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**			
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.	**PEO1** **3**	**PEO2** **3**	**PEO3** **3**	**PEO4** **2**

PROGRAM OUTCOMES (PO)

The graduates of M. Tech. (Turbomachines) 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.	Code No.	Subject	Teaching Scheme			Exam Scheme			Total	Credits
			L	T	P	Theory Marks	Tuto. Marks	Pract. Marks		
1.	METM101	Core-1 Fluid Dynamics for Turbomachinery	3	1	0	100	-	-	100	4
2.	METM102	Core-2 Applied Gas Dynamics	3	1	0	100	-	-	100	4
3.	METM103	Core-3 Thermodynamics and Heat Transfer for Turbomachinery	3	1	0	100	-	-	100	4
4.		Elective-1	3	0	0	100	-	-	100	3
5.		Elective-2	3	0	0	100	-	-		3
6.	METM104	Software Laboratory – I (Turbomachines)	0	0	4	-	-	100	100	2
7.	METM105	Laboratory Practice – I (Turbomachines)	0	0	4	-	-	100	100	2
Tota1			**15**	**3**	**8**	**500**	**-**	**200**		**22**
Total Contact Hours per week			**26**							

Elective -1

1	Combustion (METM110)	4	Design of Reacting Systems (METM113)
2	Nonlinear Dynamics and Chaos (METM111)	5	Atomization and Sprays (METM114)
3	Jet and Rocket Propulsion (METM112)		

Elective -2

1	Measurements and Data Analysis (METM120)	4	Unconventional Turbomachines (METM123)
2	Energy and Exergy Analysis of Turbomachines (METM121)	5	Hydrogen Energy Applications To Propulsion And Future Modes of Transport (METM124)
3	Rotor Dynamics, Vibration and Stress Analysis (METM122)		

SEMESTER – II

Sr. No.	Code No.	Subject	Teaching Scheme			Exam Scheme			Total	Credits
			L	T	P	Theory Marks	Tuto. Marks	Pract. Marks		
1.	METM201	Core-4 Design of Thermal Turbomachines	3	1	0	100	-	-	100	4
2.	METM202	Core-5 Design of Hydro Turbomachines	3	1	0	100	-	-	100	4
3.		Elective-3	3	0	0	100	-	-	100	3
4.		Elective-4	3	0	0	100	-	-	100	3
5.		Institute Elective- 1	3	0	0	100				3
6.	METM203	Software Practice – II (Turbomachines)	0	0	4	-	-	100	100	2
7.	METM204	Laboratory Practice – II (Turbomachines)	0	0	4	-	-	100	100	2
		Total	**15**	**2**	**8**	**500**		**200**		**21**
		Total Contact Hours per week	**25**							

Elective -3

1	Computational Fluid Dynamics(METM230)	4	Turbulence and Turbulent Flows (METM233)
2	Lifecycle Analysis of Turbomachines (METM231)	5	Cascade Aerodynamics (METM234)
3	Micro Hydro-turbine (METM232)	6	Condition Monitoring and Fault Diagnosis of Rotating Machinery (METM235)

Elective -4

1	Thermo-acoustic Instabilities (METM240)	4.	Turbulent Combustion (METM243)
2	Flow and Flame Diagnostics (METM241)	5.	Fundamentals of Solid Propellant and Multi-phase Combustion (METM244)
3	Hydrodynamic Stability (METM242)		

Institute Elective -1

1.	Optimisation Techniques (METM210)	3.	Multi-phase Flow and Heat Transfer (METM212)
2.	Finite Element Methods (METM211)	4.	Wind Energy Conversion System (METM213)

SEMESTER – III

Sr. No.	Code No.	Subject	Teaching Scheme			Exam Scheme			Total	Credits
			L	T	P	Theory Marks	Tuto. Marks	Pract. Marks		
1.	METM301	Dissertation Preliminaries	0	0	12	-	-	300	300	6
2.	METM302	Industry Based Seminar	0	0	04	-	-	100	100	2
		Total			**16**			**400**	**400**	**8**

SEMESTER – IV

Sr. No.	Code No.	Subject	Teaching Scheme			Exam Scheme			Total	Credits
			L	T	P	Theory Marks	Tuto. Marks	Pract. Marks		
1.	METM401	Dissertation	0	0	24	-	-	600	600	12
		Total			**24**					**12**

DEPARTMENT OF MECHANICAL ENGINEERING

POOL OF ELECTIVES FOR ALL P.G. PROGRAMS

SEMESTER-I	
ELECTIVE-1	**ELECTIVE-2**
1. Additive Manufacturing 2. Advanced Mechanical Vibrations 3. Advanced Mechanics of Solids 4. Advanced Welding Technology 5. Atomization and Sprays 6. Bio-Mass Conversion Systems 7. CAD for Manufacturing 8. Combustion 9. Concurrent Engineering: Tools, Techniques & Applications 10. Condition Monitoring and Fault Diagnosis of Rotating Machinery 11. Design of Reacting Systems 12. Electrical Vehicles and Advanced IC Engines 13. Electro-Chemical Engineering Storage 14. Environmental Pollution and Control 15. Jet and Rocket Propulsion 16. Industrial Tribology 17. Manufacturing Metallurgy 18. Material Characterization and Testing 19. Metal Cutting and Tool Design 20. Nonlinear Dynamics and Chaos 21. Power Plant Engineering 22. Product Design & Development 23. Theory of Plasticity	1. Advanced Metrology and Computer Aided Inspection 2. Analysis and Design of Thermal Turbo Machines 3. Computational Fluid Dynamics 4. Computer Aided Production Planning 5. Concurrent Engineering 6. Design of Pressure Vessels 7. Design of Refrigeration and Air Conditioning Systems 8. Electrical Vehicles and Advanced IC Engines 9. Energy and Exergy Analysis of Turbomachines 10. Failure Analysis & NDE 11. Finite Element Method in Thermal Engineering 12. Fracture Mechanics 13. Gas Dynamics and Compressible Fluid Flow 14. Hydrogen Energy Applications to Propulsion and Future Modes of Transport 15. Industrial Robotics 16. Measurements and Data Analysis 17. Measurements and Data Analysis in Thermal Engineering 18. Operation Planning and Control 19. Optimization Techniques 20. Rotor Dynamics, Vibration and Stress Analysis 21. Sensors in Manufacturing Systems 22. Unconventional Turbomachines

