No	Subject	Code No.	Scheme L-T-P	Exam Scheme Th. Marks	T Marks	P Marks	Total	Credits	Notional hours of Learning (Approx.)
1.	**Core - 1** Advanced Fluid Dynamics	METM101	3-1-0	100	25	-	125	4	70
2.	**Core - 2** Thermodynamics and Heat Transfer for Turbomachines	METM103	3-1-0	100	25	-	125	4	70
3.	**Core-3** Jet and Rocket Propulsion	METM105	3-1-0	100	25	-	125	4	70
4.	**Core Elective – 1**		3-0-0	100	-	-	100	3	55
	1. Applied Gas Dynamics	METM111							
	2. Energy and Exergy Analysis of Turbomachines	METM113							
	3. Atomization and Sprays	METM115							
	4. Hydrodynamic Stability	METM117							
	5. Nonlinear Dynamics and Chaos	METM119							
5.	**Core Elective – 2**		3-0-0	100	-	-	100	3	55
	1. Finite Element Methods in Thermal Systems	METM121							
	2. Measurements and Data Analysis	METM123							
	3. Rotodynamic Pump and Pumping System	METM125							
	4. Unconventional Turbomachines	METM127							
	5. Rotor Dynamics, Vibration And Stress Analysis	METM129							
6.	Computational and Experimental Laboratory – I	METM107	0-0-6	-	-	150	150	3	110
Tota1				**500**	**75**	**150**	**725**	**21**	**430**
7.	Vocational Training/ Professional Experience *(Optional)(Only for PG Diploma in TM/Exit)*	METMV01 METMP01	0-0-10				5	5	200 (20 × 10)

SEMESTER – II

Sr. No.	Subject	Code No.	Scheme L-T-P	Exam Scheme Th. Marks	T Marks	P Marks	Total	Credits	Notional hours of Learning (Approx.)
1.	**Core – 4** Design of Turbomachines	METM102	3-1-0	100	25	-	125	4	70
2.	**Core - 5** Combustion for Propulsion Systems	METM104	3-0-0	100	25	-	125	3	55
3.	**Core Elective - 3**		3-0-0	100	-	-	100	3	55
	1. Micro-Hydro Power Plant	METM130							
	2. Theory and Design of Cryogenic Systems	METM132							
	3. Cascade Aerodynamics	METM134							
	4. Condition Monitoring and Fault Diagnosis of Rotating Machinery	METM136							
	5. Turbulent Combustion	METM138							
4.	**Core Elective – 4**		3-0-0	100	-	-	100	3	55
	1. Wind Energy Conversion System	METM140							
	2. Multi-phase Flows	METM142							
	3. Flow and Flame Diagnostics	METM144							
	4. Thermo-acoustic Instabilities	METM146							
	5. Machine Learning For Thermal Systems	METM148							
5.	**Institute Elective – I**		3-0-0	100	-	-	100	3	55
	1. Computational Fluid Dynamics	METM170							
	2. Hydrogen Energy Applications to Propulsion and Future Modes of Transport	METM172							
	3. Design of Reacting Systems	METM174							
	4. Turbulence and Turbulent Flows	METM176							
	5. Fundamentals of Solid Propellant and Multi-Phase Combustion	METM178							
6.	Computational and Experimental Laboratory – II	METM106	0-0-6	-	-	150	150	3	110
7.	Mini Project	METM108	0-0-4	-	-	100	100	2	70
Tota1				**500**	**50**	**200**	**800**	**21**	**470**
8.	Vocational Training/ Professional Experience *(Optional)(Only for PG Diploma in TM/Exit)*	METMV02 METMP02	0-0-10					5	200 (20 × 10)

SEMESTER – III

Sr. No.	Subject	Code No.	Scheme L-T-P	Exam Scheme			Total	Credits	Notional hours of Learning (Approx.)
				Th.	T	P			
				Marks	Marks	Marks			
1.	**MOOC course - I**		-	-	-	-	-	3/4	70/80
2.	**MOOC course - II**		-	-	-	-	-	3/4	70/80
3.	Dissertation Preliminaries	METM295	-	-	-	350	350	14	560
Tota1				-	-	**350**	**350**	**20-22**	**700-720**

***** Students may choose any available MOOC courses from SWAYAM or NPTEL with the consent of their M.Tech. supervisor.

SEMESTER – IV

Sr. No.	Subject	Code No.	Scheme L-T-P	Exam Scheme			Total	Credits	Notional hours of Learning (Approx.)
				Theory	Tuto.	Pract.			
				Marks	Marks	Marks			
1.	Dissertation	METM296	-	-	-	600	600	20	800

Total Credits: 21 + 21 + 20-22 + 20 = 82-84 credits

Credit Matrix

Category	Credit to be earned				
	Sem - I	Sem – II	Sem – III	Sem – IV	Total
Core Courses	12	07	-	-	19
Elective Courses	06	09	-	-	15
MOOC Courses	-	-	6-8	-	6-8
Software/Laboratory	03	03	-	-	06
Mini Project	-	2	-	-	02
Dissertation	-	-	14	20	34
Total Credits	21	21	20-22	20	**82-84**

METM101	:	ADVANCED FLUID DYNAMICS	L	T	P	Credits
			3	1	0	04

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Model fluid flow through complex domain
CO2	Analyse potential flow over circular cylinder
CO3	Evaluate the drag due to the boundary layer shear
CO4	Develop models for turbulent flows
CO5	Explore the fluid flow through rotating passages
CO6	Comprehend the concepts of swirling flows

2. Syllabus:

Governing Equations Of Fluid Motion	**(14 Hours)**
Lagrangian and Eulerian description, Reynolds transport theorem, Integral and differential forms of governing equations: mass, momentum and energy conservation equations, Cartesian Tensors, Stokes hypothesis for stress tensor, Navier-Stokes equations, Energy equation, Euler's equation, Bernoulli's Equation, Exact solutions of Navier-Stokes equations in Cartesian and cylindrical domain, Flow between concentric rotating cylinders, Parallel flow of a power law fluids, Stratified flow of two fluids, Fluid mechanics of different class of turbomachines with energy and angular momentum considerations.	
Potential Flows	**(6 Hours)**
Stream function and Velocity potential function, Circulation, Line vortex, Basic plane potential flows: Uniform stream; Source and Sink; Vortex flow, Doublet, Superposition of basic plane potential flows, Flow past a circular cylinder, Concept of lift and drag.	
Boundary Layer and Free Shear Layer Flows	**(8 Hours)**
Boundary layer behaviour and device performance, boundary layer equations for plane and curved surfaces, Von-Karman Momentum Integral Equation, Blasius solution, Boundary Layers with non-zero pressure gradient, separation and vortex shedding.	
Turbulence and Turbulent Flow Modeling	**(9 hours)**
Mechanism of turbulence, Kolmogorov scale, Kinetic energy of the mean flow and fluctuations, turbulent intensity, Reynolds Averaged Navier-Stokes (RANS) equations, Turbulent stresses, Eddy viscosity, Prandtl mixing length model, K-Epsilon model of turbulence, Universal velocity distribution law and friction factor, Concept of Large Eddy Simulations (LES) and Direct Numerical simulations (DNS).	
Flow in Rotating Passages and Swirling Flows	**(8 Hours)**

Rotating coordinate systems and Coriolis accelerations, Conserved quantities in a steady rotating flow, Phenomena in flows where rotation dominates (Non-dimensional parameters: the Rossby and Ekman numbers, Inviscid flow at low Rossby number: the Taylor–Proudman Theorem, Viscous flow at low Rossby number: Ekman layers), Swirling flows in radial equilibrium flows, Rankine vortex flow, waves on vortex cores, steady vortex core flows

(Total Lecture Hours: 45)

3. Books Recommended:

1	Schlichting H., "Boundary layer Theory", McGraw Hill, NY, USA, 2016.
2	Anderson Jr. John D., "Fundamentals of Aerodynamics", McGraw-Hill, NY, USA, 2010
3	Greitzer, E. M., Tan, C. S., Graf, M. B. "Internal Flow Concepts and Applications". Cambridge University Press, Cambridge, United Kingdom, 2007
4	Dixon S. L., "Fluid Mechanics Thermodynamics of Turbomachinery" Butterworth-Heinemann, Oxford, United Kingdom, 2013
5	White, Frank M., and Joseph Majdalani. Viscous fluid flow. Vol. 3. New York: McGraw-Hill, 2006.

METM103	:	THERMODYNAMICS AND HEAT TRANSFER FOR TURBOMACHINES	L	T	P	Credits
			3	1	0	04

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Calculate energy transfer, losses, and efficiency of the turbines.
CO2	Predict the performance of prototype using dimensional and similitude analysis
CO3	Express problems related to convection heat transfer in terms of mathematical equations and interpret their solutions in physical terms.
CO4	Solve radiative heat transfer between black and real surfaces, develop solutions for radiation heat transfer in participating mediums and get an overview of how to model gas radiation
CO5	Analyse the various hot spots of high temperature in turbine components
CO6	Comprehend the necessity of various turbine blade cooling techniques.

2. Syllabus:

Basic Thermodynamics of Turbomachines	(12 Hours)
Classification of turbomachines, Radial flow compressors — Energy transfer, Concept of Rothalpy, Isentropic efficiency, Effect of compressibility and pre-whirl, Diffuser, Non-dimensional parameters. Axial flow compressors — Energy Transfer, h-s diagram, Degree of reaction, Losses. Axial flow turbines (Impulse and Reaction) — stage work, Losses in turbines, Reheat factor and condition curve, constant stage efficiency, forms of actual condition curve, Turbine total wheel speed. Radial flow turbine —Radial Turbine Characteristics; Losses and efficiency, estimation of stage performance in outward-Flow Radial turbines. Thermodynamic properties of fluids, Compressible flow relationships, Concept of Polytropic efficiency, Dimensional Analysis – Similitude.	
Heat Transfer	**(20 Hours)**
Fundamentals of Heat Transfer Heat transfer terms in basic and tensor forms of governing equations. Conduction: General three-dimensional heat conduction equation in Cartesian, cylindrical & spherical coordinates, Initial condition and various boundary conditions. Convection: Free & Forced convection. Similarity & Simulation of convection heat transfer, Boundary layer theory. Laminar internal and external flow heat transfer, Turbulent flow heat transfer. Analogy between momentum &heat transfer. Heat transfer in high velocity flow. Natural convection under different situations. Radiation : Radiation Heat Exchange between surfaces —Gas Radiation —Equivalent beam length, Enclosure theory in the presence of a radiating gas, Radiative Transfer Equation, General and Exact solution of RTE, Isothermal gas enclosures, Well-stirred furnace model, Gas radiation in complex enclosures, Interaction between radiation and other modes of heat transfer.	

Applications of Heat Transfer	(06 Hours)
Turbine Heat Transfer: Turbine-stage heat transfer, cascade vane heat transfer, cascade blade heat transfer, airfoil endwall heat transfer, contouring and its measurements, turbine rotor blade tip and casing heat transfer, leading edge region heat transfer and its modifications for reducing secondary flows, flat surface heat transfer, deposition and surface roughness effects on heat transfer, combustor-turbine effects, transition-induced effects and modelling.	
Turbine Blade Cooling	**(07 Hours)**
Effect of High gas Temperature, Cooling techniques, Convective cooling — Internal Heat transfer in stationary and rotating blades, External Heat transfer, Film cooling — Adiabatic Film cooling effectiveness, HTC, analysis of single and multiple film cooling, Full-coverage film cooling, effect of various parameters on film cooling. Transpiration cooling, Aerodynamics, losses and efficiency of cooling. Heat exchange in cooled blade, ideal cool stage and actual cool stage, discrete three dimensional jets, thermal turbulence modeling techniques and transport equations, experimental methods for thermal parameters including liquid crystal thermography on the rotating surfaces of turbomachinery.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Cohen, Longman, R. “Theory of gas turbines “Pearson, London, UK, 2017.
2	Ganesan V.., “Gas Turbines”, Tata McGraw Hill Education (India) Private Limited, 2017.
3	Dixon, S. L. and Hall, C. A., “Fluid Mechanics and Thermodynamics of Turbomachinery”, Elsevier Publisher, USA, 2014.
4	Srinath E, Dutta S. “Gas Turbine Heat Transfer and Cooling Technology”, CRC press, Australia, 2012
5	Incropera & Dewitt, “Fundamentals of Heat and Mass Transfer”, John Wiley, USA, 2011.

