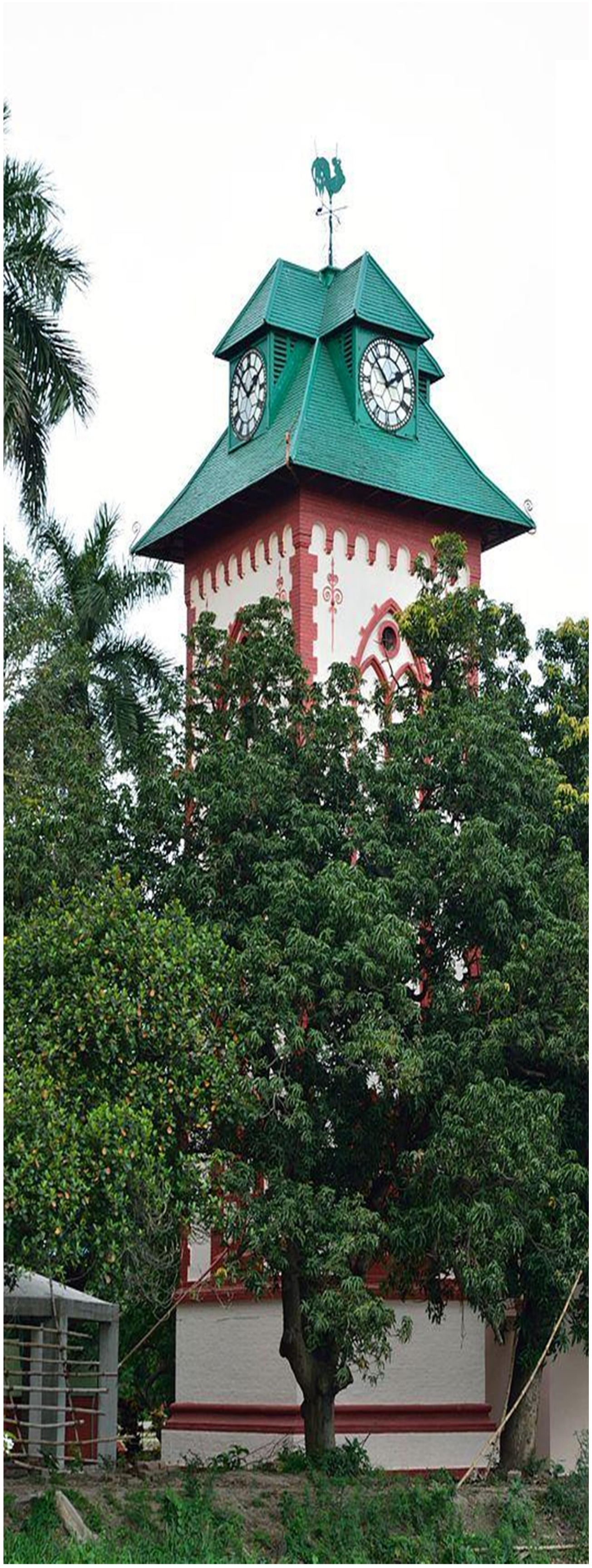

Department of Aerospace Engineering and Applied Mechanics

Postgraduate Programmes

Course Structure and Syllabus

(Effective from 2025-26 admitting batch onwards)

Indian Institute of Engineering Science and Technology (IIEST), Shibpur

Botanic Garden, Howrah

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Course Structure

M.Tech in Aerospace Engineering

COURSE STRUCTURE FOR M. TECH. IN AEROSPACE ENGINEERING

First Semester

Sl. No.	Type	Course Name	Course code	Class Load/Week L	T	P	Credit	Class load/ week	Marks
1	PC	Unsteady Aerodynamics	AE5101N	3	0	0	3	3	100
2	PC	Computational Aerodynamics	AE5102N	3	0	0	3	3	100
3	PC	Aerospace Structural Mechanics	AE5103N	3	0	0	3	3	100
4	PSE	Elements of Aerospace Engineering/ Compressors and Turbines/ Boundary Layer Theory/ Composites for Aerospace Structures/ Convective Heat Transfer/ Continuum Mechanics	AE5121N/ AE5122N/ AE5123N/ AE5124N/ AM5107N/ AM5121N	3	0	0	3	3	100
5	OE			3	0	0	3	3	100
		Theory Sub-total		**15**	**0**	**0**	**15**	**15**	**500**
6	PC	Design of unmanned aerial vehicles	AE5171N	0	0	3	2	3	50
7	PC	Computational Fluid Dynamics Simulations for Aerodynamics	AE5172N	0	0	3	2	3	50
8	PC	Software Aided Simulations in Solid Mechanics	AM5172N	0	0	3	2	3	50
		Practical Sub-total		**0**	**0**	**9**	**6**	**9**	**150**
		First Semester Total		**15**	**0**	**9**	**21**	**24**	**650**

Second Semester

Sl. No.	Type	Course Name	Course code	Class Load/Week L	T	P	Credit	Class load/ week	Marks
1	PC	Methods in Experimental Aerodynamics	AE5201N	3	0	0	3	3	100
2	PC	Structural Dynamics and Aeroelasticity	AE5202N	3	0	0	3	3	100
3	PC	Finite Element Methods in Aerospace Structures	AE5203N	3	0	0	3	3	100
4	PSE	Aerothermodynamics of Propulsion Systems/ Parallel Computation/ Hypersonic Aerothermodynamics/ Turbulence Modeling/ Aircraft Materials and Processes/ Plates and Shells/ Theory of Plasticity/	AE5221N/ AE5222N/ AE5223N/ AE5224N/ AE5225N/ AE5226N/ AM5201N/	3	0	0	3	3	100

		Compressible Flow/ Engineering Fracture Mechanics/ Nonlinear Dynamics and Chaos	AM5217N/ AM5234N/ AM5236N						
5	OE			3	0	0	3	3	100
		Theory Sub-total		**15**	**0**	**0**	**15**	**15**	**500**
6	P	M.Tech. project/Term-paper	AE5291N	0	0	3	2	3	50
7	O	Seminar/Viva Voce	AE5292N	0	0	3	2	3	50
		Practical Sub-total		**0**	**0**	**6**	**4**	**6**	**100**
		Second Semester Total		**15**	**0**	**6**	**19**	**21**	**600**

Third Semester

Sl. No.	**Type**	**Course Name**	**Course code**	**Class Load/Week**			**Credit**	**Class load/ week**	**Marks**
				L	**T**	**P**			
1	**VAC**			3	0	0	3	3	100
2	P	M. Tech. Thesis	AE6191N				12	24	300
3	O	Progress Seminar and Viva-voce	AE6192N				6		100
4	I	Summer internship (6-8 weeks) evaluation	AE6193N				2		50
		Third Semester Total					**23**		**550**

Fourth Semester

Sl. No.	**Type**	**Course Name**	**Course code**	**Class Load/Week**			**Credit**	**Class load/ week**	**Marks**
				L	**T**	**P**			
1	P	M. Tech. final thesis	AE 6291N				22	30	400
2	O	Thesis Seminar and Viva-voce	AE 6292N				8		200
		Fourth Semester Total					**30**		**600**

M. Tech. in Applied Mechanics with Specialization in Hydraulic Engineering

COURSE STRUCTURE FOR M. TECH. IN HYDRAULIC ENGINEERING									
First Semester									
Sl. No.	**Type**	**Course Name**	**Course code**	**Class Load/Week**			**Credit**	**Class load/ week**	**Marks**
				L	**T**	**P**			
1	PC	Open Channel Hydraulics	AM5109N	3	0	0	3	3	100
2	PC	Theory of Hydraulic Model	AM5127N	3	0	0	3	3	100
3	PC	Advanced Mechanics of Fluids	AM5110N	3	0	0	3	3	100
4	PSE	Viscous Fluid Flow/ Methods in Computational Fluid Dynamics/ Theory of liquid-solid interfaces/ Hydraulic Structure/ Turbomachineries/ Hydraulic Machines/ Ground Water Flow	AM5106N/ AM5108N/ AM5134N/ AM5130N/ AM5126N/ AM5131N/ AM5132N	3	0	0	3	3	100
5	OE			3	0	0	3	3	100
		Theory Sub-total		**15**	**0**	**0**	**15**	**15**	**500**
6	PC	Open Channel Flow Lab	AM5179N	0	0	3	2	3	50
7	PC	Fluid Modelling Lab	AM5180N	0	0	3	2	3	50
8	PC	Advanced Fluid Mechanics Lab	AM5181N	0	0	3	2	3	50
		Practical Sub-total		**0**	**0**	**9**	**6**	**9**	**150**
		First Semester Total		**15**	**0**	**9**	**21**	**24**	**650**
Second Semester									
Sl. No.	**Type**	**Course Name**	**Course code**	**Class Load/Week**			**Credit**	**Class load/ week**	**Marks**
				L	**T**	**P**			
1	PC	Advanced Open Channel Hydraulics	AM5218N	3	0	0	3	3	100
2	PC	Theory of Turbulence	AM5216N	3	0	0	3	3	100
3	PC	Advanced Hydraulics	AM5217N	3	0	0	3	3	100
4	PSE	Fluid Power control system/ Flow through Porous Media/ Compressible Flow/ Instrumentation in Fluid Mechanics/ Nonlinear Dynamics and Chaos	AM5219N/ AM5252N/ AM5217N/ AM5246N/ AM5236N	3	0	0	3	3	100
5	OE			3	0	0	3	3	100
		Theory Sub-total		**15**	**0**	**0**	**15**	**15**	**500**
6	P	M.Tech. project/Term-paper	AM5291N	0	0	3	2	3	50
7	O	Seminar/Viva Voce	AM5292N	0	0	3	2	3	50

		Practical Sub-total		**0**	**0**	**6**	**4**	**6**	**100**
		Second Semester Total		**15**	**0**	**6**	**19**	**21**	**600**

Third Semester

Sl. No.	Type	Course Name	Course code	Class Load/Week L	T	P	Credit	Class load/ week	Marks
1	**VAC**			3	0	0	3	3	100
2	P	M. Tech. Thesis	AM6191N				12	24	300
3	O	Progress Seminar and Viva-voce	AM6192N				6		100
4	I	Summer internship (6-8 weeks) evaluation					2		50
		Third Semester Total					**23**		**550**

Fourth Semester

Sl. No.	Type	Course Name	Course code	Class Load/Week L	T	P	Credit	Class load/ week	Marks
1	P	M. Tech. final thesis	AM6291N				22	30	400
2	O	Thesis Seminar and Viva-voce	AM6292N				8		200
		Fourth Semester Total					**30**		**600**

Open Elective Subjects for PG Level

Offered by
Dept. of Aerospace Engineering and Applied Mechanics

For 1st Semester

Launch Vehicle Aerodynamics (AE5161N)
Industrial Aerodynamics (AE5162N)
Mechatronics (AM5161N)
Human Body Mechanics (AM5162N)
Energy System Design (AM5163N)

For 2nd Semester

Basics of Parallel Computation (AE5261N)
Structural Health Monitoring (AE5262N)
Manufacturing and Characterization of Polymer Composites (AE5263N)
Free Surface Flow (AM5263N)
Cyber Physical System (AM5265N)
Elastic Stability (AM5266N)
Introduction to Microfluidics (AM5267N)

M.Tech in Aerospace Engineering

Detailed Syllabus

1st Semester Courses Syllabi

M.Tech in Aerospace Engineering

Course Code	AE5101N	**Course Name**	Unsteady Aerodynamics	**Course Category**	PC	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Aerodynamics and Engineering Applications	**Co-requisite Courses**	Boundary Layer Theory	**Progressive Courses**	Turbulence and Modelling
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	Nil

Course Objectives	This course explores the intricate realm of flow unsteadiness and turbulence dynamics, providing a comprehensive understanding of the underlying principles and phenomena governing complex fluid flows. Through a rigorous exploration of governing equations, turbulence dynamics, and coherent structures, students will gain insights into the diverse sources of flow unsteadiness and their implications across various flow regimes. The course further examines Reynolds number effects, separation bubble dynamics, low-Reynolds number aerodynamics, and fundamentals of aeroacoustics, offering a holistic perspective on the intricate interplay between flow behavior, turbulence, and aerodynamic phenomena. Through theoretical analysis and practical applications, students will develop the analytical skills and critical insights necessary to address challenges in advanced fluid dynamics and aerodynamics research and engineering.

Module	**Syllabus**	**Duration (class-hour)**	**Module Outcome**
1	**Introduction:** Flow unsteadiness and its background. Different sources of unsteadiness. Introduction to Turbulence. Governing Equations.	04	• Identify sources of flow unsteadiness and their significance. • Understand basic governing equations and turbulence introduction.
2	**Turbulence and Coherent Structures:** Flow dynamics and their interrelation. Classification schemes, free shear and wall-bounded flows, Convective and absolute instabilities. Changing paradigms of Turbulence. Visualization and statistical view of Turbulence, Coherent structures and their relevance to free shear flows and wall bounded flows.	10	• Understand turbulence classification and instability types in different flow regimes. • Analyze coherent structures and their role in shear and wall-bounded flows.
3	**Reynolds Number Effects:** Transition and its control, Critical Reynolds number, Bursting period, High-Reynolds number characteristics.	07	• Explain the role of Reynolds number in flow transition and control. • Understand critical Reynolds number and high-

			Reynolds number flow features.
4	**Separation Bubble Unsteadiness and its Control:** Phenomenon of a steady and unsteady separation, Separation control, vortex-induced separation, Three-dimensional separation and critical point theory. Separation bubble dynamics. Shock-induced separation and Low-frequency unsteadiness. Wing and Launch vehicle buffeting. Intake and control surface buzz.	09	• Understand steady and unsteady separation, and control methods. • Analyze separation bubble dynamics and associated aerodynamic instabilities.
5	**Low-Reynolds Number Aerodynamics:** Introduction, Unsteady flow past bluff bodies, Vortex-Induced Vibration (VIV), Low-Reynolds number airfoils, Dynamic Stall and hysteresis effects.	06	• Understand unsteady flow behavior in low-Reynolds number regimes. • Analyze VIV, dynamic stall, and hysteresis in bluff bodies and airfoils.
6	**Fundamentals of Aeroacoustics:** Fundamentals of Acoustics, Flow induced noise, Sources of Sound, Lighthill's theory, Noise control: passive/active control, jet noise.	06	• Understand the fundamentals of flow-induced noise and sound generation. • Apply Lighthill's theory and noise control methods to aerodynamic flows.
	Total	**42**	

Course Outcome	After successfully completing this course, students should be able to: ● Grasp the fundamentals of flow unsteadiness, including turbulence, convective instabilities, and Reynolds number effects. ● Apply fluid dynamics equations to analyze coherent structures and their interactions in unsteady flows. ● Assess separation bubble dynamics and control strategies, focusing on vortex-induced separation and low-frequency unsteadiness.

Learning Resources	1. J.M. Anderson, "Fundamentals of Aerodynamics", Mc.Graw hill, 2011. 2. J. Délery, "Three-dimensional separated flow topology: critical points, separation lines and vortical structures", John Wiley & Sons. 2013. 3. Holger Babinsky, John K. Harvey, "Shock Wave-Boundary-Layer Interactions", Cambridge University Press, 2011 4. Gad-el-Hak, M., Pollard, A., & Bonnet, J. P. "Flow control: fundamentals and practices (Vol. 53)". Springer Science & Business Media, 2003. 5. Gad-el-Hak, M. "Flow control: The future", Journal of aircraft, 2001.

Course Code	AE5102N	Course Name	Computational Aerodynamics	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Basic Fluid Mechanics	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	Computational Fluid Dynamics (CFD) plays a major role in aerodynamic design. These methods are used in every field starting from the design of aircrafts, missiles, turbo machineries, etc. This course has three objectives: • Introduce basics of computational fluid dynamics and its applications • Provide theoretical knowledge and practical knowledge about finite volume method in CFD; • Provide knowledge in basic CFD programming

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**GOVERNING DIFFERENTIAL EQUATIONS:** Basics of computational fluid dynamics – Governing equations of fluid dynamics – Continuity, Momentum and Energy equations – Physical boundary conditions – Mathematical behaviour of PDEs on CFD – Elliptic, Parabolic and Hyperbolic equations – Finite Difference, Finite Volume, Finite Element Methods.	07	• Students will understand the fundamental governing equations of fluid dynamics (continuity, momentum, and energy), the classification of partial differential equations (PDEs), and the role of various numerical methods (Finite Difference, Finite Volume, and Finite Element) in CFD.
2	**DISCRETISATION TECHNIQUES:** Initial and Boundary Conditions – Discretisation techniques using finite difference methods – Taylor's Series - Uniform and non-uniform Grids, Numerical Errors, Grid Independence Test.	05	• Students will be able to apply discretization methods using finite difference techniques for initial and boundary value problems, understand numerical errors, and evaluate grid independence in CFD simulations.
3	**DIFFUSION PROCESSES: FINITE VOLUME METHOD** Steady one-dimensional diffusion, Two- and three-dimensional steady state diffusion problems, Discretisation of unsteady diffusion problems – Explicit, Implicit and Crank Nicholson's schemes, Stability of schemes.	10	• Students will gain the ability to model steady and unsteady diffusion problems using the finite volume method and assess the stability and accuracy of explicit, implicit, and Crank-Nicholson schemes.

4	**CONVECTION - DIFFUSION PROCESSES: FINITE VOLUME METHOD:** One dimensional convection – diffusion problem, Central difference scheme, upwind scheme – Hybrid and power law discretization techniques – different schemes of pressure velocity coupling.	10	• Students will learn to model one-dimensional convection-diffusion problems using central, upwind, hybrid, and power-law schemes, and analyze the behavior of different pressure-velocity coupling methods.
5	**COMPRESSIBLE FLOW AND TURBULENCE: FINITE VOLUME METHOD:** Euler backward/forward time integration - Characteristics and Eigenvalues - Flux vector splitting methods - Godunov method and approximate Riemann solvers. Turbulence models for aerospace applications, mixing length model, Two equation models – High and low Reynolds number models - case studies on aerodynamic applications.	10	• Students will understand compressible flow solvers including flux vector splitting and Riemann solvers, and evaluate turbulence modeling approaches using mixing-length and two-equation models. They will also be able to apply these methods to real-world aerodynamic case studies.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: • Understand the basic equations involved in CFD • Understand the concepts of finite volume method, diffusion and convection methods, turbulence modeling and compressible flow methodologies.

Learning Resources	1. Chung, T.J. “Computational Fluid Dynamics”, Cambridge University, Press, 2002. 2. Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015. 3. Anderson, John David, and J. Wendt. Computational fluid dynamics. Vol. 206. New York: McGraw-Hill, 1995. 4. Patankar, S.V. “Numerical Heat Transfer and Fluid Flow”, Hemisphere Publishing Corporation, 2004. 5. Pradip Niyogi, Chakrabarty, S.K., Laha, M.K. “Introduction to Computational Fluid Dynamics”, Pearson Education, 2005. 6. H. K. Versteeg and Weeratunge Malalasekera. “Introduction to Computational Fluid Dynamics, An: The Finite Volume Method”, Pearson Education, 2007.

Course Code	AE5103N	Course Name	Aerospace Structural Mechanics	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Strength of Materials	Co-requisite Courses	None	Progressive Courses	Advanced Finite Element Methods for Aerospace Structural Design
Course Offering Department		Department of Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	Basic aim of this course is to teach the mechanics of aerospace structural components and gain experience in identifying, formulating, and solving aerospace structural engineering problems.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Flight Vehicle Structures:** Introductions, Structural components and their functions, Materials, Airworthiness, Fail-safe and safe-life approach	3	• Students will learn the basics of flight vehicle structures, their components, materials, and key design approaches ensuring airworthiness and safety.
2	**Elasticity approach to aircraft structural problems:** Tensors, Elasticity problems in three-dimensions and two-dimensions, Equilibrium equations, Development of problem related to aerospace structures, compatibility equations, Stress-strain relationships, Airy stress function, Torsion of prismatic bars, Torsion of circular and elliptical bars, Membrane analogy to torsional problem	11	• Students will able to analyze aerospace structural problems using elasticity theory, focusing on stress-strain behavior, equilibrium, compatibility, and torsion in prismatic bars.
3	**Analysis of Thin Walled Structures:** Bending of thin walled beams, Deflections due to bending, Approximations for thin walled sections, Shear of open and closed tubes, Shear flow in thin walled single cell and multicell tubes, Torsion of closed tubes, Torsion of multicelled tubes	11	• Students will analyze thin-walled aerospace structures under bending and torsion, including shear flow in open, single-cell, and multicell sections using appropriate approximations.
4	**Analysis of Aircraft Components:** Structural idealization, Wing spars and box beams: Tapered wing spar, Open and closed section beams, Beams having variable stringer areas; Fuselages: Shear, Torsion, Cut-outs; Wings: Three-boom shell, Bending, Torsion, Shear, Tapered wings, Cut-outs; Fuselage frames and wing ribs: Principles of stiffener/web construction, Fuselage frames, Wing ribs	11	• Students will understand structural idealization techniques and analyze key aircraft components such as wing spars, box beams, fuselages, and wings under various loads, considering effects of cut-outs, taper, and stiffener/web construction.
5	**Smart Structures:** Smart Materials Technologies and Applications, Piezoelectric elements, Shape	6	• Students will understand smart materials and their applications in adaptive aerospace

	memory alloys, Adaptive aerospace structures - Structural Health Monitoring (SHM)		structures, including piezoelectric, shape memory alloys, and structural health monitoring.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: ● Understand deformation, stress, and strain developed in Aerospace structural components. ● Solve axial deformation, torsion, and bending problems related to Aerospace structures ● Analyze torsion of thin walled single and multi-celled tubes

Learning Resources	1. Aircraft Structures – D. J. Peery and J.J. Azar 2. Aircraft Structures for Engineering Students – T.H.G. Megson 3. Analysis and Design of Flight Structures – E.F. Bruhn 4. Applied Elasticity – C.T. Wang 5. Elasticity in Engineering – E.E. Sechler 6. Smart Material Structures: Modeling, Estimation and Control – H. T. Banks, R. C. Smith and Y. Wang 7. Adaptive Structures: Engineering Applications – D. Wagg, I. Bond, P. Weaver and M. Friswell

Course Code	AE5121N	Course Name	Elements of Aerospace Engineering	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid and Solid Mechanics	Co-requisite Courses	None	Progressive Courses	Aerodynamics, Aerospace Structures, Flight Mechanics, Propulsion
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	This course is designed to introduce some of the core fundamental subjects of aerospace engineering like aerodynamics, structure, propeller propulsion and flight mechanics to the students of non-aerospace background.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Fundamentals of Aerodynamics:** Introduction: Parts of fixed wing aircraft, understanding of Lift, Drag, Pitching moment, Thin Aerofoil Theory, Prandtl's lifting line theory, Blade element momentum theory for propeller	05	• Explain basic aerodynamic forces and apply airfoil and propeller theories.
2	**Basics of Flight Mechanics:** Longitudinal stick fixed static stability, Tail Sizing, elevator effectiveness, Lateral stability: Dihedral effect, low wing, high wing, Aileron sizing, Directional stability and control: Crosswind landing, sideslip and rudder sizing. Introduction to 6-dof rigid body equation of motion applied to aircraft, long period, short period, spiral, Dutch roll and roll modes.	05	• Analyze aircraft stability, control, and dynamic motion modes.
3	**Basics of Aircraft Structures:** Introduction - General types of aircraft construction, Monocoque, semi-monocoque and geodesic Constructions, typical wing and fuselage structure. Function of structural components – Structural idealization – Material selections–Use of Aluminium alloy, titanium, stainless steel and composite materials	09	• Identify aircraft structural types, components, and material choices.
4	**Airframe Loads:** Airworthiness requirements – Load factors – Reserve factor and margin of safety – Basic flight loading conditions – Flight vehicle aerodynamic loads – Flight vehicle inertia loads – Maneuver loads, V-n Diagram	08	• Evaluate airframe loads using load factors and V-n diagrams.
5	**Aircraft Instruments** Air data systems, Airspeed indicator, Altimeter, angle of attack indicators, Rate of	05	• Interpret key flight instruments and their operating principles.

	climb, ILS, Altimeter.		
6	**Airplane Performance** Equations of Motion , Thrust Required for Level, Unaccelerated Flight , Thrust Available and Maximum Velocity , Power Required for Level, Unaccelerated Flight , Power Available and Maximum Velocity, Altitude Effects on Power Required and Available , Rate of Climb , Gliding Flight , Absolute and Service Ceilings , Time to Climb , Range and Endurance-Propeller-Driven Airplane (Physical Considerations, Quantitative Formulation, Breguet Formulas), Range and Endurance-Jet , Relations between C_{D0} and C_{Di}, Take-off Performance , Landing Performance , Turning Flight.	10	• Compute aircraft performance metrics using motion and power equations.
	Total	**42**	

Course Outcome	After successfully completing the course, students would be able to get the necessary understanding of the functioning of various parts of the aircraft, Why the aircraft is naturally stable and its characterization, the aerodynamic modeling of the wing and propeller performance. basics of aircraft structure, building materials, performance estimation etc.