DEPARTMENT OF MECHANICAL ENGINEERING

POOL OF ELECTIVES FOR ALL P.G. PROGRAMS

<table>
<tr><th colspan="2"><u>SEMESTER-II</u></th></tr>
<tr><th>ELECTIVE-3</th><th>ELECTIVE-4</th></tr>
<tr><td>1. Advanced Welding Technology
2. Automation in Manufacturing
3. Bio fluidic and Bio Heat Transfer
4. Cascade Aerodynamics
5. Combustion
6. Composite Design and Manufacturing
7. Computational Fluid Dynamics
8. Computer Aided Tool Design
9. Condition Monitoring and Fault Diagnosis of Rotating Machinery
10. Design of Heat Exchangers
11. Design of Pressure Vessel & Piping
12. Finite Elements Methods
13. Industrial Tribology
14. Instrumentation and Experimental Methods
15. Laser Based Micro Manufacturing
16. Lifecycle Analysis of Turbomachines
17. Metal Cutting
18. Micro Hydro Turbine
19. Quality Engineering and Management
20. Renewable Energy Systems
21. Smart Materials & Manufacturing
22. Theory and Design of Cryogenic Systems
23. Turbulence and Turbulent Flows</td><td>1. Combustion
2. Concurrent Engineering
3. Design of Heat Exchangers
4. Flow & Flame Diagnostics
5. Fundamentals of Solid Propellant and Multi-Phase Combustion
6. Hydrodynamic Stability
7. Industrial Refrigeration
8. Industrial Tribology
9. Mechanics of Composite Laminates
10. Mechanics of Composite Materials
11. Nano fluid and its Applications in Thermal Systems
12. Non Destructive Techniques
13. Numerical Methods in Manufacturing
14. Operations Research
15. Optimization Techniques
16. Quality Engineering and Management
17. Surface Engineering
18. Theory of Elasticity and Plasticity
19. Thermo-Acoustic Instabilities
20. Transport in Porous Media
21. Turbulent Combustion</td></tr>
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SEMESTER – I

METM101	:	FLUID DYNAMICS FOR TURBOMACHINERY	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 the fluid flow through different class of turbomachines
CO2	Analyse the flow through turbomachine cascades
CO3	Evaluate the drag on turbomachine blades due to the boundary layer shear
CO4	Develop turbulent flow model through turbomachine passage
CO5	Explore the fluid flow through two and three-dimensional rotating passages
CO6	Comprehend the concepts of swirling flow through turbomachines

2. Syllabus

GOVERNING EQUATIONS OF FLUID MOTION (12 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 for different class of turbomachines with energy and angular momentum considerations.

INVICID CASCADE 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, Cascade nomenclature, Energy losses, Velocity triangles, conformal transformation methods, Cascade analysis by method of surface singularity.

BOUNDARY LAYER FLOWS (6 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 (8 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 **(6 Hours)**

Rotating coordinate systems and Coriolis accelerations, Conserved quantities in a steady rotating flow, Phenomena in flows where rotation is dominant, Flow in two-dimensional rotating straight channels (Inviscid flow, Coriolis effects on boundary layer mixing and stability), Two-dimensional flow in rotating diffusing passages, Three-dimensional flow in rotating passages.

SWIRLING FLOWS **(6 Hours)**

Swirling flows in radial equilibrium, Rankine vortex flow, waves on vortex cores, steady vortex core flows, Vortex core response to external conditions in confined and unconfined geometries, swirling flow boundary layers, swirling jets, recirculation in axi-symmetric swirling flows, vortex breakdown.

(Total Lecture Hours: 42)

Reference

1. Greitzer, E. M., Tan, C. S., Graf, M. B. “Internal Flow Concepts and Applications”. Cambridge University Press, Cambridge, United Kingdom, 2007
2. Schlichting H., “Boundary layer Theory”, McGraw Hill, NY, USA, 2016.
3. Anderson Jr. John D., “Fundamentals of Aerodynamics”, McGraw-Hill, NY, USA, 2010
4. Dixon S. L., “Fluid Mechanics and Thermodynamics of Turbomachinery” Butterworth-Heinemann, Oxford, United Kingdom, 2013
5. Lakshminarayana, B. “Fluid dynamics and heat transfer of turbomachinery.” John Wiley & Sons, USA, 1995

METM102	**:**	**APPLIED GAS 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	Predict the effect of compressibility and flow behaviour in the field of gas dynamics
CO2	Solve 1-D design problems based on Isentropic, Fanno and Rayleigh flow
CO3	Evaluate the different possible conditions for flow without chocking in 1-D duct with variable area, friction and heat transfer.
CO4	Identify the position and effect of shock within the 1-D duct and learn to use shock polar diagram for 2-D flows.
CO5	Analyse Beltrami flows through turbomachines
CO6	Apply method of characteristics for compressible flows

2. Syllabus

BELTRAMI FLOWS (10 Hours)

Introduction to Beltrami flows - Cylindrical stream surfaces - Axisymmetric Beltramic flows - of free - vortex type of forced - vortex type and with constant flow angle - Mass flow rate through annulus - Chocking of flow through annulus.

ONE-DIMENSIONAL COMPRESSIBLE FLOW (08 Hours)

One dimensional flow concept, Isentropic flows, Stagnation/Total conditions, Characteristics speeds of gas dynamics, Dynamic pressure and pressure coefficients, Normal shock waves, Rankine-Hugoniot equations, Rayleigh flow, Fanno flow, Crocco's theorem, isentropic flow through converging nozzle, influence of friction on flow through nozzle, supersonic nozzle, moving shocks, combined influence of area changes, head addition, and friction in nozzle.

TWO-DIMENSIONAL FLOWS (08 Hours)

Oblique shock wave and its governing equations, θ-B-M relations, The Hodograph and Shock Polar, 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, Approximation of continuous expansion waves by discrete waves,

METHOD OF CHARACTERISTICS (06 Hours)

Concepts of Characteristic, Compatibility Relation, Theorems for Two-Dimensional Flow, characteristics and their association with Riemann Invariants, characteristics and their approximations by weak waves, Design of Supersonic Nozzle.

GAS DYNAMICS OF WET STEAM (04 Hours)

Clausius-Clapeyron equation, adiabatic exponent, conservation equations for wet steam, Applications.

APPLICATION OF GAS DYNAMICS TO JET PROPULSION (06 Hours)

Aerothermodynamics of Engine Components, Flow Through Inlets, Shock-Boundary Layer Interaction. Two-shock Intakes, Multi-shocks intakes, Limits of External Shock Attachments, Internal and External Shock attachment.