METM105	:	JET AND ROCKET PROPULSION	L	T	P	Credits
			3	1	0	04

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Illustrate various types of jet systems and understand difference between air breathing and non-air breathing engines.
CO2	Analyze the thermodynamics cycles and performance parameters of air breathing systems
CO3	Demonstrate rocket propulsion theory and discuss classifications of rockets
CO4	Illustrate rocket nozzle types and their flow behavior at design and off-design conditions.
CO5	Analyse the performance parameters of rocket propulsion systems
CO6	Explain types of chemical rockets and details of its propellant

2. Syllabus:

Introduction	**(09 Hours)**
Introduction of gas turbine cycle and various components of gas turbine engine, Introduction of jet propulsion systems, Computation of stagnation properties, Basic components of air breathing engines, Inlet ducts for aircraft gas turbines, Brief idea about compressor, combustion chamber, turbine, and aircraft nozzles, Classification of propulsive device, types of rocket engines, application of rocket engines. Non-chemical rocket engines: Electric propulsion, Nuclear rocket engines, Solar Energy rockets.	
Air Breathing Engines	**(06 Hours)**
Performance parameters for air breathing engine (Thrust, Efficiency, Aircraft Range, Take-off Thrust, Specific Fuel Consumption), Basic gas generator & its variations, Turbojet, Turboprop, Turbofan, Pulse jet, Ram jet, Scramjet, Thrust Augmentation.	
Parametric Cycle Analysis of Air Breathing Gas Turbine Engines	**(09 Hours)**
Parametric Cycle Analysis of Ideal Turbo Jet Engine, Real Turbojet Cycle, Analysis of Turbofan Engine, Analysis of Turbofan Engine, Analysis of Turboprop Engine, Ramjet & Scramjet Engine.	
Rocket Performance Parameters	**(06 Hours)**
Laws of thermodynamics, combustion parameters, rudiments of gas dynamics, Ideal rocket performance, thrust equation, Total impulse and Specific Impulse, Specific impulse efficiency, volume specific impulse, impulse-to-weight ratio, energy balance, efficiencies and coefficients of rocket engines.	
Nozzles for Rocket Engines	**(03 Hours)**

Rocket nozzles; expansion of gases from high-pressure chamber. Convergent divergent nozzle, choking and variation of parameters in nozzle. Expansion ratio of nozzles and performance loss in nozzles. Under-expanded and over-expanded nozzles. Losses and performance analysis of rocket engines.

Rocket Propellants and Engines	**(12 Hours)**
Classification of Chemical propellants, Solid propellants, Liquid propellants, Gel Propellants and Hybrid Propellants. Solid-propellant rocket engines—Burning mechanism, Propellant Burning and regression rates, Propellant grain configuration, Ignition system. Liquid-propellant rocket engines—Classification of engines, Combustion of Liquid Propellants, Combustion chamber geometry, Ignition systems, cooling systems, Hybrid-propellant rocket engines— combustion chamber, grain configuration, Ignition of hybrid propellants	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Ganesan V.., "Gas Turbines", Tata McGraw Hill Education (India) Private Limited, 2017.
2	Venkanna B. K. , "Fundamentals of Turbomachinery", PHI, India, 2010
3	Mattingly, J. D., "Elements of gas turbine propulsion", Tata McGraw-Hill Edition, NY, USA, 2005.
4	Jack D. Mattingly, "Elements of Propulsion: Gas Turbines and Rockets," AIAA Publication, USA, 2016.
5	Sutton, G. P. and Biblarz O., "Rocket propulsion elements" Wiley Publications, USA, 2016.
6	Mukunda H. S., "Understanding aerospace propulsion," Interline Publishing, Bengaluru, India, 2017.

METM111	:	APPLIED GAS DYNAMICS	L	T	P	Credits
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Predict the effect of compressibility and flow behaviour in the field of gas dynamics
CO2	Solve 1-D design problems for Isentropic flow in variable area passages
CO3	Analyse compressible flow with normal shock
CO4	Model flow with heat transfer and friction
CO5	Apply gas dynamics concepts to propulsion systems
CO6	Describe the equipment and its arrangement to carry out measurements in compressible fluid flows.

2. Syllabus:

Introduction	**(03 Hours)**
Thermodynamics of compressible flow, Compressibility of Fluids, Compressible and incompressible flows, Perfect gas equation of state, Calorically perfect gas, Acoustic wave propagation speed: Mach number, Reference states: Sonic state and Stagnation state, T-s and P-v diagrams in compressible flows.	
One-Dimensional, Steady, Isentropic Flow in Variable Area Passages	**(04 Hours)**
Introduction, governing equations, Effect of area change in the fluid properties, Equations for Isentropic flow, Geometric choking, Area Mach number relation for choked flow, Maximum mass flow rate, Flow through nozzles and diffusers.	
Normal Shock	**(05 Hours)**
Governing equations, classification of shock, Normal shock solution, Rankine Hugoniot Relations, Normal shock solution on T-s and P-v diagram	
Flow with Heat Transfer	**(05 Hours)**
Governing equations, Slope of Rayleigh line on p-v diagram, Fundamental equation of Rayleigh line, Maximum heat transfer, thermal chocking and its consequences.	
Flow in Constant area Duct with Friction	**(05 Hours)**
Governing equations, Illustration on T-s diagram, Fanno flow equations, Variation of Mach number with duct length, Friction choking and its consequences.	
Two-Dimensional Flows	**(06 Hours)**
Oblique shock wave and its governing equations, θ-B-M relations, Supersonic flow over wedges Mach line, Attached and Detached shock, Reflections and interaction of oblique shock waves, Mach Reflection, Expansion waves, Prandtl-Meyer flow and its governing equations, Supersonic flow over convex and concave corners.	

Application of Gas Dynamics to Propulsion Systems	(09 Hours)
Introduction to Beltrami flows - Axisymmetric Beltrami flows, Mass flow rate through annulus - Chocking of flow through annulus. Brayton Cycle, Propulsion Engines, Flow Through Inlets, Air-breathing propulsion systems performance parameters and Rocket propulsion systems performance parameters.	
Measurements in Compressible Flows	**(08 Hours)**
Compressible flow visualization, High-speed wind tunnels, Measurement of thermodynamic properties in high speed flows.	

(Total Lecture Hours: 45)

3. <u>Books Recommended:</u>

1	Rathakrishnan, Ethirajan. "Applied gas dynamics." Wiley, USA, 2019.
2	Anderson, J.D., Jr., “Modern Compressible Flow”, Tata McGraw Hill Education Private Limited, Third Ed.,NY, USA, 2012.
3	Zucker, Robert D., and Oscar Biblarz. “Fundamentals of gas dynamics”. John Wiley & Sons, USA, 2019.
4	S.M. Yahya, Fundamental of Compressible Flow with Aircraft & Rocket Propulsion, New Age International Ltd., 2016
5	E. Rathakrishnan, Gas Dynamics, PHI Learning Pvt. Ltd., India, 2017

			L	T	P	Credits
METM113	**:**	**ENERGY AND EXERGY ANALYSIS OF TURBOMACHINERY SYSTEMS**	**3**	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Model the thermal and turbomachines as well as integrated systems based on energy analysis
CO2	Calculate the exergy and perform exergy balances for thermodynamic systems
CO3	Model exergy transfer and exergy losses in thermal and turbomachinery systems
CO4	Evaluate exergy analysis of integrated systems
CO5	Model the of steam power plants and turbomachines based on exergy analysis
CO6	Apply energy analysis concepts to turbomachines integrated systems

2. Syllabus

Energy Analysis	**(06 Hours)**
Application of First law of thermodynamics to turbines, compressors, and pumps, Thermal power plant, Gas turbine plants, Cogeneration and combined cycle plants and Turbomachines integrated with other systems.	
Exergy Concepts	**(12 Hours)**
Second Law of Thermodynamics, High grade and low grade energy, Difference between energy and exergy, Classification of forms of exergy, Physical exergy, Chemical exergy, Exergy concepts for a control region, Exergy concepts for closed system analysis. Pictorial representation of exergy balance, Exergy-based property diagrams.	
Exergy Analysis for Various Processes	**(06 Hours)**
Exergy analysis for Expansions process, Compression processes, Heat transfer process, Mixing and separation Process, Chemical process mainly combustion.	
Energy Analysis of Turbomachines	**(12 Hours)**
Exergy analysis of Gas and steam turbine, hydraulic turbines, Compressors, Nozzles, Exergy analysis of a turbojet (exergy flow through a turbojet, exergy efficiencies of a turbojet, cumulative exergy loss, breakdown of exergy of emission, environmental impact and sustainability.	
Energy Analysis of Turbomachine Integrated Systems	**(09 Hours)**
Introduction to systems of steam power plant, balance equations of exergy, exergy values, process description, exergy efficiency, simplified process diagrams, exergy losses, environmental impact and sustainability.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Kotas T.J., "The Exergy Methods of Thermal Plant Analysis", Krieger Publ. Corp. USA, 2013.
2	Yahya S. M., "Turbines, Compressors and Fans" Tata McGraw Hill, New Delhi, India, 2010
3	Dixon S.L. and Hall C.A. "Fluid Mechanics and Thermodynamics of Turbomachinery", Butterworth-Heinemann (Sixth Edition), Oxford, England, 2010
4	Turner, W.C., (Ed.), "Energy Management Handbook", John Wiley & Sons, N.Y., USA, 2002.
5	Ibrahim D, Marc A. R. "Exergy – Energy, Environment and sustainable Development", Elsevier, Netherlands, 2021.

METM115	:	ATOMIZATION AND SPRAYS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Illustrate theory of atomization and evaporation
CO2	Model jet breakup and drop formation theoretically
CO3	Explain the application of multiphase models for studying spray transport
CO4	Design spray nozzle and atomizers and discuss potential applications in combustion systems
CO5	Describe experimental evidence in support of theoretical models of drop formation and atomization
CO6	Apply spray models and perspective simulations to realistic gas turbine engines

2. Syllabus:

Introduction	**(03 Hours)**
Atomizers, Factors influencing atomization, Spray characteristics, Applications.	
Drop Size Distribution of Sprays	**(04 Hours)**
Number distributions, Mass/volume distributions, Empirical distributions, Theoretical distributions.	
Basic Process in Atomization	**(08 Hours)**
Sheet and ligament breakup —Instability analyses for ligaments and sheets, Design models based on instability analyses. Drop formation—Static and dynamic force balances, Continuity considerations, Secondary atomization, Collisions and coalescence.	
Drop Motion and Spray-Surroundings Interactions	**(04 Hours)**
Steady trajectories (gas turbines, spray cooling, paint sprays), Entrainment.	
Drop Evaporation	**(03 Hours)**
Steady evaporation, Unsteady evaporation, Convective effects.	
Internal and External Fluid Mechanics	**(05 Hours)**
Atomization models, Swirl atomizers, Impinging jet atomizers, flash sprays, supercritical and trans-critical injection, evaporating sprays, reacting sprays, spray group combustion, droplet evaporation in the non-continuum regime, droplet freezing and solidification, numerical techniques for simulating the atomization process, modelling atomization using boundary element methods, continuum-based methods for spray, lattice Boltzmann method for sprays, spray-wall impact, interacting sprays., Cone angle, Radial and circumferential mass flux distributions	
Atomizers	**(06 Hours)**

Flow in Atomizers, Spray Nozzles, drop on demand drop generators, droplet stream generator, plain orifice spray nozzles, pintle injectors, atomization of a liquid jet in a crossflow, impinging jet atomization, splash plate atomizers, electrosprays, swirl, T-jet and vibration-mesh atomizers, Modern design models for pressure-swirl atomizers, impinging jet atomizers, transient pressure (Diesel) atomizers.	
Measurement Techniques	**(06 Hours)**
Drop sizing by Malvern and P/DPA, Drop velocity by P/DPA, Mass flux distribution via patternators and P/DPA.	
Spray Applications	**(06 Hours)**
Spray applications in Internal Combustion Engines, Spray Modelling and Predictive Simulations in Realistic Gas-Turbine Engines, Melt Atomization, Spray Drying, Spray Pyrolysis, Spray Freeze Drying, Low-pressure Spray Pyrolysis, Flame Spray Pyrolysis, Particle production via. Emulsion combustion spray method, Pharmaceutical aerosol spray for drug delivery to the lungs, fire suppression.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Lefebvre, A.H. and McDonell, V. G. “Atomization and Sprays,” CRC Press, 2017
2	Bayvel, L. and Orzechowski Z. “Liquid Atomization,” Routledge, Taylor and Francis: Washington DC, USA, 2019.
3	Ashgriz N., “Handbook of atomization and sprays: theory and applications,” Springer Science & Business Media, Heidelberg, Germany, 2011.
4	Nasr GG, Yule AJ, Bendig L., “Industrial sprays and atomization: design, analysis and applications” Springer Science & Business Media, Heidelberg, Germany, 2013.
5	Ashgriz N., Yarin A. L., “Handbook of Atomization and Spray – Theory and Applications”, Springer, Heidelberg, Germany, 2011.