Learning Resources	1. E L Houghton and N B Carpenter, Aerodynamics for Engineering Students, Edward Arnold 2. J D Anderson, Jr., Fundamentals of Aerodynamics, McGraw-Hill International 3. Aircraft Structures for Engineering Students – T.H.G. Megson 4. J Katz and A E Plotkin, Low Speed Aerodynamics, Cambridge University Press J D Anderson, Introduction to Flight, McGraw-Hill Education

Course Code	AE5122N	Course Name	Compressors and Turbines	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Thermodynamics and Fluid Dynamics	**Co-requisite Courses**	Turbomachinery	**Progressive Courses**	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	Compressors and Turbine Design Handbook

Course Objectives	The focused objective of the course is to discuss the working details of different aircraft engines and their components. The major focus will be on the working of compressors and turbines. Working cycle, thermodynamics, aero-thermodynamics, and efficiencies of different types of compressors and turbines used in aircraft engines will be covered under this subject. Following aircraft/rocket engines will be covered in this course, a) turbojet, b) turbofan, c) turboshaft, d) turboprop, and e) rocket engines.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction to aircrafts compressor and turbines:** Introduction to aircrafts, Aircraft working cycle, Classification of aircrafts, Thrust and efficiencies, Turbine and compressor as turbomachines, Classification of turbomachines, Various components of aircraft engines (Inlet, diffuser, compressor, combustion chamber, turbine, afterburner, and nozzle), Working details of turbojet, turboprop, turbofan, and turboshaft.	10	• Module will familiarize students with different components of aircraft engines. Afterwards, brief introduction to various kind of turbomachines will be introduced with thermodynamical analysis.
2	**Energy exchange in turbomachines:** Euler's turbine equation, Alternate form of Euler's turbine equation, Components of energy transfer, Impulse and reaction turbomachines, velocity triangles, Degree of reaction (DOR), utilization factor (UF), Relation between degree of reaction and Utilization factor, Velocity triangles for different values of degree of reactions.	10	• Students will be able to understand the principles of energy transfer by using velocity triangles. Module will also help to evaluate the impact of losses, blade design parameters, and to optimize turbomachinery systems.
3	**Axial flow Compressors and turbines:** Description of operation, Velocity triangles, Derivation of DOR and UF, Various efficiencies, Expression for pressure ratio developed in a stage, work done and reheat factor. **Centrifugal Compressors and turbines**: Description of operation, Velocity triangles slip factor, efficiencies, power input factor, Stage work, Pressure developed, Reheat Factor.	10	• Module will help to understand the working principles of gas turbines and compressors. Students can apply thermodynamic and fluid dynamic principles for a**nalyzing and compare different cycles for des**ign of simple gas turbine or compressor systems

4	**Aircraft engines noise and control:** Introduction, Scale and ratings for noise, compressor and fan noise, turbine noise, acoustic treatment.	6	• Module will help to understand the sources and mechanisms of noise generation, to analyze the acoustic behavior and propagation. Students will be able to examine and compare noise reduction techniques.
5	**Introduction to rocket engines:** Introduction to rockets, Classification of rockets, Solid rockets and types, liquid rockets and types, hybrid rockets and types, cryogenic rockets.	6	• Thermodynamics and fluid mechanics governing rocket engine. Module will help to understand the usage of turbomachines in rocket engines.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: ● Understand the working of aircraft engines. ● Aerodynamics and thermodynamics of compressors and turbines. ● Understand the aero-thermodynamics of air flow and movement of combustion gases inside the aircraft engines.

Learning Resources	1. S.M. Yahya, Turbines, Compressors and Fans, Tata Mcgraw Hill. 2. R.K.Turton, Principles of Turbomachinery, E & F N Spon Publishers, London & New York. 3. G. Oates, Aerothermodynamics of aircraft engine components, AIAA Education series. 4. A. Sayed, Fundamentals of aircraft and rocket propulsion, Springer publications. 5. K. Ramamurthy, Rocket propulsion, Trinity publications.

Course Code	AM5123N	Course Name	Boundary Layer Theory	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Viscous flows, Ordinary differential equations, C/C++	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	This subject is intended to cover the fundamentals of fluid mechanics from an advanced point of view, with emphasis on the mathematical treatment of viscosity effects in laminar flows of a Newtonian fluid. We begin with the conservation equations in the cylindrical coordinate system. Attention is given to the boundary layer equations for two-dimensional steady flow, exact and approximate methods of the solution of two-dimensional steady state incompressible boundary layer equations. We also provide an introduction to the compressible laminar boundary layers and numerical study of compressible flows using density based CFD techniques.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	Introduction, Vector & Tensor	3	• Understand vector and tensor basics for describing aerodynamic flow fields.
2	Navier-Stokes Equations & Exact Solutions, Vorticity Dynamics	6	• Interpret incompressible Navier-Stokes equations and analyze vorticity in fluid flows.
3	Laminar Boundary Layer, Blasius solution, Falkner-Skan solution momentum integral equations	8	• Apply classical solutions and integral methods to evaluate laminar boundary layers.
4	Instability and Transition to Turbulence Equations for Turbulent Flows.	6	• Understand mechanisms of transition and model governing equations for turbulence.
5	Turbulent Boundary Layer	4	• Analyze turbulent boundary layer behavior using empirical and theoretical models.
6	Basics of Boundary Layer Separation and Control Advanced Topics on Boundary Layers	5	• Understand flow separation and explore basic control techniques in incompressible flows.
7	Compressible laminar boundary layers and numerical study of compressible flows using density based CFD techniques	5	• Understand flow separation and explore basic control techniques in compressible flows.

8	Asymptotic Analysis Methods	5	• Understand the Asymptotic Analysis
	Total	**42**	

Course Outcome	After successfully completing this course, students will be able to: • Develop the capability of transforming the physics of viscous fluid flow problems into its equivalent mathematical model. • Attain of the capability of solving the viscous fluid flow problems analytically. • Acquire knowledge of boundary layer theory.

Learning Resources	1. F.M.White, Viscous Fluid Flow, McGraw-Hill international editions. 2011. 2. H.Schlichting, Boundary Layer Theory, McGraw-Hill Series in Mechanical Engineering, 1979 3. An Introduction to Fluid Dynamics – G. K. Batchelor – Cambridge University Press, 2000. 4. T. C. Papanastasiou, G. C. Georgiou, A. N. Alexandrou, Viscous Fluid Flow, CRC Press, 2000

Course Code	AE5124N	Course Name	Composites for Aerospace Structures	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Strength of Materials	Co-requisite Courses	None	Progressive Courses	Micromechanics of Composite Materials
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	The course provides thorough knowledge on micromechanics, Mechanics of architecture materials, computational homogenization, laminate theory and the analysis of composite structural components.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introductions:** Composite materials in aerospace structures, metal matrix, ceramic matrix and carbon-carbon composites; polymer matrix composites, manufacturing techniques of fiber composite by different methods	3	By the end of this module, students will be able to: • Understand the role and significance of composite materials in aerospace structures. • Gain knowledge of various fiber composite manufacturing techniques (e.g., hand lay-up, filament winding, pultrusion, RTM).
2	**Micro-mechanics of lamina:** Prediction of elastic properties using strength of materials approach, elasticity approach, Halpin-Tsai model, strength predictions and failure modes, prediction of thermal properties; discontinuous fiber composites, load transfer, prediction of elastic properties, homogenization, averaging schemes, Eshelby's approach, Self-consistent model, Mori Tanaka method, introduction to computational homogenization	8	By the end of this module, students will be able to: • Predict the elastic properties of a single lamina. • Understand mechanical behaviour of discontinuous fiber composites and load transfer mechanisms.
3	**Macro-mechanics of lamina:** Three-dimensional (3-D) material anisotropy, transformation of elastic constants and compliance: 2-D and 3-D cases, unidirectional (UD) and bidirectional (BD) lamina, stress-strain relationships, failure theories (maximum stress, strain, Tsai-Hill and Tsai-Wu, Hashin-Rotem)	5	By the end of this module, students will be able to: • Transform stiffness and compliance matrices under coordinate transformation. • Develop stress-strain relationships for UD and BD lamina.
4	**Macro-mechanics of laminate:** Analysis of laminate: basic assumptions, strain-displacement relationships, symmetric laminates, balanced laminates, classical	9	By the end of this module, students will be able to: • Apply Classical Laminate Theory (CLT) to analyze

	laminate theory (CLT), failure analysis of laminates using CLT: first ply failure, progressive failure analysis, hygro-thermal stresses in laminates		multilayered laminates. • Identify laminate types: symmetric, balanced, cross-ply, angle-ply.
5	**Analysis of aircraft composite structures:** Overview of composite airframe, governing equations of composite plate, buckling of composite plates under axial, shear and combined loads, design and analysis of composite beams, laminated composite structures, thin-walled composite beams under axial load, bending, shear, torsion for closed and open sections, skin-stiffened structure, membrane and bending stiffnesses, failure modes of a stiffened panel, bending, buckling, wrinkling, crimping of sandwich structure	14	By the end of this module, students will be able to: • Understand the design philosophy and configuration of composite aircraft structures. • Design and analyze composite beams and thin-walled structures under axial, bending, shear, and torsional loads.
6	**Experimental methods:** characterization of constituent materials and different test methods for determining elastic constants and strength	3	By the end of this module, students will be able to: • Characterize constituent materials (fiber and matrix) of composites. • Understand and apply experimental methods for determining elastic constants
	Total	**42**	

Course Outcome	After successfully completing this course, students will be able to: ● Select the appropriate composite material or structure to meet design requirements for Aerospace Structures ● Understand the different failure mechanisms of composite structures ● Assess the advantages and limitations of homogenization techniques

Learning Resources	1. Analysis and Performance of Fiber Composites, B. D. Agarwal, L. J. Broutman, K. Chandrashekhara, Wiley (2015) 2. Engineering Mechanics of Composite Materials, I. M. Daniel & O. Ishai, Oxford University Press (1994) 3. Mechanics of Composite Materials, A.K. Kaw, Taylor & Francis, 2nd edition (2006) 4. Mechanics of Composite materials with MATLAB, G.Z. Voyiadjis, P.I. Kattan, Springer (2005) 5. Design and analysis of composite structures with applications to aerospace structures, C. Kassapoglou, John Wiley & Sons, Ltd. (2010) 6. Finite Element Analysis of Composite Materials Using Abaqus, Ever J. Barbero, CRC Press (2013)

Course Code	AM5107N	Course Name	Convective Heat Transfer	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Mathematics (ODE and PDE)	**Co-requisite Courses**	Nil	**Progressive Courses**	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	Nil

Course Objectives	This is one of the departmental elective subjects of the specialization of Aerospace Engineering - intended to cover the fundamentals of Convection heat transfer from an advanced point of view, with emphasis on the analytical (mathematical) treatment of laminar flows in both internal and external flow configurations. We begin with the conservation equations for energy and its dimensionless form. Specific attention is given to the theory of thermal boundary layer, fully developed and developing internal flows, exact and approximate methods of the solution for steady-state, incompressible flows. We also delineate the basics of turbulent convection and natural convection in brief.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction:** Different modes of heat transfer, Energy equation - derivation and dimensionless form, Dimensionless parameters in heat transfer	07	• Formulate the governing transport equations, • Identify important dimensionless numbers and understand their physical significance
2	**Forced convection in internal flow:** Thermally fully developed flow through circular ducts and parallel plate channels, uniform temperature and uniform heat flux boundary conditions; Thermally developing flow; Heat transfer with viscous dissipation	10	• Formulate energy balance for internal flow, • Obtain analytical solutions (Nusselt No.) for parallel-plate channel and circular tube with constant wall temperature and uniform wall heat flux BC, • Analyse a channel flow problem with viscous dissipation
3	**Forced convection in external flow:** Equations for hydrodynamic boundary layer and thermal boundary layer; Reynolds analogy; Scale analysis; Similarity solutions for thermal boundary layer; Integral method; heat transfer correlations	10	• Formulate integral boundary layer equations for momentum and energy, and evaluate Nusselt No. for the limiting cases of high and low Prandtl numbers (Pr) • Obtain exact solutions for three cases ($Pr = 1$, $Pr \ll 1$, and $Pr \gg 1$)

			• Apply superposition principle for complex problems with arbitrary wall temperature
4	**Turbulent forced convection and applications:** Time-averaged energy equation for turbulent boundary layer, thermal eddy diffusivity; Convection correlations for internal and external flows	07	• Understand the effects of turbulent flow on heat convection, • Calculate convective heat transfer rate for engineering problems
5	**Free convection:** Laminar natural convection along a vertical plate, exact solutions for constant wall temperature and constant wall heat flux; Integral (approximate) solutions	08	• Identify dimensionless numbers relevant for natural convection and understand their physical significance • Perform boundary layer calculations for free convection
	Total	**42**	

Course Outcome	After successfully completing this course, students will: • develop an understanding of the fundamentals of convective heat transfer – both physics and appropriate mathematical models. • develop the ability of solving various engineering problems involving thermal convection. • improve their overall knowledge of transport phenomena and analytical ability.

Learning Resources	1. Convective Heat and Mass Transfer by W M Kays& M E Crawford, McGraw-Hill 2. Fundamentals of Heat and Mass Transfer by Incropera, Dewitt, Bergman &Lavine, John Wiley & Sons, Inc. 3. Convection Heat Transfer by Adrian Bejan, Wiley-India.

Course Code	AM5121N	Course Name	Continuum Mechanics	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Engineering Mechanics, Mechanics of Materials, Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Continuum Damage Mechanics
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	● Provide a general framework unifying the seemingly diverse fields of Solid Mechanics and Fluid Mechanics ● Obtain the laws governing the behavior of continuum in a coordinate frame free manner.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Mathematical Preliminaries:** Introduction, Vector space, Second Order Tensors, Higher Order Tensors, Symmetric Tensors, Skew-Symmetric Tensors, Orthogonal Tensors, Tensor Calculus: Differentiation of Tensors, Directional Derivatives, Gradient, Divergence and Curl, Integral Theorems.	15	• Students will understand the basics of Tensor Algebra and Tensor Calculus
2	**Kinematics:** Lagrangian and Eulerian Descriptions, Length, Area and Volume Elements in the Deformed Configuration, Velocity and Acceleration, Rate of Deformation, Examples of Simple Motions,	8	• Students will be able to analyze the kinematics of deformable bodies using Lagrangian and Eulerian descriptions, evaluate deformation measures and strain rate
3	**Balance Laws:** The First Transport Theorem, Conservation of Mass, The Second Transport Theorem, Balance of Linear Momentum, Balance of Angular Momentum, Properties of the Cauchy Stress Tensor, The Equations of Motion in the Reference Configuration, Energy Equation.	9	• Students will be able to apply the fundamental balance laws—including conservation of mass, linear and angular momentum, and energy and write the governing equations of a continua both in spatial and reference configurations.
4	**Constitutive Relations:** Frame of Reference, Transformation of Kinematical Quantities, Principle of Frame-Indifference, Principle of Material Frame-Indifference, Material Symmetry, Classification of Materials, Linear Elasticity, Thermo-mechanics of Fluid.	10	• Students will be able to formulate constitutive relations based on principles of material frame-indifference and material symmetry

	Total	**42**	

Course Outcome	After successfully completing this course, students will: ● Understand the basic foundation of mechanics ● Get exposure to finite deformation regime in Solid and Fluid Mechanics.

Learning Resources	1. C. S. Jog, Continuum Mechanics: Foundations and Applications of Mechanics, Volume I, Third edition, 2015, Cambridge University Press. 2. L.E. Malvern, Introduction to the mechanics of continuous medium, 1969, Prentice-Hall Inc. 3. R.C. Batra, Elements of Continuum Mechanics, 2005, AIAA Education Series

Course Code	AE5171N	Course Name	Design of unmanned aerial vehicles	Course Category	PC	L	T	P
						0	0	3

Pre-requisite Courses	Aerodynamics, Flight mechanics Matlab, MS Excel, Linux terminal, C++	Co-requisite Courses	Basic Electronics, Control Systems	Progressive Courses	Avionics and Navigation
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/ Standards	See the Learning Resources

Course Objectives	Drones/UAVs are becoming popular in several applications like delivery of goods, transport, agriculture etc. This course is designed to introduce basic design principles considering conceptual design of fixed wing UAVs and extending up to preliminary level and autonomous navigation.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction:** Phases of aircraft design, Conceptual design, Initial Sizing, Configuration, Aircraft Layout Choices, Electric propulsion systems, various components of a UAV.	3	• Understand aircraft design phases and identify UAV components.
2	**Wing design and performance estimation:** Airfoil characteristics, Analysis of sample airfoil data. Selection of airfoil for specific requirements, geometric and aerodynamic twist, planform, Sweep and taper.	11	• Design wings using airfoil data, twist, sweep, and planform features.
3	Example of design of a flying wing, Sailplane, V-Tail aircraft. Drag estimation of complete aircraft. Sizing of tail and control surfaces, Propeller characteristics and selection	11	• Estimate drag, size control surfaces, and select propellers.
4	**Flight controller setup:** Generic Autopilot hardware with onboard sensors, airspeed sensor, GPS, telemetry, Introduction to open source autopilots systems: Ardupilot/PX4, Setting up toolchain, Git commands, building firmware and setting up for a particular type of aircraft,	12	• Set up autopilot systems and configure firmware for UAVs.
5	Ground control station, Flight modes, log analysis and tuning	5	• Analyze flight logs, configure control modes, and tune performance.
	Total	**42**	

Course Outcome	Students will apply their theoretical understanding of the subjects to design a fixed wing aircraft. They will be assigned a target for example a VTOL, fixed wing UAV to carry out a certain mission. They will learn to use and design and optimize tools using MATLAB, EXCEL, CAD modeling, and compile autopilot firmware.

Learning Resources	1. Snorri Gudmundsson, - General Aviation Aircraft Design. Applied Methods and Procedures 2. Raymer, D. P., Aircraft Design - A Conceptual Approach, AIAA Educational Series, 4th Ed., 2006. 3. Brandt, S. A., Stiles, R. J., Bertin, J. J., Whitford, R., Introduction to Aeronautics: A Design Perspective, AIAA Educational Series, 2nd ed., 2004 4. Fred Thomas-Fundamentals of Sailplane Design-College Park Press (1999). 5. Andrew J. Keane, AndrásSóbester, James P. Scanlan-Small Unmanned Fixed wing Aircraft Design: A Practical Approach 6. NACA reports/datasheets shall be provided 7. Ardupilot/ PX4 documentation

Course Code	AE5172N	Course Name	Computational Fluid Dynamics Simulations for Aerodynamics	Course Category	PC	L	T	P
						0	0	3

Pre-requisite Courses	Fluid Dynamics Basic Programming	Co-requisite Courses	Nil	Progressive Courses	Parallel Computation
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	The objective of this course is to provide a comprehensive foundation in programming and algorithm development, specifically tailored to engineering applications in numerical methods and fluid dynamics. Students will gain hands-on experience in solving ordinary and partial differential equations, developing algorithms for computational implementation, and applying these methods to simulate real-world aerodynamic problems using computational fluid dynamics (CFD) tools. The course emphasizes both theoretical understanding and practical skills, including mesh generation, solver integration, and aerodynamic coefficient evaluation for different flow regimes.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	Introduction to basic programming and practice	03	• Understand the basics of programming languages and develop logic-building skills.
2	Programming for numerical methods to solve ordinary differential equations	03	• Apply numerical methods to solve ODEs using programming techniques.
3	Programming for numerical methods to solve partial differential equations	03	• Develop and implement numerical algorithms to solve PDEs.
4	Implementation of matrix solvers for linear systems	03	• Implement and test numerical solvers (e.g., Gauss elimination, LU decomposition) for linear systems.
5	Numerical solution of the heat equation	03	• Analyze and solve transient and steady-state heat conduction problems numerically.
6	Simulation of wave propagation using numerical techniques	03	• Simulate and interpret wave motion in 1D domain using numerical schemes.
7	Mesh generation for aerodynamic bodies	03	• Create structured/unstructured

			meshes suitable for aerodynamic simulations.
8	Simulation of external flows under different Reynolds numbers	03	• Investigate flow regimes and their numerical behavior at varying Reynolds numbers.
9	Calculation and analysis of aerodynamic coefficients	03	• Compute and analyze lift, drag, and moment coefficients from CFD simulations.
10	Validation and post-processing of CFD results	03	• Validate simulation results with benchmarks and interpret post-processed flow data.
Viva voce		03	
	Total	**33**	

Course Outcome	• Develop and implement basic programming algorithms for solving engineering problems. • Apply numerical methods to solve ODEs and PDEs relevant to physical systems. • Generate and manipulate computational grids for solving heat and wave equations. • Use commercial or open-source CFD software to simulate external aerodynamic flows. • Analyze flow characteristics and compute aerodynamic coefficients for various flow regimes.

Learning Resources	1. Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015. 2. Anderson, John David, and J. Wendt. Computational fluid dynamics. Vol. 206. New York: McGraw-Hill, 1995.

Course Code	AM5172N	Course Name	Software-Aided Simulation in Solid Mechanics	Course Category	PC	L	T	P
						0	0	3

Pre-requisite Courses	Strength of Materials	Co-requisite Courses	None	Progressive Courses	Research Project
Course Offering Department		Department of Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	To develop students' practical skills using simulation software for analyzing solid mechanics problems, focusing on modeling, finite element analysis, and interpretation of results for real-world engineering applications.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Overview of Finite Element Analysis:** Basic concepts, Discretization, Interpolation or shape function, Basic element shapes, Approximation and exact solutions, Basic steps in finite element analysis	03	Students will gain foundational knowledge of the finite element method.
2	**Introduction to ANSYS Workbench and APDL:** Geometry creation, Meshing, Materials, Loads and boundary conditions, Solution, General post-processing	09	Students will learn about the basics of Ansys Workbench and APDL.
3	**Classical problems using ANSYS Workbench and APDL:** Static structural analysis (Linear and Nonlinear), Contact problems, Modal analysis, Buckling analysis, etc.	30	Students will be able to model, analyze, and interpret results of structural engineering problems using ANSYS Workbench and APDL
	Viva voce		
	Total	**42**	

Course Outcome	● Apply simulation software to model and analyze solid mechanics problems. ● Perform finite element analysis (FEA) for structural and mechanical components. ● Interpret simulation results to evaluate stress, strain, and deformation. ● Validate simulation outcomes with theoretical and experimental data. ● Solve real-world engineering problems using computational methods.

Learning Resources	1. A First Course in the Finite Element Method, Daryl L. Logan 2. ANSYS documentation

2nd Semester Courses Syllabi

M.Tech in Aerospace Engineering

Course Code	AE5201N	Course Name	Methods in Experimental Aerodynamics	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Basic Electronics, and Engineering Mechanics.	Co-requisite Courses	Advanced Mathematics, Basic Electronics	Progressive Courses	Instrumentation Measurement and Experiments in Fluids
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	The aim of the course is to introduce various instrumentations, principles of operation and data acquisition of measuring various physical quantities in the aerospace and fluid mechanics domain. The course will cover theoretical background as of now but may be integrated with laboratory class in future.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction:** Essential requirements of a measuring system.	01	• Understand essential components and requirements of measurement systems.
2	**Wind tunnels:** Low speed wind tunnels: Open, closed type, functioning of various parts of the tunnel, calculation of various losses in low speed tunnels, Design methodology of low speed wind tunnel, Instrumentation and calibration, Turbulence characteristics. Introduction to supersonic and hypersonic wind tunnels.	06	• Explain types, design, losses, and turbulence characteristics of wind tunnels.
3	**Measuring instruments in aerodynamics:** Intrusive and non-intrusive measurements, Turbulence measurements using pressure sphere, yaw sphere, and hot wire anemometry. Measurement of velocity using pitot static tube, Laser Doppler anemometer. Measurement of mass flow rate, Coriolis mass flow meter. Discharge measurements, Vortex flow meter, ultrasonic flow meter, electromagnetic flow meter. Measurement of pressure, Types of pressure measuring sensors, pressure scanner.	12	• Identify and use various instruments for pressure, velocity, and flow measurements.
4	**Flow visualization techniques:** Quantitative and qualitative flow measurements, Density gradient based flow measurements (Schlieren, Shadowgraph), Methods of flow visualization. Stroboscope.	05	• Apply qualitative and quantitative flow visualization methods.

5	**Data acquisition systems:** Introduction to DAQ, ADC, communication protocols using I2C, UART, Multiplexing, Processing and uncertainty analysis	06	• Understand DAQ systems, ADC, communication protocols, and uncertainty analysis.
6	**Force Measurements:** Working principle of Load cell, strain gauge, wind tunnel balance, external balance, sting balance, measurement of wall stress	07	• Use load cells, strain gauges, and balances to measure aerodynamic forces.
7	**Particle image velocimetry:** Working principle of PIV, Experimental setup of PIV, auto-correlation and cross-correlation techniques.	05	• Understand and apply PIV techniques to capture velocity fields.
	Total	**42**	

Course Outcome	After successful completion of this course students will be able to identify the appropriate measuring instruments, setup experimental setup. Learn about windtunnel and quantify its quality and turbulence characteristics, flow visualization and quantitatively obtain velocity fields using PIV, load cells etc. Learn about DAQ systems and communication protocols, ADC and multiplexing. With proper understanding, the student can even design and build their own DAQ using open source hardware and software.