Flow with heat addition—Heat addition and flow state changes in propulsion devices,

(Total Lecture Hours: 42)

References

1. Rathakrishnan, Ethirajan. "Applied gas dynamics." Wiley, USA, 2019.
2. Somasundaram S.L., “Gas Dynamics & Jet Propulsion”, New Age International (P) Ltd., New Delhi, 1996
3. Zucker, Robert D., and Oscar Biblarz. “Fundamentals of gas dynamics”. John Wiley & Sons, USA, 2019.
4. Vavra, M.H . “Aerothermodynamics and flow in turbomachines”, John Wiley, USA, 1974.
5. Shapiro A.H. “The dynamics and thermodynamics of compressible fluids, Vol. I & II,” Ronald Press, UK, 1965.

METM103	:	THERMODYANCMICS AND HEAT TRANSFER FOR TURBOMACHINERY	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

Fundamentals of Heat Transfer (20 Hours)

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

Turbine Heat Transfer **(04 Hours)**

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 **(06 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: 42)

References

1. Cohen, Longman, R. “Theory of gas turbines “Pearson, London, UK, 2017.
2. Horlack, H.H., “Axial flow turbines” Butter worth, London,1973.
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.

METM110	:	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 different combustion mechanisms and how these can be efficiently used in engineering applications.
CO2	Analyse the combustion system using principles of thermodynamics.
CO3	Model combustion kinetics and chemical explosion mechanisms
CO4	Explain basic concepts about various types of flames; modelling and application to energy systems.
CO5	Analyse combustion characteristics and how these can be measured.
CO6	Illustrate different type of pollutants generated by combustion, their effects on health and on the environment.

2. Syllabus

INTRODUCTION **(02 Hours)**

Introduction to combustion, Applications of combustion, Types of fuel and oxidizers, Characterization of fuel, Various combustion mode, Scope of combustion.

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.

PHYSICS OF COMBUSTION **(03 Hours)**

Fundamental laws of transport, Conservations equations for combustion and their physical interpretations.

PREMIXED FLAMES **(07 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 **(07 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, Emission control methods. 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.

(Total Lecture Hours: 42)

References

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, Telangan, 2009.

METM111	:	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 systesm

2. Syllabus

ONE-DIMENSIONAL SYSTEMS AND ELEMENTARY BIFURCATIONS (4 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: **(6 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. **(6 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 **(9 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.

MPPINGS OF SYSTESMS **(9 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 **(4 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 **(4 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: 42)

References

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.

METM112	**:**	**JET AND ROCKET PROPULSION**	**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 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	Explain types of chemical rockets and details of its propellant
CO6	Apply rocket principles to hybrid rockets

2. Syllabus

AIR BREATHING AND NON-AIR BREATHING ENGINES (8 Hours)

Introduction to various air breathing engines such as turbojet, turboprop, turbofan engines, Ramjet, Scramjet and non-air breathing engines. Conservation equations and derivation of the thrust equation for air breathing and non-air breathing engines. General performance parameters. Efficiencies of air breathing and non-air breathing engines.

CYCLE ANALYSIS (6 Hours)

Thermodynamic analysis of working cycle of turbojet, turboprop, turbofan and ramjet engines. Engine Thrust, Propulsion Measures, Power-Generation Measures, System Matching and Analysis (Matching of Gas Turbine System Components – Gas Generator, Jet Engine, Power Generation Gas Turbine), Component Modelling, Solution of Matching Problems, Dynamic / Transient Response, Matching of Engine and Aircraft, use of matching and cycle analysis in second-stage design.

ROCKET TURBOMACHINERY FUNDAMENTALS: (4 Hours)

Elements of Rocket Turbopumps, Pump Design, Inducer Design, Impeller Design, thrust Balance, Pump Operating Envelop, Turbine Fundamentals, Shafts, Bearings, Seals, Rotordynamics, additive manufacturing.

ROCKET PRINCIPLE (3 Hours)

Rocket principle and rocket equation. Mass ratio of rocket, desirable parameters to achieve high velocities and propulsive efficiency. Performance parameters of a rocket, staging and clustering and classification of rockets.

NOZZLES **(5 Hours)**

Rocket nozzles; expansion of gases from high pressure chamber, efflux velocity and shape of nozzle. Convergent divergent nozzle, choking and variation of parameters in nozzle. Expansion ration of nozzles and performance loss in nozzles. Under-expanded and over-expanded nozzles. Flow separation in nozzle, mass flow rates and characteristic velocities. Thrust developed by a rocket, thrust coefficient, vacuum and sea level impulse, efficiencies and thrust correction factor.

CHEMICAL PROPELLANTS **(4 Hours)**

Chemical propellants: Choice from considerations of molecular mass, specific heats, specific heat ratios, temperature and pressure. Choice of chemical propellants: heats of formation, moles and mixture ratio; choice of mixture ratio. Calculation of heat of combustion, temperature, molecular mass and rocket performance parameters. Solid propellants: double base, composite, composite modified double base and nitramine propellants. Liquid propellants: Energy content and classification, earth storable and space storable propellants, hypergolic and other features, hybrid propellants. Influence of dissociation on propellant performance, frozen and equilibrium analysis

SOLID PROPELLANT ROCKETS **(5 Hours)**

Solid propellant rockets: burn rate of double base and composite propellants, parameters influencing burn rates. Choice of burn rates for stable operation. Propellant grain configurations: design of solid propellant rocket. Ignition of solid propellant rockets, ignition problems and solutions. Characteristic burn times and action times of solid propellant rockets, variation of burn rates with rocket size, erosive burning, components solid propellant rocket.

LIQUID PROPELLANT ROCKETS **(5 Hours)**

Introduction to liquid propellant rockets, propellant feed systems, cycles of operation, gas generator, topping/staged combustion cycle, expander and other cycles, factors influencing choice of cycle. Thrust chamber, injector types and combustion chamber. Calculation of efficiency of liquid propellant rockets from non-uniform distribution of propellants and incomplete vaporization, and characteristic length of chamber. Cooling of thrust chamber and nozzle. Performance and choice of feed system cycle, Choice of parameters for liquid propellant rockets. Turbo-pumps for liquid propellant rockets. Expulsion of propellants using high pressure gas and mass requirements. Complexities of liquid propellant rockets and determination of performance.