METM117	:	HYDRODYNAMIC STABILITY	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concept of stability of fluid flows
CO2	Identify indicators and metrics of instability
CO3	Analyse the stability of hydrodynamic systems
CO4	Evaluate the influence of real-world, engineering conditions on flow stability
CO5	Explain a working knowledge of current analytical and numerical techniques to characterize hydrodynamic instability
CO6	Apply numerical techniques to characterize hydrodynamic instability

2. Syllabus:

Introduction	**(4 Hours)**
Methods of Hydrodynamic stability, Temporal and Spatial Instability, Bifurcation, Stability and Linearized Problem, generalized solutions in hydrodynamic stability, branching and stability of solutions of the Navier-Stokes equation, Nature of turbulence, influence of presence of a porous medium on hydrodynamic stability	
Instability Mechanisms	**(6 Hours)**
Dynamic Stability of Still Atmosphere, Kelvin–Helmholtz Instability — Description of Instability, Equations for Perturbations, Surface and internal gravity waves, Rayleigh-Taylor Instability, Shear driven instability. Capillary Instability — Rayleigh' theory.	
Rayleigh-Benard Convection	**(5 Hours)**
Thermal convection, linearized problem, stability characteristics, Nonlinear Convection.	
Centrifugal Instability	**(5 Hours)**
Coordinate system, 2D and 3D disturbances, Axisymmetric disturbances, Taylor Problem, Dean Problem, Swirling Flows, Instability of Couette Flow, Gortler Instability, Pipe flow, rotating disk, trailing vortex, round jet.	
Instability and Transition in Flows	**(8 Hours)**
Parallel Flow Approximation and Inviscid Instability Theorems—Inviscid Instability Mechanism. Viscous Instability of Parallel Flows— Eigenvalue Formulation for Instability of Parallel Flows, Temporal and Spatial Amplification of Disturbances. Properties of the Orr–Sommerfeld Equation and Boundary Conditions, Instability Analysis from the Solution of the Orr–Sommerfeld Equation, Receptivity Analysis of the Shear Layer, Nonparallel and Nonlinear Effects on Instability and Receptivity.	

Nonlinear Effects: Multiple HOPF Bifurcations and Proper Orthogonal Decomposition	(8 Hours)
Receptivity of Bluff-Body Flows to Background Disturbances, Numerical Simulation of Flow Past a Cylinder, Multiple Hopf Bifurcations, Landau Equation and Flow Instability, Instability of Flow Past a Cylinder, Role of FST on Critical Reynolds Number for a Cylinder, POD Modes and Nonlinear Stability, Landau–Stuart–Eckhaus Equation, Universality of POD Modes.	
Stability and Transition of Mixed Convection Flows	**(5 Hours)**
Schneider's Similarity Solution, Linear Spatial Stability Analysis of the Boundary Layer over a Heated Plate, Nonlinear Receptivity of Mixed Convection Flow over a Heated Plate	
Instabilities of Three-Dimensional Flows	**(4 Hours)**
Linear Stability Theory for Three Dimensional Flows, Stability of the Falkner–Skan–Cooke Profile, Stationary and Travelling Waves Over Swept Geometries, Stability of the Falkner Skan–Cooke Profile.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Drazin P. G., "Introduction to Hydrodynamic Stability," Cambridge, England, 2002.
2	Charru F., "Hydrodynamic Instabilities," Cambridge, England, 2011.
3	Schmid P. and Henningson D., Stability and Transition in Shear Flows, Springer, USA 2001.
4	Sengupta T.K. "Instabilities of flows and transition to turbulence." Taylor & Francis; England, 2012.
5	Chandrasekhar S., "Hydrodynamic and Hydromagnetic Stability," Oxford, England, 2013.

METM119	:	NONLINEAR DYNAMICS AND CHAOS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Identify fixed points and determine their stability
CO2	Analyze the various types of bifurcations in one dimension and two dimension
CO3	Construct bifurcation diagrams and stability diagrams
CO4	Construct phase portraits and find basins of attraction
CO5	Analyze limit cycles and their stability
CO6	Apply time series analysis in rotating fluid flow systems

2. Syllabus:

One-Dimensional Systems and Elementary Bifurcations	(05 Hours)
Fixed points and stability, Linear stability analysis, existence and uniqueness, potentials, Saddle-node bifurcation, Transcritical bifurcation, Pitchfork bifurcation, Imperfect bifurcation, uniform and non-uniform oscillator.	
Two-Dimensional Systems; Phase Plane Analysis, Limit Cycles, POINCARÉ-BENDIXSON Theory	**(06 Hours)**
Classifications of linear systems, Phase portraits, existence, uniqueness and topological consequences, fixed points and linearization, conservative and reversible systems, Ruling out closed orbits, Poincaré-Bendixson theorem, Linear systems, Relaxation oscillators, Weakly nonlinear oscillators.	
Nonlinear Oscillators, Qualitative And Approximate Asymptotic Techniques, HOPF Bifurcations	**(06 Hours)**
Saddle-Node, Transcritical, and Pitchfork Bifurcations, Hopf Bifurcations, Global Bifurcations of Cycles, Coupled Oscillators and Quasiperiodicity.	
Lorenz and Rossler Equations, Chaos, Strange Attractors And Fractals	**(09 Hours)**
Lorenz Equation properties, Chaos on a strange attractor, Lorenz map, chaos application to send secret message, Fixed points and Cobwebs, Logistics Map: Numeric and Analysis, Periodic windows, Liapunov Exponent, Universality and experiments, Renormalization, Countable and uncountable sets, Cantor set, Dimension of self-similar fractals, Box dimension, Pointwise and Correlation Dimensions, Henson Map, Rosseler system, Forced double- well oscillator.	
Mappings of Systems	**(09 Hours)**
Iterated mappings, period-doubling, chaos, renormalization, universality, Hamiltonian systems; complete integrability and ergodicity, Area preserving mappings, KAM theory, Floquet theory, Infinite Dimensional Hamiltonians, On-Off Dissipative Systems.	

Non-Linear Dynamics in Turbomachinery Components	(04 Hours)
Thermo-fluid dynamic equations, time dependent equations of continuity, motion and energy, numerical treatment, Non-linear Gas Turbine dynamic Simulation.	
Chaos in Rotating Fluid Flow System	**(06 Hours)**
Theoretical models of transition to turbulence, spherical Couette flow, Taylor-Couette flow, rotating annulus heated from within, methods of time series analysis, route into chaos in the spherical Couette flow, route into chaos in the Taylor-Couette flow, time series analysis of Rossby waves.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Strogatz, Steven H. “Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering”. Westview Press, United States, 2018.
2	Wiggins, S. “Introduction to Applied Nonlinear Dynamical Systems and Chaos”. Springer, Berlin, Germany, 2006.
3	Drazin, P. G. “Nonlinear Systems” Cambridge University Press, Cambridge, United Kingdom, 2012.
4	Peitgen, H-O, H. Jurgens, and D. Saupe. Chaos and Fractals: New Frontiers of Science. Springer, Berlin, Germany, 2012.
5	Parker, T. S., and L. O. Chua. “Practical Numerical Algorithms for Chaotic Systems” Springer, Berlin, Germany, 2012.

METM121	:	FINITE ELEMENT METHOD IN THERMAL ENGINEERING	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Develop weighted residual methods
CO2	Classify the concepts of Nodes and elements
CO3	Apply finite element modelling techniques for 1-D problems.
CO4	Build finite element modelling techniques for 2-D problems.
CO5	Formulate and solve fluid and heat transfer problems using FEM
CO6	Extend the FEM to transient problems.

2. Syllabus:

Introduction to Finite Element Method	**(03 hours)**
General introduction to finite element method, Types of analysis methods, Boundary Information, Initial Value Problem, Boundary Value Problem, Numerical methods, Direct Finite Element Method, Minimum potential energy method, weighted residual method: Co-location method, Sub-domain method, Least-Square method, Galerkin method and Methods of moments.	
One-Dimensional analysis	**(12 hours)**
Solution of second-order linear model boundary value problem: Discretisation of the domain, 1-D Iso-parametric element, weak form development, Lagrange interpolation functions: linear and quadratic, elemental response, Connectivity of elements, Assembly of elemental responses. Incorporation of boundary conditions, solution for unknown: elimination and penalty approach. Application to 1-D Heat Transfer: with and without heat generation and constant and variable cross-section. 1-D Fluid flow analysis.	
Two Dimensional Analysis	**(09 hours)**
Two-dimensional steady-state heat conduction equation, Triangular elements, development of elemental stiffness matrix and load vector, Assembly of elemental response. Solution of 2-D heat conduction problem with and without heat generation.	
Dynamic Analysis	**(09 hours)**
1-D transient heat conduction in pin-fin: derivation of the fundamental equation in matrix form, assembly of elements, solution using the trapezoidal rule. Stability Analysis. Solution of Transient temperature distribution along the length of the pin fin.	
Coupled Boundary Value Problems: Heat Transfer and Fluid Mechanics	**(12 hours)**

Convection Heat Transfer, Governing Equations, Non-Dimensional Form of Governing Equations, Convection-diffusion problem, Finite element solution to the steady and transient convection-diffusion problem: Laminar heat transfer, Forced convection, Buoyancy-driven convective heat transfer, and mixed convection.

(Total Lecture Hours: 45)

3. Books Recommended:

1	Logan, D. L., A first course in the finite element method, Cengage Learning, UK, 2012.
2	Rao S. S., Finite element method in engineering, Pergaman Int. Library of Science, UK, 2013.
3	Frieswell M.I., et al. Dynamics of Rotating Machines, Cambridge university press, England 2015
4	Reddy J.N., Finite Element Method, McGraw -Hill International Edition, NY, USA, 2007.
5	Seshu P., Finite Element Analysis, PHI learning Pvt. Ltd., New Delhi, 2012.

METM123	:	MEASUREMENTS AND DATA ANALYSIS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Recognize the basic concepts of measurement systems
CO2	Evaluate error and uncertainty analysis of thermal system
CO3	Execute the working principles of various instruments used to measure the flow properties.
CO4	Demonstrate the measurement of flow angle and torque of turbomachines
CO5	Illustrate the operational details and interpret the data obtained by the measurement techniques
CO6	Analyse data using data post-processing techniques

2. Syllabus:

Characteristics of Measurement Systems	**(06 Hours)**
Need of Experiments, design of experiments, calibration, sensitivity and error analysis, uncertainty analysis, Response characteristics of instruments-1st & 2nd order instruments	
Measurement of Flow Properties & Flow Visualization	**(15 Hours)**
Pressure measurement, temperature measurement, velocity measurement (obstruction type, variable area, anemometry, LDV), shadow-graphy, Schlieren method, background-oriented Schlieren, Interferometry, modern flow visualization techniques, image processing, particle image velocimetry.	
Measurement of Flow Angle and Torque of Turbomachines	**(06 Hours)**
Measurement of pitch angle, measurement of torque by dynamometer, strain gauge and transducer.	
Data Processing and Analysis	**(18 Hours)**
Statistical analysis of experimental data – statistical principles, stationary random processing, estimator expectation and variance, probability, rejection of data: Chauvenets Criterion with example, error propagation: function of two variables, several variables, The methods of least square, linear regression analysis, gauge R & R, fundamentals of data Processing – Fourier Transform, correlation function, Hilbert Transform, proper orthogonal decomposition, conditional averages and stochastic estimation, wavelet transforms ,and imaging detectors	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Holman J. P., "Experimental methods for engineers", McGraw Hill, NY, USA, 2017.
2	Doebelin E.O. and Manik D. N. "Measurement systems: application and design", Mc. Graw Hill, NY, USA, 2019.
3	Venktesh S. P. "Mechanical measurements", John Wiley & Sons Ltd, USA, 2021.
4	Goldstein R. "Fluid mechanics measurements," Taylor & Francis, USA, 2017.
5	Sheldom M. R., "Introduction to probability and statistics for engineers and scientist", Elsevier, Fifth Edition, Amsterdam, Netherland, 2014.