Learning Resources	1. Fluid Mechanics Measurement, by Richard J. Goldstein Springer. 1983 2. Experimental Methods for Engineers by J.P. Holman McGraw-Hill 2008 3. Measurement in Fluid Mechanics by Stavros Tavoularis. Cambridge 2005 4. Particle Image Velocimetry: A Practical Guide by M. Raffel, C. Willert & J. Kompenhans. Springer, 1998. 5. The Laser Doppler Technique, by L. E. Drain, John Wiley & Sons 1980. 6. Hot-wire anemometry, by Perry A. E. Oxford University Press, 1982. 7. Particle Image Velocimetry, by Ronald J. Adrian and Jerry Westerweel Cambridge Aerospace Series, 2010.

Course Code	AM5202N	Course Name	Structural Dynamics and Aeroelasticity	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Theory of Vibration, Solid Mechanics	**Co-requisite Courses**	None	**Progressive Courses**	Computational Aeroelasticity, Fluid-Structure Interaction
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	1. To study the vibration and dynamic responses of basic aerospace structural components idealized as one-dimensional continua (e.g., beams and rods). 2. To develop the ability to model and analyze the interaction between structural deformations and aerodynamic forces. 3. To understand and perform simplified analysis of aeroelastic phenomena such as Divergence, Aileron Reversal and Flutter

Module	Syllabus	Duration (class-hour)	Module Outcome
	Structural Dynamics		
1	**Introduction:** Review of Mechanical Vibration, Elements of aerospace structures	2	• Students will be able to review the fundamentals of mechanical vibration and aerospace structures
2	**Introduction to Variational Methods in Mechanics:** Calculus of Variation, Functional, Extremization of a Functional, Variational Operator, Fundamental Lemma, Euler-Lagrange Equation, Boundary Conditions, Principle of Minimum Potential Energy, Hamilton's Principle, Derivation of Lagrange's Equation.	10	• Students will be able obtain governing equations of motions of systems using energy based approach
3	**Structural Dynamics of one-dimensional systems:** Derivation of the governing PDE, Solution of homogeneous equations, Sturm-Liouville problem, Properties of Eigenvalues and Eigenfunctions, Orthogonality of Eigenfunctions Natural frequencies and mode shapes of one-dimensional continuous systems subjected to different boundary conditions, Rigid body modes, Forced Vibration, Approximate methods, Relevant example problems.	10	• Students will be familiar with modal representation of bars and beams and be able to solve dynamic problems involving aerospace structural elements idealized as these elements

	Aeroelasticity		
4	**Introduction**: Historical Perspective	1	• Students will be able to describe the historical development of aeroelasticity
5	**Static Aeroelasticity:** Torsional divergence of spring restrained lifting surfaces, Torsional divergence of uniform cantilever wing, Control Effectiveness and Reversal, Airload Redistribution, Effects of wing sweep	9	• Students will be able to formulate and solve static aeroelasticity problems such as wing divergence and aileron reversal.
6	**Dynamic and Unsteady Aeroelasticity** Torsional and Bending-Torsion Flutter models; Solution of Flutter Determinant, Aerodynamic damping; Bending-Torsion Flutter of Prismatic Wing using Strip Theory based Aerodynamics; Methods of Flutter Analysis, Flutter Analysis by Approximate Analytical Techniques, Theodorsen's Function, Wagner's Function, Finite State Models, Flutter Testing and models	10	• Students will be able to use quasi-steady and unsteady aerodynamic theories and solve typical problems on aeroelastic flutter
	Total	**42**	

Course Outcome	After successful completion, students will be ● able to formulate basic vibration problems involving aerospace structural elements idealized as beams and bars ● familiar with modal representation of beams in bending and torsion and solve related problems ● formulate and solve static aeroelasticity problems such as wing divergence and aileron reversal problems. ● use simplified quasi-steady and unsteady aerodynamic theories and solve typical problems on binary flutter ● develop a qualitative understanding of the role of aeroelastic phenomena in aircraft design and performance

Learning Resources	1. Introduction to Structural Dynamics and Aeroelasticity – D. H. Hodges and G. A. Pierce, Cambridge University Press 2. Elements of Vibration Analysis – L. Meirovitch, McGraw-Hill 3. Energy and Finite Element Methods in Structural Mechanics – I.H. Shames and C.L. Dym, CRC Press 4. Aeroelasticity – R.L. Bisplinghoff, H.Ashley and R.L.Halfman, Dover 5. E.H. Dowell et al., "A Modern Course in Aeroelasticity", Sijthoff & Noordhoff, 1980. 6. R.L. Bisplinghoff and H. Ashley, "Principles of Aeroelasticity", Dover, 1962. 7. R.H. Scanlan and R. Rosenbaum, "Introduction to the study of Aircraft Vibration and Flutter" Macmillan, 1951. 8. Y.C. Fung, "An Introduction to the Theory of Aeroelasticity", John Wiley & sons, 1955. 9. H. Ashley, "Aeroelasticity", Applied Mechanics Reviews, Feb. 1970. 10. Current Literatures

Course Code	AE5203N	Course Name	Finite Element Methods in Aerospace Structures	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Strength of materials	Co-requisite Courses	None	Progressive Courses	Advanced FEM for Aerospace Structural Design
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	The goal of this course is to introduce the theory behind finite element calculations of stress, strain, and deformation in aerospace structures. This course teaches the numerical method for solving problems in the field of aerospace structural mechanics, vibration, nonlinearities, heat transfer etc. The formulation of finite element procedure to solve boundary value problems including nonlinearities will be discussed. Stress update procedures in elasto-plasticity, consistent linearization, and solution of discrete equilibrium equations by the iterative Newton-Raphson method will be emphasized.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Linear Finite Element Analysis:** Finite Element discretization, adaptive methods, interpolation model, order of polynomial, generalized and natural coordinates, derivation of Finite Element equations through direct and variational approach (Raleigh-Ritz) and Weighted Residual approach, Stiffness matrix of truss, beam, rigid element, laminated composite plate element, Jacobian matrix, Gauss quadrature, transformation matrix, assembly and derivation of system equations, lumped and consistent mass matrices, Finite element in vibration, Numerical solution of FEM equations.	11	• Apply linear finite element analysis techniques for structural problems using discretization, interpolation, stiffness and mass matrices, variational methods, and numerical solutions including vibration analysis.
2	**Nonlinear Finite Element Analysis:** Geometric Nonlinearity, Material Nonlinearity, Kinematic nonlinearity, Force nonlinearity, Solution procedure, Newton-Raphson method, Modified Newton–Raphson method, Incremental Secant method, Incremental Force method, State determination, Residual calculation, Convergence check, Linearization and solution.	7	• Analyze nonlinear finite element problems involving geometric and material nonlinearity using iterative solution methods like Newton-Raphson and assess convergence and state determination.
3	**Finite Element Analysis for Nonlinear Elastic Problems:** Deformation gradient, Lagrangian and Eulerian strains, Polar decomposition, Deformation of surface and volume, Cauchy and Piola-Kirchhoff Stresses, Total Lagrangian formulation, Principle of Minimum	7	• Apply finite element methods to nonlinear elastic problems using deformation gradients, stress measures, Lagrangian formulations, and material models like hyperelasticity for

	Potential Energy, Linearization (Tangent stiffness), Updated Lagrangian formulation, Hyperelasticity, Mooney-Rivlin material, Mixed formulation, Algorithm for stress calculation, Finite Element Formulation for Nonlinear Elasticity.		accurate stress and deformation analysis.
4	**Finite Element Analysis for Nonlinear Elastoplastic Problems:** Finite Element Procedure for Elastoplasticity, Numerical Integration, Return-mapping algorithm, Consistent tangent operator, Elastoplasticity with finite rotation, Objective stress rate, Finite deformation elastoplasticity, Multiplicative decomposition, Principle of maximum dissipation, time integration, Return mapping in principal stress space, consistent tangent operator.	9	• Apply finite element methods to nonlinear elastoplastic problems using return-mapping algorithms, consistent tangent operators, and finite deformation theory with objective stress rates and time integration.
5	**Finite Element Analysis for Contact Nonlinearity:** Contact problem, Boundary nonlinearity, General contact formulation, Normal contact, Friction slip, Variational inequality and constrained optimization, Linearization of contact form, Gap element.	4	• Analyze contact nonlinearities in finite element problems using general contact formulations, friction models, variational inequalities, and linearization techniques.
6	Finite Element programming and application of FEM packages in aerospace structure.	4	• Develop and implement finite element programming and apply FEM software tools for analysis and design of aerospace structures.
	Total	**42**	

Course Outcome	After successfully completing this course, students will be able to: • Develop the finite element method for any given set of partial differential equations. • Implement algorithms in finite element codes and debug them through aerospace structural problems. • Understand the formulation of different types nonlinearities and their applications • Apply commercial finite element software for linear and nonlinear aerospace structural analysis

Learning Resources	1. Concepts and Applications of Finite Element Analysis by R. D. Cook, D. S. Malkus and M. E. Plesha 2. A First Course in the Finite Element Method by Daryl L. Logan 3. An Introduction to The Finite Element Method by J. N. Reddy 4. Fundamentals of Finite Element Analysis by D. V. Hutton 5. The Finite Element Method by S. S. Rao 6. Nonlinear Finite Elements for Continua and Structuresby T. Belytschko 7. Finite Element Procedures by K. J. Bathe. 8. Finite Element Method by O. C. Zienkiewicz and R. L. Taylor 9. Computational Inelasticity by J .C. Simo and T. J. R. Hughes

Course Code	AE5221N	Course Name	Aerothermodynamics of propulsion systems	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Advanced Thermodynamics, and Basic of aerodynamics	Co-requisite Courses	None	Progressive Courses	Compressible Flows
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	The focused objective of the course is to discuss the aerothermodynamics of combustion mechanism of aerospace fuels which are used in different aerospace vehicles propulsion in details. Under the scope of this course, various combustion modes, combustion theories, and combustion controlling parameters will be discussed elaborately in the context of different aircraft/ rocket engines.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Thermodynamics of Ignition and combustion:** Introduction to combustors for aerospace vehicles, Ignition and combustion mechanism of solid fuels, Ignition and combustion mechanism of liquid fuels (droplets and sprays), Ignition and combustion mechanism of gaseous fuels, Metal combustion.	10	• Module will help to understand the fundamental thermodynamic principles governing ignition and combustion processes in gaseous and liquid fuels. Students can evaluate different types of combustion systems and ignition methods.
2	**Aerothermodynamics of Gas turbine:** Introduction, Gas turbine combustors, Combustion process, Flow phenomena, Pressure loss in combustion chamber, Combustion chamber arrangements, Operating characteristics, Gas turbine engine emissions, Gas turbine blade cooling, Gas turbine engine fuel alternatives	8	• Module will help to understand the fundamental principles of aerothermodynamics related to gas turbine operation, including fluid flow, and combustion processes. Students can apply aerodynamic and thermodynamic concepts to design and optimize turbine blade profiles for improved performance.
3	**Gas turbine inlet and exhaust treatment:** Inlet treatment: The environment, Inlet air filters, Inlet air cooling, Wet compression Exhaust treatment: Water or steam injection, Selective catalytic reduction	6	• Helps to understand the importance of inlet and exhaust systems in gas turbine performance, reliability, and emissions control. Students can explain the design principles and functioning of inlet air filtration, and cooling.
4	**Aerothermodynamics of Afterburner:** Introduction, Diffuser, Fuel injection, Atomization and vaporization, Ignition, Stabilization process, Nozzle and fuel control systems, Complete afterburner systems, Combustion instabilities	8	• Module will help to understand the thermodynamic and fluid dynamic principles governing the operation of afterburners in jet propulsion systems. Students can explain combustion processes and flame

			stabilization mechanisms, apply aerothermodynamic principles to the design and optimization**.**
5	**Aerothermodynamics of Chemical Rockets:** Introduction to propellants, Solid rocket propellants combustion mechanism and theories, Liquid rocket propellants combustion mechanism and theories, Hybrid rocket propellants combustion mechanism and theories.	10	• Module will focus on thermo- and fluid-dynamics. Students can explain the combustion processes and energy conversion in solid, liquid, and hybrid rocket engines.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: ● Understand the combustion processes inside aircraft engines and rocket engines. ● Can calculate the combustion efficiencies. ● Understand how the aerospace vehicle engine design governs the combustion processes of different fuels. ● How combustion controls the thrust of aerospace vehicles.

Learning Resources	1. G. Oates, Aerothermodynamics of aircraft engine components, AIAA Education series 2. G. Oates, Aerothermodynamics of jet and rocket propulsion, AIAA Education series. 3. Eugene, Applied Combustion, Taylor and Francis. 4. M.J. Zucrow, Principles of jet propulsion and gas turbines, John Wiley and sons. 5. An introduction to combustion by Stephen R. Turns, McGraw Hill Publications 6. Fuels and Combustion by Samir Sarkar, University Press 7. Sutton, Rocket propulsion elements, John Wiley and Sons.

Course Code	AE5222N	Course Name	Parallel Computation	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	FORTRAN, C, and C++	Co-requisite Courses	None	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	● Introduce the basic principles of parallel computation. ● Introduce the importance of parallel computation and high-performance computations in practical simulations or computations. ● Expose the students to theoretical and practical techniques used to develop the parallel computation methodologies.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction to parallel computation:** Needs for parallel computations. Challenges of parallel programming- Parallel Programming Paradigms – Parallel Architecture - Overview of some parallel systems. Multiprocessors and multi-computers.	6	Students will understand the necessity of parallel computing in modern applications and identify the major challenges associated with parallel programming. They will be able to describe different parallel architectures, programming paradigms, and the structure of multiprocessor and multi-computer systems.
2	**Modeling and analysis of parallel computations:** Efficiency characteristics of parallel computation: speedup, efficiency, scalability - Model analysis: determining the parallel method execution time, estimating the maximum possible parallelization, computational load balancing - The Amdahl's and Gustavson-Barsis's laws - Aggregating the computation model.	8	Students will be able to evaluate the performance of parallel systems by analyzing speedup, efficiency, and scalability. They will develop the skills to model parallel execution time, estimate maximum parallelism, and apply Amdahl's and Gustafson-Barsis's laws to understand the limitations of parallelization.
3	**Parallel programming with MPI and communication:** Overview of the MPI standard. Point-to-point communication operations. Synchronous and asynchronous modes of data transmission. Collective operations. Derived data types. Process management. Logical topologies.	8	Students will gain practical knowledge of the MPI standard and its application in point-to-point and collective communication. They will be able to distinguish between synchronous and asynchronous communication and manage parallel processes using derived data types and logical topologies.
4	**Basics of GPU Programming:** Introduction to GPU Architecture - History, graphics processors, graphics processing units, GPGPUs. Clock speeds, CPU / GPU comparisons, heterogeneity. Accelerators,	10	Students will develop a foundational understanding of GPU architectures and learn how to program using CUDA, OpenCL, and OpenACC. They will be able to compare CPUs

	parallel programming, CUDA / OpenCL / OpenACC,		and GPUs in terms of performance and understand the challenges of heterogeneous computing environments.
5	**Case study on parallel programming:** Algorithm development – selection of communication operations - Case studies: matrix computations, solving partial differential equations – 1D Wave Equation.	10	Students will be able to design and implement parallel algorithms for real-world problems. They will gain hands-on experience in developing parallel solutions for matrix computations and solving partial differential equations such as the 1D wave equation, with a focus on selecting suitable communication and computation strategies.
	Total	**42**	

Course Outcome	Students will become familiar with fundamental parallel computation methods. ● Students will become familiar with parallel paradigms, architecture and different kinds of memory systems. ● Students will become familiar with the applications of parallel computation in industry problems. ● Students will be able to develop their own parallel implementations for their problems.

Learning Resources	1. Grama, Ananth, et al. Introduction to parallel computing. Pearson Education, 2003. 2. Pacheco, Peter. An introduction to parallel programming. Elsevier, 2011. 3. Kirk, David B., and W. Hwu Wen-Mei. Programming massively parallel processors: a hands-on approach. Morgan kaufmann, 2016. 4. Schmidt, Bertil, et al. Parallel programming: concepts and practice. Morgan Kaufmann, 2017. 5. Cai, Yiyu, and Simon See, eds. GPU computing and applications. Singapore: Springer, 2015.

Course Code	AE5223N	Course Name	Hypersonic Aerothermodynamics	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Thermodynamics and Heat Transfer, Aerospace Vehicle Design and Mathematical Methods	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	Nil

Course Objectives	After successfully completing this course, students should be able to:
	● Understanding historical and engineering applications of hypersonic aerodynamics. ● Analyzing distinguished flight conditions and general characteristics of hypersonic flow. ● Proficiency in inviscid hypersonic flow analysis and applying relevant theories.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Basics of hypersonic Aerodynamics:** Historical aspects. Engineering applications: Re-entry spacecrafts, inter-continental ballistic missiles, hypersonic cruise aircrafts. Distinguished flight conditions leading to hypersonic flow phenomena, General characteristics of hypersonic flow.	4	• Understand the historical development and real-world applications of hypersonic flight. • Recognize key flow features and conditions unique to hypersonic regimes.
2	**Inviscid hypersonic flows:** Hypersonic limit relations for shock waves. Newtonian theory. Newton Busemann centrifugal corrections. The role of the density ratio in hypersonics. The combined limit of high Mach numbers and large density ratios. The Taylor-Maccoll theory for supersonic flows over cones. Mach-number independence principle. Van Dyke's small-disturbance equations for slender bodies. Tsien's hypersonic similarity parameter. The shock standoff distance from blunted bodies. Shock layer and entropy layer.	11	• Use simplified models to analyze inviscid hypersonic flow over slender and blunt bodies. • Understand key effects like shock stand-off, entropy layers, and Mach number independence.
3	**Viscous hypersonic flows:** The role of flight altitude. Boundary-layer transition pheno-menology: The Shuttle Orbiter case. Endo-atmospheric and trans-atmospheric hypersonic vehicles. Non-continuum effects. Compressible	12	• Understand boundary-layer behavior, transition, and aerodynamic heating in hypersonic flight. • Apply self-similar solutions

	laminar boundary layers. Recovery factor. Basic self-similar formulations for flat plates and forebody stagnation-point flows. The Fay-Riddell correlation. Aerodynamic heating.		and correlations to analyze viscous effects on high-speed vehicles.
4	**High-speed thermo-chemical effects:** Non-calorically and non-thermally perfect effects at high flight speeds. Air dissociation, ionization, and vibrational excitation. Chemical and vibrational nonequilibrium effects.	5	• Understand real gas effects like dissociation, ionization, and vibrational excitation at high speeds. • Recognize chemical and thermal nonequilibrium phenomena in hypersonic flows.
5	**Aerodynamic forces and moments:** Aerodynamics of typical hypersonic vehicles, dynamic stability, design considerations.	4	• Analyze aerodynamic forces, moments, and stability aspects of hypersonic vehicles. • Understand key design considerations influencing hypersonic vehicle performance.
6	**Experimental methods for hypersonic flows:** Hypersonic wind tunnels, shock tunnels, gun tunnels, free piston shock tunnels, expansion tubes	6	• Understand the working principles of hypersonic test facilities like shock tunnels and expansion tubes. • Identify suitable experimental setups for simulating hypersonic flow conditions.
	Total	**42**	

Course Outcome	After successfully completing this course, students should be able to: ● Understanding historical and engineering applications of hypersonic aerodynamics. ● Analyzing distinguished flight conditions and general characteristics of hypersonic flow. ● Proficiency in inviscid hypersonic flow analysis and applying relevant theories.

Learning Resources	1. J.M. Anderson, “Hypersonic and High-Temperature Gasdynamics”, AIAA, 2006. 2. J. Bertin, "Hypersonic Aerothermodynamics", AIAA, 1991. 3. W. Hayes & R.F. Probstein: "Hypersonic Flow Theory", Academic Press, 1959. 4. H.W. Liepmann& A. Roshko, “Elements of Gas Dynamics”, Dover, 1957. 5. Wilbur L. Hankey “Reentry Aerodynamics”, AIAA Education series, Washington DC, 1988 6. Ernst Heinrich Hirschel, “Basics of Aerothermodynamics”, Springer Verlag Berlin, 2005

Course Code	AE5224N	Course Name	Turbulence Modeling	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid flows with understanding of momentum and energy equations, partial differential equations and calculus and algebra of complex numbers	Co-requisite Courses	NA	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	● Introduce the basic properties of turbulence: Random fluctuating structures over a large range of length- and time-scales. ● Introduce the importance of turbulent mixing and transport of momentum in practical flows. ● Make students understand the RANS based approach to turbulence modeling and the expose them to the different turbulence modeling approaches ● Complex turbulent flow in Aerodynamic applications show multiscale behavior which can be captured through Large eddy simulation and Direct Numerical methods. Thus, expose students to Large eddy simulation and Direct Numerical methods-based turbulence modeling approaches

Module	Syllabus	Duration (class-hour)	Module Outcome
1	The transition to turbulence: Experiments of Taylor, Benard and Reynolds, Role of the non-linear term of the Navier Stokes equation, Introduction to instability theory in the context of transition to turbulence, The scales of turbulent motion, the energy cascade and Kolmogorov hypothesis, Energy spectrum	6	• Students will become familiar with the fundamental characteristics of turbulent flow
2	The statistical description of turbulent flows: the random nature of turbulence, characterization of random variables, probability distributions, joint random variables, random process, probability and averaging, correlation time, correlation length, two point correlation, Fourier transform and Fourier transform of derivatives, Fourier representation of a stationary velocity field in frequency domain: periodic case, non-periodic case, Complex form of Fourier series, Orthogonality property of the Fourier modes, The Dirac delta function and its properties, Taylor series representation, The Heaviside function, Convolution Theorem, Parseval's theorems, Filtering and its relation to convolution, high pass, band pass and notch filters, spectral leakage and windowing, discrete Fourier	10	• Students will become familiar with the statistical description of turbulence, spectral representation of the turbulence and the background mathematical framework for large eddy simulation based approaches.

	transform, Fast Fourier transform and aliasing.		
3	Reynolds equation of motion, Reynolds stress tensor, the closure problem of turbulence, Reynolds stress equation, Kinetic energy equation of the mean motion and the fluctuating motion, Energy transfer between the mean motion and the fluctuating motion, intercomponent transfer of energy, role of pressure, dissipation equation	12	• Students will become familiar with the different conservation and transport equations in the context of the time averaged analysis and computation of turbulent flows.
4	**Introduction to turbulence modelling:** eddy viscosity model, one equation turbulence models, two equation turbulence models	6	• Students will become familiar with the the RANS based turbulence modelling
5	**Direct Numerical simulation:** Pseudo spectral methods, the computational cost, artificial modifications and incomplete resolution and requirement of filtered approaches, Application areas and simulation results **Large-eddy simulation (LES):** Filtering in one dimension, Spectral representation, the filtered energy spectrum. Filtered momentum conservation equation, decomposition of residual stress. Types of filters – Gausian Filter, Box filter, Cauchy filter, sharp spectral filter, Pao's filter. The Smagorinsky model: the definition of the model, the behaviour at the inertial subrange. The Smagosinsky filter.	8	• Students will become familiar with the framework of Direct Numerical simulation and the Large Eddy Simulation
	Total	**42**	

Course Outcome	Students will become familiar with fundamental physics of turbulent flows, Transport of momentum and energy in turbulent flows, Applications of turbulence in aerodynamics, Different turbulence modeling techniques, Digital filtration techniques as applied to fluid flows. Students will be able to characterize the energy distribution across different scales of motion, and understand the working of Direct Numerical Simulation algorithms. Understanding the filtration techniques adopted for Large Eddy Simulation and the Governing equations and working of Large eddy Simulation

Learning Resources	1. D. C. Wilcox (Main): Turbulence modelling for CFD, DWC Industries Inc. (1993). 2. 2. Steven A. Pope (Main): Turbulence, Cambridge (2004). 3. Tennekes & Lumley (Secondary text): A first course in turbulence, MIT Press (1972) 4. P. A. Davidson (Secondary text): Turbulent Flows, Oxford (2000) 5. L. C. Berselli, T. Iliescu, W. J. Layton (Secondary text): Mathematics of Large Eddy Simulation of Turbulent Flows, Springer, 2006

Course Code	AE5225N	Course Name	Aircraft Materials and Processes	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Elements of Aerospace Engineering and Aerospace Structures	Co-requisite Courses	None	Progressive Courses	Manufacturing Techniques of Aerospace Materials
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	This course is specifically focused on aircraft structural materials with the objective to • Impart knowledge about important materials used in airframe: their nomenclature, their constitution and treatments and the underlying scientific concepts, properties and usage as well as some of the processes commonly used in their treatments or for making airframe parts. • Develop understanding of relationship of materials and processes with structural performance.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction to Aircraft Materials:** General properties of materials, Requirements of aircraft materials, Testing of aircraft materials, Inspection methods, Application and trends in usage in aircraft structures and engines, Selection of materials for use in aircraft. Historical Evolution of Aircraft structures and materials: Early Requirements & Early materials (Wood, Fabric), Semi-monocoque structures – Use of sheet metal work; Development of Al-alloys through several decades. Advent of Ti alloys; Use of Steels. Emergence of composites as major structural materials.	5	By the end of this module, students will be able to: • Understand the general properties and performance requirements of materials used in aircraft structures and engines. • Identify and evaluate materials based on mechanical, thermal, and environmental criteria specific to aerospace applications.
2	**Metal:** Fatigue, fatigue performance and its characterization, Damage Tolerance, use of fracture mechanics and related material parameters, fracture toughness, crack-growth resistance, crack growth in fatigue. Material characterization: Important properties and their assessment: strength, stiffness, hardness, fatigue, fracture occurred in different aircraft components.	6	By the end of this module, students will be able to: • Explain fatigue behavior, damage tolerance, and fracture mechanics principles relevant to metallic aircraft components. • Understand the characterization of metals in terms of strength, stiffness, hardness, fatigue resistance, and fracture mechanisms.