MONOPROPELLANT AND HYBRID ROCKETS **(2 Hours)**

Basic theory of monopropellant and hybrid rockets.

(Total Lecture Hours: 42)

References

1. Hill, P. G. and Peterson, C. R., "Mechanics and thermodynamics of propulsion" Wesley Publishing Company, USA, 1992.
2. Mattingly, J. D., "Elements of gas turbine propulsion", Tata McGraw-Hill Edition, NY, USA, 2005.

3. Jack D. Mattingly, “Elements of Propulsion: Gas Turbines and Rockets,” AIAA Publication, USA, 2016.
4. Sutton, G. P. and Biblarz O., “Rocket propulsion elements” Wiley Publications, USA, 2016.
5. Mukunda H. S., “Understanding aerospace propulsion,” Interline Publishing, Bengaluru, India, 2017.

METM113	**:**	**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 (4 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 **(12 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: 42)

References

1. Turns, S.R., "An introduction to combustion," McGraw-Hill, NY, USA, 2017.
2. Lefebvre, Henry, A. "Gas Turbine Combustor Design Problems". Hemisphere Pub, London, England, 1980.
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.

METM114	:	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	Modelling 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 (3 Hours)

Atomizers, Factors influencing atomization, Spray characteristics, Applications.

DROP SIZE DISTRIBUTION OF SPRAYS (4 Hours)

Number distributions, Mass/volume distributions, Empirical distributions, Theoretical distributions.

BASIC PROCESS IN ATOMIZATION (8 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 (4 Hours)

Steady trajectories (gas turbines, spray cooling, paint sprays), Entrainment.

DROP EVAPORATION (2 Hours)

Steady evaporation, Unsteady evaporation, Convective effects.

INTERNAL AND EXTERNAL FLUID MECHANICS (5 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 **(6 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 **(4 Hours)**

Drop sizing by Malvern and P/DPA, Drop velocity by P/DPA, Mass flux distribution via patternators and P/DPA.

SPRAY APPLICATIONS **(6 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: 42)

References

1. Lefebvre, A.H. "Atomization and Sprays," Hemisphere: New York, USA, 1989
2. Bayvel, L. and Orzechowski Z. "Liquid Atomization," Taylor and Francis: Washington DC, USA, 1993.
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.

METM120	**:**	**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-1^{st} & 2^{nd} order instruments

MEASUREMENT OF FLOW PROPERTIES & FLOW VISUALIZATION (13 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 (6 Hours)

Measurement of pitch angle, measurement of torque by dynamometer, strain gauge and transducer.

DATA PROCESSING AND ANALYSIS: **(17 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: 42)

References

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.

			L	T	P	Credits
METM121	**:**	**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	Modelling 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 **(04 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 **(08 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: 42)

References

1. Kotas T.J., “The Exergy Methods of Thermal Plant Analysis”, Krieger Publ. Corp. USA, 2013.
2. Lakshminarayana B. “Fluid dynamics and heat transfer of turbomachinery” John Wiley, USA, 1995.
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.

METM122	**:**	**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 (8 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 (14 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 (8 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: 42)

References

1. Rao J. S. “Rotor Dynamics”, New Age International Publication, New Delhi, India, 1996
2. Goodwin M. J. “Dynamics of Rotor-Bearing Systems,” Unwin Hyman, Sydney, 1989.
3. Krämer E., “Dynamics of Rotors and Foundations,” Springer-Verlag, New York, 1993,
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.

METM123	**:**	**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 **(6 Hours)**

Elements of solar power plants, solar collectors, solar receivers, solar energy storage, solar ponds, solar turbines

GEOTHERMAL POWER PLANTS **(6 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 **(4 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 **(4 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 YURBOMACHINES **(8 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: 42)

References

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

METM124	:	HYDROGEN ENERGY APPLICATIONS TO PROPULSION AND FUTURE MODES OF TRANSPORT	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	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	Elucidate hydrogen applications to the propulsion

2. Syllabus

INTRODUCTION (8 Hours)

Hydrogen as a source of energy, physical and chemical properties, salient characteristics, relevant issues and concerns

HYDROGEN STORAGE (10 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: 42)

References

1. James L. and Andrew D. “Fuel Cell Systems” John Wiley, New York, USA, 2003.
2. “Fuel Cell Handbook”, EG&G Services, Washington DC, USA, October 2016:
3. Bent Sorensen (Sorensen), “Hydrogen and Fuel Cells: Emerging Technologies and Applications”, Elsevier Academic Press, UK, 2018
4. Kordesch, K and Simader G., “Fuel Cell and Their Applications”, Wiley-Vch, Germany, 1996.
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

METM104	:	SOFTWARE PRACTICE-I (TURBOMACHINES)	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	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	Derive solution of ordinary differential equations (ODEs), and partial differential equations (PDEs)
CO5	Develop code to solve optimization problems
CO6	Analyse equations and develop skills like plotting graphs, and performing data analysis in Microsoft excel

2. 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

3. 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.

METM105	:	LABORATORY PRACTICE- I (TURBOMACHINES)	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	Understand the concept of laminar and turbulent flow measurements
CO2	Perform given practical task independently on flow systems
CO3	Analyse and evaluate the observations and deduce conclusions therein
CO4	Represent results graphically and deduce conclusions therein
CO5	Demonstrate skills to work on practical flow problems independently
CO6	Develop team effort and coordination through group practical performance

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

SEMESTER – II

METM201	:	DESIGN OF THERMAL 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 axial compressors and turbines.
CO3	Determine the off-design behavior of axial turbines and compressors
CO4	Design radial compressor and turbine
CO5	Establish performance characteristics curves of thermal turbomachines.
CO6	Assess & analyze the performance outcomes of thermal turbomachines.

2. Syllabus

DESIGN OF CENTRIFUGAL COMPRESSORS (08 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 (work coefficient, degree of Reaction), Centrifugal compressor — Inlet section, Impeller passages, Effect of impeller blade shape on performance, Impeller channel, Vaneless and vaned diffusers, Effect of Mach number, Design procedure, inducer, flow instability, surging, rotating stall, chocking, characteristic curves, operational range, velocity variation at constant radius in a rotor, Losses.

DESIGN OF AXIAL FLOW COMPRESSORS (12 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, effect of end wall boundary layers, blade profile (subsonic, supercritical, transonic, and supersonic cascades), 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, Effect of carryover velocity on energy distribution, 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.