METM125	:	ROTODYNAMIC PUMP AND PUMPING SYSTEM	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concepts of rotodynamic pumps and the classification of the rotodynamic machines
CO2	Understand the basic theory and construction of centrifugal pumps, their characteristics, and their common terminology
CO3	Learn about mixed and axial flow pumps and analyze their performance characteristics
CO4	Understand and analyze pump operation, range for multiple pump systems, and protection strategies
CO5	Evaluate the performance of the pump in a piping system and understand various flow regulation methods for process control
CO6	Apply the knowledge of fluid machinery and learn about the special applications of pumps

2. Syllabus:

Introduction	(06 Hours)
Principle and Classification of Pumps, Basic Parameters of Pump, Pump Construction, Losses in Pumps and Efficiency, Similarity Laws in Pumps.	
Centrifugal Pumps	**(12 Hours)**
Overview of centrifugal pump, construction and working, Energy equation and its importance, flow physics in centrifugal pump, velocity triangles, performance characteristics and system characteristics of centrifugal pump, slip factor, Axial and radial thrust, priming, cavitation in pumps, NPSH required and NPSH available, specific speed of the pump, series and parallel arrangement of a pump.	
Mixed and Axial Pump	**(08 Hours)**
Overview of mixed and axial flow pumps, Construction and operating principles, velocity triangles, performance characteristics, and applications.	
Integration of Pumps and Piping System	**(10 Hours)**
Pump operating point and range of operation, system curve, single and branch pipe system, variable system curves, multiple pump systems, water hammer, and protection.	
Capacity Regulation of Pump in Piping System	**(06 Hours)**
Throttle regulation, regulation with bypass, speed regulation and proportional pressure control, constant pressure control, and constant temperature control.	
Special Applications of Pumps	**(03 Hours)**
Pumps used in mines and other systems for special purpose	

(Total Lecture Hours: 45)

3. **Books Recommended:**

1	Jagdish Lal, Hydraulic Machines including Fluidics, Metropolitan Book Company, 2016.
2	S. K. Som, G. Biswas, S. Chakraborty, Introduction to Fluid Mechanics and Fluid Machines, McGraw Hill, 2017
3	Gülich, J.F. Centrifugal Pumps; Springer International Publishing: Cham, Switzerland, 2020
4	Srinivasan, K. M. Rotodynamic pumps (centrifugal and axial). Second edition, New Age International, 2018.
5	Charles C. Heald, Igor J. Karassik, Joseph P. Messina, Paul Cooper; Pump Handbook, 4th Edition, McGraw Hill Publications 2008

METM127	**:**	**UNCONVENTIONAL TURBOMACHIERY**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Analyse wind resource and energy production for a wind turbine from wind speed distribution and wind shear
CO2	Examine and should be able to design a unconventional turbomachines
CO3	Illustrate and value diverse approaches to solving critical problems in new frontiers of research and creating new knowledge judged by international standards
CO4	Explain the unconventional power plants while extending knowledge to economics and environmental aspects.
CO5	Evaluate the importance of integration of power plants
CO6	Elucidate recent advances in unconventional turbomachines

2. Syllabus:

Wind Turbines	**(14 Hours)**
Wind resources **—**The nature of wind, Geographical variation in wind resources, Long term wind speed variations, Turbulence, Extreme wind speed, Turbulence in wakes and Wind farms. Aerodynamics of Horizontal Axis Wind Turbine —Introduction, Actuator disc concept, Rotor disc theory, Vortex cylinder model of the actuator disc, Rotor blade theory, Breakdown of momentum theory, blade geometry, The effect of discrete number of blades, calculated results for an actual turbine. Wind Turbine Performance —The performance curves, constant rotational speed Operation, Comparison of measured with theoretical performance, variable speed operation, Estimation of energy capture, Wind turbine performance measurement, Aerodynamic Performance measurement**.** Conceptual Design of Horizontal Axis Wind Turbine —Introduction, Rotor diameter, Machine rating, Rotational speed, number of blades, Power control, Braking system, Fixed Space, Two Speed or variable speed operation, Type of generator. Component Design —Blades, Pitch bearings, Rotor Hub, Gearbox, Generator, Mechanical Brake, yaw drive, Tower, Foundations	
Solar Turbines	**(06 Hours)**
Elements of solar power plants, solar collectors, solar receivers, solar energy storage, solar ponds, solar turbines	
Geothermal Power Plants	**(06 Hours)**
Technology Applied in Turbines for Geothermal Plants, Recent Technologies for Geothermal Steam Turbines, Optimal design of geothermal power plants, Small Geothermal Power plants, Design performance and Economics.	
Micro – Turbine Generators	**(05 Hours)**

Introduction to Micro-Turbine Generators, Analysis of Micro and Mini Turbine, Design reliability, Design Problems in Micro-turbine Generators, Tip leakage flow in Axial and Radial Turbines.	
Tesla Turbine	**(05 Hours)**
Operating principle, Description of Tesla's Flat Disk Turbine, Rotor, Stator, Stator end support, bearings, bearing caps, retainers, inlet plumbing, nozzle details, stresses in the discs, performance calculations.	
Recent Advance in Unconventional Turbomachines	**(09 Hours)**
Supercritical mini CO2 turbine— Introduction to carbon dioxide turbines, design. organic Rankine cycle's turbine— Mini-ORC radial inflow turbine and ORC radial-outflow turbine stage. IGCC— Introduction, Major IGCC Blocks and Components: Gasification, Fuel types for use in IGCC systems, Syngas production and cooling, Syngas cleaning, separation of CO2 and hydrogen enrichment, Current status and future prospects for IGCC systems.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Duffie, J.A., and Bechman, "W. A., "Solar Engineering of Thermal Processes", John Wiley, N. Y., USA, 2013.
2	Maths, D. A., "Hydrogen Technology for Energy", Noyes Data Corp., New York, 2002.
3	Freris, L. L. "Wind Energy Conversion System", Prentice Hall, New Jersey, 2001.
4	Spera, D.A., "Wind Turbine Technology, Fundamental Concepts of Wind Turbine Engineering", ASME Press. N. Y., USA, 2001.
5	Twidell, J.W., and Weir, A.D., "Renewable Energy Resources", Taylor & Francis, New York, 2006

METM129	:	ROTOR DYNAMICS, VIBRATION AND STRESS ANALYSIS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Design rotor blades
CO2	Analyze the transverse, torsional vibrations of rotors
CO3	Illustrate the dynamics of cracked shaft under vibrations
CO4	Explain the fundamental concepts of rotating machinery balancing
CO5	Evaluate the governing FE equations for solving vibration problems pertained to rotor systems
CO6	Apply finite element methods to rotor dynamics

2. Syllabus:

Stress Analysis of Rotors	(09 hours)
Stresses in Rotating discs and blade, disc of uniform strength, thermal stresses, blade design for strength, formulation of eigenvalues problem, Dunkerley's procedure, root-squaring process, application with dissipative and continuous systems.	
Vibration Analysis of Rotating Machinery	**(12 hours)**
Transverse vibration-Single, two and three rotor systems, Critical speeds of shafts, Torsional vibrations of rotors: One and two disc torsional rotor system, Three disc rotor system, Frequency of torsional vibration systems, Coupling of Torsional and bending vibrations due to Pre twist and eccentricity, rotor failure modes, forward and backward rotor whirl model, variable elasticity effects in rotating systems, flow induced vibration in rotating systems, Newkirk effect, dynamics of cracked shaft and identification by vibration analysis, thermal effects induced due to vibration of shaft.	
Rotating Machinery Balancing	**(15 hours)**
Rotor-bearing interactions. Fluid film bearings: Steady state characteristics of bearings. Rolling element bearings, Simple rotor bearing foundation systems and gyroscopic effects, Rotor-bearing interactions, influence of bearing support pedestal stiffness on rotor critical frequency, U-rotor mode, S-Rotor mode, rotor-bearing support pedestal modeling, testing methods, fluid-film, steam and gas seal influences on rotor dynamics. Instability in rotors, Sources of unbalance in rotors, Rigid and flexible rotors balancing, field balancing of turbine-tenerator trains, natural frequency, mode shapes and critical vibration, actual heavy spot angle, indicated heavy spot angle, balancing analysis, rotor train alignment.	
Finite Element Analysis in Rotor Dynamics	**(09 hours)**
Introduction to finite element methods-Finite element vibration analysis of simple rotor systems, orthogonality, Eigen Value problem, modal analysis, damped vibrations. Finite	

element analysis of rotors including gyroscopic effects, time domain solutions, frequency domain solutions, free vibration solutions, modal solutions, static condensation, dynamic reduction, lanczos method, orthogonal factorization, block lanczos method, solutions of periodic equation, frequency response with and without rotation, transient response with and without rotation, FE case studies of turbine wheel with shaft and blade, analysis of aircraft propeller.

(Total Lecture Hours: 45)

3. Books Recommended:

1	Rao J. S. "Rotor Dynamics", New Age International Publication, New Delhi, India, Third Ed., 2018
2	Chen, Wen Jeng, and Edgar J. Gunter. "Dynamics of rotor-bearing systems." Victoria, Canada: Trafford Publishing , 2010.
3	Krämer E., "Dynamics of Rotors and Foundations," Springer-Verlag, New York, 2013.
4	Rao S.S. "The finite element method in Engineering," Elseiver, 2005.
5	Raj S. and Littleson J. E., "Rotor and Structural Dynamics of Turbomachinery – A Practical Guide for Engineers and Scientist", Springer International Publishing, Heidelberg, Germany, 2018.

METM107	:	COMPUTATIONAL AND EXPERIMENTAL LABORATORY – I	L	T	P	Credits
			0	0	6	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Learn overview of data analysis and programming and machine learning softwares
CO2	Solve linear and non-linear algebraic equations using numerical techniques and computer programming
CO3	Solve initial value problems and boundary value problems using computer programming
CO4	Apply the concept of laminar and turbulent flow measurements
CO5	Analyse and evaluate the observations and deduce conclusions in flow systems
CO6	Develop team effort and coordination through group practical performance

Software based practices

1. Introduction to MATLAB
2. Introduction to Mathematica
3. Introduction to functions of Microsoft Excel
4. Introduction to C and C++ programming
5. Introduction to Fortran programming
6. Introduction to Labview Coding
7. Introduction to SCADA Coding

Coding

1. Introduction to compiler, scripts, loops, logical statements
2. Solving ODE using Rung-Kutta method of 2nd order: Heun's method, Mid-point method, and Ralston's method
3. Solving ODE using Rung-Kutta method of 3rd order, and 4th order
4. FDM code to solve PDE: elliptic equation
5. FDM code to solve PDE: parabolic equation
6. FDM code to solve PDE: hyperbolic equation
7. Lab view programming of simultaneous mass flow controller operation
8. Lab view programming for simultaneous triggering
9. Demonstration of SCADA panel for controlling and monitoring thermo-fluid parameters for combustor test-rig.
10. Demonstration of SCADA panel for controlling and monitoring thermo-fluid parameters for heat-exchanger test-rig.

2. Laboratory Experiments

1. Estimation of velocity distribution for flow through rectangular and circular passage in laminar and turbulent regime
2. Estimation of momentum and energy correction factor for flow through rectangular and circular passage
3. Identification of flow regimes in two-phase flow
4. Estimation of pressure drop in single phase flow with or without obstruction
5. Estimation of two-phase pressure drop for flow through circular passage.
6. Estimation of drag on bluff and streamlined body using wind tunnel
7. Estimation of impact of jet on planer and curved surfaces
8. Calibration of reference velocity and longitudinal static pressure variation in the test section of an open-type subsonic wind tunnel.
9. Measurement of pressure distribution over an airfoil surface using subsonic type wind tunnel.
10. Use of Method of Characteristics for design of nozzles

METM102	:	DESIGN OF TURBOMACHINES	L	T	P	Credits
			3	1	0	04

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the working principles of turbomachines and apply it to various types of turbomachines
CO2	Design compressors and gas turbines.
CO3	Determine the off-design behavior of axial and Radial turbines and compressors
CO4	Design pumps and hydro turbines
CO5	Establish performance characteristics curves of thermal and hydro turbomachines
CO6	Assess & analyze the performance outcomes of thermal and hydro turbomachines.