3	**Crystal Structures and Properties:** Elements of crystal structure, polycrystalline nature of metals, Important aspects: dislocations, slip. Yielding related to dislocation movement, Solid Solutions and alloying Strengthening through solid solutions, dispersion and precipitation hardening, Grain Boundary strengthening, Strain hardening; Alloying for other properties, Fatigue and corrosion characteristics.	6	By the end of this module, students will be able to: • Understand concepts such as **dislocations, slip systems, and yielding** in crystalline materials. • Evaluate the effect of **alloying elements** on fatigue, corrosion resistance, and other critical properties.
4	**Al-alloys:** Classification and Nomenclature; Cast and wrought, Heat-treatable and non-heat-treatable. Alloy and temper designations; Wrought Al-alloys Al-Cu, Al-Zn, Properties and treatments, usage; Other Al-Alloys. Ti-alloys: Classification; Nomenclature, properties and usage. Other miscellaneous alloys in airframe: Ferrous Alloys, Steels, Cast Iron, Steels used in Aircraft; Mg Alloys, others. General overview of processes of fabrication.	8	By the end of this module, students will be able to: • Understand the classification and designation systems of Al- and Ti-alloys. • Differentiate between heat-treatable and non-heat-treatable Al-alloys and explain their respective processing and applications.
5	**Ceramics and Composites:** Raw materials: Fibers - Carbon, Glass, Aramid, Other miscellaneous. Matrix materials - Polymeric Thermosets vs thermoplastics, high temperature; Epoxies, various resins, Curing process of thermosets (mainly epoxy), role of various additives, cure cycles. Modern ceramic materials, cermets, glass ceramic, production of semi-fabricated forms, Carbon/Carbon composites, Fabrication processes and its aerospace applications involved in metal matrix composites, polymer composites. Processes: Autoclave and non-autoclave processes.	9	By the end of this module, students will be able to: • Understand the curing processes of thermosets, especially epoxy systems, and the role of additives and curing cycles. • Describe the nature and applications of modern ceramics, glass ceramics, cermets, and carbon-carbon composites.
6	**Material Testing:** Corrosion, its detection and prevention, thermal barrier, Stealth, Paints. Protective finishes. Testing: Destructive and non – destructive testing techniques. Crack detection, inspection of parts by hot oil and chalk, dye-penetrant, fluorescent and magnetic particles, X-ray, ultrasonic, eddy current and acoustic emission methods. Joining. Fasteners and adhesives (materials).	8	By the end of this module, students will be able to: • Analyze corrosion mechanisms, detection methods, and protection strategies including coatings, paints, and thermal barriers. • Understand destructive and non-destructive testing (NDT) methods for material evaluation and integrity
	Total	**42**	

Course Outcome	Equip the students with awareness and basic knowledge of • Aircraft structural materials, both metallic and composites, their treatments and usage • Relationship of materials with aircraft structural performance and issues involved in choice of materials
Learning Resources	1. Aircraft Materials & Processes, 5th Edition George F. Titterton | Publisher: Sterling Book 2. Fundamentals of Aircraft Material Factors by Charles E. Dole 3. Aircraft Composite Design Handbook for Training: Basic knowledge of aircraft composite material and process by Bruce Yu 4. Introduction to Aerospace Materials by Adrian P.Mouritz, Woodhead Publishing 5. Engineering Mechanics of Composite Materials, I. M. Daniel & O. Ishai, Oxford University Press (1994) 6. Analysis and Performance of Fiber Composites, B. D. Agarwal, L. J. Broutman, K. Chandrasekhar, Wiley (2015) 7. Design and analysis of composite structures with applications to aerospace structures, C. Kassapoglou, John Wiley & Sons, Ltd. (2010) 8. Modern Manufacturing Processes for Aircraft Materials by Selim Gurgen, Catalin I. Prunc

Course Code	AE5226N	Course Name	Plates and Shells	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Solid Mechanics	Co-requisite Courses	None	Progressive Courses	FEM for Plates and Shells
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	The course is designed to provide a comprehensive and methodical presentation of the fundamentals of plate and shell theories, based on a solid foundation of mechanics and mathematics. Classical series solutions as well as approximate analytical methods are included.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	Introduction to plates, Different types of plates, Kirchhoff's assumption of thin plates. Bending of long rectangular plates to a cylindrical surface. Pure bending of plates: relation between bending moment and curvature. Equilibrium of plate under twisting moment.	4	• students will be able to classify different types of plates, understand Kirchhoff's assumption for thin plates, and analyze bending and twisting behavior of plates under various special loading conditions.
2	Small deflection of laterally loaded plate: Differential equation of deflection surface, boundary conditions [SS edge, clamped edge, free edge, elastically supported edge]	4	• Students will be to obtain the equation of equilibrium of thin plates and apply different boundary conditions
3	Rectangular plate: Elementary Cases of Plate Bending, Navier's Method (Double Series Solution), Rectangular Plates subjected to patch and concentrated loads. Levy's method for solution of transversely loaded rectangular plates for various end conditions. Analysis of plates on elastic foundations.	7	• Students will be able to obtain approximate analytical solutions of thin plate bending problems subjected to certain boundary and loading conditions
4	Circular Plates: Basic relations in polar coordinate, Axis-symmetric bending of circular plate, asymmetric problems of circular plate	5	• Students will be able to obtain governing equation of equilibrium of thin circular plates in polar coordinates and obtain approximate an
5	Approximate methods of plate solution: The Ritz Method, The Galerkin Method	4	• Students will be able to formulate and solve plate bending problems using energy-based approaches
6	Basic analysis of orthotropic plates. Governing equation and solution of plates with in-plane loading. Basic solution of uniaxial and biaxial buckling of thin rectangular plates. Governing equation of	5	• A miscellaneous module after which Students will be able to formulate and solve plate buckling problems, obtain the

	thermal stress of plate		governing equation of thin plate with thermal stress and carry out basic analysis of orthotropic plates
Shells			
7	Introduction to shells, General strain-displacement relations, stress resultants, constitutive equations for a thin shell, equation of equilibrium of thin shells	9	• Students will be able to understand the fundamental behavior of thin shells, derive strain-displacement relations, evaluate stress resultants, apply constitutive equations, and formulate equilibrium equations for thin shell structures.
8	Membrane theory of thin cylindrical shells. Analysis of thin circular cylindrical shells with symmetric loading and applications	4	• Students will be able to apply the membrane theory to analyze thin circular cylindrical shells under symmetric loading and solve related practical engineering problems.
	Total	**42**	

Course Outcome	After successful completion, students will be able to: ● Understand the simple bending of rectangular Plates subjected to different boundary conditions and loads ● Analyze circular plates subjected to different kinds of loads ● Develop a basic quantitative understanding of shell structures

Learning Resources	1. Theory of Plates and Shells by Timoshenko and Woinowsky-Krieger (TMH) 2. Thin Plates and Shells by Ventsel and Krauthammer (Marcel Dekker Inc.) 3. Theory of Plates by K. Chandrashekhara (University Press) 4. Theory and Analysis of Elastic Plates and Shells by J.N. Reddy (CRC Press)

Course Code	AM5201N	Course Name	Theory of Plasticity	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Mechanics of Solids, Numerical Methods	Co-requisite Courses	None	Progressive Courses	Computational modeling of Plasticity
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	None

Course Objectives	This course is intended to enhance the synergistic research efforts on plasticity and failure mechanisms of advanced materials in Applied Mechanics relevant to Mechanical Engineering, Material Science and Engineering, Aerospace Engineering, Civil Engineering and other Engineering disciplines due to tensile, bending, torsion, fatigue, thermal loadings.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction:** Large Strain Definitions, Finite Strain Tensors, Polar Decomposition	4	• Understand large strain measures and polar decomposition for analyzing nonlinear deformation.
2	**Yield Criteria:** Yielding of Ductile Isotropic Materials, Experimental Verification, Anisotropic Yielding in Polycrystals	2	• Understand and apply yield criteria for ductile isotropic and anisotropic materials based on experimental observations.
3	**Non-Hardening Plasticity:** Classical Theories of Plasticity of Hencky-Ilyushin, Prandtl-Reuss, Application of Classical Theory to Uniform Stress States, Thick-Walled, Pressurised Cylinder with Closed-Ends	4	• Apply classical non-hardening plasticity theories to uniform stress states and pressurized thick-walled cylinders.
4	**Elastic-Perfect Plasticity:** Elastic-Plastic Bending of Beams, Shape Factor, Load Factor, Plastic Hinge, Residual Bending Stresses, Influence of Hardening, Elastic-Plastic Torsion of Solid Cylinder, Residual Shear Stress, Residual Angular Twist	6	• Analyze elastic-perfect plastic behavior in bending and torsion of structural members, including plastic hinges, residual stresses, and the influence of hardening.
5	**The Flow Curve:** Equivalent Stress of von-Mises and Drucker, Equivalent Plastic Strain, Uniaxial Tests under Tension and Torsion	2	• Understand and apply flow curves using equivalent stress and strain
6	**Plasticity with Hardening**: Conditions Associated with the Yield Surface, Loading Function, Drucker's Postulate, Isotropic Hardening, Levy-Mises, Drucker Theory, Non-Associated Flow Rules, Kinematic Hardening, Bauschinger Effect, Translation Rules, Reversed Yield Stress, Reversed Flow Curve, Plastic Instability	4	• Analyze plasticity with hardening using yield surface evolution, flow rules, and hardening models including isotropic and kinematic hardening with the Bauschinger effect.

7	**Classical Elasto-Plasticity and One-Dimensional Cyclic Plasticity Model:** Classical One-Dimensional Model of Elasto-Plasticity: Yield function, Flow rules and Hardening Laws; Kuhn-Tucker Conditions; Softening and Hardening Material Behaviors; One Dimensional Cyclic Plasticity; Kinematic Hardening Rules of Armstrong and Frederick and Chaboche. Isotropic Hardening, Combined Hardening, Plastic Multiplier, Hardening Modulus in One Dimension, One Dimensional Viscoplasticity, Return Mapping Algorithm.	6	• Apply classical and one-dimensional cyclic elasto-plasticity models using yield functions, hardening laws, and return mapping algorithms to simulate material behavior under cyclic loading.
8	**Three-Dimensional Model of Cyclic Plasticity:** Three-Dimensional Model of Plasticity, Dissipation Inequality, Plastic Multiplier, Tangent Operator, Hardening Modulus, Return Mapping Algorithm, Consistent Tangent Operator, Finite Strain Elasto-Plasticity, Multiplicative Decomposition of the Deformation Gradient, Additive Decomposition of Rate of Deformation.	6	• Apply three-dimensional cyclic plasticity models using return mapping, hardening laws
9	**Crystal Plasticity:** Resolved Shear Stress and Strain, Lattice Slip Systems, Hardening of Single and Polycrystals, Schmid's Law, Slip Systems, Kinematics of Crystal Deformation, Hardening of Single Crystals, Integration of the Elastoplastic Equations	6	• Analyze crystal plasticity using resolved shear stress, slip systems, and hardening behavior in single and polycrystals based on Schmid's law and elastoplastic integration.
10	**Cyclic Plasticity Simulation:** Material Modelling with Plasticity in ABAQUS/ANSYS, Programming, Simulation.	2	• Simulate cyclic plasticity using material modeling and programming in ABAQUS/ANSYS for advanced structural analysis.
	Total	**42**	

Course Outcome	This course is made of particular interest, the graduate students, research scholars who will work on project based on their research topics of plasticity, cyclic plasticity, fracture mechanics, low cycle fatigue, ratcheting, crack growth, micromechanical modeling of materials, crystal plasticity-based simulation etc.

Learning Resources	1. Basic Engineering Plasticity,An introduction with Engineering and Manufacturing Applications by D.W.A. Rees. 2. Computational Inelasticity by J.C. Simo and T.J.R. Hughes, Springer, 1998., ISBN: 0387975209 3. Mechanics of Deformable Solids: Linear, Nonlinear, Analytical and Computational Aspects, Issam Doghri,Springer,2000 4. Introduction to Computational Plasticity by Fionn Dunne and Nik Petrinic 5. Continnum Mechanics and Plasticity by Han-Chin Wu

	6. Plasticty Theory by J. Lubliner 7. Continuum theory of defects by E. Kroener 8. Studies in large plastic flow and fracture by P W Bridgman. 9. Dislocations and plastic flow in crystals by A. H. Cottrell.

Course Code	AE5217N	Course Name	Compressible Flow	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		**Data Book / Codes/Standards**	Nil

Course Objectives	This course offers a comprehensive overview of supersonic flow aerodynamics, covering its fundamental principles and potential applications.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**One-Dimensional Flow:** One Dimensional Flow revisited; Hugoniot Equations; One Dimensional Flow with Heat Transfer; One Dimensional Flow with Friction. Problems.	6	• Introduction, Review of Fluid Mechanics and thermodynamics, Basic ideas over governing equations of compressible flows and its parameters • Idea on shock wave, Fanno and Rayleigh lines
2	**Two-Dimensional Flow:** Two-Dimensional Flow revisited; Shock Polar; Shock Reflection and Intersection; Bow Shock in front of a Blunt Body; Three-Dimensional Shock Waves; Prandtl-Meyer Expansion Waves; Shock-Expansion Theory. Problems.	8	• Effects of Shock and Expansion waves on aerodynamic characteristics.
3	**Quasi One-Dimensional Flow:** Quasi One-Dimensional Flow revisited; Nozzles; Diffusers. Problems.	6	• Exploring the relationship between area and Mach no
4	**Unsteady Wave Motion:** Introduction; Moving Normal Shock Waves; Reflected Shock Waves; Elements of Acoustic Theory; Finite Waves; Incident and Reflected Expansion Waves; Shock tube Relations; Finite Compression Waves.	8	• Unsteady Wave Motion
5	**Linearised Flow:** Introduction; Differential Conservation equations for Inviscid Flow; Crocco's Theorem; Velocity Potential Equation: Linearised Velocity Potential Equation; Linearised Subsonic Flow; Linearised Supersonic Flow; Method of Characteristics.	6	• Ideas over linearized supersonic flows
6	**Three-Dimensional Flow:** Cones at Angle of Attack; Blunt Bodies at Angle of attack.	4	• Three-Dimensional Flow

7	**Numerical Techniques:** Steady and Unsteady Supersonic Flow	4	• Basic ideas over numerical techniques for different flow regimes
	Total	**42**	

Course Outcome	After successfully completing this course, students should be able to understand and apply 1D, 2D flow and governing equations for shock waves and expansion waves, linearised high speed flows and its applications.

Learning Resources	1. J. D. Anderson Jr., Modern Compressible Flow with Historical Perspective, McGraw Hill 2. A H Shapiro, Dynamics and Thermodynamics of Compressible Fluid Flow-Volume **I& II**, Ronald Press 3. H W Liepmann and A Roshko, Elements of Gas Dynamics, John Wiley & Sons

Course Code	AM5234N	Course Name	Engineering Fracture Mechanics	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Mechanics of Solids	Co-requisite Courses	None	Progressive Courses	Fracture Mechanics of Composite Materials
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	The objective of the course is understanding and exposure to linear elastic and elasto-plastic fracture mechanics, dynamic and time dependent fracture mechanics, viscoelastic fracture mechanics, fatigue crack growth, fracture toughness testing and computational fracture mechanics.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	Overview and Application of Fracture Mechanics Approach to Engineering Design, Effect of Material Properties on Fracture, Failure, Combined Bending and Torsion, Historical Development, Contributions of Inglis, Griffith and Irwin, Classification of LEFM and EPFM, Modes of Loading: Mode-I, Mode-II and Mode-III, Photoelastic Fringes, Fatigue Crack Growth Model, Fracture Mechanisms: Brittle Fracture, Ductile Fracture, Fracture Mechanism in Metals and Non Metals, Void Nucleation and Growth, Ductile Brittle Transition.	6	• Apply fracture mechanics principles to engineering design by analyzing failure modes, crack growth, and material behavior under various loading conditions, including historical and theoretical foundations.
2	Linear Elastic Fracture Mechanics (LEFM), Griffith Theory of Energy Balance, Energy Release Rate (G), Instability and R Curve, Stress Intensity Factor, (SIF) K, Relationship Between K and G, Crack-tip Stress and Displacement Field Equations, Airy's Stress Function for Mode-I, Westergaard Solution of Stress Field for Mode-I, Mode II, Mode III, Irwin's Model.	11	• Apply Linear Elastic Fracture Mechanics (LEFM) to analyze crack behavior using energy release rate, stress intensity factors, and analytical solutions for various loading modes.
3	Elastic Plastic Fracture Mechanics (EPFM), Crack Tip Opening Displacement (CTOD), J Contour Integral, Relationship Between J and CTOD,J Controlled Fracture, Crack Growth Resistance Curves, HRR Field, Dynamic and Time Dependent Fracture, Creep Crack Growth (C* Integral), Viscoelastic Fracture Mechanics.	11	• Apply Elastic-Plastic Fracture Mechanics (EPFM) to evaluate crack behavior using CTOD, J-integral, resistance curves, and time-dependent fracture models including creep and viscoelasticity.
4	Fracture Toughness Testing of Metals, Specimen Configurations, Fatigue Precracking, K_{IC} Testing, K-R Curve Testing, J Testing, CTOD Testing, Dynamic and Crack Arrest Toughness, Fracture Testing of Non-Metals, Plane Strain and Plane Stress	7	• Conduct and interpret fracture toughness testing of materials using standardized methods for KIC, J, CTOD, and dynamic fracture parameters

	Fracture Toughness Testing, Important Standards and Practices.		under plane strain and plane stress conditions.
5	Crack Initiation and Crack Growth, Paris Law, Crack ΔK_{eff} ΔK_{th} Closure, Fatigue Threshold.	4	• Analyze crack initiation and growth under cyclic loading using Paris Law, crack closure concepts, and fatigue threshold criteria.
6	Computational Fracture Mechanics using ANSYS/ABAQUS/other softwares, Application of XFEM in Computational Fracture Mechanics.	3	• Apply computational fracture mechanics using ANSYS/ABAQUS to simulate crack initiation and propagation in engineering materials.
	Total	**42**	

Course Outcome	The students are expected to perform design and safety analysis of the machines and structures in aerospace, automobiles, power plants, chemical plants, oil exploration, shipping, defense, civil applications etc.

Learning Resources	1. Fracture Mechanics - Fundamentals and Applications, 3rd Edition by T.L. Anderson, Taylor and Francis Group, 2005. 2. Elementary Engineering Fracture Mechanics, by D. Broek, Kluwer Academic Publishers, Dordrecht, 4th revised Edition, 1982. 3. Fracture Mechanics, by C.T. Sun, Z. –H. Jin, Academic Press, 2nd Edition, 2006. 4. Elements of Fracture Mechanics by Prashant Kumar, Tata McGraw Hill, New Delhi, India, 2009. 5. Fracture Mechanics for Modern Engineering Design, by K.R.Y.Simha.

Course Code	AM5236N	Course Name	Nonlinear Dynamics and Chaos	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fundamentals of Mechanics, Elementary Mathematics and Calculus	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	None

Course Objectives	From the Newton's law of motion, it appears that, for the known initial conditions and the interacting forces, history of motion of a particle may be predicted forever into the future. It has, however, been uncovered now that such infinite predictability in dynamics may not be possible even for simple dynamical systems if they are essentially nonlinear in nature. In this background, the goal of this course is to introduce the ideas of nonlinear dynamics and standard mathematical approaches to explore problems of nonlinear dynamics and chaos that essentially exist in nature. Indeed, nonlinearity does exist in natural phenomena, virtually covering every area of science and engineering. This course may thus be of significant interest to students of engineering and science even for interdisciplinary research.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**Introduction:** Review of linear and non-linear vibration and introduction to bifurcations, Concepts of maps and flows, Overview of chaos and fractals.	4	• Students will be able to distinguish between linear and nonlinear systems and develop basic ideas of maps, flows, chaos and fractals
2	**1-D Dynamical Systems:** Fixed points, Stability, Bifurcations – Ideal and imperfect, Some canonical forms, A connection with physical problem.	5	• Students will be able to analyze fixed points and their stability, understand ideal and imperfect bifurcations through canonical forms, and relate these concepts to relevant physical problems
3	**2-D Dynamical Systems:** Phase plane, Fixed points and linear stability analysis, Limit cycles, Bifurcations revisited, Index theory, Examples from Newtonian dynamics.	8	• Students will be able to analyze dynamical systems using phase plane methods, determine the stability of fixed points, identify limit cycles, apply index theory, and interpret various types of bifurcations.
4	**Analytical Methods:** Averaging techniques, Perturbative methods, Duffing and Van der Pol oscillators	8	• Students will be able to solve weakly nonlinear systems using approximate analytical methods like Averaging and Perturbation techniques

5	**Parametric Oscillators:** Introduction, Floquet theory, Mathieu equation, Linearly damped Mathieu equation.	5	• Students will be able to qualitatively analyze parametric oscillators using Floquet theory, understand the behavior of the Mathieu equation and its solutions
6	**Discrete Dynamical Systems:** Introduction, Bernoulli shift, Lyapunov exponent, Logistic map and Conjugate tent map, Routes to Chaos.	6	• Students will be able to analyze discrete dynamical systems, interpret the behavior of maps such as the Bernoulli shift, logistic map, and tent map, compute Lyapunov exponents, and understand various routes to chaos.
7	**3-D Dynamical Systems:** Lorenz model, Geometry of strange attractor, Relation between dimension definitions and Lyapunov exponent, Fractal basin boundaries	6	• Students will be able to analyze 3-D dynamical systems using the Lorenz model, interpret the geometry of strange attractors, relate various definitions of dimension to Lyapunov exponents, and understand the concept of fractal basin boundaries
	Total	**42**	

Course Outcome	After successfully completing this course, students are expected to achieve: (a) a newer insight into the subject 'Dynamics' far beyond the Newtonian Dynamics (b) understanding on the predictability/unpredictability of various physical systems (c) realization to different inter-disciplinary problems involving nonlinearity and (d) renewed interest in the area of promising research.

Learning Resources	1. Nonlinear Dynamics and Chaos by S. H. Strogatz, Westview 2. Nonlinear Oscillations by A.H. Nayfeh and D.T. Mook, Wiley, 1979 3. Nonlinear Oscillation in Physical Systems by C. Hayashi 4. Chaotic Vibrations: An Introduction for Applied Scientists and Engineers by F. C. Moon, Wiley

M. Tech. in Applied Mechanics with Specialization in Hydraulic Engineering

Detailed Syllabus

1st Semester Courses Syllabi

M. Tech. in Applied Mechanics with Specialization in Hydraulic Engineering

<table>
<tr><td rowspan="2">Course Code</td><td rowspan="2">AM5109N</td><td rowspan="2">Course Name</td><td rowspan="2">Open Channel Hydraulics</td><td rowspan="2">Course Category</td><td rowspan="2">PC</td><td>L</td><td>T</td><td>P</td></tr>
<tr><td>3</td><td>0</td><td>0</td></tr>
</table>

<table>
<tr><td>Pre-requisite Courses</td><td>Hydraulics and Fluid Mechanics</td><td>Co-requisite Courses</td><td>None</td><td>Progressive Courses</td><td>Advanced Open Channel Hydraulics</td></tr>
<tr><td colspan="2">Course Offering Department</td><td colspan="2">AE & AM</td><td>Data Book / Codes/Standards</td><td>NA</td></tr>
</table>

<table>
<tr><td>Course Objectives</td><td>In recent years water-resources projects and hydraulic engineering works have been developing rapidly throughout the world. The knowledge of open channel hydraulics which is essential to the design of many hydraulic structures has thus advanced by leaps and bounds. This course has the following objectives:

• To introduce basic principles, the types of flow in open channels classified according to the variation in the parameters of flow with respect to space and time, coefficients for velocity and pressure distributions.

• To provide knowledge about the energy and momentum principles constituted the basis of interpretation for most hydraulic phenomena.

• To introduce uniform flow, several uniform flow formulae, the design of erodible, non erodible and grassed channels.

• To provide knowledge on gradually varied flow, several methods for the computation of flow profiles, new method of direct integration, the method of singular point which is a powerful tool for the analysis of flow profiles.

• To provide knowledge in rapidly varied flow involving hydraulic jump, its use as energy dissipater, its control, flow over spillway analyzing and implementing the real engineering problems.</td></tr>
</table>

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Basic principles: velocity and pressure distribution, effects of slope and curvature on Pressure distribution, application of energy and momentum principles.	06	• Explain the distribution of velocity and pressure in open channel flow. • Analyze the effects of bed slope and channel curvature on pressure distribution.
2.	Uniform Flow: development of uniform flow and its formulas, computation of uniform flow, theoretical concepts of surface roughness, velocity distribution and instability of Uniform flow, design of channels for uniform flow.	08	• Understand the development and characteristics of uniform flow in open channels.