DESIGN OF REACTION TURBINE FLOW PASSAGES (04 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.

FLOW PASSAGE WITH RADIAL EQUILIBRIUM (04 Hours)

Velocity diagrams, stage efficiencies, spouting velocity, degree of reaction, kinematic parameters, operating characteristics, The free vortex turbine, Turbine with constant specific mass flow, Turbines with constant nozzle angle, comparison of radial equilibrium design - off design performance using radial equilibrium theory, Actuator disc theory, Single parameter analysis, Stream line curvature methods.

(Total Lecture Hours: 42)

References

1. Lee J.E., "Steam & Gas Turbine", McGraw Hill, NY, USA, 1962.
2. Harlock J.H., "Axial Flow Compressors", Butter Worth London, London 1958.
3. Harlock J.H., "Axial Flow Turbines", Butter Worth London, London 1973.
4. Yahya S.M., "Turbo Machine", Tata McGraw Hill, NY, USA, 1992
5. Sawhney G. S., "Thermal and Hydraulic Machines", Prentice Hall India Learning Pvt. Ltd., India, 2011.

METM202	**:**	**DESIGN OF HYDRO 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 hydro turbomachines and apply it to various types of hydro turbomachines
CO2	Design pumps and turbines
CO3	Construct performance characteristics curves of hydro-turbomachines.
CO4	Analyse the performance outcomes of hydro-turbomachines.
CO5	Determine cavitation in hydro-turbomachines
CO6	Apply design concepts to impulse and reaction turbines

2. Syllabus

HYDRAULIC DESIGN OF CENTRIFUGAL PUMPS (08 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 - meridional geometry inlet and exit blade angles, slip factors as per Stodola, Meizel, Karl Pfliderer, Proscura, Coefficient of Reaction, stream surfaces and empirical techniques for flow calculation, first calculation of flow path, blade geometry, mixed flow pumps, elementary pump - design of twisted blade, method of error triangles, design of volute, radial and axial thrust calculations, wear ring design, vaned diffuser and return passage, suction spiral.

HYDRAULIC DESIGN OF AXIAL FLOW PUMPS (08 Hours)

Operating principles and construction, flow characteristics of axial flow pump, design of axial flow pump as per Jowkovski's Lift methods, real fluid flow over blade, Selection of speed - pump casing geometry hub diameter -number of blades and cascade solidity - selection of blade geometry on different flow surfaces - diffuser design, selection of aspect ratio at periphery, radial clearance between impeller and impeller casing, estimation of axial thrust, calculation of hydraulic losses and hydraulic efficiency, calculation of profile losses using boundary layer thickness, cavitation in axial flow pump, characteristic curves of axial flow pump.

HYDRAULIC TURBINE DESIGN (08 Hours)

Classification of Hydraulic Turbines based on the action of water and moving blades, direction of flow of water in runner, disposition of turbine shaft, and specific speed, Type series and diameter series -selection of type and diameter - Reaction turbine runner spaces – meridional velocity field - elementary turbines - Hydraulic design of Francis turbine - Choice of basic parameters - Inlet and Outlet edges of runner blade – blade profiles on flow surfaces

- shape of blade duct-velocity diagrams on different flow surfaces - certain guide lines to finalize the runner design - Guide wheel -Vane geometry and torque on controlling mechanism - Discharge and circulation - spiral - speed ring - draft tube.

HYDRAULIC DESIGN OF AXIAL TURBINE RUNNERS (04 Hours)

Whirl chamber, Characteristics of some aero-foils -meridional flow field - blade geometry on each flow surface - procedure to finalize the runner design.

HYDRAULIC DESIGN OF IMPULSE TURBINE (06 Hours)

Work done and efficiency of a Pelton wheel turbine, heads and efficiencies of Pelton wheel turbine, Different layouts of Pelton Turbines (arrangements of jets, runners and shaft), Guide mechanism, Number of nozzles and their diameter, multi-jets -runner mean diameter - number of buckets - positioning of buckets – bucket geometry and size -- needle regulator – deflector, casing, hydraulic brake, governing of Impulse turbines.

HYDRAULIC DESIGN OF REACTION TURBINE (08 Hours)

Inward and outward flow reaction turbine, velocity diagrams and work done by water on the runner of reaction turbines, Force, Torque and Power calculations, Efficiencies – Head, Volumetric, Hydraulic, Mechanical and Overall, spiral casing, guide vanes – diameter, depth and length, runner designs (thickness and number of runner blades) and advantage of runner pitch variation, main turbine shaft, draft tube theory, different types of draft tubes like straight divergent tube, Moody's spreading tube or hydro-cone, elbow tubes, cavitation and methods of avoiding viz. installation of turbine below tail race level, cavitation free runner, use of special materials, speed selection, runway speed, blade adjustments, governing of Impulse Turbines.

(Total Lecture Hours: 42)

References

1. Kovats A. "Design and Performance at Centrifugal & Axial flow pumps & Compressors", Pergamon, United Kingdom, 1964.
2. Nechleba M., "Hydraulic Turbine", Constable & Co., London,1957.
3. Stapanoff, A.J., "Centrifugal & Axial Flow Pumps", John Wiely, USA, 1962.
4. Lazarkieniz & Troskolanrkis, "Impeller Pumps", Pergamon Press, United Kingdom, 1965.
5. Dixon S. L., "Fluid Mechanics and Thermodynamics of Turbomachinery", Butterworth-Heinemann, UK, 2013

METM230	:	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 (08 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 FLOWS (10 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: 42)

REFERENCES:

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.

METM231	:	LIFE CYCLE ANALYSIS OF TURBOMACHINES	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	Understand the basic concepts and terminology used in engineering economics
CO2	Compare and evaluate alternatives based on present, annual, rate of return, and benefit over cost analyses
CO3	Analyse concepts of cash flows, time value of money in evaluation of investments and projects in real life
CO4	Identify and analyse the impact of depreciation, taxation and other economic factors on feasibility of real life projects.
CO5	Recognize the economic impact of engineering solutions and Conduct sensitivity analysis on key compounding parameters, so as make financially prudent decisions in everyday life.
CO6	Establish environmental impact assessment of power plant

2. Syllabus

COST ESTIMATION METHODS AND ENGINEERING ECONOMICS (10 Hours)

Estimate costs using account analysis, the high-low method, the scattergraph method, and regression analysis, Concept of engineering economics, Break even analysis, P/V ratio, Elementary economics analysis, Material selection for product design.