2. Syllabus:

Design of Centrifugal Compressors	**(06 Hours)**
Components of centrifugal compressor, velocity diagrams, slip factor, energy transfer, power input factor, mollier chart, stage pressure rise and loading coefficient, degree or reaction, pre-whirl and inlet guide vanes, kinematic parameters, Centrifugal compressor — Inlet section, Impeller passages, operational range, velocity variation, Losses.	
Design of Axial Flow Compressors	**(15 Hours)**
Description of axial flow compressor, Mollier chart, velocity diagrams, Stage characteristics, Blading efficiency, Design parameters, Blade loading, reaction ratio, Lift coefficient and solidity, Three dimensional flow considerations, Radial equilibrium design approach, Actuator disc theory approach, Design procedure and calculations, free vortex blade, forced vortex or solid rotation blades, constant reaction blade, multistage compression, secondary flow (passage vortex, trailing vortex, corner vortex, horseshoe vortex, leakage vortex, scraping vortex) and loss assessment, rotating stall, surge, chocking, operating range.	
Design of Turbine Flow Passages	**(06 Hours)**
Introduction, Isentropic Velocity ratio, Energy distribution in turbines, different efficiencies (nozzle efficiency, carryover efficiency, blade passage efficiency, vane efficiency, stage efficiency), reheat factor, losses in turbine, h – s diagrams of turbines.	
Design of Impulse Turbine Flow Passages	**(08 Hours)**
Velocity triangles, work and energy relationship, stage efficiency, Blade pitch and width, Blade height, Blade entrance and exit angles, Geometry of impulse blade profiles, Losses in impulse blade passages, Design procedure for single stage and multistage impulse turbines, diagram efficiency of a two stage turbine, Pressure compounding (Rateau Turbine), Velocity	

compounding (Curtis Turbine), Pressure and Velocity compounding. Work done and efficiency of a Pelton wheel turbine, heads and efficiencies of Pelton wheel turbine.	
Design of Reaction Turbine Flow Passages	**(06 Hours)**
Reaction blade profiles, Blade angles, Blade width and height, Losses in reaction blade passages, Degree of reaction, design procedure for impulse reaction turbines, Calculations for axial thrust, Turbines for optimum capacity.	
Hydraulic Design of Centrifugal Pumps	**(04 Hours)**
Fundamental Equation of centrifugal pump, work done and manometric efficiency, pressure rise in pump impeller, overall, mechanical, volumetric and manometric efficiency, ideal, virtual and Manometric heads, Net Positive Suction Head, one dimensional theory, Selection of speed - determination of impeller inlet and outlet dimensions	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Yahya S. M., “Turbines, Compressors and Fans” Tata McGraw Hill, New Delhi, India, 2010
2	Saravanamuttoo, H. I., Rogers, G. F. C., & Cohen, H. “Gas turbine theory” Pearson education, 2001
3	Ganesan V.., “Gas Turbines”, Tata McGraw Hill Education (India) Private Limited, 2017.
4	Venkanna B. K. , “Fundamentals of Turbomachinery”, PHI, India, 2010
5	Sawhney G. S., “Thermal and Hydraulic Machines”, Prentice Hall India Learning Pvt. Ltd., India, 2011.

METM104	:	COMBUSTION FOR PROPULSION SYSTEMS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Analyse the combustion system using principles of thermodynamics.
CO2	Model combustion kinetics and chemical explosion mechanisms
CO3	Explain basic concepts about various types of flames; modelling and application to energy systems.
CO4	Analyse combustion characteristics and how these can be measured.
CO5	Illustrate different type of pollutants generated by combustion, their effects on health and on the environment and various methods to control it.
CO6	Describe different combustion mechanisms and how these can be efficiently used in engineering applications.

2. Syllabus:

Introduction	**(04 Hours)**
Introduction to combustion, Applications of combustion, Types of fuel and oxidizers, Characterization of fuel, Various combustion mode, Scope of combustion, Fundamental laws of transport phenomena, Conservations Equations.	
Thermodynamics of Combustion	**(08 Hours)**
Mixture composition, energy and entropy properties of gaseous mixtures, Thermodynamic properties of reacting mixtures, Laws of thermodynamics, Stoichiometry, Thermochemistry, adiabatic temperature, chemical equilibrium. Conditions of chemical equilibrium, equilibrium constant, challenges in chemical equilibrium.	
Combustion Kinetics	**(08 Hours)**
Basic Reaction Kinetics, Elementary reactions, Chain reactions, Multistep reactions, simplification of reaction mechanism, Global kinetics reaction rate formula, approximations for construction of global reaction rate, global rates of hydrocarbon fuels.	
Chemical Mechanisms	**(03 Hours)**
Explosive and oxidative characteristics of fuels, Criteria for explosion, Explosion limits and oxidation of hydrogen, Carbon monoxide and hydrocarbons.	
Premixed Flames	**(06 Hours)**
Laminar premixed flame, laminar flame structure, Stability limits of laminar flames, Laminar flame speed, Flame speed measurements, Flame stabilizations, Ignition and	

quenching, Turbulent flames, turbulent flame speed, external aided ignition (spherical propagation, plane propagation), auto ignition, flammability limits.	
Diffusion Flames	**(06 Hours)**
Laminar Diffusion flames, turbulent diffusion flames, Schvab-Zel'dovich formulation, Burke-Schumann problem, Gaseous Jet diffusion flame, Droplet Combustion, Liquid fuel combustion, Atomization, Spray and Solid fuel combustion.	
Combustion and Environment	**(04 Hours)**
Atmosphere, Chemical Emission from combustion, Quantification of emission, mechanisms of pollutant formation during combustion, pollutants reduction in conventional combustors, pollutants reduction by control of flame temperature, dry low-oxides of nitrogen combustors, lean premix per vaporize combustion, rich-burn quick-quench lean burn combustor, catalytic combustion, correlations and modelling of oxides of nitrogen and carbon monoxide emission.	
Combustion Process in Propulsion Systems	**(06 Hours)**
Principal ideas of combustion in gas turbine, solid propellant rockets: Erosive burning, and liquid propellant rockets.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Kuo K.K., "Principles of Combustion", John Wiley, USA, 2005.
2	Turns S.R., "An Introduction to Combustion", New York: McGraw-Hill, NY, USA, 2017.
3	Law C.K., "Combustion Physics", Cambridge University Press, Cambridge, United Kingdom, 2010.
4	Mishra D.P., "Fundamentals of Combustion", Prentice Hall of India, New Delhi, INDIA, 2010.
5	Mukunda H. S., "Understanding Combustion", Universities Press, Hyderabad, Telangana, 2009.

METM130	**:**	**MICRO-HYDRO POWER PLANT**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concepts of hydro-electric power plants and classify different hydro-electric and micro-hydro-electric power plant
CO2	Analyze flow prediction methods and evaluate flow transfer systems required based on site conditions
CO3	Identify different types of turbines and analyze the performance characteristics of various turbines
CO4	Explain the working of different components of governing systems, and select the appropriate governing and drive for suitable application
CO5	Compare the working of different electrical power sources
CO6	Prepare maintenance schedule of components of micro hydro plant and carry out fault diagnosis

2. Syllabus:

Introduction	**(06 Hours)**
Classification of Hydro-Electric Power Plant, micro hydro power plant overview and components.	
Hydrology, Site Survey, and Civil Works	**(10 Hours)**
Introduction, flow prediction, head measurements, site measurements of flow, civil works, system layout, Weir, spillways, channel, penstocks.	
Turbines	**(12 Hours)**
Overview of Turbines, Construction, and operating principles, Types: impulse, Pelton, Turgo, Crossflow, Reaction, Francis, Propeller, Kaplan, and reverse pump: selection of turbine.	
Governing and Drive System	**(06 Hours)**
Purpose of governing, approaches to the governing, direct couple drives: components.	
Electrical Power	**(06 Hours)**
Basic electricity, choosing the supply, generators, synchronization.	
Operation and Maintenance	**(05 Hours)**
Maintenance of components of micro hydro plant, fault diagnosis.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	P. Fraenkel, O. Parish, V. Bolkalders, A. "Harvey, Micro-hydro Power: A guide for development workers", ITDG Publishing,1991.
2	L. Kindberg, "Micro-Hydro Power: A Beginners Guide to Design and Installation, National Center for Appropriate Technology", 2014.
3	A. Harvey, "Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes", Intermediate Technology Publications, 1993.
4	V. Schnitzer, "Micro hydro Power scout guide" Hydro Power GTZ, 2009.
5	J.M. Chapallaz, P. Eichenberger, G. Fischer. "Manual on pumps used as turbines", Vieweg, 1992.

METM132	**:**	**THEORY AND DESIGN OF CRYOGENIC SYSTEMS**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course, the students will be able to:

CO1	Select suitable cryogen and material for developing cryogenic systems for different applications.
CO2	Design and analyze of gas liquefaction systems and cryogenic refrigeration systems, including cryocoolers.
CO3	Select proper cryogenic insulating material and designing of cryogenic insulation.
CO4	Analyse gas purification and separation system using cryogenics.
CO5	Select and design storage, handling, and transfer systems for cryogens.
CO6	Design vacuum system for the cryogenic application.

2. Syllabus:

Introduction and Applications	**(02 Hours)**
Cryogenics Fluids	**(02 Hours)**
Properties of Air, Oxygen, Nitrogen, Hydrogen, Helium and its isotopes	
Properties and Selection of Materials	**(03 Hours)**
Study of material properties & their selection for the cryogenic application.	
Gas Liquefaction and Refrigeration Systems	**(10 Hours)**
Basics of Refrigeration, Ideal system, Linde Hampson system, Precooled Linde Hampson system, Linde dual pressure system, Claude system, Heylandt system, Kapitza system, Collins cycle.	
Cryogenic Insulation	**(07 Hours)**
Vacuum insulation, Multilayer insulation (MLI), Methods of measuring the effective thermal conductivity of MLI, Liquid & vapor shield, Evacuated porous insulation, Gas-filled powders, and fibrous materials, Solid foams, Vacuum technology.	
Cryocoolers	**(06 Hours)**
Ideal Stirling cycle, Design parameters (Schmidt's Analysis), GM cryocooler, Pulse Tube cryocooler, Phasor Analysis.	
Cryogenic Instrumentation	**(04 Hours)**
Peculiarities of cryogenic strain measurement, Pressure, Flow, Density, Temperature, and liquid level measurement for cryogenic application.	

Storage & Handling Systems	**(04 Hours)**
Dewar vessel design, Piping, Support systems, Vessel safety devices and storage systems, Industrial storage systems.	
Transfer Systems	**(04 Hours)**
Transfer from storage, Uninsulated transfer lines, Insulated lines, and Transfer system components.	
Gas Separation	**(03 Hours)**
Principles of gas separation, Ideal system	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Haselden, C., Cryogenic Fundamentals, Academic Press, 2001.
2	Barron R., Cryogenic Systems, Plenum Press, 2001.
3	Walker G., Cryocoolers, Springer, 2014.
4	Mikulin, Y., Theory and Design of Cryogenic systems, MIR Publication, 2002.
5	Barron, R. F., Cryogenics Systems, Oxford Press., USA, 2002

METM134	:	CASCADE AERODYNAMICS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concept of cascade and its terminology
CO2	Explain the difference between low speed and high speed cascade testing
CO3	Illustrate 3-D flows and non-rectilinear cascades
CO4	Explore effects of design parameters on cascade
CO5	Apply the knowledge of different flow theories and their behavior in cascade
CO6	Elucidate different flow and their behavior in cascade

2. Syllabus:

Introduction of Cascade Model	**(08 hours)**
Meridional & cascade planes, Cascade notation & definitions, Equations of motion & efficiency, Cascade force analysis, Brief about Tandem cascade.	
Low Speed Cascade Testing	**(06 hours)**
Introduction, Axial velocity variation through cascades, Influence of Reynolds number, Effect of free stream turbulence, Details about design feature of low speed cascade tunnel.	
3-D Flows & Non- Rectilinear Cascades	**(07 hours)**
Axial velocity ratio effect, Aspect ratio effect, Applications of cascade to mixed and radial flow, Secondary flow and losses, End-wall boundary layers.	
High Speed Cascade Testing	**(09 hours)**
Subsonic and transonic wind tunnels, Testing of high speed compressor and turbine cascades, Instrumentation and observation techniques.	
Design Application of Cascade Information	**(09 hours)**
The effect of geometric parameters, The effect of aerodynamic parameters, Interactive parameters	
Different Flow and Their Behavior in Cascade	**(06 hours)**
Potential flow, compressible flow, viscous flow, stalled and unsteady flow	

(Total Lecture Hours: 45)

3. Books Recommended:

1	William R. Hawthorne “Aerodynamics of turbines and compressors”, Princeton university press, New Jersey, 2017
2	Saravanamuttoo, H. I., Rogers, G. F. C., & Cohen, H. “Gas turbine theory” Pearson education, 2001.
3	Dixon S. L., C.A. Hall “Fluid Mechanics and Thermodynamics of Turbomachinery” Elsevier Inc., Netherlands 2014
4	Yahya S. M. “Turbines, compressors and fans” Tata McGraw hill education private limited, USA, 2011.
5	Boyce, M. P., Gas turbine engineering handbook. Elsevier, 2011.