3.	Gradually Varied Flow: continuity and dynamic equations, analysis of flow profile, method of singular point, method of computation, backwater effect of a dam.	10	• Classify and analyze different types of flow profiles based on channel slope and flow depth. • Apply numerical and graphical methods for GVF profile computation.
4.	Spatially Varied Flow: basic principles and assumptions, dynamic equation of spatially Varied flow, analysis of flow profile, method of numerical integration.	10	• Understand the principles and assumptions underlying spatially varied flow. • Derive and apply the dynamic equation for spatially varied flow scenarios.
5.	Rapidly Varied Flow: characteristics of flow, hydraulic jump and its use as energy Dissipator, control of jump, stilling basin, flow over spillway.	08	• Analyze the hydraulic jump, its types, and conditions for occurrence. • Evaluate the use of hydraulic jumps as energy dissipators.
	Total	42	

Course Outcome	After successfully completing this course, students will: •Understand how extensive use of free surface flow is made for different practical real problems related to water resources and hydraulic engineering works. •Understand the modern numerical methods for solving the governing equations of different problems and also understand the solution of dam break problems both by numerical and simplified methods of computations. •Understand the treatment of rapidly varied flow problem largely supported by experimental data because this type of flow is so complicated that a mere theoretical analysis in most cases will not yield sufficient information for the purpose of practical design. •Be able to design different channels like lined and unlined channel, stable channel, earthen channel and grass-lined channel considering both economic and seepage losses. •Be able to have the ideas of flow through bridge contractions, the control of hydraulic jumps with sharp and broad-crested weirs, abrupt rises and drops, stilling basins, spillway structures and the design of channel transitions, the design, construction and use of physical models in the study of open channel hydraulics.

Learning Resources	1. Open Channel Hydraulics by VenTe Chow 2. Open Channel Hydraulics by Richard H. French

Course Code	AM5127N	Course Name	Theory of Hydraulic Models	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Hydraulics, Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Experimental River Hydraulics and Fluid Machines
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	Dimensional analysis plays a vital role in theory of hydraulic model. It treats the general forms of equations that describe natural phenomena. Applications of dimensional analysis abound in nearly all fields of engineering particularly in fluid mechanics and hydraulics. This course has the following objectives: • To introduce a systematic and thorough treatment of the principles of dimensional analysis for the solution of different engineering problems. • To provide knowledge in modelling and designing different types of problems • To provide knowledge of a routine numerical procedure for calculating a fundamental system of solutions of any set of homogeneous linear algebraic equation. • To provide knowledge in analyzing and implementing the real engineering problems

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	General: Dimensional considerations, algebraic theory of dimensional analysis, Buckingham's theorem and Rayleigh's method of analysis-application to standard problems, standard dimensionless numbers, dimensional matrix and its rank, systematic calculation of dimensionless products. Distorted models of open channels. Dimensional analysis applied to the theory of heat.	12	• Understand the significance of dimensional homogeneity in physical equations. • Apply the algebraic theory of dimensional analysis to engineering problems.
2.	Similitude: Kinds of similarity, similitude requirement, conditions for incompressible and compressible fluids, model laws from differential equations.	10	• Explain the different types of similarity: geometric, kinematic, and dynamic. • Formulate the conditions of similitude for both incompressible and compressible fluid flows.
3.	Similarity in hydraulic machinery, surge tanks, flow over weirs and spillways, flow through sluice gates, water and wind tunnel model and cavitation model.	12	• Apply the principles of similitude to the design and analysis of hydraulic structures and machinery such as: • Surge tanks

			• Flow over weirs and spillways • Flow through sluice gates
4.	Analogue models: Electrical analogy model, Hele-Shaw model and Membrane analogy model.	08	• Understand the principle and utility of analogue models in fluid mechanics.
	Total	42	

Course Outcome	After successfully completing this course, students will: •Understand how extensive use of scale-models for investigating problems of engineering raises many important questions that are resolved by dimensional analysis. •Understand the method of deriving model laws from the differential equations that govern particular phenomena. •Understand how the knowledge of this subject is also helpful in the analysis of problems of stress and strain •Be able to find the applications of dimensional analysis to some thermal problems. •Be able to have the ideas underlying the dimensions of electrical and magnetic entities to solve the problems applied to the electromagnetic theory.

Learning Resources	1. Dimensional Analysis and Theory of Models by Henry L. Langhaar 2. Theory of Hydraulic Model by M. Selim Yalin

Course Code	AM5110N	Course Name	Advanced Mechanics of Fluids	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Computational Fluid Mechanics
Course Offering Department		AE & AM		Data Book / Codes/Standards	N.A.

Course Objectives	Main objective is to provide fundamental knowledge of Fluid Mechanics from an advanced point of view, with an emphasis on elaborate mathematical treatment of fluid motion. Other objectives are as follows. • To deduce the governing equations of fluid flow in both integral as well as differential forms and to discuss a few exact solutions. • Offer in depth knowledge of Boundary layer equation in two-dimensions, Laminar and turbulent boundary layer, boundary layer separation and control. • To introduce compressible fluid flow and associated engineering problems

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Hydrodynamics: Continuity equation, rotation, vorticity and circulation, Euler's Equation and general Energy Equation, flow net, standard pattern of flows	09	• Formulate general transport equation • Formulate relationships between derived variables (*e.g.*, vorticity and strain rate) and primitive variables (*e.g.*, velocity and pressure) characterising fluid flow, • Understand the physical significance of stream function and velocity potential • Superimpose basic potential flow patterns to obtain more complex flow field
2.	Flow of Viscous Fluid: Navier-Stokes Equations and few exact solutions, approximate solutions for very slow motions. Boundary layer equation in two-dimensions, Laminar and turbulent boundary layer, boundary layer along a flat plate, mixing length theory, velocity distribution law-applications to open channel and pipe flows. Boundary layer separation and control, wakes, flow around immersed objects, lift and drag.	18	• Develop analytical ability for solving various laminar flow problems, • Formulate boundary layer equations and estimate the scale for BL thickness, • Evaluate skin friction drag for a flat surface, • Learn integral methods for boundary layer

			calculations • Understand the physics of boundary layer separation
3.	Closed conduit flow: pipe network, pressure waves in closed conduits, water hammer, surge chambers and tanks	10	• Understand the role of Reynolds number on pressure drop, • Calculate head loss, pipe size and flow rate for pipe network, • Evaluate the pressure surge associated with water hammer effect
4.	Compressible Fluid Flow: Fundamental concepts regarding velocity of sound, Mach number. Flow around a slender body-supersonic and transonic flow. Normal and oblique shock waves	05	• Determine sound speed in a medium (say, an ideal gas) • Understand the physics of shock waves
	Total	**42**	

Course Outcome	• Students will learn analytical methods of solving real-life fluid flow problems in two- and three-dimensions. • Develop thorough understanding of the fundamentals of flow physics and appropriate mathematical models. • be able to design pipe network systems which is very useful in engineering

Learning Resources	3. Viscous Fluid Flow, F.M. White, McGraw-Hill International. 4. Boundary Layer Theory, H. Schlichting, McGraw-Hill. 5. Applied Hydrodynamics by H. R. Vallentine, Springer Publications.

Course Code	AM5106N	Course Name	Viscous Fluid Flow	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Basic knowledge of Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Boundary Layer
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	This subject is intended to cover the fundamentals of fluid mechanics from an advanced point of view, with emphasis on the mathematical treatment of viscosity effects in laminar flows of a Newtonian fluid. Attention is given to the boundary layer equations for two dimensional steady flow, exact and approximate methods of the solution of two dimensional steady state incompressible boundary layer equations. We also provide an introduction to the compressible laminar boundary layers and numerical study of compressible flows using density based CFD techniques.

Module	Syllabus	Duration (class-hour)	Module Outcome
Viscous Fluid Flow (AM5106)			
1.	Review of basic concepts: continuum hypothesis, strain rates, origin of forces in viscous fluid flow	4	• Understand the continuum hypothesis and its implications in fluid mechanics modeling. • Analyze strain rates in deforming fluids and their role in viscous stresses.
2.	Dynamics of ideal fluid motion, applications, integrations of Euler's Equation of Motion, generalized form of Bernoulli Equation, potential flows, Principle of superposition.	4	• Understand and apply the concept of potential flow and the principle of superposition to idealized flow problems.
3.	Reynolds transport theorem and applications	4	• Formulate and apply the Reynolds Transport Theorem (RTT) for mass, momentum, and energy conservation in control volumes.
4.	Derivation of generalized differential continuity and momentum equations for viscous fluid flow in Cartesian and Curvilinear co-ordinates	8	• Derive generalized continuity and momentum equations

			(Navier-Stokes equations) for viscous flows in both Cartesian and curvilinear coordinate systems.
5.	Some exact solutions of N-S equations- Steady and unsteady parallel flows: Couette-Poiseulle flow, parallel plates; Flow at very low Reynolds number- Stokes flow equations	8	• Analyze steady and unsteady parallel flows using exact solutions of the Navier-Stokes equations.
6.	Boundary layer equations for two-dimensional steady flow. Separation of boundary layer. Integration of boundary layer equations. General properties of boundary layer equations. Exact and approximate methods of the solution of two dimensional steady state incompressible boundary layer equations. Flow in the wake of flat plate zero incidence	8	• Derive and apply the boundary layer equations for two-dimensional steady incompressible flow. • Analyze boundary layer separation, its causes, and implications on aerodynamic performance.
7.	Compressible laminar boundary layers and numerical study of compressible flows using density based CFD techniques	6	• Understand and analyze compressible laminar boundary layers, including their governing equations and properties.
	Total	**42**	

Course Outcome	After successfully completing this course, students will be able to: •Develop the capability of transforming the physics of viscous fluid flow problems into its equivalent mathematical model. • Attain the capability of solving the viscous fluid flow problems analytically. • Acquire the knowledge of boundary layer theory.

Learning Resources	1. F.M.White, Viscous Fluid Flow, McGraw-Hill international editions., 2011. 2. H.Schlichting, Boundary Layer Theory, McGraw-Hill Series in Mechanical Engineering, 1979 3. An Introduction to Fluid Dynamics – G. K. Batchelor – Cambridge University Press, 2000. 4. T. C. Papanastasiou, G. C. Georgiou, A. N. Alexandrou, Viscous Fluid Flow, CRC Press, 2000

Course Code	AM5108N	Course Name	Methods in Computational Fluid Dynamics	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Basic Fluid dynamics and mathematics	Co-requisite Courses	. None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	Computational Fluid Dynamics (CFD) plays a major role in engineering design. These methods are used in every field starting from the design of aircrafts, automobiles, turbo machineries, biomedical instruments, etc This course has three objectives: • Introduce basics of computational fluid dynamics and its applications •Provide theoretical knowledge and practical knowledge about finite volume method in CFD; • Provide knowledge in basic CFD programming

Module	Syllabus	Duration Class (hours)	Module Outcome
1.	**Governing equations:** Basics of computational fluid dynamics – Governing equations of fluid dynamics – Continuity, Momentum and Energy equations – Physical boundary conditions – Mathematical behaviour of PDEs on CFD – Elliptic, Parabolic and Hyperbolic equations, Grid generation and types – Finite Difference, Finite Volume, Finite Element Methods.	8	• Understand the basic principles of computational fluid dynamics (CFD) and its role in fluid flow analysis. • Derive and apply the governing equations of fluid dynamics: continuity, momentum (Navier-Stokes), and energy equations.
2.	**Finite volume method for incompressible flow:** Spatial Discretization - Convective and diffusive fluxes - Representation of the pressure gradient term and continuity equation – Staggered grid – Momentum equations – Pressure and Velocity corrections – Pressure Correction equation, SIMPLE algorithm and its variants – PISO Algorithms - QUICK Schemes.	10	• Implement the pressure gradient term and continuity equation using staggered grid layouts. • Derive and solve the momentum equations for incompressible flows.
3.	**Introduction to Numerical modeling of multiphase flows:** Introduction to multiphase flows and their classifications, Governing equations for multiphase flows; Lagrangian and Eulerian viewpoints, Two-fluid model, quadrature-based method of moment; Two-way interphase coupling, drag modeling.	8	• Understand the concept and classification of multiphase flows (gas-liquid, solid-liquid, gas-solid, etc.).
4.	**Turbulence modelling:** Introduction to turbulence - scales of turbulence, Reynolds Averaged Navier Stokes (RANS) equation, closure problem, eddy viscosity		• Comprehend the nature and characteristics of turbulence and its scales.

	model, k-ε and k-ω model - introduction to large eddy simulation (LES) - direct numerical simulation.	8	• Derive and interpret the Reynolds-Averaged Navier-Stokes (RANS) equations.
5.	**Numerical methods and programming practice:** Numerical methods – Programing and algorithm –1D heat conduction - 1D advection-diffusion – Flux schemes – 1D Euler solver	8	• Apply numerical algorithms for solving classical transport problems. • Develop and test a 1D Euler solver for inviscid compressible flow.
	Total	**42**	

Course Outcome	Computational Fluid Dynamics (CFD) plays a major role in engineering design. These methods are used in every field starting from the design of aircrafts, automobiles, turbo machineries, biomedical instruments, etc This course has three objectives: • Introduce basics of computational fluid dynamics and its applications •Provide theoretical knowledge and practical knowledge about finite volume method in CFD; • Provide knowledge in basic CFD programming

Learning Resources	1. Chung, T.J. “Computational Fluid Dynamics”, Cambridge University, Press, 2002. 2. Blazek, Jiri. Computational fluid dynamics: principles and applications. Butterworth-Heinemann, 2015. 3. Anderson, John David, and J. Wendt. Computational fluid dynamics. Vol. 206. New York: McGraw-Hill, 1995. 4. Patankar, S.V. “Numerical Heat Transfer and Fluid Flow”, Hemisphere Publishing Corporation, 2004. 5. ProdipNiyogi, Chakrabarty, S.K., Laha, M.K. “Introduction to Computational Fluid Dynamics”, Pearson Education, 2005. 6. Anil W. Date “Introduction to Computational Fluid Dynamics” Cambridge University Press, 2005.

Course Code	AM5134N	Course Name	Theory of liquid-solid interfaces	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fundamentals of Fluid dynamics, Basics of Physics and Chemistry, Engineering mathematics.	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	The focused objectives of the course are to discuss the physics of various processes which takes place at the liquid-solid interfaces. These interactions play a key role in our world in general and in many modern technologies in particular. Phenomena like adsorption, adhesion, crystallization, evaporation, dissolution, corrosion, film growth etc. are of fundamental importance in many engineering areas. Interfaces exist between any two phases which may be solid, liquid or gaseous. An understanding of interfacial processes is based on a detailed knowledge of the properties of the respective interface. In particular Surface-Science has been extremely successful in the advancement of understanding of properties and processes at free surfaces under different conditions. Under the scope of this course, theory and mathematical details of liquid-solid interfaces will be discussed elaborately.

Sl.	Article	No of Classes	Module Outcome
1	**Unit I: Introduction** Introduction to surfaces and interfaces, Surface energy, Surface area to volume ratio, Solid and solid surface roughness, Chemical heterogeneneity of solid surfaces, Surface tension, Capillarity and viscosity	8	• Students will get familiarize with interfaces and their types. Module will also focus on properties of solid, liquid, and solid-liquid interfaces.
2	**Unit-II: Liquid-solid contact** Thermodynamical concepts of interfaces, Gibb's dividing interface, Thermodynamics of adsorbtion, Conditions of equilibrium where several surfaces intersect, Relation of Thermodynamic Parameters with Intermolecular Forces, Contact angles, static contact angles and measurement, Dynamic contact angles and measurement, Temperature dependence of contact angles, Young's Equation and Use of Contact Angles in Industry, Contact Angle Hysteresis and its Interpretation, Solid Surface Tension Calculations from Contact Angle Results, Gravity effects, hydrophobicity, Super-hydrophobicity, Leidenfrost drops, Wetting dynamics, Capillarity, Effects of surface roughness, Effects of chemical heterogeneity	18	• Module will cover complete thermodynamical aspects of formation of liquid -solid interfaces in details. The module will help students in understanding the fundamental concepts and mechanisms involved in liquid-solid contact processes, including mass transfer, adsorption, and reaction phenomena. Module will also cover design and select suitable liquid-solid contact equipment's for engineering applications.

3	**Unit-III: Engineering Applications of Liquid-Solid Interfaces** Heat Transfer and Solidification During the Impact of a Droplet on a Surface, Interactions between Drops and Hot Surfaces, Low Speed Drop Impact Onto Dry Solid Surface, Asymptotic Theory of Droplet Spreading after Collision with a Solid Surface	8	• Module will cover various engineering applications where in-depth knowledge of droplets dynamics is required when liquid droplets gets interacted with solid surfaces.
4	**Unit-IV: Multiphase flows** Introduction to multiphase flows, Properties of dispersed phase flows, Size distribution, Particle-fluid interaction, Particle-particle interaction	8	• Understand and classify multiphase flow regimes, and to apply conservation laws to multiphase systems.
Total		**42**	

Course Outcome	After successfully completing this course, students will: ● Differentiate between surfaces and interfaces ● How liquid interacts with solid surfaces under different conditions ● Engineering applications of liquid-solid interfaces ● Multiphase flows and its application in engineering

Learning Resources	1. Surface chemistry of solid and liquid interfaces, H. Yildirim Erbil, Blackwell Publishing. 2. Drop-surface Interactions, Martin Rein, Sringer-Verlag Wein GmbH 3. Multiphase flows with droplets and particles, Clayton T. Crowe, CRC Press

Course Code	AM5130N	Course Name	Hydraulic Structures	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Hydraulics and Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	• To Introduce the basic considerations concerning the design of hydraulic structures, selection of construction materials, types of construction and foundation • To Introduce the analysis and design of structures on permeable foundation, uplift pressure, seepage flow, exit gradient • To provide knowledge about the analysis and design of earth dams • To provide knowledge about the design of concrete and masonry dams • To provide knowledge about the analysis and design of hydraulic structures for control and regulation-head regulator, intake, spillway, siphon, canal fall and cross drainage works.

Sl No.	Subject: Hydraulic Structure	No of classes	Module Outcome
1	Basic considerations concerning the design of hydraulic structures, calculation of strength and equilibrium, selection of construction materials, types of construction and foundation.	10	• Understand the basic principles and design considerations for hydraulic structures, including stability, safety, and functionality.
2	Analysis and design of structures on permeable foundation, uplift pressure, seepage flow, exit gradient	08	• Analyze the behavior of hydraulic structures built on permeable foundations.
3	Analysis and design of earth dams and rock fill dams.	06	• Understand failure modes such as slope instability, seepage failure, and piping. • Analyze the seepage through embankments using analytical and graphical methods.
4	Analysis and design of concrete and masonry dams-gravity, arch, counterfort, buttres and hollow	08	• Understand the loading conditions acting on these structures (water pressure, uplift, silt pressure, seismic forces).
5	Analysis and design of hydraulic structures for control and regulation-head regulator, intake, spillway, siphon, canal fall and cross drainage works.	10	• Design structures for hydraulic efficiency, structural integrity, and sediment control.
	Total	**42**	

Course Outcomes	After successfully completing this course, students will: ● become familiar with the different types of hydraulic structures including calculation of strength and equilibrium, selection of construction materials, types of construction and foundation ● become familiar with the analysis of uplift pressure, seepage flow, exit gradient ● be acquainted with the analysis and design of Earth dams, Concrete gravity dams, head regulator, Spillway, Siphon, canal Fall and Cross drainage works.

Learning Resources	1. Irrigation Engineering and Hydraulic Structures by S. K. Garg 2. Irrigation Engineering and Hydraulic Structures by V. C. Agarwal

Course Code	AM5126N	Course Name	Turbomachineries	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	Fluid Machines
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	The focused aim of the course is to discuss various types of turbo machines used in engineering for energy transformations. Some important energy generating turbo machines are steam, gas, and hydraulic turbines, while energy absorbing turbo machine are pumps, fans, blowers and compressors. All kinds of turbo machineries play an important role in the day to day life. The course focuses on the applications of turbo machinery in power generation, and transport.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	**Unit I: Introduction to turbo machines:** Classification of Turbomachines, Comparison with positive displacement machines, Dimensionless parameters and their significance, Model and prototype, Second Law of Thermo dynamics - turbine/compressor work, Fluid equations - Euler's, Bernoulli's equation and its applications, principles of impulse and reaction machines, degree of reaction.	8	• Module will familiarize students with different components of aircraft engines. Afterwards, brief introduction to various kind of turbomachines will be introduced with thermodynamical analysis.
2.	**Unit II: Energy exchange in turbo machines:** Euler's turbine equation, Alternate form of Euler's turbine equation, Velocity triangles for different values of degree of reaction, Components of energy transfer, Degree of Reaction, utilization factor, Relation between degree of reaction and Utilization factor	9	• Students will be able to understand the principles of energy transfer by using velocity triangles. Module will also help to evaluate the impact of losses, blade design parameters, and to optimize turbomachinery systems.
3.	**Unit III: Hydraulic Turbines:** Classification, Pelton, Francis, and Kaplan turbines, velocity diagrams and work-done, draft tubes, governing of water turbines. **Centrifugal Pumps:** Classification and parts of centrifugal pump, different heads and efficiencies of centrifugal pump, Minimum speed for starting the flow, Maximum suction lift, Net positive suction head, Cavitation, Need for priming, Pumps in series and parallel, Slip factor	8	• Module will help in understanding the principles of fluid flow and energy transfer. Students can classify, design, and explain working of different types of hydraulic turbines. Analyze the performance characteristics and efficiency, Design simple hydraulic turbine and pump systems.
4.	**Unit IV: Gas turbines and Compressors:** **Centrifugal Compressors**: Stage velocity triangles, slip factor, power input factor, Stage work, Pressure developed, stage efficiency and surging, Expansion and compression processes, Reheat Factor **Axial flow Compressors:** Expression for pressure ratio developed in a stage, work done factor,	10	• Module will help to understand the working principles of gas turbines and compressors. Students can apply thermodynamic and fluid dynamic principles for

	efficiencies and stalling **Axial turbine**-Description of operation, flow losses, turbine cooling, overall performance		**a**nalyzing and compare different cycles for d**es**ign of simple gas turbine or compressor systems
5.	**Unit V: Fans and Blowers:** Introduction to fans and blowers, Flow through Axial flow fans, Principles of Axial fan, Application of fans for air circulation and ventilation, Stage pressure rise and work done, Performance and characteristics of Axial fans, Fan laws.	7	• Module Will help to understand the fundamental principles and classifications, and to analyze fan and blower performance using velocity triangles, affinity laws, and characteristic curves.
Total		**42**	

Course Outcome	After successfully completing this course, students will: • Recognize typical designs of turbomachines • Explain the working principles of turbomachines and apply it to various types of machines • Determine the velocity triangles in turbomachinery • Explain the working principle of various types of hydro turbines and know their application range • Perform the preliminary design of turbomachines (pumps, compressors, turbines) on a 1-D basis • Determine the off-design behaviour of turbines and compressors and relate it to changes in the velocity triangles. • Recognize and discuss today's and tomorrow's use of turbomachines for enabling a sustainable society.