VALUE ENGINEERING AND CASH FLOW (10 Hours)

Make or buy decision, Time value of money, Single payment compound amount factor, Equal payment series sinking fund factor, Effective interest rate, Method of comparison of alternatives, Present worth method, Future worth method, Annual equivalent method, Rate of return method

REPLACEMENT, MAINTENANCE ANALYSIS AND DEPRECIATION (10 Hours)

Define failure rate, reliability, availability, and mean time to failure (MTTF) to best time inspections and maintenance, Replacement and maintenance analysis, Type of maintenance, Types of replacement problem, Determination of economic life of asset. Capital recovery with return and concept of challenger and defender, Straight line method of depreciation, Declining balance method of depreciation, Sum of the years digits method of depreciation, Sinking fund method of depreciation, Inflation adjusted decision.

SIMULATION BASED COSTING AND ESTIMATION (6 Hours)

Advantages and Disadvantages of simulation, probability and statistics, discrete process generators, continuous process generators, simulation practice, using readiness levels for model inputs, simulation using spreadsheets, building system simulation, sensitivity analysis, issues surrounding turbomachinery systems, management costs, software-intensive systems, cost estimation techniques.

CASE STUDIES ON LIFE CYCLE ANALYSIS **(6 hours)**

Case studies on life cycle analysis of thermal turbomachines, hydro turbomachines and power plant units including environmental impact assessment.

(Total Lecture Hours: 42)

References

1. Selvam P. "Engineering Economics", Prentice Hall of India Ltd, India, 2001.
2. Chan S. P. "Contemporary Engineering Economics", Prentice Hall of India, India, 2002.
3. Donald.G. Newman, Jerome. P. Lavelle, "Engineering Economics and analysis" Engg. Press, Texas, 2002
4. Damodaran S., "Managerial economics", Oxford university press, London, 2006.
5. Smith, G.W., "Engineering Economy", Lowa State Press, Iowa, 1973.

METM232	:	MICRO HYDROTURBINE	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 working principles of hydrokinetic and low head turbines
CO2	Choose a proper turbine type by utilizing different turbine selection charts based on available head and flow.
CO3	Analyse components of micro hydro plants
CO4	Understand hydrodynamics of micro hydro turbines
CO5	Design micro hydro turbines
CO6	Elucidate micro hydro turbine plants and components

2. Syllabus

FUNDAMENTALS OF HYDROKINETIC AND LOW HEAD TURBINES (6 Hours)

Impulse momentum principle, Basic equation of energy transfer in a low head turbines, Impulse and reaction turbines, Torque, power and efficiency calculations using velocity triangle approach, Unit quantities, specific speed and performance characteristics.

SYSTEM FOR MICRO HYDRO TURBINES (12 Hours)

Ocean energy resource — Ocean tidal energy, Ocean wave energy, Ocean thermal energy conversion, Tidal power, Range and currents. Open channel flow — Introduction, Uniform flow, Specific Energy: Critical Depth, The Hydraulic Jump, Gradually Varied Flow. Run off river and energy recovery system. Benefits, Potential in India, Civil works of medium and high head micro hydro schemes, gates for the schemes, turbines and generators.

HYDRO KINETIC TURBINES (12 Hours)

Hydrodynamics for micro hydro turbines — Hydrofoils, Actuator disk, Axial momentum, Blade element theory, Strip theory. Hydrokinetic and low head turbines — Performance parameters of hydrokinetic turbines, Savonius hydrokinetic turbine, Darrieus hydrokinetic turbines, Axial flow hydrokinetic turbines, Vortex turbine, Screw turbine.

MICRO HYDRO TURBINE PLANTS AND COMPONENTS (12 Hours)

Components of micro hydro plant, Pelton and Turgo turbine, Francis, Propeller, Kaplan and special types of turbines, Reverse pump, selection of turbine, Maintenance of components of micro hydro plants and fault diagnosis

(Total Lecture Hours: 42)

References

1. David M. Demon “Hydro Plant Electrical System” HCI Publications, USA, 1999.
2. Masony “Mechanical Design of Hydro Plants – American Society of Mechanical Engineers” Water Power Development, 1996
3. Varshney R. S. “Hydro Power Structures”, Nem Chand & Bros., India, 2001.
4. Ray H., “Micro Hydro Electric Power”, Intermediate Technology Publishers, London, 1983.
5. Harvey A., Brown A., Hettiarachi P., and Allen I. "Micro-hydro design manual.", Intermediate Technology Publishers, London (1993).

METM233	:	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 (2 Hours)

Nature of turbulence, Method of analysis, generation and diffusion of turbulence, Length scales in turbulent flows.

TURBULENT TRANSPORT OF MOMENTUM AND HEAT (10 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 TURBULANCE (6 Hours)

The probability density, Fourier transforms and characteristic functions, joint statistics and statistical independence, Correlation functions and spectra, The central limit theorem.

SPECTRAL DYNAMICS (6 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 (6 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: 42)

References

1. Tennekes, H. and Lumley, J.L. “A first course on turbulence”, MIT Press, Cambridge, 1972.
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.

METM234	:	CASCADE AERODYNAMICS	L	T	P	Credits
			3	0	0	03

Course Outcomes (COs):

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

CO1	Understand 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 (8 hours)
Meridional & cascade planes, Cascade notation & definitions, Equations of motion & efficiency, Cascade force analysis, Brief about Tandem cascade.

LOW SPEED CASCADE TESTING (6 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 (7 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 (8 hours)
Subsonic and transonic wind tunnels, Testing of high speed compressor and turbine cascades, Instrumentation and observation techniques

DESIGN APPLICATION OF CASCADE INFORMATION (8 hours)
The effect of geometric parameters, The effect of aerodynamic parameters, Interactive parameters

DIFFERENT FLOW AND THEIR BEHAVIOR IN CASCADE (5 hours)
Potential flow, compressible flow, viscous flow, stalled and unsteady flow

(Total Lecture Hours: 42)

References

1. William R. Hawthorne "Aerodynamics of turbines and compressors", Princeton university press, New Jersey, 2017
2. Gosteflow J. P. "Cascade Aerodynamics", Pergamon press, UK, 1984
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. Yahya S.M. , "Turbo Machine", Tata McGraw Hill, USA, 1992

METM235	:	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 (6 Hours)

Introduction to condition monitoring, Maintenance approach, Basics of machinery vibration, Conventions and characteristics - amplitude, frequency and phase.