METM136	:	CONDITION MONITORING AND FAULT DIAGNOSIS OF ROTATING MACHINERY	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe basic terminologies used in condition monitoring of rotating machinery.
CO2	Examine vibration analysis of complex rotating systems with non-linear effects included.
CO3	Identify and analyse rotating machinery faults using different methods.
CO4	Illustrate the utility of instrumentation and terminology used in signal analysis for fault detection in rotating machinery.
CO5	Analyse various plots used in condition monitoring of rotors predict rotor faults.
CO6	Analyse faults in rotating machinery

2. Syllabus:

Introduction to Condition Monitoring	**(06 Hours)**
Introduction to condition monitoring, Maintenance approach, Basics of machinery vibration, Conventions and characteristics - amplitude, frequency and phase.	
Vibration Analysis of Complex Rotating Systems	**(12 Hours)**
Asymmetric rotors, Axial vibrations, Torsional vibration - Holzer`s method, Transfer Matrix method, Geared and Branched systems, Effect of isotropic and anisotropic supports, Alford force, Whirling of rotor, Campbell diagram, Overhung rotors, Morton effect, Temperature effect on vibration.	
Rotating Machinery Faults and Detection	**(12 Hours)**
Rotating machinery faults and its detection - Unbalance, Misalignment, Bent rotors, Bearing defects, Oil Whirl, Oil whip, Looseness, Electric motor defect, Rotor stator rub etc., frequency range of faults, Non-destructive testing, Acoustic emission technique and applications, Introduction to Active magnetic bearing.	
Instrumentation and Signal Analysis	**(09 Hours)**
Instrumentation and Fault Detection Transducers - Displacement, Velocity and Acceleration, Computer aided data acquisition, Oscilloscope, Vibration Exciter systems, Signal Analysis, Basics of FFT, Trend plot, Time domain plot, Frequency domain plot, Spectrum plot, Waterfall plot, RMS, Peak and Peak-peak value, Case studies - Spectrum interpretation charts, Correlation analysis, cepstrum analysis, time averaging and trend analysis, wavelet analysis, model-based information extraction, signal conditioning, data acquisition	

Condition Monitoring of Rotors	(06 Hours)
Diagnostic Data and Tools (Shaft Relative Vibration Measurement, Seismic Vibration Measurement of Structures, Shaft Absolute Vibration Measurement, Bearing Metal Temperature Measurement), Load Variations, Pressure Variations, Diagnostic Data (Bode Plot, Polar Plot, Shaft Centreline Plot, Spectrum Plot), Angular Velocity Measurement methods in shaft, closing of rotor-stator clearances, cylinder distortion/misalignment, ingress of a cooling media (cool steam / water induction), lube oil influence on increased rotor vibration, faults detectable from the stator force wave, torsional oscillation monitoring (IAS), shock pulse monitoring.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Tiwari R., Rotor Systems: “Analysis and identification,” CRC Press, Florida, 2017.
2	Michael I. F., John E. T. Penny, Seamus D. Garvey, Arthur W. Lees, “Dynamics of Rotating machines”, Cambridge University Press, England, 2010.
3	Davies A., “Handbook of Condition Monitoring: Techniques and Methodology”, Springer Science & Business Media, Germany ,2012.
4	Rao J. S. “Rotor Dynamics”, New Age International Publication, New Delhi, India, Third Ed., 2018.
5	Peter T., Li Ran and Christopher Crabtree, “Condition Monitoring of Rotating Electrical Machines”, The Institution of Engineering and Technology, 3 rd Edition, India, 2020.

METM138	:	TURBULENT COMBUSTION	L	T	P	Credits
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Formulate turbulence in reacting and non-reacting flows
CO2	Explain various scales in turbulent premixed
CO3	Model premixed turbulent flames
CO4	Describe measurements in premixed turbulent flame
CO5	Model turbulent non-premixed flames
CO6	Demonstrate measurements in premixed turbulent flame

2. Syllabus:

Introduction	**(08 Hours)**
Introduction of various governing equations in the combustion, concepts of laminar premixed and non-premixed flames, concepts of turbulent-flows — Characteristics, Statistical understanding of turbulence, conventional averaging methods, turbulence model, probability density function, turbulent scales, LES and DNS simulation	
Turbulent Premixed Flames	**(10 Hours)**
Introduction and basic concepts of turbulent premixed flames, Correlation — Damkholer Analysis, Schelkin's Analysis, Karlovitz, Denniston and Wells's Analysis, Summerfield's Analysis, Kovasznay's Characteristic Time Approach, Limitations of the Preceding Approaches. Characteristic Scale of Wrinkles in Turbulent Premixed Flames — Structure of Wrinkled Laminar Flames, Measurements of Scales of Unburned and Burned Gas Lumps, Length Scale of Wrinkles	
Premixed Turbulent Flame Modeling and Measurements	**(09 Hours)**
Development of Borghi Diagram for Premixed Turbulent Flames — Physical Interpretation of Various Regimes in Borghi's Diagram, Turbulent Combustion Modeling Approaches, G-Equation, Scales in Turbulent Combustion, Closure of Chemical Reaction Source Term, Probability Density Function Approach to Turbulent Combustion.	
Non-Premixed Turbulent Flames	**(10 Hours)**
Introduction- non-premixed flames, non-premixed turbulent flame limitations. Turbulent Damkohler number, Turbulent Reynolds Number, Scales in Non-premixed Turbulent Flames, Turbulent Non-premixed Combustion Regime Diagram, Turbulent Non-premixed Target Flames — Simple Jet Flames, Piloted Jet Flames, Turbulence-Chemistry Interaction-Infinite Chemistry assumptions, unity Lewis number and non-unity Lewis number.	

Non-Premixed Turbulent Flame Modeling and Measurements	(06 Hours)
Probability Density Approach for Turbulent Non-premixed Combustion— Physical Models, Turbulent Transport in Velocity-Composition Pdf Methods, Molecular Transport and Scalar Mixing Models, Flamelet Models— Laminar Flamelet Assumption, Unsteady Flamelet Modeling, Flamelet Models and PDF. Interactions of Flame and Vortices— Flame Rolled Up, Experimental Setups for Flame/Vortex Interaction Studies, Generation and Dissipation of Vorticity Effects, Non-premixed Flame–Vortex Interaction, Flame Instability in Non-premixed Turbulent Flames.	
Partially Premixed Flames or Edge Flames	**(02 Hours)**
Formation of Edge Flames, Triple Flame Stabilization of Lifted Diffusion Flame, Analysis of Edge Flames	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Turns S.R., “An introduction to combustion”, New York: McGraw-Hill, USA, 2017.
2	Kuo K.K., “Principles of Combustion,” John Wiley, USA, 2005.
3	Kuo, Kenneth Kuan-yun, and Ragini Acharya. “Fundamentals of turbulent and multiphase combustion.” John Wiley, USA, 2012.
4	Peters, N. "Turbulent combustion. Cambridge, UK: Cambridge University Press.", UK, 2000.
5	Swaminathan, Nedunchezhian, Bai X-S., Haugen N. E. L., Christer Fureby, and Geert Brethouwer, eds. “Advanced Turbulent Combustion Physics and Applications”. Cambridge University Press, UK, 2022.

METM140	:	WIND ENERGY CONVERSION SYSTEMS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe the importance of wind energy sector
CO2	Analyse aerodynamic loads on wind turbines
CO3	Evaluate the performance parameters of wind turbines
CO4	Design the components of wind energy systems.
CO5	Analyse horizontal axis wind turbine systems
CO6	Examine the economics and feasibility of wind energy systems.

2. Syllabus:

Introduction	**(07 Hours)**
The nature of wind, Geographical variation in wind resources, Long term wind speed variations, Turbulence, Extreme wind speed, Turbulence in wakes and Wind farms	
Aerodynamics of Horizontal Axis Wind Turbine	**(09 hours)**
Introduction, Actuator disc concept, Rotor disc theory, Vortex cylinder model of the actuator disc, Rotor blade theory, Breakdown of momentum theory, blade geometry, effect of discrete number of blades, calculated results for an actual turbine	
Wind Turbine Performance	**(06 hours)**
The performance curves, constant rotational speed Operation, Comparison of measured with theoretical performance, variable speed operation, Estimation of energy capture, Wind turbine performance measurement, Aerodynamic Performance measurement	
Conceptual Design of Horizontal Axis Wind Turbine	**(07 hours)**
Introduction, Rotor diameter, Machine rating, Rotational speed, number of blades, Power control, Braking system, Fixed Space, Two Speed or variable speed operation, Type of generator	
Component Design	**(06 hours)**
Blades, Pitch bearings, Rotor Hub, Gearbox, Generator, Mechanical Brake, yaw drive, Tower, Foundations, Wind Turbine Control	
Wind Energy System Economics and Feasibility	**(05 hours)**
Engineering Economics Basics, Wind Turbine Cost Analysis, Wind Farm Feasibility Studies, Environmental and Wildlife Impact, Noise Issues	
Special Topics	**(05 hours)**

Vertical Axis Turbine, Floating Windmill, Diffuser augmented wind turbines, Airborne wind turbine, Recent developments in wind energy conversion

(Total Lecture Hours: 45)

3. <u>Books Recommended:</u>

1	Ahmed S., “Wind Energy: Theory and Practice”, PHI learning, India, 2011.
2	Maxwell J. F., McGowan J. G., and Rogers A. L., “Wind Energy Explained – Theory, Design, and Applications,” John Wiley & Sons, USA,2010
3	Hansen M., “Aerodynamics of Wind Turbines,” Routledge, UK, 2015.
4	Heier S., “Grid Integration of Wind Energy Conversion Systems,” Wiley, USA, 2014.
5	Nelson V., “Innovative wind turbines- an Illustrated guide book, CRC press Taylor & Francis, US, 2020

METM142	**:**	**MULTIPHASE FLOWS**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Identify multiphase flows regimes
CO2	Assess diverse approaches to solving critical problems in multiphase reactor
CO3	Formulate computational models for multiphase flow.
CO4	Establish the residence time distribution and measurement techniques for various systems
CO5	Examine how to apply the concepts of multiphase fluid flow
CO6	Apply two-Fluid Models in multiphase flow with interphase exchanges

2. Syllabus:

Fundamentals of Multi Phase Flow	**(12 Hours)**
Introduction to multiphase flow, types and applications, Common terminologies, flow patterns and flow pattern maps. Governing equations for homogeneous, separated and drift-flux models; lockhart and Martinelli procedure, gas-liquid flow in pipes, flow regimes in vertical, horizontal and inclined pipes, pressure drop and void fraction modelling for specific flow regimes. Dynamics of particles submerged in fluids, flow through packed bed, fluidization, calculation of pressure drop in fixed bed, determination of minimum fluidization velocity, expanded bed, dilute phase, moving solid fluidization, elutriation in fluidized bed, semi-fluidization, pulsating columns, oscillating fluidized bed. Gas-liquid particle process, gas liquid particle operation, flow of gas-bubble formation, bubble growth gas holdup, gas mixing liquid holdup, liquid mixing, flow of liquid mixing, gas liquid mass transfer	
Types of Multiphase-Reactors	**(08 Hours)**
Various types of multiphase reactors. e.g. Packed bed, packed bubble column, trickle bed reactor, three phase fluidized bed reactor, slurry bubble column, stirred tank reactor. Characteristics of above mentioned reactors such as; fluid flow phenomena and flow regimes, flow charts/ correlations, pressure drop, liquid hold up etc.	
Computational Models in Multiphase Flow	**(04 Hours)**
Overview of numerical approach, Direct Numerical Simulations of Gas-Liquid Flow, Lattice Boltzmann Method, Immersed Boundary Method, PDF models for particle transport mixing and collisions in Turbulent flow, Euler-Lagrange Methods, Two-Fluid Model in multiphase flow with interphase exchanges, Uncertainty Quantification.	

RTD in Multiphase Flow Systems	(09 Hours)
Residence time distribution of fluid in vessel, E, F & C Curve, Mean and variance, the Dirac delta function, residence time, linear and non-linear processes, models for non ideal flow, dispersion model, N tanks in series model, model for small deviations from plug flow and long tails, conversion in a reactor using RTD data, diagnosing ills of operating multiphase reactors, models for multiphase reactors. Two parameter model; PD model; three parameter models; PE Model	
Measurement Techniques in Multiphase Flow	**(06 Hours)**
Conventional and novel measurement techniques for multiphase systems (Laser Doppler anemometry, Particle Image Velocimetry)	
Applications of Multiphase Flow	**(06 Hours)**
One Dimensional Three Phase Flow example – Pump model: Variables defining the pump behaviour, theoretical basis, Suter Diagram, Computational Procedure, Centrifugal Pump Drive Model, Extension of the Theory to Multiphase Flow. Detonation waves due to chemical reactions: Introduction, Single phase theory (Laprace Continuum Sound Waves, Rankine Hugoniot Discontinuum Shock waves, Landau and Lifshitz Analytical Solution for detonation in perfect gas, numerical solution for detonation in closed pipe), multiphase flow (continuum sound wave, discontinuous shock waves, comparison with Yeun and The of Anous Formalism, numerical solution)	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Carey V. "Liquid-Vapor Phase-Change Phenomena," Taylor and Francis:, USA, 2007.
2	Fan, L. S. and Zhu, C., "Principles of Gas-solid Flows," Cambridge University Press, England,1999
3	Westerterp K.R., van Swaaij W.P.M., and Beenackers "Chemical Reactor Design and Operation," Wiley, USA, 1991.
4	Efstathios E. Michaelides, Clayton T. Crowe, John D. Schwarzkopf, "Multiphase Flow Handbook", CRC Press, Florida,2017
5	Kolev N. I., "Multiphase Flow Dynamics 1 – Fundamentals", Springer Publications, UK, 2015.