Learning Resources	1. S.M. Yahya, Turbines, Compreessors and Fans, Tata Mcgraw Hill. 2. Gopalakrishnan G, Prithvi Raj D, "A treatise on Turbomachines", Scitech Publications, Chennai, 2002. 3. Sheppard, Principles of Turbomachinery. 4. R.K.Turton, Principles of Turbomachinery, E & F N Spon Publishers, London & New York. 5. Venkanna BK; turbomachinery; PHI 6. Kadambi V Manohar Prasad; An introduction to EC Vol. **III**-Turbomachinery; Wiley Eastern Delhi

Course Code	AM5131N	Course Name	Hydraulic Machines	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Hydraulics and Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	● To Introduce the basic knowledge of Momentum and energy relations for fluid masses ● To Introduce the importance of Energy Transfer in the Turbomachines ● To provide knowledge about general classification, performance, similarity laws of Pelton turbines, Francis turbine, and Kaplan turbine. ●To provide knowledge about the Pump Casing, suction, pressure distribution and radial thrust in volute casing, performance characteristics of Centrifugal Pump.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Momentum and energy relations for fluid masses: Laws of motion for open systems, Kutta-Joukeski theorem, energy transfer, simple propeller theory.	6	• Understand and apply the laws of motion for open systems to analyze forces and momentum exchange in fluid machinery.
2.	Energy Transfer in the Turbomachines: analysis of Torque, Axial force and energy balance, Classical turbine theory.	6	• Analyze and explain the classical turbine theory and its application to axial and radial flow machines.
3.	Theory of Centrifugal Pump Impeller: discussion on Euler's characteristics and Euler's velocity triangle, flow through impeller, dimensionless group, effect of reduction of impeller diameter, different design constants and coefficients.	10	• Understand the significance of dimensionless groups (e.g., specific speed, flow and head coefficients) in pump design.
4.	Pump Casing: suction nozzle, volute, pressure distribution and radial thrust in volute casing.	5	• Evaluate radial thrust generated due to non-uniform pressure distribution and its implications for shaft loading and bearing design.
5.	Hydraulic turbines: general classification, performance, regulation and selection, similarity laws and scale effects, Pelton turbines, Francis turbine, Propeller and Kaplan turbine.	10	• Understand the regulation mechanisms for various turbines and criteria for their selection based on site conditions.
6.	Consideration of water hammer and surge	5	• Understand the phenomenon of water

			hammer in pipelines and assess its causes and consequences.
Total		**42**	

Course Outcome	After successfully completing this course, students will: ● become familiar with the different types of hydraulic machines ● become familiar with the energy transfer in the turbomechanics ● be acquainted with the performance characteristics of turbines ad pumps ● develop an understanding of water hammer and surge

Learning Resources	1. Theory of Hydraulic Mchines by V. P. Vasandani 2. Fluid Mechanics and Hydraulic Machines by R. K. Rajput

Course Code	AM5132N	Course Name	Ground Water Flow	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Hydraulics and Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	● To Introduce the basic knowledge of properties of porous media,laws of seepage flow ● To introduce the importance of Flownet, Conformal mapping, numerical, graphical, experimental, and other analogy methods. ● To provide knowledge about structures of permeable foundation and pressure wells ● To provide knowledge about the seepage through earth dams.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	General hydrodynamic equation of flow, properties of porous media, and laws of seepage flow, velocity potential and stream functions.	8	• Understand and formulate the general hydrodynamic equations of flow in porous media.
2.	Flownet, boundary conditions, conditions for non-uniform flow.	4	• Construct and interpret flow nets for two-dimensional seepage problems in isotropic and anisotropic media.
3.	Elements of conformal transformation, conformal mapping, Schwarz-Christoffel transformation.	6	• Understand the principles of conformal transformation and its application in seepage and flow field analysis.
4.	Methods of solution-analytical, numerical, graphical, experimental, viscous and other analogy methods.	6	• Compare and apply different solution techniques for seepage problems.
5.	Confined flow of a single fluid: structures on permeable foundation, pressure wells	6	• Apply solutions to practical problems involving pressure wells, flow beneath dams, and other hydraulic structures.
6.	Unconfined flow of a single fluid: Dupit's assumptions, Dupit-Forchheimer theory, seepage through earth dams.	5	• Understand and apply Dupuit's assumptions and Dupuit-Forchheimer theory for unconfined aquifer flow.
7.	Basic concepts and equation of unsteady ground water flow, applications to simple problems.	7	• Understand the basic concepts and governing equation of unsteady groundwater flow.

Total	**42**	

Course Outcome	After successfully completing this course, students will: ● become familiar with porous media, laws of seepage flow ● become familiar with Conformal Transformation, Schwarz-Christoffel Transformation ● be acquainted with numerical, graphical, experimental and other analogy methods ● develop an understanding of structures on permeable foundation, pressure wells, seepage flow through earth dams

Learning Resources	1. Groundwater and Seepage by M.E. Harr 2. Groundwater Hydrology by V.C. Agarwal

2nd Semester Courses Syllabi

M. Tech. in Applied Mechanics with Specialization in Hydraulic Engineering

Course Code	AM5218N	**Course Name**	Advanced Open Channel Hydraulics	**Course Category**	PC	L	T	P
						3	0	0

Pre-requisite Courses	Open Channel Hydraulics	**Co-requisite Courses**	None	**Progressive Courses**	River Mechanics
Course Offering Department		AE & AM		**Data Book / Codes/Standards**	NA

Course Objectives	In recent years' water-resources projects and hydraulic engineering works have been developing rapidly throughout the world. The knowledge of open channel hydraulics which is essential to the design of many hydraulic structures has thus advanced by leaps and bounds. This course has the following objectives: • To introduce basic principles, the types of unsteady flow in open channels classified according to the variation in the parameters of flow with respect to space and time, coefficients for velocity and pressure distributions. • To introduce unsteady gradually varied flow, rapidly varied unsteady flow, design of erodible, non-erodible and grassed channels. • To provide knowledge on gradually varied unsteady flow, wave profile, wave propagation, several methods for the computation of flow profiles, solution of unsteady flow. • To provide knowledge in rapidly varied unsteady flow involving moving hydraulic jump, its use as energy dissipater, positive and negative surges in canals, channel transitions, different methods in flood routing and implementing the real engineering problems

Module	**Syllabus**	**Duration (class-hour)**	**Module Outcome**
1.	Gradually Varied Unsteady Flow: continuity and dynamic equations, wave profile, monoclonal rising wave, uniformly progressive flow, wave propagation, solution of unsteady flow equation.	10	• Understand the development and characteristics of wave profiles, including monoclonal rising waves and uniformly progressive flows.
2.	Rapidly Varied Unsteady Flow: moving hydraulic jump, positive and negative surges in canals, channel transitions and channel junctions, pulsating flow.	10	• Analyze flow conditions involving rapid changes, such as moving hydraulic jumps in open channels.
3.	Flood Routing: characteristic method, diffusion analogy method, hydrologic routing, routing in non-prismatic channel.	10	• Understand and apply various methods of flood routing for open channel systems:
4.	Propagation of tidal waves in rivers and channels	12	• Understand the influence of tidal dynamics, channel geometry, and boundary conditions on wave behavior.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: •Understand how extensive use of open channel flow is made for different practical real problems related to water resources and hydraulic engineering works. •Understand the modern numerical methods for solving the governing equations of different problems and also understand the solution of dam break problems both by numerical and simplified methods of computations. •Understand the treatment of rapidly varied unsteady flow problem largely supported by experimental data because this type of flow is so complicated that a mere theoretical analysis in most cases will not yield sufficient information for the purpose of practical design. •Be able to design different channels like lined and unlined channel, stable channel, earthen channel and grass-lined channel considering both economic and seepage losses. •Be able to have the ideas of flow through bridge contractions, the control of hydraulic jumps with sharp and broad-crested weirs, abrupt rises and drops, stilling basins, spillway structures and the design of channel transitions, the design, construction and use of physical models in the study of open channel hydraulics.

Learning Resources	1. Open Channel Hydraulics by VenTe Chow 2. Open Channel Hydraulics by Richard H. French

Course Code	AM5216N	Course Name	Theory of Turbulence	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Differential Equation	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	• Introduce the basic properties of turbulence: Random fluctuating structures over a large range of length- and time-scales. • Introduce the importance of turbulent mixing and transport of momentum in practical flows. • Expose the students to theoretical and experimental techniques used to describe and quantify the effects of turbulence

Module	Syllabus	Duration (class-hour)	Module Outcome
1	The transition to turbulence: Experiments of Taylor, Benard and Reynolds. Role of the non-linear term of the Navier Stokes equation. Introduction to instability theory in the context of transition to turbulence.	4	• Students will become familiar with why a laminar flow transit to the turbulent regime
2	The statistical description of turbulent flows: the random nature of turbulence, characterization of random variables, probability distributions, joint random variables, random process, probability and averaging, correlation time, correlation length, two point correlation, Fourier modes	4	• Students will become familiar with the statistical description of turbulent flows
3	The scales of turbulent motion, the energy cascade and Kolmogorov hypothesis, Energy spectrum	3	• Students will become familiar with the scales to turbulent flow and the spectral representation
4	Reynolds equation of motion in Cartesian and cylindrical coordinates, Reynolds stress tensor, the closure problem of turbulence	4	• Students will be familiar with the RANS equations and why turbulence modelling is required
5	Reynolds stress equation, Kinetic energy equation of the mean motion and the fluctuating motion, Energy transfer between the mean motion and the fluctuating motion, intercomponent transfer of energy, role of pressure, dissipation equation	6	• Students will understand the equations for turbulence closure for the RANS based approach
6	Vortex terms in the equation of motion, Reynolds stress and vortex stretching, The vorticity equation, Vortex line, Vortex tube, Vorticity in turbulent flows	4	• Students will understand the vorticity-based approach for quantifying turbulent flows
7	Wall flows: balance of mean forces, near wall shear stress, mean velocity profile, the law of the wall, the log law, the wall region and different	6	• Students will understand the characteristics of turbulent flows over a flat plate and duct

	layers, the velocity defect law, length scales and mixing length		flows
8	Free shear flows, Plane turbulent free jet: experimental observations, equations of motion, the integral momentum equation, similarity analysis of the equations of motion, the integral energy equation, entrainment hypothesis, integral moment of momentum equation.	5	• Students will understand the treatment of free shear turbulent flows
9	Introduction to turbulence modelling: eddy viscosity model, one equation turbulence models, two equation turbulence models	6	• Students will be introduced to the RANS based turbulence modelling
	Total	**42**	

Course Outcome	• Students will become familiar with fundamental physics of turbulent flows. • Students will become familiar with transport of moment, energy and vorticity in turbulent flows. • Students will become familiar with the applications of turbulence in industry and environment. • Students will be able to analyze simple shear, wall bounded and boundary layer flows with the use of phenomenological models of turbulence. • Students will become familiar with different turbulence modelling techniques

Learning Resources	1. Tennekes & Lumley (Main text): A first course in turbulence (1972) 2. Steven A. Pope (Supplementary text): Turbulence, Cambridge (2004). 3. P. A. Davidson (Secondary text): Turbulent Flows, Oxford (2000)

Course Code	AM5217N	Course Name	Advanced Hydraulics	Course Category	PC	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics and Hydraulics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	● To Introduce the basic knowledge of conformal transformation with some simple transformation like Uniform flow, Vortex, doublet, source and sink, flow into a rectangular channel ● To Introduce the importance of Graphical flow nets and experimental analogies including the membrane analogy, the electrical analogy and the viscous flow analogy ● To provide knowledge about the Ground Water Flow, Waves and Wave Forces ● To provide knowledge about the principles of sediment transport.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Ideal Flow: Conformal Transformation, Analytic functions, singularities, Inverse Transformation, Successive Transformation, Some simple Transformation-uniform flow, Vortex, Doublet, Source and Sink, flow into a rectangular channel	10	• Understand and apply complex potential theory, including analytic functions and singularities, in fluid flow modeling.
2.	Graphical Flow Nets: principle, method of construction, flow net for flow over a weir, flow net and pressure distribution for flow under a sluice gate, seepage flow nets, confined and unconfined flow. Numerical Analysis: principle and method. Experimental Analogies: the membrane analogy, the electrical analogy and the viscous flow analogy.	10	• Explain the principle of flow net construction and its importance in solving two-dimensional potential flow problems.
3.	Ground Water Flow: Laws of seepage, steady confined and unconfined flows, methods of solution, well hydraulics	07	• Apply numerical analysis techniques for approximating solutions to flow problems governed by Laplace's or Poisson's equations.
4.	Waves and Wave forces: Theories of wave motion-small amplitude and finite amplitude wave theories, wave deformation, wave forces on structures.	08	• Understand theories of wave motion, including small amplitude (Airy) and finite amplitude wave theories.
5.	Principles of sediment transport: Hydraulic properties of sediment, sediment transporting capacity, description of transport process	07	• Understand the transport processes of bed load, suspended load, and total load in open channels.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: ● become familiar with fundamentals of conformal transformation and be able to do some simple Transformation-uniform flow, Vortex, Doublet, Source and Sink, flow into a rectangular channel ● be able to draw flow net for flow over a weir, flow net and pressure distribution for flow under a sluice gate, seepage flow nets of earthen dam which are essential to design the hydraulic structures in the practical field. ● become familiar with the sediment transport principles which will be helpful in the construction of any river training works in the real field.

Learning Resources	1. Applied Hydrodynamics by H. R. Vallentine 2. Irrigation Engineering and Hydraulic Structure by S. K. Garg

Course Code	AM5219N	Course Name	Fluid Power control system	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	
	• Introduce fluid power components, circuits, and systems • Provide theoretical knowledge in designing, analyzing and implementing control systems for real and physical systems; • Provide knowledge in modeling, control and other dynamical systems concepts. • Understand hazards of hydraulic and pneumatic circuits and be able to work safely. • Understand the concepts of fluid statics and dynamics as applied to commercial and industrial control. • Recognize standard schematic symbols for common fluid power components.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	**Fluid Power Systems and Fundamentals:** Introduction, Advantages and Disadvantages of Fluid Power System, Types and Applications of Fluid Power Systems, Hydraulic Oil and its Characteristics.	2	• By the end of this module, students will be able to explain the fundamentals of fluid power systems, identify their advantages, disadvantages, and applications, differentiate between types of systems, and understand the properties and characteristics of hydraulic fluids.
2.	**Hydraulic Systems and Components:** Sources of Hydraulic Power, Pumping Theory, Pump Classification, Gear Pumps, Vane Pumps, Piston Pumps.	3	• Students will be able to understand the sources of hydraulic power, explain the principles of pumping theory, and classify and analyze the working of various hydraulic pumps including gear, vane, and piston pumps
3.	**Fluid Power Actuators:** Hydraulic Actuators, Hydraulic Cylinders, Hydraulic Motors.	2	• Students will be able to describe the operating principles and applications of fluid power actuators, including hydraulic actuators, cylinders, and motors.

4.	**Hydraulic Elements in the Design of Circuits:** Introduction to the design of Hydraulic Circuits, Control elements, Direction Control valve, Check Valves, Flow Control and Pressure Control valves. Filters and Filtration Technology, Accessories and Connections	3	• Students will be able to design basic hydraulic circuits and understand the function and operation of key control elements including direction control valves, check valves, flow control valves, and pressure control valves.
5.	**Accumulators and Intensifiers:** Function of Accumulators, Types of Accumulators, Accumulator-Applications and Circuits, Intensifiers.	3	• Students will be able to explain the functions and types of accumulators, analyze their applications in hydraulic circuits, and understand the operation and role of intensifiers in fluid power systems.
6.	**Design and Drawing of Hydraulic Circuits**	4	• Students will be able to design and interpret hydraulic circuits and create schematic drawings for various fluid power applications
7.	**Fluid Power in Machine Tools and Other Equipment:** Introduction, Hydraulic Clamping Circuits in machine Tools, Speed Control in One Direction (DCV and FCV Combination), Meter-in Feed Circuit (DCV and FCV Combination), Meter-out Circuit DCV and FCV Combination), Speed Control in Both Directions (DCV and FCV Combination)— Tank Line Feed Control, Hydraulic circuit for Plastic Injection Moulding Machine, Hydraulic Press Application.	4	• Students will be able to analyze and design hydraulic circuits used in machine tools and industrial equipment, including clamping, speed control, and specific applications such as plastic injection molding machines and hydraulic presses
8.	**Pneumatic systems-Concepts and Components:** Introduction, Comparison of Pneumatic/Hydraulic/ and Electrical Systems, Air-Compression System, Types of Compressors, Compressor Specifications, Understanding Pneumatic Circuits, Control Valves	4	• Students will be able to understand the fundamental concepts and components of pneumatic systems, compare them with hydraulic and electrical systems, and analyze pneumatic circuits including air compression systems and direction control valves
9.	**Design of Pneumatic Circuits:** Pneumatics Circuit Design, Control Air vs Signal Air, Building a Pneumatic Circuit, Speed control	4	• Students will be able to design pneumatic circuits, differentiate between control air and signal air, and

	Circuits, Position Sensing in Pneumatic Cylinders, Pressure Sensing in Pneumatic Circuits. **Introduction to Fluidics:** Coanda or Wall Attachment Effect, Fluid Sensors		implement speed control, position sensing, and pressure sensing techniques in pneumatic systems.
10.	**Electropneumatics:** Pilot-operated Solenoid Valve, Electrical Connections to the Solenoids, Electrical limit Switches and Proximity Switches, Relays, Solenoids.	3	• Students will be able to understand and apply the principles of electropneumatics, including the operation of pilot-operated solenoid valves, electrical connections, limit switches, proximity switches, relays, and solenoids in fluid power control systems
11.	**Servo and Proportional Systems:** Conventional Valves vs Proportional Valves, Hydromechanical Servo System, Proportional Valves in Hydraulic Circuits, Closed-loop Control with Servo System, Electro-hydraulic Servo System, Dynamic Characteristics of Proportional Valves and Servo Valves, Control Electronics, Design Criteria, Filtration of Hydraulic System with Servo and Proportional Valve, Example of Application using Proportional and Servo Valves	6	• Students will be able to understand the principles and applications of servo and proportional systems in fluid power control, differentiate between conventional, proportional, and servo valves, and analyze their roles and characteristics in hydraulic circuits.
12.	**PLC applications in Fluid Power:** Introduction, Logic in Ladder Diagrams, Low-Cost Automation	2	• Students will be able to understand the basics of Programmable Logic Controllers (PLCs) and apply ladder logic and mnemonic programming to control fluid power systems.
13.	**Failure and Troubleshooting in Fluid Power Systems:** Installation, Maintenance and Troubleshooting of Oil Hydraulics and Pneumatics	2	• Students will be able to identify common failures in fluid power systems and apply systematic troubleshooting techniques for both hydraulic and pneumatic systems.
	Total	**42**	

Course Outcome	After successful completion of the course, the students will • Understand and troubleshoot basic fluid power, electro-hydraulic, and electro-pneumatic circuits using schematic diagrams. • Understand the operation, application, and maintenance of common fluid power components such as pumps, compressors, valves, cylinders, motors, rotary actuators, accumulators, pipe, hose, and fittings. • Be able to find component application data online. • Be able to select components from manufacturer's catalogs.

Learning Resources	1. Introduction to Hydraulics and Pneumatics by Ilango and Soundararajan (PHI) 2. Hydraulics and Pneumatics by Jagadeesha T (I.K. international) 3. Hydraulic and Pneumatic Controls by R Srinivasan 4. Pneumatics Systems: Principles and Maintenance - S Majumdar

Course Code	AM5252N	Course Name	Flow through Porous Media	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	The understanding of flow and transport processes in porous media is pertinent to many important applications in engineering. In this course basic theory and mathematics of porous media flow is developed. The students will learn to set up mathematical models relevant to applications and solve these in simplified settings.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Properties of porous media, laws of seepage, and general hydrodynamic equations of flow.	11	• Students will be able to describe the properties of porous media, apply seepage laws, and formulate general hydrodynamic equations governing flow through porous materials.
2.	Flow of a single fluid: Steady state flow of incompressible and compressible fluids, unsteady flow theory, linear and radial unsteady flow problems.	11	• Students will be able to analyze the steady and unsteady flow of single-phase fluids through porous media, including both incompressible and compressible cases, and solve linear and radial unsteady flow problems.
3.	Elements of the flow of two or more immiscible fluids.	10	• Students will be able to understand and analyze the fundamental principles governing the flow of two or more immiscible fluids through porous media
4.	Methods of solutions-analytical, numerical, graphical, and experimental methods, electric and viscous analogue methods.	10	• Students will be able to apply analytical, numerical, graphical, and experimental methods—including electric and viscous analogues—to solve flow problems in porous media.
	Total	**42**	

Course Outcome	After successfully completing this course, students are expected to be able to: ● Describe notions like porosity, permeability, or saturation ● Describe miscible and immiscible flow in porous media ● Describe the principle of capillarity pressure and relative permeability ● Give a complete model for two-phase flow

Learning Resources	1. The physics of flow through porous media by Adrian E. Scheidegger

Course Code	AM5217N	Course Name	Compressible Flow	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Basic fluid mechanics	Co-requisite Courses	None	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	This course offers a comprehensive overview of supersonic flow aerodynamics, covering its fundamental principles and potential applications.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**One-Dimensional Flow:** One Dimensional Flow revisited; Hugoniot Equations; One Dimensional Flow with Heat Transfer; One Dimensional Flow with Friction. Problems.	6	• Introduction, Review of Fluid Mechanics and thermodynamics, Basic ideas over governing equations of compressible flows and its parameters • Idea on shock wave, Fanno and Rayleigh lines
2	**Two-Dimensional Flow:** Two-Dimensional Flow revisited; Shock Polar; Shock Reflection and Intersection; Bow Shock in front of a Blunt Body; Three-Dimensional Shock Waves; Prandtl-Meyer Expansion Waves; Shock-Expansion Theory. Problems.	8	• Effects of Shock and Expansion waves on aerodynamic characteristics.
3	**Quasi One-Dimensional Flow:** Quasi One-Dimensional Flow revisited; Nozzles; Diffusers. Problems.	6	• Exploring the relationship between area and Mach no
4	**Unsteady Wave Motion:** Introduction; Moving Normal Shock Waves; Reflected Shock Waves; Elements of Acoustic Theory; Finite Waves; Incident and Reflected Expansion Waves; Shock tube Relations; Finite Compression Waves.	8	• Unsteady Wave Motion
5	**Linearised Flow:** Introduction; Differential Conservation equations for Inviscid Flow; Crocco's Theorem; Velocity Potential Equation: Linearised Velocity Potential Equation; Linearised Subsonic Flow; Linearised Supersonic Flow; Method of Characteristics.	6	• Ideas over linearized supersonic flows

6	**Three-Dimensional Flow:** Cones at Angle of Attack; Blunt Bodies at Angle of attack.	4	• Three-Dimensional Flow
7	**Numerical Techniques:** Steady and Unsteady Supersonic Flow	4	• Basic ideas over numerical techniques for different flow regimes
	Total	**42**	

Course Outcome	After successfully completing this course, students should be able to understand and apply 1D, 2D flow and governing equations for shock waves and expansion waves, linearised high speed flows and its applications.

Learning Resources	**1.** J. D. Anderson Jr., Modern Compressible Flow with Historical Perspective, McGraw Hill **2.** A H Shapiro, Dynamics and Thermodynamics of Compressible Fluid Flow-Volume **I**& **II**, Ronald Press **3.** H W Liepmann and A Roshko,Elements of Gas Dynamics, John Wiley & Sons

Course Code	AM5246N	Course Name	Instrumentation in Fluid Mechanics	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Basic knowledge of Fluid Mechanics	Co-requisite Courses	Advanced Mathematics, Basic Electronics and Instrumentation.	Progressive Courses	None
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	This course will deal with the details of various instruments as well as measurements of physical quantities related to fluid flow. The course will deal with both theoretical understanding and numerical problems of flow measurement, uncertainty, error analysis etc.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Introduction, Flow Properties and Basic Principles, Wind Tunnels and Water Tunnels	5	• Understand the fundamental properties of fluid flow and their relevance in experimental fluid mechanics.
2.	Flow visualization techniques, Introduction to measuring instruments Measurement Uncertainty	9	• Understand the significance of visualization in validating computational models and in qualitative flow analysis.
3.	Measurement of Pressure and volume flow rate, velocity, Force Measurements, Temperature measurements, Hotwire Measurements	9	• Measure velocity using Pitot-static tubes, hotwire anemometry, and modern optical methods. • Conduct force measurements using load cells and force balances in wind tunnel testing.
4.	Data Acquisition, Processing and uncertainty analysis, Static and dynamic response of measuring systems	9	• Analyze and model the static and dynamic response of sensors and measurement systems to improve measurement fidelity.
5.	PIV Measurements, Integral optical measurement techniques: Shadowgraph, Schlieren & Interferometers, LDV Measurements	10	• Understand and utilize Laser Doppler Velocimetry (LDV) for point-wise velocity measurements with high accuracy.
	Total	**42**	

Course Outcome	After successfully completing this course, students will: (1) Understand the physics behind fluid flow visualisation and techniques (2) Fundamentals of flow measurements and proper selection of instruments, range, uncertainty (3) Learn computerized data acquisition (4) Physics of optical measurements, measurement of flow field using PIV (5) Intrusive and non-intrusive measurements.

Learning Resources	1. Tavoularis, S., Measurement in Fluid Mechanics, Cambridge University Press, 2005 2. R.J. Goldstein (Editor), 1996. Fluid Mechanics Measurements, 2nd Edition, Taylor and Francis, Washington. 3. E. Rathakrishnan, 2007. Instrumentation, Measurements and Experiments in Fluids, CRC Press, Boca Raton, Florida.

Course Code	AM5236N	Course Name	Nonlinear Dynamics and Chaos	Course Category	PSE	L	T	P
						3	0	0

Pre-requisite Courses	Fundamentals of Mechanics, Elementary Mathematics and Calculus	Co-requisite Courses	Nil	Progressive Courses	Application in atmospheric science and biological science
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	From the Newton's law of motion, it appears that, for the known initial conditions and the interacting forces, history of motion of a particle may be predicted forever into the future. It has, however, been uncovered now that such infinite predictability in dynamics may not be possible even for simple dynamical systems if they are essentially nonlinear in nature. In this background, the goal of this course is to introduce the ideas of nonlinear dynamics and standard mathematical approaches to explore problems of nonlinear dynamics and chaos that essentially exist in nature. Indeed, nonlinearity does exist in natural phenomena, virtually covering every area of science and engineering. This course may thus be of significant interest to students of engineering and science even for inter-disciplinary research.

Serial No.	Article	No. of classes	Module Outcome
01.	**Introduction:** Review of linear and non-linear vibration and introduction to bifurcations, Concepts of maps and flows, Overview of chaos and fractals.	**04**	• Students will be able to distinguish between linear and nonlinear systems and develop basic ideas of maps, flows, chaos and fractals
02.	**1-D Dynamical Systems**: Fixed points, Stability, Bifurcations – Ideal and imperfect, Some canonical forms, A connection with physical problem.	**05**	• Students will be able to analyze fixed points and their stability, understand ideal and imperfect bifurcations through canonical forms, and relate these concepts to relevant physical problems
03.	**2-D Dynamical Systems:** Phase plane, Fixed points and linear stability analysis, Limit cycles, Bifurcations revisited, Index theory, Examples from Newtonian dynamics.	**08**	• Students will be able to analyze dynamical systems using phase plane methods, determine the stability of fixed points, identify limit cycles, apply index theory, and interpret various types of bifurcations.