VIBRATION ANALYSIS OF COMPLEX ROTATING SYSTEMS (10 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 (8 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 (6 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: 42)

References

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 Ltd, India, 1996.
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.

METM240	**:**	**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 (4 Hours)

Boundary Layer Flashback, Core Flow Flashback and Combustion Induced Vortex Breakdown

FLAME STRETCH, EDGE FLAMES, AND FLAME STABILIZATION CONCEPTS (6 Hours)

Introductory Concepts, Flame Stretch, Edge Flames, Flame Stabilization in Shear Layers, Flame Stabilization by Stagnation Points

DISTURBANCE PROPAGATION AND GENERATION IN REACTING FLOWS (8 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 (8 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 (4 Hours)

Types and Methods to control combustion instability by active and passive methods.

(Total Lecture Hours: 42)

References

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.

METM241	:	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 (8 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 (10 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: 42)

References

1. Van de Hulst H. C. "Light Scattering by Small Particles", Dover, New York, USA, 2012

2. McCay T. D. and Roux J. A., “Combustion Diagnostics by Nonintrusive Methods,” Progress in Astronautics and Aeronautics Series, Vol. 92, AIAA, Washington, DC, USA, 1984
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.

METM242	:	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 **(4 Hours)**

Thermal convection, linearized problem, stability characteristics, Nonlinear Convection.

CENTRIFUGAL INSTABILITY **(4 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 (4 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: 42)

References

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, 1961.

METM243	**:**	**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 (8 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 (08 Hours)

Development of Borghi Diagram for Premixed Turbulent Flames — Physical Interpretation of Various Regimes in Borghi's Diagram, Wrinkled Flame Regime, Wrinkled Flame with Pockets Regime, Thickened Wrinkled Flames, Thickened Flames with Possible, Extinctions/Thick Flames, Klimov-Williams Criterion, Wrinkled Flames, Measurements in Premixed Turbulent Flames, Eddy-Break-up Model- Spalding's EBU Model, Magnussen and Hjertager's EBU Model, Intermittency, Flame-Turbulence Interaction, Bray-Moss-Libby Model, 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 **(04 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 in a Single Vortex, Flame in a Shear Layer, Jet Flames, Karman Vortex Street/V-Shaped Flame Interaction, Burning Vortex Ring, Head-on Flame/Vortex Interaction, Experimental Setups for Flame/Vortex Interaction Studies, Generation and Dissipation of Vorticity Effects, Non-premixed Flame–Vortex Interaction Combustion Diagram, Flame Instability in Non-premixed Turbulent Flames, 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: 42)

References

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.

METM244	:	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] Systems Relevant to Combustion of Nitramines, Reactivity of Azide Polymer Propellants, Effect of Molecular Structure on Combustion of Polynitrogen Energetic Materials, Molecular Structure Tailoring of Binders in solid propellants, Effects of Microstructure on Explosive Behavior, Advances in Solid Propellant Formulations, Synthesis and Characterization of Dinitramidic Acid and its salts, Hazards Associated with Solid Propellants.

COMBUSTION OF SOLID ENERGETIC MATERIALS (06 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 Nitramind Azide Propellant Combustion.

OPTICAL DIAGNOSTICS OF SOLID-PROPELLANT FLAME STRUCTURES (04 Hours)

Introduction, Experimental techniques, Laser-Supported Deflagration of RDX and HMX at 0.094 megapascal Effect of Pressure on HMX Flame Structure, Self-Deflagration of RDX at 0.1 Megapascal, HMX Self-Deflagration at 0.1 Megapascal, Ignition of HMX and RDX, Comparison Between HMX and RDX, Diffusion Flame Studies via Sandwiches, Counter flow Diffusion Flames, Formulated Propellants: XM39 Self-Deflagration at 0.094 Megapascal (0.92 Atmosphere), Metal Combustion.

THERMAL DECOMPOSITION AND COMBUSTION **(12 Hours)**

GAP/AN/Nitrate Ester Propellants, Experimental Methods, flame structures, Correlation of Thermal Decomposition and Burning-Rate Characteristics, Thermal Decomposition of Potassium Dinitramide at Elevated Pressure. Combustion Mechanism of 3-Azidomethyl-3-Methyloxetane(AMMO) Composite Propellants, Burning Rate Characteristics of Glycidyl Azide Polymer (GAP) Fuels and Propellants, Effects of Carbon Substances on Combustion Properties of Catalyzed RDX-CMDB Propellants, Modelling of RDWGAP Propellant Combustion with Detailed Chemical Kinetics, Energetic-Material Combustion Modelling: A Practical Approach, Burning-Rate Prediction of Double-Base Plateau Propellants, Structure and Stability of Deflagrations in Porous Energetic Materials, Modelling of Cook-Off Reaction Violence of Confined Energetic Materials, Solid Propellant Combustion Response: Quasi-Steady (QSHOD) Theory Development and Validation, Burn-Rate Response Functions, Combustion of Aluminized Solid Propellants, Detailed Studies on the Flame Structure of Aluminum Particle Combustion, Combustion of Aluminum Particles in Solid-Rocket, Measurements of the Physico-Chemical Properties of Liquid Alumina Using Contactless Techniques.

MULTIPHASE COMBUSTION **(10 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: 42)

References

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. Kuo, Kenneth K., ed. "Fundamentals of solid-propellant combustion." American Institute of Aeronautics and Astronautics, USA, 1984.

METM210	**:**	**OPTIMIZATION TECHNIQUES**	**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	Understand the concept of optimization, related terms and formulate mathematical models for practical problems based on the information provided.
CO2	Use linear programming to solve real life linear programming problems
CO3	Solve transportation and transhipment problems, travelling salesman problem and integer programming
CO4	Determine solutions that will be deployed in real world situations after conducting sensitivity and post optimality analysis
CO5	Apply classical methods to solve nonlinear programming problems
CO6	Use evolutionary algorithms to solve complex engineering problems where classical methods are not suitable.

2. Syllabus

INTRODUCTION **(04 Hours)**

Introduction to Optimization, Linear Programming – Formulation, Graphical method, simplex method and special cases

SENSITIVITY AND POST OPTIMALITY ANALYSIS **(08 Hours)**

Sensitivity Analysis and post optimality analysis of linear programming problems – changes in resources and objective function, changes affect feasibility and optimality, duality, dual simplex algorithm, generalize simplex algorithm.