METM144	:	FLOW AND FLAME DIAGNOSTICS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe the need for diagnostics experiments in fluid flow and reacting flow
CO2	Differentiate the intrusive and non-intrusive techniques
CO3	Explain the concepts and methods of various diagnostics techniques in fluid flow and reacting flow
CO4	Describe the equipment and its arrangement to carry out diagnostics experiments in non-reacting and reacting systems.
CO5	Demonstrate different analysis techniques commonly used in diagnostics experimental work
CO6	Interpret diagnostics data in fluid mechanics and combustion

2. Syllabus:

Introduction to Optical Flow Diagnostics	**(09 Hours)**
Overview of probe measurement techniques, limitation of the probe measurement techniques, Importance of diagnostics, Intrusive vs. Non-Intrusive Measurements, Point vs. Planar Measurements, Spatial vs. Temporal Resolution, Time vs. Ensemble Averaging.	
Equipments For Diagnostics	**(12 Hours)**
Lasers, Camera, Synchronization, Seeding, Light sheet optics, Image Processing	
Techniques	**(12 Hours)**
Heat Release Rate — Chemiluminescence Imaging (CH, OH, C2, CO2), PLIF (CH, OH, HCHO, H), Temperature —2 Line PLIF, IR Camera, Thermographic Phosphors, Mixture Fraction, Acetone PLIF, Rayleigh Scattering, LDV, Velocity — 2D-2C PIV, 2D-3C PIV (Stereo), 3D-3C PIV (Tomographic).	
Advanced Topics	**(12 Hours)**
Soot — LII, Droplet & Spray Measurements — ILIDS-(Droplet Sizing), PDPA (Velocity & Size), Density Gradient —Schlieren, Rhodhamine PLIF, Shadowgraphy.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Van de Hulst H. C. “Light Scattering by Small Particles”, Dover, New York, USA, 2012
2	Tropea, C., Yarin, A. L., & Foss, J. F. (Eds.). “Springer handbook of experimental fluid mechanics”, Berlin: Springer, 2007.
3	Eckbreth C. “Laser Diagnostics for Combustion Temperature and Species”, Gordon & Breach, USA,1996.
4	Kohse-Höinghaus K., Barlow R. S., M. Aldén and J. Wolfrum, “Combustion at the focus: laser diagnostics and control”, Comb Inst, 2005.
5	Raffel M., Willert C. E., Kompenhaus J. “Particle Image Velocimetry: A Practical Guide,” Springer-Verlag, USA, 1998.

METM146	:	THERMOACOUSTIC INSTABILITIES	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe various instability observed in combustion systems
CO2	Derive governing equations in thermo-acoustic problem
CO3	Explain the origin of thermo-acoustic instabilities in a combustor
CO4	Evaluate the natural frequency of a combustor
CO5	Examine disturbance and flame response to harmonic excitation
CO6	Assess active and passive control of combustion instability

2. Syllabus:

Introduction to Acoustics and Combustion Driven Oscillations	(12 Hours)
Derivation of the wave equation, Traveling wave solutions, Standing wave solutions, Effect of inhomogeneous media on sound propagation, Multi-dimensional acoustics, Fundamentals of combustion instability, Basic principles, Rayleigh criteria	
Flame Aerodynamics and Flashback	**(04 Hours)**
Boundary Layer Flashback, Core Flow Flashback and Combustion Induced Vortex Breakdown	
Flame Stretch, Edge Flames, and Flame Stabilization Concepts	**(06 Hours)**
Introductory Concepts, Flame Stretch, Edge Flames, Flame Stabilization in Shear Layers, Flame Stabilization by Stagnation Points	
Disturbance Propagation and Generation in Reacting Flows	**(09 Hours)**
Introduction, Decomposition of Disturbances into Fundamental Disturbance Modes, Disturbance Energy, Nonlinear Behavior, Acoustic Wave Propagation Primer, Unsteady Heat Release Effects and Thermoacoustic Instability	
Flame Response to Harmonic Excitation	**(09 Hours)**
Governing Equations: Premixed Flame Dynamics, General characteristics of excited flames, Wrinkle convection and flame relaxation processes, Excitation of wrinkles, Interference processes, Destruction of wrinkles, Non Premixed Flame Dynamics, Global heat release response and Flame Transfer Functions.	
Active and Passive Control of Combustion Instability	**(05 Hours)**
Types and Methods to control combustion instability by active and passive methods.	

(Total Lecture Hours: 45)

3. **Books Recommended:**

1	Kinsler L. E., Frey A. R., A. B. Coppens and J. V. Sanders “Fundamentals of Acoustics”, Wiley, USA, 2000.
2	Lieuwen, Tim C. Unsteady combustor physics”. Cambridge University Press, England 2012.
3	Anderson, William E., and Vigor Yang, eds. “Liquid rocket engine combustion instability”. American Institute of Aeronautics and Astronautics, USA, 1995.
4	Natanzon MS. “Combustion instability.” American Institute of Aeronautics and Astronautics, USA, 2008.
5	Novozhilov, Vasily B., and Boris V. Novozhilov. “Theory of Solid-Propellant Nonsteady Combustion.” John Wiley & Sons, USA, 2020.

			L	T	P	Credits
METM148	**:**	**MACHINE LEARNING FOR THERMAL SYSTEMS**	**3**	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain different types of machine learning and map problems to different classes of machine learning algorithms
CO2	Describe and apply machine-learning algorithms including decision trees, naïve Bayes, and logistic regression.
CO3	Design and implement advanced neural network architectures, including Multilayer Perceptrons (MLPs), Convolutional Neural Networks (CNNs), and Recurrent Neural Networks (RNNs) (including LSTM and GRU variants), to solve complex real-world problems.
CO4	Utilize Bayesian Regression, Binary Trees, Random Forests, Support Vector Machines (SVM), Naïve Bayes, k-Means, k-Nearest Neighbors (kNN), Gaussian Mixture Models (GMM), and Expectation Maximization (EM) to analyze and optimize mechanical systems
CO5	Evaluate the performance of algorithms and compare different machine learning techniques.
CO6	Apply structured probabilistic models, Monte Carlo methods, autoencoders, and generative adversarial networks (GANs) to analyze and optimize mechanical systems

2. Syllabus:

Mathematical Basics	**(04 Hours)**
Introduction to Machine Learning, Linear Algebra, Probability	
Computational Basics	**(05 Hours)**
Numerical computation and optimization, Introduction to Machine Learning packages	
Linear and Logistic Regression	**(05 Hours)**
Bias/Variance Tradeoff, Regularization, Variants of Gradient Descent, MLE, MAP, Applications.	
Neural Networks	**(14 Hours)**
Multilayer Perceptron, Backpropagation, Applications, Convolutional Neural Networks: CNN Operations, CNN architectures, Training, Transfer Learning, Applications, Recurrent Neural Networks: RNN, LSTM, GRU, Applications	
Classical Techniques	**(09 Hours)**
Bayesian Regression, Binary Trees, Random Forests, SVM, Naïve Bayes, Applications, k-Means, kNN, GMM, Expectation Maximization, Applications.	
Advanced Techniques	**(08 Hours)**

Structured Probabilistic Models, Monte Carlo Methods, Autoencoders, Generative Adversarial Networks

(Total Lecture Hours: 45)

3. Books Recommended:

1	Ian Goodfellow, Yoshua Bengio, Aaron Courville, Deep Learning (Adaptive Computation and Machine Learning series), The MIT Press, 2016
2	Christopher Bishop, Pattern Recognition and Machine Learning, Springer, 2016
3	Geoff Dougherty, Pattern Recognition and Classification: An Introduction, Springer, 2013
4	Sebastian Raschka, Yuxi (Hayden) Liu, Vahid Mirjalili, Dmytro Dzhulgakov, Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python. Packt Publishing Ltd., 2022
5	Manaranjan Pradhan, U Dinesh Kumar, Machine Learning using Python, Wiley, 2020
6	Andreas C. Müller, Sarah Guido, Introduction to Machine Learning with Python: A Guide for Data Scientists, 2016

METM170	**:**	**COMPUTATIONAL FLUID DYNAMICS**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Develop mathematical model for fluid flow through turbomachine passage
CO2	Discretize the fundamental equations of flow and other transport processes
CO3	Apply finite volume method for numerical modeling of flow
CO4	Solve flow problems using semi-explicit and semi-implicit algorithms.
CO5	Generate mesh for flow domain in complex turbomachinery geometry
CO6	Solve Navier-Stokes equations for flow through complex turbomachine passages

2. Syllabus:

Governing Equations and Discretization	**(08 Hours)**
Navier-Stokes equations in Integral and differential form for incompressible and compressible flow through turbomachine passage, Energy Equation, Initial and Boundary Conditions, Finite Difference discretization, Errors, Consistency and Von–Neumann Stability Analysis	
Finite Volume Method for Fluid Flow Modeling	**(09 hours)**
Discretization of Unsteady, Diffusion, Advection and Source Terms, Advection Schemes: Central Difference Scheme, First Order Upwind Scheme, Second Order Upwind Scheme, QUICK scheme and Other Higher Order Schemes, Finite Volume Solution of Unsteady Advection, Diffusion Problems with Source Term	
Solution of Navier-Stokes Equations for Viscous Incompressible Flows	**(16 Hours)**
Stream function–vorticity formulation for Two Dimensional Incompressible Viscous Flow, Collocated and Staggered Grid, Solution of Unsteady Navier-Stokes Equations using Semi explicit method for Collocated and Staggered grid, Momentum Interpolation, SIMPLE Algorithm, Formulation for Coupled Flow and Heat Transfer or Other Scalar Transport	
Computational Methods for Complex Domain	**(12 Hours)**
Grid generation in complex geometry: O-type, C-type and H-Type grids around airfoil blades, Algebraic grid generation, Elliptic, hyperbolic and parabolic grid generation, Finite volume discretization of Navier-Stokes equations in complex domain, Grid-free vortex methods, decomposition of flux vector, applications in turbine cascade	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Versteag H. K., and Malalsekara W., An Introduction to Computational Fluid Dynamics, Pearson, UK, 2008.
2	Chung T. J., Computational Fluid Dynamics, Cambridge University Press, England, 2010.
3	Anderson D. A., Tannehill J. C., Pletcher R. H., “Computational Fluid Mechanics and Heat Transfer”, CRC Press, Florida, 2012
4	Murlidhar K. and Sunderarajan T. “Computational Fluid Flow and Heat Transfer”, Narosa Publisher, New Delhi, India 2013.
5	Anderson J. D., “Computational Fluid Dynamics”, McGraw Hill, NY, USA, 2017.

			L	T	P	Credits
METM172	**:**	**HYDROGEN ENERGY APPLICATIONS TO PROPULSION AND FUTURE MODES OF TRANSPORT**	**3**	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Asses and demonstrate the hydrogen production technologies, storage methods and strategies for transition to hydrogen economy
CO2	Analyze the concepts and characteristics of various types of fuel cell
CO3	Explain and demonstrate the working of fuel cells
CO4	Evaluate the economic and environment aspects fuel cells with analysis
CO5	Examine the use of hydrogen fuel in various application of transportation
CO6	Explain hydrogen applications to the propulsion

2. Syllabus:

Introduction	**(09 Hours)**
Hydrogen as a source of energy, physical and chemical properties, salient characteristics, relevant issues and concerns	
Hydrogen Storage	**(12 Hours)**
Production of hydrogen, steam reforming, water electrolysis, gasification and woody biomass conversion, biological hydrogen production, photo dissociation, direct thermal or catalytic splitting of water, hydrogen storage options, compressed gas, liquid hydrogen, hydride, chemical storage, safety and management of hydrogen, applications of hydrogen	
Fuel Cells Types Application and Economics	**(12 Hours)**
Brief history, principle, working, thermodynamics and kinetics of fuel cell process, types of fuel cells; AFC, PAFC, SOFC, MCFC, DMFC, PEMFC – relative merits and demerits, performance evaluation of fuel cell, comparison of battery Vs fuel cell. Fuel cell usage for domestic power systems, large scale power generation, automobile, space applications, cost expectation and life cycle analysis of fuel cells, future trends of fuel cells.	
Hydrogen Application to the Propulsion and Transport	**(12 Hours)**
Cryogenic Fuel Technology and Elements of Automotive Vehicle Propulsion Systems, Hydrogen Engines, Pre-Ignition Problems and Solutions, Fuel Delivery Systems, Power output, current status, cryo-engines types, Indigenous Cryogenic Engine and Stage. MIRAI Fuel Cell Vehicle, Residential Application (ENE-FARM), Distributed Power Generation, Triple Combined Cycle Power Generation, Fuel Cell with Biofuels, Portable Applications.	