04.	**Analytical Methods**: Averaging techniques, Perturbative methods, Duffing and Van der Pol oscillators.	**08**	• Students will be able to solve weakly nonlinear systems using approximate analytical methods like Averaging and Perturbation techniques
05.	**Parametric Oscillators**: Introduction, Floquet theory, Mathieu equation, Linearly damped Mathieu equation.	**05**	• Students will be able to qualitatively analyze parametric oscillators using Floquet theory, understand the behavior of the Mathieu equation and its solutions
06.	**Discrete Dynamical Systems**: Introduction, Bernoulli shift, Lyapunov exponent, Logistic map and Conjugate tent map, Routes to Chaos.	**06**	• Students will be able to analyze discrete dynamical systems, interpret the behavior of maps such as the Bernoulli shift, logistic map, and tent map, compute Lyapunov exponents, and understand various routes to chaos.
07.	**3-D Dynamical Systems:** Lorenz model, Geometry of strange attractor, Relation between dimension definitions and Lyapunov exponent, Fractal basin boundaries	**06**	• Students will be able to analyze 3-D dynamical systems using the Lorenz model, interpret the geometry of strange attractors, relate various definitions of dimension to Lyapunov exponents, and understand the concept of fractal basin boundaries
Total		**42**	

Course Outcome	After successfully completing this course, students are expected to achieve: (a) a newer insight into the subject 'Dynamics' far beyond the Newtonian Dynamics (b) understanding on the predictability/unpredictability of various physical systems (c) realization to different inter-disciplinary problems involving nonlinearity and (d) renewed interest in the area of promising research.

Learning Resources	1. 1. Nonlinear Dynamics and Chaos by S. H. Strogatz, Westview 2. 2. Nonlinear Oscillations by A.H. Nayfeh and D.T. Mook, Wiley, 1979 3. 3. Nonlinear Oscillation in Physical Systems by C. Hayashi 4. Chaotic Vibrations: An Introduction for Applied Scientists and Engineers by F. C. Moon, Wiley

Open Elective Subjects

Detailed Syllabus

1st Semester Syllabus for Open Elective Subjects

Course Code	AE5161N	Course Name	Launch Vehicle Aerodynamics	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics, Thermodynamics, Gas Dynamics	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	After completing the course, students will be able to: • Develop proficiency in launch vehicle technology and relevant theories. • Analyze aerodynamic forces and moments acting on launch vehicles under different flow conditions. • Understand and appreciate design considerations involved in developing launch vehicles.

Module	Syllabus	Duration (class-hour)	Module Outcome
I	**Fundamentals of high-speed flows:** Isentropic flow relations, Mathematical relationships of flow properties across Normal and oblique shock waves, Taylor-Maccoll equation and flow behind conical shock waves, Prandtl-Meyer function	9	• To understand the basics of compressible flows • To revisit key elements of external high-speed flow.
II	**Launch vehicle design:** Types of rockets and missiles, different configurations, components-nose cone design, inter-stage flares, boattailing, slender body theory, forces and moments induced during atmospheric flight, pressure and skin-friction drag estimation, base drag, wake and vortex shedding dynamics	10	• To be introduced to the various components of typical launch vehicles. • To be able to calculate the aerodynamic force and moment coefficients due to these components.
III	**Viscous effects on slender bodies:** Fundamentals of boundary layer theory, Compressible boundary layers, shock wave/boundary layer interaction,	10	• To study the interaction of shock waves and boundary layers

	asymmetric flow separation, shock-induced unsteadiness, aero-elastic effects-launch vehicle buffeting		• To understand the nature and significance of aero-elastic phenomenon
IV	**Wind-Body Interference:** Planar and cruciform configurations, lift distribution in wing and body, canard and tail arrangements, wing-tail interference	6	• To analyse the complex flow behaviour at the wing-body juncture. • To study how lifting surfaces are optimally arranged
V	**Aerodynamics of atmospheric ascent:** Stability and control of launch vehicles, cross-wind effects, boosters-integration and separation	7	• To introduce the concepts of aerodynamic stability and control • To explore how launch vehicles remain robustly stable even in highly dynamic environments.

Course Outcome	After completing the course, students will be able to: • Develop proficiency in launch vehicle technology and relevant theories. • Analyze aerodynamic forces and moments acting on launch vehicles under different flow conditions. • Understand and appreciate design considerations involved in developing launch vehicles.

Learning Resources	1. Jack N. Neilsen, H. Guyford Stever, "Missile Aerodynamics," McGraw Hill, New York, 1960. 2. S. S. Chin, "Missile Conffiguration Design,", McGraw Hill, New York, 1961. 3. John. D. Anderson Jr., "Modern Compressible Flow,", McGraw Hill Book Co., New York, 1999.

Course Code	AE5162N	Course Name	Industrial Aerodynamics	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	NIL	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		AE&AM		Data Book / Codes/Standards	Nil

Course Objective	The objective of this course is to provide students with a comprehensive understanding of wind effects on natural and engineered systems. It aims to develop fundamental knowledge of atmospheric circulations, boundary layer flows, and turbulence, while introducing advanced concepts in wind energy aerodynamics, vehicle aerodynamics, and structural aerodynamics. The course further seeks to build analytical and computational skills to evaluate aerodynamic loads, wake interactions, aeroelastic instabilities, and flow-induced vibrations. Emphasis is placed on applying theoretical principles, experimental methods, and computational tools to design safe, efficient, and sustainable engineering solutions in the fields of energy, transportation, and infrastructure.

Module	Syllabus	Duration (class-hrs)	Module Outcomes
Unit 1	**Atmosphere and Wind Characteristics:** Atmosphere and Atmospheric Circulations, Atmospheric Condition Monitoring Devices, Types of winds, Causes of variation of winds, Atmospheric boundary layer, Effect of terrain on gradient height, Structure of turbulent flows.	7	Students will be able to describe the nature of atmospheric and mesoscale circulations, identify different types and causes of variation of winds, and analyze the atmospheric boundary layer with its stability characteristics. They will gain skills to assess the effect of terrain on wind gradients, evaluate turbulent flow structures, and use monitoring devices for measuring.
Unit 2	**Wind Energy Aerodynamics:** Horizontal-axis wind turbine (HAWT) aerodynamics: blade element momentum (BEM) theory, tip losses, wake rotation -Vertical-axis wind turbines (VAWT): dynamic stall, wake interaction, efficiency limits - Betz–Joukowsky limit and extensions - Unsteady aerodynamics in wind farms: wake interference, array effects, blockage - Aerodynamic noise and mitigation strategies.	9	Students will be able to explain the aerodynamic principles of horizontal- and vertical-axis wind turbines, apply blade element momentum theory to estimate turbine performance, and analyze wake rotation, dynamic stall, and efficiency limits. They will also acquire the ability to evaluate wake interactions and array effects in wind farms, identify aerodynamic noise sources.
	Vehicle Aerodynamics: Ground vehicle aerodynamics: flow separation, underbody flows, cooling drag - Active flow control - Drag reduction strategies: boat tails, diffusers, base		Students will have the capability to analyse aerodynamic flow features around ground vehicles, including flow separation, underbody flows, and drag-producing

Unit 3	bleed - High-speed train aerodynamics: tunnel entry/exit effects, slipstreams, pressure waves - Emerging personal aerial vehicle aerodynamics.	**8**	regions. They will develop an understanding of transient effects, stability in crosswinds, and aerodynamic aspects of emerging personal aerial vehicles.
Unit 4	**Building and Structural Aerodynamics:** Bluff body aerodynamics: pressure distribution, vortex shedding, Strouhal scaling - Tall buildings: interference effects, torsional loading, aeroelastic instabilities - Computational wind engineering (CWE): CFD modeling strategies, LES/DES for built environments - Wind tunnel modeling: similarity laws, scaling, boundary layer generation.	**10**	Students will be able to investigate bluff body aerodynamics with a focus on vortex shedding and Strouhal scaling, analyse wind effects on tall buildings, including torsional loading and aeroelastic instabilities, and assess pedestrian comfort in urban environments. They will also gain experience with Computational Wind Engineering (CWE) methods, including CFD, LES, and DES for built structures, and apply similarity laws and boundary layer modelling for reliable wind load predictions.
Unit 5	**Flow Induced Vibrations:** Vortex-induced vibration (VIV): lock-in phenomena, amplitude response curves. Galloping, flutter, buffeting, and wake galloping.	**8**	Students will be able to explain the mechanisms of vortex-induced vibrations and interpret lock-in phenomena using amplitude response curves. They will gain the ability to analyze aeroelastic instabilities such as galloping, flutter, buffeting, and wake galloping, and evaluate their effects on structural performance.
	TOTAL	**42**	

Course Outcome	• Understands the atmospheric circulations, boundary layer structure, wind spectra, and turbulence, and apply them for wind engineering applications. • Apply aerodynamic principles and blade element momentum theory to analyze and evaluate the performance, wake effects, and noise characteristics of horizontal- and vertical-axis wind turbines. • Analyze vehicle aerodynamics including drag sources, flow separation, active flow control, and assess aerodynamic stability of ground and high-speed vehicles. • Evaluate wind effects on buildings and structures, investigate bluff body aerodynamics and aeroelastic instabilities, and apply Computational Wind Engineering (CWE) tools for structural safety and comfort. • Demonstrate understanding of flow-induced vibrations and aeroelasticity, and propose mitigation strategies for wind-induced responses of flexible structures.

Learning Resources	1. M.Sovran (Ed), “Aerodynamics and drag mechanisms of bluff bodies and road vehicles”, Plenum press. New York, 1978. 2. Sachs. P., “Winds forces in Engineering”, Pergamon Press, 1978. 3. Blevins. R.D., “Flow Induced Vibrations”, Van Nostrand, 1990. 4. Calvent. N.G., “Wind Power Principles”, Charles Griffin & Co., London, 1979.

Course Code	AM5161N	Course Name	Mechatronics	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Engineering background	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Dept. of Aerospace Engg. & Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	
	- Learn the fundamentals of mechatronics functions involved in product development which is the synergistic integration of many aspects of engineering knowledge base in precision mechanics, electronics, control and computer systems. - Identify, formulate and solve complex mechatronics engineering problems properly applying the principles, methods, techniques and tools of engineering, science and mathematics. - Develop an understanding of the basic elements underlying mechatronic systems: motion transmission devices, analog electronics, digital electronics, sensors, actuators, microcontrollers, and embedded software. - Understand how to interface interdisciplinary knowledge for industrial problem solving.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	**Mechatronics:** What is Mechatronics? Mechatronics Systems, Measurement systems, Control systems, Microprocessor-based controllers, response of systems, Mechatronics approach, **Critical design thinking and problem solving**	4	• Understanding of the architecture of mechatronic systems; • Design thinking for problem solving.
2.	**Sensors and transducers:** Sensors and transducers, Performance terminology, Displacement, position and Proximity, Force, Fluid Pressure, Liquid Flow, Liquid level, Selection of sensors.	2	• Designing measurement systems using different sensors.
3.	**Signal conditioning:** Signal conditioning, The Operational amplifier, Wheatstone bridge, Digital signals, Data acquisition, Digital Signal Processing.	2	• Understanding different types of signals, including analog and digital signals, their characteristics, signal conditioning.
4.	**Pneumatic and hydraulic actuation systems:** Actuation systems, Pneumatic and hydraulic systems, Directional control valves, Pressure control valves, Cylinders,	4	• Understanding of how fluid power systems convert energy into controlled mechanical motion[redacted]

	Process control valves, Rotary actuators.		
5.	**Mechanical actuation systems:** Mechanical systems, Types of motion, kinematic chains, Cams, Gear trains, rachet and pawl, Belt and chain drives, Bearings, Mechanical aspects of motor selection problems.	3	• Understanding how machines and mechanisms function for motion transmission.
6.	**Electrical actuation systems:** Electrical systems, Mechanical switches, D.C. motors, A.C. motors, Stepper motors.	2	• Understanding how electrical energy is converted into mechanical motion to drive various devices and systems
7.	**Basic system models:** Mathematical models, Mechanical system building blocks, Electrical system building blocks, Fluid system building blocks, Thermal system building blocks, Rotational–translational systems, Electromechanical Systems, Hydraulic mechanical systems.	3	• Understanding how to represent complex systems using mathematical equations and fundamental components
8.	**Dynamic responses of systems:** Modeling dynamic systems, First-order systems, Second-order systems.	2	• Understanding how systems react to changes in input over time, providing insights into their behavior and predicting their future responses
9.	**Control System:** Transfer function, First-order systems, Second-order systems, Sinusoidal input, Frequency response, Bode plots, Continuous and discrete control processes, Control modes, Proportional mode, Derivative control, Integral control, PID controller, Adaptive control.	6	• Designing basic control systems with feedback.
10.	**Microprocessors:** Microprocessor systems, Microcontrollers, Embedded System, Applications.	2	• Understanding of analogue and digital interfacing.
11.	**Man-Machine Interface Devices:** Joystick, teach pendent, analog and digital display devices.	1	• Understanding human interaction with machines
12.	**Programmable logic controllers:** Interfacing and programming.	2	• Understanding of PLC programming
13.	**Robotics and Artificial Intelligence:** Algorithms for machine learning, deep learning, and other AI techniques used in robotics, automation, manufacturing, healthcare and transportation	5	• Understanding robot motion and intelligent operation

14.	**Mechatronics systems:** Traditional and Mechatronics designs, Possible Mechatronics design solutions, Case studies of mechatronic systems.	4	• Integrate mechanical, electronic and control system to design, build, and maintain intelligent machines and automated systems
		Total 42	

Course Outcome	On completion of this course, students will be able to: • apply knowledge and practice in mechatronics engineering fields including dynamics and control, systems design and integration, intelligent engineering solution, based upon the interconnection of mechanical, electrical, electronics and computing systems. • apply their knowledge to analyse and design mechatronics systems and processes; • develop problem solving and trouble shooting skills that may be applied in professional practice.

Learning Resources	1. Mechatronics - by W. Bolton (Pearson) 2. Mechatronics - An introduction by Robert H. Bishop (Taylor & Francis) 3. Mechatronics System Design - by Shetty and Kolk (Cengage) 4. Mechatronics - an Integrated Approach by Clarence W. de Silva (CRC Press)

Course Code	AM5162N	Course Name	Human Body Mechanics	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Nil	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	The primary objective of this course is to • This course will help students to understand how mechanics is involved in the human body from unit cell structure to the overall skeletal system. • Students can also understand the role of fluid mechanics in the circulatory system of the human body.

Module	Syllabus	Duration (class-hour)	Module Outcome
I	Human Body Mechanics: definition and perspective	02	• Understand and clearly articulate the **definition** of human body mechanics as the study of how the body moves and maintains posture, incorporating principles of **physics, biomechanics**, and **anatomy.**
II	Quantitative versus qualitative problems, Structure, movements and loads on the 8 shoulder, Structure, movements and loads on the elbow and wrist, Structure, movements and loads on the hip, Structure, movements and loads on the knee, Structure, movements and loads on the spine, Structure, movements and loads on the foot, Common injuries in shoulder, elbow wrist, hip knee, spine and foot	08	• Understand and analyze the mechanical loads and stress acting on the shoulder during various activities. • Understand the coordination between elbow and wrist in kinetic chain movements.
III	Equilibrium and Torque, Resultant Joint Torques, Levers, Anatomical levers, Equations 4 of static and dynamic equilibrium, Center of gravity and locating the center of gravity, Locating the human body Center of Gravity, Stability and	04	• Understand how muscle forces, external forces, and joint structures contribute to resultant torque at joints.

	balance		
IV	Stress in three-dimensional continuous media	05	• Explain the symmetry of the stress tensor and its significance in biomechanics and materials science.
V	Properties of Bone, Maxwell & Voight Models of bone, Biomechanics of human skeletal 3 muscle, Biomechanics of human Skeletal Articulations	04	• Understand the adaptive nature of bone (Wolff's Law) in response to mechanical stresses and physical activity.
VI	Material Characterization of Tissues: Classification of Tissues, Properties of Tissues 3 from Mechanics Point of View, Modeling of Tissues	03	• Understand the composition and hierarchical organization of tissues from a materials science perspective.
VII	Mechanical Property of the Human Body Material components of the body and their 6 elastic properties, time-independent deviations in hookean materials, static equilibrium of deformable bodies, time-dependent deviations from elastic behavior: viscoelasticity, viscoelasticity in bone, bone fractures, common sports injuries, avoiding fractures and other injuries: materials for helmets	06	• Understand how the composition and structure of these materials relate to their mechanical performance. • Solve problems involving internal forces, bending moments, and stress distributions in loaded structures like bones and tendons.
VIII	Motion: The time as an extra dimension	02	• Understand how motion is described as change in position over time, forming a path through space-time.
IX	Deformation and rotation, deformation rate and spin	02	• Explain the significance of deformation rate in viscoelastic and dynamic analysis of soft tissues.
X	Cardiovascular Mechanics: Cardiovascular Physiology, Blood Flow Models, Blood 4 Vessel Mechanics, Heart Valve Dynamics, Prosthetic Valve Dynamics	06	• Understand the structure and function of the cardiovascular system, including the heart, blood vessels, and circulatory pathways.

Course Outcome	At the end of the course, the student will be able to: • Apply knowledge of engineering, biology • Biomechanical principles to the design, development, and evaluation of biological systems and products, such as artificial organs, prostheses, instrumentation, and health care delivery systems.

Learning Resources	**<u>Text Book</u>:** • Basic Biomechanics: S. J. Hall • Fundamentals of Biomechanics - Equilibrium, Motion, and Deformation: N.Özkaya, M. Nordin, D. Goldsheyder, D.Leger • Biomechanics - Mechanical Properties of Living Tissues: Y.C. Fung • Human Body Mechanics: D.N. Ghista

Course Code	AM5163N	Course Name	Energy System Design	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Nil	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	• To provide knowledge, understanding and application-oriented skills on conventional and non-conventional sources of energy and relevant technologies towards their effective utilization for meeting energy demand. • To understand the present scenario for energy conservation and utilization of renewable energy sources for both domestic and industrial applications.

Module	Syllabus	Duration (class-hour)	Module Outcome
I	**Introduction** Energy and development, conventional and non-conventional sources of energy, fossil, non-fossil and renewable energy resources, Importance of electrical energy in modern industrial society, Usefulness, advantages and disadvantages of energy sources and need of alternative energy sources. **Economics and Planning of Energy Systems:** Law of demand, Theory of firm: Production function, output maximization, cost minimization and profit maximization principles. Theory of market, National income and other macroeconomic parameters, Basic concepts of Energy Economics, Socio-economic evaluation of Energy Conservation Programmes, Overview of Energy Policies.	10	Understand the fundamentals of energy, its sources, measurement, and role in modern industrial society, including the advantages, disadvantages, and necessity of alternative energy sources. Apply principles of economics and planning—such as demand, production, cost, profit, market theory, and national income—to analyze and evaluate energy systems, policies, and conservation programs from both economic and socio-economic perspectives.
II	**Wind Energy Systems:** Wind Energy Fundamentals, Wind Energy Basics, Principles ofAerodynamics of wind turbine blade, Power Content, Betz's Limit, Instrumentation for wind measurements,	6	Gain knowledge of wind energy fundamentals, resource assessment, site selection, and aerodynamic principles governing wind

	Wind data analysis, Wind resource estimation, Vertical and Horizontal Axis Wind Turbine, Torque-Speed and Power-Speed Characteristics of Wind Turbines, Wind Turbine Control System and Control strategy.		turbine operation. Analyze wind turbine types, performance characteristics, control systems, and strategies for efficient wind energy conversion.
III	**Hydro Energy Systems:** Hydro energy fundamentals and basics, Micro and mini hydropower system, Horizontal and vertical axis current turbine, Tidal and wave energies.	6	Understand the fundamentals of hydro energy and the working principles of micro and mini hydropower systems. Explain the operation of horizontal/vertical axis current turbines and assess the potential of tidal and wave energy resources.
IV	**Solar Energy Systems:** solar cell fundamentals, Photovoltaic effect: Principle of direct solar energy conversion into electricity in a solar cell. Solar cells, modules and arrays, fill factor, efficiency, Solar PV modules: series and parallel connection of cells, mismatch in cell/module, mismatch series and parallel connections, commercial solar cells PV Modelling: Equivalent circuit of PV cell, output characteristics, Double and single diode models, PV module equivalent parameters, effect of solar irradiance, effect of temperature on PV module power output.	6	Understand the fundamentals of solar cells, photovoltaic effect, solar modules/arrays, and factors affecting efficiency and performance. Analyze PV cell/module modeling using equivalent circuits, diode models, and evaluate the impact of irradiance and temperature on solar power output.
V	**Nuclear Energy Systems:** Nuclear Power Plant, Nuclear power systems, Main components of NPP, Advantages of NPP, Site selection, Applications, Economics of NPP, Safety measures for NPP, Future of NPP, Nuclear Power Plants in India, Useful byproducts of Nuclear power generator and their uses	6	Understand the fundamentals, components, site selection, applications, and economics of nuclear power plants. Evaluate the advantages, safety measures, byproducts, and future prospects of nuclear power, with reference to nuclear power development in India.

VI	**Energy System design & Applications:** Energy storage for renewable energy sources, Large scale applications/ Stationary (Grid applications) – Power and energy applications, Small scale applications - Portable storage systems/medical devices, Mobile storage applications (Electric vehicles - Introduction and types of EV's, Batteries and fuel cells – future technologies), Hybrid systems for energy storage.	8	Understand energy storage technologies for renewable integration across large-scale, small-scale, and mobile applications. Analyze the role of batteries, fuel cells, electric vehicles, and hybrid storage systems in modern and future energy applications.
VII			
VIII			

Course Outcome	• Know the need of energy resources, historical and latest developments. • To gain knowledge on market parameters governing economic analysis and energy conservation. • To gain knowledge on regional and national level energy policies.

Learning Resources	1 J. Twidell and T Weir, "Renewable energy Recources", Taylor and Francis group 2007. 2 Renewable Energy- Power for a Sustainable Future, Godfrey Boyle, Oxford University Press. 3 EA Diulio, Macroeconomic Theory, Schaum's Outline Series, 2nd Ed, McGraw-Hill Publishing Company (1990) 4 R Loulou, P R Shukla and A Kanudia, Energy and Environment Policies for a sustainable Future, Allied Publishers Ltd, New Delhi, 1997 5 S. N. Bhadra, D. Kastha, S. Banerjee, Wind Electrical Systems, Oxford Univ. Press, New Delhi, 2005. 6 Wind energy Handbook, Edited by T. Burton, D. Sharpe, N. Jenkins and E. Bossanyi, John Wiley & Sons, 2001. 7 Chetan Singh Solanki., Solar Photovoltaic: "Fundamentals, Technologies and Application", PHI Learning Pvt., Ltd., 2009. 8 Jha .A.R, "Solar Cell Technology and Applications", CRC Press, 2010. 9 Energy Storage - Technologies and Applications, Ed: Ahmed Faheem Zobaa, ISBN 978-953-51-0951-8, 328 pages, Publisher: InTech, 2013. 10 J. Jensen and B. Sorenson. Fundamentals of Energy Storage. Wiley-Interscience, New York (1984)

2nd Semester Syllabus for Open Elective Subjects

Course Code	AE5261N	Course Name	Basics of Parallel Computation	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Basic programming	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		AE&AM		Data Book / Codes/Standards	Nil

Course Objective	The objective of Basics of Parallel Computation is to provide students with fundamental concepts and techniques of parallel computing. It aims to develop an understanding of the need for parallel computations and the challenges involved in parallel programming. Students will learn about various parallel architectures and programming paradigms, as well as gain the ability to model and analyse the performance of parallel computations using speedup, efficiency, and scalability metrics. The course also provides hands-on training in parallel programming using the MPI (Message Passing Interface) standard for communication in distributed systems. Additionally, it introduces the basics of GPU programming, covering architectures, accelerators, and frameworks such as CUDA, OpenCL, and OpenACC. Through practical case studies, students will learn to design and implement parallel algorithms for solving scientific and engineering problems, such as matrix computations and partial differential equations.