SPECIAL TYPES OF LINEAR PROGRAMMING PROBLMES **(06 Hours)**

Transportation problems, Transshipment problems, Travelling salesman problems, Integer programming

INTRODUCTION TO MATLAB AND SOLVING LINEAR AND NONLINEAR PROBLEMS USING MATLAB **(06 Hours)**

Introduction to MALAB, creating and manipulating vectors and matrix, user defined function, special built-in function to create special vectors and matrices, symbolic math, built-in function to solve linear programming problems

NONLINEAR PROGRAMMING PROBLEMS **(04 Hours)**

Nonlinear Programming problems: Graphical method, convex function and convex region, necessary and sufficient conditions, Lagrangian method, Karush-Kuhn-Tucker (KKT) conditions, solving nonlinear problems using MATLAB.

EVOLUTIONARY ALGORITHMS **(14 Hours)**

Introduction to evolutionary algorithm, introduction to multi-objective optimization, genetic algorithms, differential evolution algorithm, Particle swarm optimization, tabu search, simulated Annealing technique, solving real life engineering problems using MATLAB.

(Total Lecture Hours: 42)

References

1. Hillier, F.S. and Lieberman, G.J. Introduction to operations research: Concepts and Cases, Tata McGraw-Hill Education 8th edition, 2008.

2. Taha, H.A. Operations research: an introduction. Pearson Education India, 10th edition, 2016.

3. Rao, S.S. Engineering optimization: theory and practice. John Wiley & Sons, 3rd edition, 2018.

4. Xin- She Yang, Nature-Inspired Optimization Algorithms. Elsevier,1st edition, 2014.

5. Goldberg, D.E. Genetic algorithms: in search, optimization and machine learning. Pearson Education India, 1st edition, 2008.

METM211	:	FINITE ELEMENT METHODS	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	Able to understand different mathematical Techniques used in FEM analysis
CO2	Understand the concepts of Nodes and Elements
CO3	Formulate and solve fluid and heat transfer problems using FEM.
CO4	Analyse engineering structure with Truss and Beam Elements.
CO5	Use finite element method for transient problems.
CO6	Apply finite element method to vibrating systems

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-DIMENSIONALANALYSIS (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, Development of 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, 1-D Fluid flow and Solid Mechanics problems.

TRUSS AND BEAM ANALYSIS (12hours)

Transformation of coordinates, Truss elements, FEA of truss subjected to different boundary conditions. Reaction and stress calculation. Beam elements, Hermit interpolation function, formulation of stiffness matrix and load vectors and their assembly. Beam examples: Cantilever Beam, Simply supported Beam and Stepped Beam with concentrated, uniformly distributed and linearly varying distributed load.

TWO DIMENSINAL ANALYSIS (09 hours)

Two dimensional steady state heat conduction equation, Triangular elements, development of elemental stiffness matrix and load vector, Solution of 2-D heat conduction problem. Elasticity equations,Plane stress and Plain strain element, LST element, CST element, Rectangular elements, Higher Order element, iso-parametric element, Numerical examples.

DYNAMIC ANALYSIS **(09 hours)**

Need of dynamic analysis, Structural dynamics problem and wave propagation problems, Analysis of axially vibrating bar. Determination of natural frequencies with consistent and lumped mass matrix. Determination of mode shapes. 1-D transient heat conduction in pin fin: derivation of elemental equation in matrix form, assembly of elements, solution using trapezoidal rule.

(Total Lecture Hours: 45)

References

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.

METM212	:	MULTIPHASE FLOW	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 (8 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 (4 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 (8 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 (6 Hours)

Conventional and novel measurement techniques for multiphase systems (Laser Doppler anemometry, Particle Image Velocimetry)

APPLICATIONS OF MULTIPHASE FLOW: **(4 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: 42)

References

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,1998
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.

METM213	:	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	Evaluate the importance of wind energy sector.
CO2	Illustrate the technical focal point for wind power development in India
CO3	Develop the understanding of aerodynamics and performance of wind energy systems.
CO4	Evaluate the design of components of wind energy systems.
CO5	Examine the economics and feasibility of wind energy 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 (08 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 (04 hours)
Engineering Economics Basics, Wind Turbine Cost Analysis, Wind Farm Feasibility Studies, Environmental and Wildlife Impact, Noise Issues

SPECIAL TOPICS (04 hours)
Vertical Axis Turbine, Floating Windmill, Diffuser augmented wind turbines, Airborne wind

turbine, Recent developments in wind energy conversion

(Total Lecture Hours: 42)

References

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
5. Nelson V., "Innovative wind turbines- an Illustrated guide book, CRC press Taylor & Francis, US, 2020

METM203	:	SOFTWARE PRACTICE-II (TURBOMACHINES)	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	Understand an overview of the features available in meshing software, turbo-grid, CFD and AXSTREAM solver
CO2	Solve thermo-fluid and turbomachines problems using a CFD and AXSTREAM solver.
CO3	Solve lid-driven cavity problem
CO4	Derive numerical solutions of various convection-diffusion problems using various schemes
CO5	Design and optimization of power consuming turbomachines; axial and radial compressors, fans and blowers using AXSTREAM and CFD solver
CO6	Design and optimization of power producing turbomachines; axial and radial turbines and propellers using AXSTREAM and CFD solver

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
7. Design and optimization of axial compressor using AXSTREAM
8. Design and optimization of axial turbines using AXSTREAM
9. Design and optimization of radial compressor using AXSTREAM
10. Design and optimization of radial turbines using AXSTREAM

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.

METM204	:	LABORATORY PRACTICE – II (TURBOMACHINES)	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	Describe the working of reacting systems, thermal turbomachines and hydro turbomachines
CO2	Analyze the nozzle performance
CO3	Calculate the performance parameters of thermal turbomachines
CO4	Analyze the performance of thermal turbomachines
CO5	Calculate the performance parameters of hydro turbomachines
CO6	Analyze the performance of hydro turbomachines

2. Laboratory Experiments:

1. Performance analysis of the centrifugal blower for three different vanes
2. Performance analysis of the axial turbines
3. Performance analysis of the centrifugal compressor
4. Performance analysis of high rpm centrifugal blower
5. Performance analysis on a nozzle test rig
6. Performance analysis of Hydraulic ram
7. Performance analysis of Centrifugal pump
8. Performance analysis of Pelton turbine
9. Performance analysis of Francis turbine
10. Performance analysis of Kaplan turbine