(Total Lecture Hours: 45)

3. Books Recommended:

1	James L. and Andrew D. “Fuel Cell Systems” John Wiley, New York, USA, 2003.
2	Gou, B., Na, W., & Diong, B. “Fuel cells: modeling, control, and applications”, CRC press, 2017.
3	Bent Sorensen (Sorensen), “Hydrogen and Fuel Cells: Emerging Technologies and Applications”, Elsevier Academic Press, UK, 2018
4	Srinivasan, Supramaniam. “Fuel cells: from fundamentals to applications”, Springer Science & Business media, 2006
5	Kazunari Sasaki, Hai-Wen Li, Akari Hayashi, Junichiro Yamabe, Teppei Ogura, Stephen M. Lyth, “Hydrogen Energy Engineering – A Japanese Perspective”, Springer Publishers, Heidelberg, Germany 2016

METM174	:	DESIGN OF REACTING SYSTEMS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Formulate different types of reacting systems
CO2	Discriminate various type of reacting systems
CO3	Analyse reacting system thermally and chemically
CO4	Design the gas turbine combustion chambers
CO5	Design the rocket engines
CO6	Describe flame holding and ignition systems

2. Syllabus:

Simplified Conservation Equations for Reacting Flows	**(04 Hours)**
Mass conservation, species mass conservation equation, multicomponent diffusion equation, momentum conservation, energy conservation, the concepts of a conserved scalar.	
Thermal and Chemical Analysis of Reacting Systems	**(10 Hours)**
Constant-Pressure, Fixed-mass reactor, Constant-Volume, Fixed-mass reactor, Well-Stirred Reactor, Plug-Flow Reactor, Application to Combustion systems.	
Design of Gas Turbine Combustion Chambers	**(16 Hours)**
Introduction, Combustor Diffuser — Geometry, performance, Design considerations- Faired diffuser, Dump diffuser, Splitter Vanes, Vortex-Controlled diffuser, Hybrid diffuser, Diffuser for tubular and Tub annular Combustors, testing of diffusor. Aerodynamics of Combustor — Reference quantities, Pressure-Loss parameters, Flow in annulus, Flow through liner holes, Jet Trajectories, Jet Mixing, Dilution zone Design, Correlation of pattern Factor Data, Swirler Aerodynamics, Axial Swirlers, Radial Swirlers, Flat vanes versus curved Vanes. Combustor Performance — Combustion Efficiency, Reaction-controlled systems, Mixing-Controlled systems, Evaporation-Controlled systems, Reaction- and Evaporation-Controlled Systems, Flame Stabilization— Definition of Stability Performance, Measurement of Stability Performance, Water Injection Technique. Bluff-Body Flame holders, Mechanism of Flame stabilization. Ignition— Spark ignition- igniter design, life and performance, Other form of ignition. The ignition process and methods of improving ignition performance. Fuel injection system analysis, Combustion noise. Combustor Cooling system analysis, Emission and Alternative fuels	
Design of Rocket Engines	**(15 Hours)**
Introduction of rocket-engines, Engine requirements and preliminary design, Design of thrust chamber— Thrust chamber layout, Thrust chamber cooling, Injector design, Gas-	

generating device, ignition devices, combustion instability. Design of Gas-pressured and turbo prop-propellant feed system, design of rocket engine control, design of propeller tank, design of liquid propellant space engine. Solid rocket motor design and performance

(Total Lecture Hours: 45)

3. Books Recommended:

1	Turns, S.R., "An introduction to combustion," McGraw-Hill, NY, USA, 2017.
2	Ganesan V.., "Gas Turbines", Tata McGraw Hill Education (India) Private Limited, 2017.
3	Lefebvre, Arthur H., and Dilip R. B. "Gas turbine combustion: alternative fuels and emissions." CRC press, Australia, 2010.
4	Huzel, Dieter K. "Modern engineering for design of liquid-propellant rocket engines" American Institute of Aeronautics & Astronautics, USA, 1992.
5	Jim R. "Design of Liquid Propellant Rocket Engines." Lulu Press, Incorporated, North Carolina, United States, 2016.

METM176	:	TURBULENCE AND TURBULENT FLOWS	L	T	P	Credits
			3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Evaluate of turbulent flows
CO2	Explain various types of shear flows
CO3	Analyse turbulent flows statistically
CO4	Explain spectral dynamics of turbulence
CO5	Evaluate and interpret experimental measurements
CO6	Choose a turbulence model for computational flow analysis (CFD)

2. Syllabus:

Introduction	**(03 Hours)**
Nature of turbulence, Method of analysis, generation and diffusion of turbulence, Length scales in turbulent flows	
Turbulent Transport of Momentum and Heat	**(12 Hours)**
The Reynolds equations, elements of kinetic theory of gases, Estimates of Reynolds stress, Turbulent heat transfer, Turbulent shear flow near rigid wall. Transport in stationary, homogeneous turbulence, Transport in shear flows, Dispersion of contaminants, Turbulent transport in evolving flows**.** Dynamics of Turbulence — Kinetic energy of mean flow, Kinetic energy of the turbulence, Vorticity dynamics, The dynamics of temperature fluctuations	
Shear Flows	**(12 Hours)**
Boundary Free Shear Flows —Almost parallel two dimensional flows, Turbulent wakes, The wake of self-propelled body, Turbulent jets and mixing layers, comparative structure of wakes, jets and mixing layers, Thermal plumes. Wall Bounded Shear Flows —The problem of multiple scales, Turbulent flows in pipes and channels, Planetary boundary layers, The effects of a pressure gradient on the flow in surface layers, The downstream development of turbulent boundary layers	
The Statistical Description of Turbulence	**(06 Hours)**
The probability density, Fourier transforms and characteristic functions, joint statistics and statistical independence, Correlation functions and spectra, The central limit theorem.	
Spectral Dynamics	**(06 Hours)**
Velocity and Length scales in laminar and turbulent boundary layers, molecular versus	

turbulent dissipation, Kolmogorov Microscales of Dissipation, One and three dimensional spectra, The energy cascade, The spectrum of turbulence, The effects of production and dissipation, Time spectra, Spectra of passive scalar contaminants.	
Turbulence Simulations and Modelling	**(06 Hours)**
URANS, eddy viscosity models Zero-order models (Algebraic Models), One-Equation Models, Two-Equation Models, appropriate turbulence modelling for turbomachinery flows using a two-equation turbulence model, Large Eddy Simulation, Direct Numerical Simulation	

(Total Lecture Hours: 45)

3. Books Recommended:

1	Tennekes, H. and Lumley, J.L. “A first course on turbulence”, MIT Press, Cambridge, 2018.
2	Pope S.B. "Turbulence" Cambridge University Press, Cambridge, U.K., 2000.
3	Davidson P.A, “Turbulence” Oxford University Press, Oxford, U.K., 2004.
4	Biswas G. and Eswaran, V. "Turbulent flows" Narosa Publishing House New Delhi, India, 2002.
5	Wilcox, D.C. "Turbulence modeling for CFD", DCW Industries, La Canada, CA, 2006.

METM178	**:**	**FUNDAMENTALS OF SOLID PROPELLANT AND MULTI-PHASE COMBUSTION**	**L**	**T**	**P**	**Credits**
			3	**0**	**0**	**03**

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe chemistry and synthesis of propellant
CO2	Explain combustion mechanism of solid energetic materials
CO3	Demonstrate optical diagnostics of solid propellant combustion
CO4	Analyse the thermal decomposition of the solid propellant
CO5	Model multiphase combustion
CO6	Describe measurements in multiphase combustion

2. Syllabus:

Propellant Chemistry, Synthesis, and Formulation	**(10 Hours)**
Flash Pyrolysis of Ammonium Perchlorate-Hydroxyl-Terminated-Polybutadiene Mixtures Including Selected Additives, Gas-Phase Chemical Kinetics of [C. H. N. O], Effect of Molecular Structure on Combustion, Effects of Microstructure on Explosive Behavior, Advances in Solid Propellant Formulations, Hazards Associated with Solid Propellants.	
Combustion of Solid Energetic Materials	**(09 Hours)**
Overview of Combustion Mechanisms and Flame Structures for Advanced Solid Propellants, Physico-Chemical Mechanisms of Solid Propellant Combustion, Flame Structure of Solid Propellants, Experimental Studies of Propellant Combustion.	
Optical Diagnostics of Solid-Propellant Flame Structures	**(05 Hours)**
Introduction, Experimental techniques, Laser-Supported Deflagration of RDX and HMX, Effect of Pressure on HMX Flame Structure, Diffusion Flame Studies via Sandwiches, Counter flow Diffusion Flames, Metal Combustion.	
Thermal Decomposition and Combustion	**(09 Hours)**
GAP/AN/Nitrate Ester Propellants, Experimental Methods, flame structures, Correlation of Thermal Decomposition and Burning-Rate Characteristics.	
Multiphase Combustion	**(12 Hours)**
Droplet evaporation and Burning— applications, simple model of Droplet evaporation—Gas phase Analysis, Droplet Life times, Simple Model of Droplet Evaporation— Mass Conservation, Species Conservation, Energy Conservation, Lifetimes, Spray Statistics—Distribution Function, Simplified Spray Combustion Model for Liquid-Fuel Rocket Engines, Classification of Models Developed for Spray Combustion Processes— Simple Correlations, Droplet Ballistic Models, One-Dimensional Models, Stirred-Reactor Models,	

Locally Homogeneous-Flow Models, Two-Phase-Flow (Dispersed-Flow) Models. Locally Homogeneous Flow Models. Two-Phase-Flow (Dispersed-Flow) Models, Droplet Collison, Optical Techniques for Particle Size Measurements, Effect of Droplet Spacing on Spray Combustion

(Total Lecture Hours: 45)

3. Books Recommended:

1	Turns S.R., "An introduction to combustion", New York: McGraw-Hill, USA, 2017.
2	Kuo K.K., "Principles of Combustion," John Wiley, USA, 2005.
3	Kuo, Kenneth Kuan-yun, and Ragini Acharya. "Fundamentals of turbulent and multiphase combustion". John Wiley, USA, 2012.
4	Yang, Vigor, ed. "Solid propellant chemistry combustion and motor interior ballistics "American Institute of Aeronautics & Astronautics, USA, 2000.
5	Huggett, Clayton, Charles E. Bartley, and Mark M. Mills. Solid propellant rockets. Vol. 2373. Princeton University Press, 2015

METM108	:	COMPUTATIONAL AND EXPERIMENTAL LABORATORY – II	L	T	P	Credits
			0	0	4	02

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the features available in meshing software, turbo-grid, and CFD solver
CO2	Solve thermo-fluid and turbomachines problems using a CFD solver.
CO3	Solve lid-driven cavity problem
CO4	Derive numerical solutions of various convection-diffusion problems using various schemes
CO5	Analyse the performance of thermal turbomachines
CO6	Calculate the performance parameters of hydro turbomachines

2. Soft tool based and coding based practices

ANSYS-FLUENT

1. Introduction to mesh generation software (ICEM/Workbench)
2. Introduction to ANSYS-FLUENT solver
3. Fluid flow simulation through confined and unconfined passages (Laminar/ Turbulent)
4. Non-isothermal flow simulations through channel/enclosure/over bodies (Laminar + Turbulent)
5. Flow and associated scalar transport simulations for complex engineering applications
6. Multiphase transport modelling and simulation

CODING

1. FVM code for diffusion transport with and without source term
2. FVM code for advection-diffusion problem based on central difference scheme
3. FVM code for advection-diffusion problem based on upwind scheme
4. FVM code to analyse false-diffusion of upwind scheme
5. FVM code for advection-diffusion problem based on hybrid differencing scheme
6. FVM code for semi-explicit time marching of fluid flow problems
7. FVM code for semi-implicit time marching of fluid flow problems
8. Development of Coupled solvers for flow and associated transport
9. Introduction to Lattice Boltzmann Method (LBM)
10. LBM code for flow through confined and unconfined passages.

3. Laboratory Experiments:

1. Performance analysis of the centrifugal blower for three different vanes
2. Performance analysis of the centrifugal compressor
3. Performance analysis of high rpm centrifugal blower
4. Performance analysis of Hydraulic ram and Centrifugal pump
5. Performance analysis of Pelton turbine, Francis turbine and Kaplan turbine
6. Study of Schlieren and Shadowgraph flow visualization techniques.
7. Flow velocity measurements using intrusive and non-intrusive techniques
8. Study of flash point, fire point and auto ignition point
9. Analysis of modes of flames and different type of open flame burners
10. Study of different types of gas turbine combustion chamber