Module	Syllabus	Duration (class-hrs)	Module Outcomes
Unit 1	**Introduction to parallel computation:** Needs for parallel computations. Challenges of parallel programming- Parallel Programming Paradigms – Parallel Architecture - Overview of some parallel systems. Multiprocessors and multi-computers.	**6**	Students will understand the necessity of parallel computing in modern applications and identify the major challenges associated with parallel programming. They will be able to describe different parallel architectures, programming paradigms, and the structure of multiprocessor and multi-computer systems.
Unit 2	**Modeling and analysis of parallel computations:** Efficiency characteristics of parallel computation: speedup, efficiency, scalability - Model analysis: determining the parallel method execution time, estimating the maximum possible parallelization, computational load balancing - The Amdahl's and Gustavson-Barsis's laws - Aggregating the computation model.	**8**	Students will be able to evaluate the performance of parallel systems by analyzing speedup, efficiency, and scalability. They will develop the skills to model parallel execution time, estimate maximum parallelism, and apply Amdahl's and Gustafson-Barsis's laws to understand the limitations of parallelization.
	Parallel programming with MPI and communication: Overview of the MPI		Students will gain practical knowledge of the MPI standard and its application in

Unit 3	standard. Point-to-point communication operations. Synchronous and asynchronous modes of data transmission. Collective operations. Derived data types. Process management. Logical topologies.	**8**	point-to-point and collective communication. They will be able to distinguish between synchronous and asynchronous communication and manage parallel processes using derived data types and logical topologies.
Unit 4	**Basics of GPU Programming:** Introduction to GPU Architecture - History, graphics processors, graphics processing units, GPGPUs. Clock speeds, CPU / GPU comparisons, heterogeneity. Accelerators, parallel programming, CUDA / OpenCL / OpenACC.	**10**	Students will develop a foundational understanding of GPU architectures and learn how to program using CUDA, OpenCL, and OpenACC. They will be able to compare CPUs and GPUs in terms of performance and understand the challenges of heterogeneous computing environments.
Unit 5	**Case study on parallel programming:** Algorithm development – selection of communication operations - Case studies: matrix computations, solving partial differential equations – 1D Wave Equation.	**10**	Students will be able to design and implement parallel algorithms for real-world problems. They will gain hands-on experience in developing parallel solutions for matrix computations and solving partial differential equations such as the 1D wave equation, with a focus on selecting suitable communication and computation strategies.
	TOTAL	**42**	

Course Outcome	● Understand the need for parallel computing and the challenges involved in parallel program design. ● Analyze and model the performance of parallel algorithms using metrics such as speedup, efficiency, and scalability. ● Develop parallel programs using MPI for communication in distributed memory systems. ● Gain foundational knowledge of GPU architectures and implement basic GPU programs using CUDA and OpenCL. ● Design and implement parallel solutions for computational problems such as matrix operations and differential equations.

Learning Resources	1. Grama, Ananth, et al. Introduction to parallel computing. Pearson Education, 2003. 2. Pacheco, Peter. An introduction to parallel programming. Elsevier, 2011. 3. Kirk, David B., and W. Hwu Wen-Mei. Programming massively parallel processors: a hands-on approach. Morgan kaufmann, 2016. 4. Schmidt, Bertil, et al. Parallel programming: concepts and practice. Morgan Kaufmann, 2017. 5. Cai, Yiyu, and Simon See, eds. GPU computing and applications. Singapore: Springer, 2015.

Course Code	AE5262N	Course Name	Structural Health Monitoring	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Strength of Materials / Mechanics of Solids/ Structural Analysis-I	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	The objective of this course is to introduce the fundamentals of Structural Health Monitoring (SHM) and its critical role in aerospace and applied mechanics. It aims to familiarize students with various sensing technologies, data acquisition methods, and signal processing techniques used in SHM. The course is designed to develop a comprehensive understanding of damage detection, diagnostics, and prognostics in aerospace structures, enabling students to assess structural integrity and predict remaining service life. Furthermore, it provides exposure to real-world case studies and practical applications of SHM in aerospace systems, helping learners relate theoretical concepts to industrial practices.

Module	Syllabus	Duration (class-hour)	Module Outcome
I	**Introduction to Structural Health Monitoring:** Definition, scope, and evolution of SHM in engineering. Need for SHM in aerospace, civil, and mechanical structures. Types of structural damage: fatigue cracks, impact damage, corrosion, delamination, material degradation. SHM vs. Non-Destructive Testing (NDT). Components of an SHM system and overall workflow. Life-cycle cost benefits and safety implications	6	**Understand the need and benefits of SHM in interdisciplinary applications. Differentiate SHM from conventional NDT methods. Recognize common damage modes in metallic, composite, and concrete structures.**
II	**Sensing and Data Acquisition Systems:** Strain gauges, displacement sensors, accelerometers. Fiber Bragg Grating (FBG) sensors and optical sensing principles. Acoustic emission sensors and piezoelectric transducers. Embedded and surface-mounted sensors for composites,	8	Identify suitable sensing technologies for various structural materials and configurations. Explain working principles and operational requirements of sensors. Evaluate sensor

	metals, and concrete. Wireless sensor networks, energy harvesting sensors, and sensor placement optimization. Data acquisition hardware/software and sampling requirements		network design for effective coverage and accuracy.
III	**Structural Dynamics and Signal Processing for SHM:** Fundamentals of structural vibrations relevant to SHM. Modal analysis and mode shapes for damage detection. Signal processing tools: filtering, Fast Fourier Transform (FFT), wavelet transforms. Time–frequency analysis for transient events. Feature extraction: modal parameters, statistical features, frequency/wavelet coefficients. Noise reduction, data fusion, and multi-sensor correlation.	7	**Relate structural dynamic characteristics to damage-sensitive parameters.** **Apply basic and advanced signal processing methods to SHM data. Extract and interpret features for condition assessment.**
IV	**Damage Detection and Diagnostics:** Vibration-based methods: changes in natural frequency, damping, mode shapes. Ultrasonic and guided wave techniques. Acoustic emission monitoring for crack initiation and growth. Lamb wave–based inspection for aerospace structures. Model-based methods: finite element model updating and residual analysis. Data-driven approaches: machine learning classifiers for damage detection (Intro level).	7	**Compare strengths and limitations of vibration, wave, and model-based approaches.** **Select appropriate detection methods based on material and damage type. Integrate experimental and numerical methods for diagnostics.**
V	**Prognostics and Health Management (PHM):** Damage growth modelling. Remaining useful life estimation. Probabilistic approaches and uncertainty. Prognostic algorithms. Decision support for maintenance.	7	Understand PHM relevance. Apply prognostic models. Use results for maintenance planning.
VI	**Applications and Case Studies:** SHM in aircraft fuselage, wing structures, landing gear, and composite components. SHM in bridges, tall buildings, and offshore platforms. SHM for rotating machinery and heavy mechanical systems. UAV structural monitoring challenges and strategies Emerging trends: AI, digital twins, and	7	**Describe SHM applications across aerospace, civil, and mechanical engineering.** **Analyze lessons from industrial and field-deployed SHM systems.** **Formulate a conceptual SHM framework for a**

	autonomous SHM systems.		**real-world problem.**
	Total	42	

Course Outcome	The outcomes of this course are designed to ensure that students gain both theoretical knowledge and practical skills in Structural Health Monitoring (SHM) for aerospace, civil, and mechanical structures. By the end of the course, students will be able to explain the necessity, scope, and interdisciplinary nature of SHM across these engineering domains. They will be able to identify and select suitable sensing, actuation, and data acquisition systems tailored to specific structural applications. The course will enable them to apply vibration-based, wave-based, and model-based approaches for effective damage detection. Students will also develop the ability to analyze SHM data using advanced signal processing and feature extraction techniques to carry out both diagnostics and prognostics. Finally, they will be capable of designing a conceptual SHM framework for a real-world structural problem, taking into account operational and practical implementation constraints.

Learning Resources	**1. Balageas, D., Fritzen, C. P., & Güemes, A. (Eds.). Structural Health Monitoring. ISTE Ltd. and John Wiley & Sons, 2006.** **2. Farrar, C. R., & Worden, K. Structural Health Monitoring: A Machine Learning Perspective. John Wiley & Sons, 2013.** **3. Kessler, S. S. Structural Health Monitoring: An Implementation Guide for Aerospace Structures. McGraw-Hill, 2012.** **4. Inman, D. J. Engineering Vibration (4th ed.). Pearson, 2014. (For vibration-based SHM fundamentals)** **5. Giurgiutiu, V. Structural Health Monitoring of Aerospace Composites. Academic Press, 2016.**

Course Code	AE5263N	Course Name	Manufacturing and Characterization of Polymer Composites	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Composite Materials	Co-requisite Courses	None	Progressive Courses	Cutting Edge Research on Composite Materials
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	
	• The course covers the fundamentals of polymer composites and their associated manufacturing processes. • Develop an understanding of the mechanical behavior of polymer composites. • Enable students to analyze the influence of fibre, matrix, interface, and processing parameters on composite performance. • The course provides students with in-demand specialized skills and expertise in aerospace, automotive, and manufacturing, enhancing their job prospects.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	**1. Introduction to Polymer Composites:** Processing of Polymers: Engineering Materials and Processing Techniques, Thermoplastics and Thermosets, General classification of composite materials; Reinforcement materials; Matrix materials, Advantages/Disadvantages of Polymer Composite.	04	• Differentiate between thermoplastics and thermosets with respect to their structure, properties, and applications. • Analyze the advantages and disadvantages of polymer composites compared to conventional engineering materials.
2	**2. Mechanics of Polymer Composites:** Generalized Hooke's law, Engineering constants for orthotropic materials, Prediction of elastic properties using strength of materials approach, Introduction to elasticity based approach for prediction of elastic constants, Classical lamination theory, Stiffness of commonly used stacking sequences, Failure analysis of laminates using CLT: First ply failure, Hygro-thermal stresses in laminates, Failure analysis, Discussion on interlaminar stresses **Note: Hands on commercial software to predict the elastic properties.**	10	• Correlate microscale behavior with macroscale performance of polymer composites. • Develop simplified models for estimating effective mechanical properties of polymer composites under various loading conditions. • Predict the mechanical responses of laminated composites under different loading conditions. • Assess failure criteria and strength analysis methods for laminated polymer composites.
3	**Primary Manufacturing of Polymer Composites:** Manufacturing of Polymer Composites: Hand	10	• Analyze the influence of processing parameters on the quality and performance of

	layup technique, Spray layup technique; Compression Molding, Injection Molding, Autoclaving, Resin transfer moulding, Vacuum-assisted resin injection/transfer, Filament Winding, Pultrusion and Pre-Pegging.		polymer composites. • Evaluate the advantages, limitations, and suitability of various composite manufacturing techniques.
4	**4. Secondary Manufacturing of Polymer Composites:** Drilling of Composites, Drilling Induced Damage and Their Prevention Strategies, Unconventional and Intelligent Drilling of Polymer Composites. Joining of Polymer Composites: Mechanical, Adhesive, and Microwave Joining.	08	• Differentiate various joining techniques including mechanical fastening, adhesive bonding, microwave joining, induction and resistance welding. • Analyze the effect of drilling parameters, tool design, and joining methods on the structural integrity of composites.
5	**5.Characterization of Polymer Composites** Characterization, Repairing, and Recycling: Mechanical, Thermal, Physical, and Chemical Characterization. Repairing and Salvaging, Measurement of physical properties; Measurement of mechanical properties; Damage identification and testing of composite materials.	10	• Identify suitable characterization techniques for evaluating composite microstructure and properties. • Interpret characterization outcomes to assess performance, defects, and failure mechanisms in polymer composites.
	Total	**42**	

Course Outcome	After successfully completing this course, students should be able to: • Apply micromechanics and lamination theory to evaluate the mechanical behavior of polymer composites. • Analyze the influence of fiber orientation, stacking sequence, and processing parameters on composite performance. • Evaluate mechanical properties, testing methods, and failure mechanisms of polymer composites.

Learning Resources	• F.L. Mathews and R.D. Rawlings, Composite Materials: Engineering and Science, CRC Press, 2005 • M. Daniel & O. Ishai, Engineering Mechanics of Composite Materials, • P.K. Mallick, Fiber-Reinforced Composites: Materials, Manufacturing, and Design, 3rd Edition, CRC Press, 2007 • K. Debnath and I. Singh, Primary and Secondary Manufacturing of Polymer Matrix Composites, CRC Press, Taylor and Francis Group, 2018 • B. Astrom, “Manufacturing of Polymer Composites”, CRC Press, 1997 • F. C. Campbell (Ed), Manufacturing processes for advanced composites, Elsevier, 2004.

Course Code	AM5263N	Course Name	Free Surface Flow	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Knowledge of Mechanics	Co-requisite Courses	None	Progressive Courses	Advanced Open Channel Hydraulics
Course Offering Department		AE & AM		Data Book / Codes/Standards	NA

Course Objectives	In recent years, water resources projects and hydraulic engineering works have been developing rapidly throughout the world. The knowledge of free surface flow, which is essential to the design of many hydraulic structures, has advanced significantly. This course has the following objectives: • To introduce basic principles, the types of free surface flow are classified according to the variation in the parameters of flow with respect to space and time, and coefficients for velocity and pressure distributions. • To provide knowledge about the energy and momentum principles constituted the basis of interpretation for most hydraulic phenomena. • To introduce uniform flow, several uniform flow formulae, and the design of erodible, non-erodible, and grassed channels. • To provide knowledge on gradually varied flow, several methods for the computation of flow profiles, a new method of direct integration, and the method of singular point, which is a powerful tool for the analysis of flow profiles. • To provide knowledge in rapidly varied flow involving hydraulic jump, its use as an energy dissipater, its control, flow over spillway analyzing and implementing the real engineering problems.

Module	Syllabus	Duration (class-hour)	Module Outcome
1.	Basic principles: Basic knowledge of Fluid Mechanics, the difference between pipe flow and free surface flow, velocity and pressure distribution, effects of slope and curvature on Pressure distribution, energy and momentum principles, and their applications.	10	• Explain the basic knowledge of Fluid Mechanics and the distribution of velocity and pressure in free surface flow. • Analyze the effects of bed slope and channel curvature on pressure distribution.
2.	Uniform Flow: development of uniform flow and its formulas, Chezy's equation, Manning's equation, computation of uniform flow, theoretical concepts of surface roughness,	10	• Understand the development and characteristics of uniform flow in open channels.

	velocity distribution, and instability of Uniform flow, design of channels for uniform flow, channel transition.		
3.	Gradually Varied Flow: continuity and dynamic equations, analysis of surface profile, method of singular point, method of computation, backwater effect of a dam.	10	• Classify and analyze different types of flow profiles based on channel slope and flow depth. • Apply numerical and graphical methods for GVF profile computation.
4.	Spatially Varied Flow: basic principles and assumptions, dynamic equation of spatially Varied flow, analysis of flow profile, method of numerical integration.	06	• Understand the principles and assumptions underlying spatially varied flow. • Derive and apply the dynamic equation for spatially varied flow scenarios.
5.	Rapidly Varied Flow: characteristics of flow, hydraulic jump, and its use as an energy Dissipator, control of jump.	06	• Analyze the hydraulic jump, its types, and conditions for occurrence. • Evaluate the use of hydraulic jumps as energy dissipators.
	Total	42	

Course Outcome	After successfully completing this course, students will: •Understand how extensive use of free surface flow is made for different practical real problems related to water resources and hydraulic engineering works. •Understand the modern numerical methods for solving the governing equations of different problems and also understand the solution of dam break problems both by numerical and simplified methods of computations. •Understand the treatment of rapidly varied flow problem largely supported by experimental data because this type of flow is so complicated that a mere theoretical analysis in most cases will not yield sufficient information for the purpose of practical design. •Be able to design different channels like lined and unlined channel, stable channel, earthen channel and grass-lined channel considering both economic and seepage losses. •Be able to have the ideas of flow through bridge contractions, the control of hydraulic jumps with sharp and broad-crested weirs, abrupt rises and drops, stilling basins, spillway structures and the design of channel transitions, the design,

	construction and use of physical models in the study of open channel hydraulics.

Learning Resources	1. Open Channel Hydraulics by VenTe Chow 2. Open Channel Hydraulics by Richard H. French

Course Code	AM5265N	Course Name	Cyber Physical System	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Engineering background	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	A Cyber-Physical System (CPS) is a complex system that integrates physical and computational elements to monitor and real-time control the physical processes seamlessly. These systems combine the sensing, actuation, computation, and communication capabilities, and leverage these to improve the physical systems' overall performance, safety, and reliability. • Develop the ability to understand the concept of cyber physical systems' characteristics, requirements, architecture and design. • Apply the principles of design thinking in system term (Systems Thinking) and their application. • Understand dynamical systems, sensing, control theory, communication, computation, real-time scheduling, safety assurance, and security considerations for CPS • Understand synchronization in distributed Cyber-Physical Systems. • Understand and develop hardware and software design requirements of Cyber Physical System for engineering applications.

Module	Syllabus	Duration (class-hour)	Module Outcome
1	Cyber-Physical Systems (CPS) in the real-world, Basic principles of design and validation of CPS, Industry 4.0 AutoSAR, IIOT implications, Building Automation, Medical CPS	6	• Fundamentals of Cyber Physical Systems • Integration of computation, networking, and physical processes
2	CPS HW platforms - Processors, Sensors, Actuators CPS Network - WirelessHart, CAN, Automotive Ethernet Scheduling Real Time CPS tasks: Table-driven and Event driven schedulers, Hybrid schedulers	5	• Platform Components for Cyber Physical Systems
3	Dynamical Systems and Stability Controller Design Techniques, Performance under Packet drop and Noise	5	• Principles of Dynamical Systems
4	From features to automotive software components, Mapping software components to ECUs CPS Performance Analysis: Effect of scheduling, bus latency, sense and actuation faults on control performance, network congestion Building real-time networks for CPS	5	CPS implementation issues

5	Cyber Security Requirements, Attack Model, Countermeasures, Advanced Techniques: System Theoretic Approaches Synchronization in Distributed Cyber-Physical Systems	5	• Security of Cyber-Physical Systems Synchronization in Distributed Cyber-Physical Systems
6	Real-Time Scheduling for Cyber-Physical Systems - Basic Techniques - Scheduling with Fixed Timing Parameters, Memory Effects, Multiprocessor/Multicore Scheduling, Accommodating Variability and Uncertainty	5	Real-Time Scheduling for Cyber-Physical Systems
7	Sensor, Communication systems, digital transmission, Data structures and algorithms, Control Systems, Embedded Systems Design, Internet of Things (IoT), Robotics, Industry 4.0 and Automation, Machine Learning, Digital Twins, Cybersecurity Operating systems and hardware architecture support for CPS, CPS software synthesis.	6	Systems thinking
8	Safe Reinforcement Learning: Robot motion control, Autonomous Vehicle control Gaussian Process Learning: Smart Grid Demand Response, Building Automation CPS application in Automotive Mechatronics, Healthcare, Consumer Industry, Smart Civil Structures, Hybrid Electric Vehicle, Industrial Motor Control and Robotics, Power Grid, Railways Systems, Transportation Systems, Water/Sewage Systems and their automation architecture.	5	• Intelligent CPS Real time monitor, analyse and control of physical processes
	Total	**42**	

Course Outcome	• Should be able to create a seamless interaction between the digital and physical worlds in areas that include smart cities, autonomous vehicles, healthcare monitoring systems, and industrial automation. • Students should be able to solve the performance related problems of real time operating system. • Analyze the performance of embedded processing, memory, bus efficiencies, real time operating system performance h/w s/w codesign. • Understand CPS security and safety aspects.

Learning Resources	1. Raj Rajkumar, Dionisio De Niz, and Mark Klein, Cyber-Physical Systems, Addison-Wesley Professional. 2. Rajeev Alur, Principles of Cyber-Physical Systems, MIT Press, 2015 3. Suh, Sang C., U. John Tanik, John N. Carbone, and Abdullah Eroglu, eds. Applied cyber-physical systems. Springer New York, 2014. 4. Cyber-Physical Systems: Foundations, Principles and Applications, Houbing Song Danda Rawat Sabina Jeschke Christian Brecher, 1 st Ed., Elsevier, 2016.

Course Code	AM5266N	Course Name	Elastic Stability	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Engineering Mechanics & Strength of Materials	Co-requisite Courses	Nil	Progressive Courses	Nil
Course Offering Department		Aerospace Engineering and Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	The course is intended to enhance the indepth knowledge to solve different types of structural stability problems primarily arising out from use of thin sectioned structural materials. This type of structural instability essentially lead to service falure of the structure that is it's inability to carry the intended load without causing any material damage. The course will help to asses Elastic Stuctural Stability which is an essential component of structural design particularly for thin walled structures used in the field of Civil Engineering, Mechanical Engineering and Aerospace Engineering.

Module	Syllabus	Duration (class-hour)	Module Outcome
I	**Stability of Beam-Column**: Introduction, Differential Equations, Beam-columns with Concentrated and continuous lateral Loads, Bending of Beam- columns under couples, Approximate formula for deflections, Determination of Allowable stresses.	12	Knowledge of Stability problems and its basic methods of analysis
II	**Elastic Buckling of Frames and Bars:** Buckling of Frames, Buckling of Cuntinuous Beams, Energy Method for calculation of critical loads.	10	Knowledge of Stability problems of frame structures and different solution techniques.
III	**Torsional Buckling:** Introduction, Pure and Nonuniform torsion of thin walled bars of open cross section,	9	Knowledge of Stability problems of thin-walled structural components under twisting and different analysis methods.
IV	**Lateral Buckling of Beams:** Differential equations, Lateral Buckling of beams under Pure bending. Lateral Buckling of thin-walled cantilever and simply supported beams.	8	Knowledge of Stability problems of thin-walled deep beam sections under lateral loading and different analysis methods.

Course Outcome	This course is made of particular interest, the graduate students, research scholars who will work in the field of stability assessment of structures under different types of loading as well as geometry.

Learning Resources	1. Theory of Elastic stability by S.P. Timoshenko & J. M. Gere 2. Theory of Elastic Stability: Analysis and Sensitivity by Luis A. Godoy 3. Stability of Elastic Structures by N.A. Alfutov 4. Fundamentals of Structural Stability by Dewey H. Hodges and George J. Simitses

Course Code	AM5267N	Course Name	Introduction to Microfluidics	Course Category	OE	L	T	P
						3	0	0

Pre-requisite Courses	Fluid Mechanics / Transport Phenomena	Co-requisite Courses	Nil	Progressive Courses	NA
Course Offering Department		Aerospace Engineering & Applied Mechanics		Data Book / Codes/Standards	Nil

Course Objectives	
	• To introduce the students with the emerging and physics-rich field of micro-fluidics and micro-scale transport processes. • To cover the fundamental concepts and methods used in this subject in a self-contained manner • This interdisciplinary course brings together fluid mechanics, electrodynamics, and interface science a focused goal of preparing the modern microfluidics researcher to analyze and model continuum fluid mechanical systems encountered when working with micro- and nanofabricated devices

Module	Syllabus	Duration (class-hour)	Module Outcome (On successful completion of this module, students should be able to…)
I	**Introduction:** Advantages of miniaturization; Applications of microfluidics; Introduction to Microfabrication techniques, Lab on a CD	4	• Relate to the application areas of microfluidics • Describe modern fabrication methods of micro and nano-scale fluid mechanical systems
II	**Conservation equations and boundary conditions:** Reynolds transport theorem, mass and momentum conservation equations, First law of thermodynamics, species conservation; No-slip and slip BC	9	• Formulate the governing transport equations from conservation of mass, momentum, energy, and species • Understand the essence of no-slip and slip boundary conditions
III	**Unsteady flows:** Stokes first and second problems, some examples of oscillating flows, unsteady flows	5	• Obtain exact solutions for Stokes 1^{st} and 2^{nd} problems, unsteady flow induced by shear and oscillating pressure gradient, and discuss their relevance in micro fluidics
IV	**Pressure driven microflows:** Flow through annular pipe, rectangular duct, elliptical duct, etc.	4	• Obtain analytical solutions for the velocity field, flow rate, and friction factor for non-circular channels
V	**Surface tension driven flows:** Interfacial Equilibrium, Young-Laplace equation; Dimensionless numbers, Reduced order modelling;	5	• Formulate appropriate model to relate surface tension with interfacial curvature, pressure difference and contact angle.

	Dynamic contact angle		• Understand the working principle of a capillary-pump, and the Marangoni effect
VI	**Electrokinetics:** Electrostatics, Electric Double Layer, Electroosmotic flow, Joule heating in microchannel, Electrophoresis, Streaming potential and electroviscous effect, Sedimentation potential	10	• Identify length scales and the velocity scale associated with the electrokinetic effects • Analyse the electroosmotic flow for the special cases of thin-EDL plus low and high zeta-potential. • Formulate the charge conservation (Nernst-Planck) equation • Describe fluidic transport in nanochannels and electroviscosity
VII	**Dispersion**: Hydrodynamic dispersion in a channel, Taylor-Aris dispersion regime; Dispersion in EOF; Chromatography; Species separation – Capillary electrophoresis	5	• Analyse hydrodynamic dispersion of a species in pressure driven flow, • Discuss its relevance in micro-mixing, separation science, and other industrial applications

Course Outcome	On successful completion of this course, students should be able to: • understand the fundamental concepts and methods used in the cross-disciplinary field of microfluidics, which is a prominent branch of Micro-nano Science • use the presented theory as a practical tool, and read and understand research articles on the emerging area of micro and nano-scale transport • develop research interest on microfluidics and lab-on-a-chip systems

Learning Resources	1. *Theoretical Microfluidics* by Henrik Bruus, Oxford University Press 2. *Micro- and Nano-scale Fluid Mechanics - Transport in Microfluidic Devices* by Brian J Kirby, Cambridge University Press. 3. *Physiochemical Hydrodynamics - An Introduction* by Ronald F Probstein, John Wiley and Sons, Inc.