Syllabus

1	**Title of the course (L-T-P-C)**	**Advanced Heat Transfer (3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	**Module-1: Conduction:** Equations and boundary conduction in different coordinate systems; Analytical Solutions: separation of variables, Laplace Transform, Duhamel's theorem: Non-impulse initial conditions; Numerical Methods: Finite difference and flux conservation; Interfacial heat transfer. **Module-2: Convection:** Conservation equations and boundary conditions; Heat transfer in laminar developed and developing boundary layers: duct flows and external flows, analytical and approximate solutions, effects of boundary conditions; Heat transfer in turbulent boundary layers and turbulent duct flows; Laminar and turbulent free convection, jets, plumes and thermal wakes, phase change. **Module-3: Radiation:** Intensity, radiosity, irradiance, view factor geometry and algebra; formulations for black and non–black surfaces, spectrally–selective surfaces (solar collectors); Monte Carlo methods for radiation exchange; The radiative transfer equation, extinction and scattering properties of gases and aerosols, overview of solution methods and applications. **Module-4: Interaction between conduction, convection and radiation:** Coupled problems; Examples in manufacturing and electronic cooling applications; Micro channels and micro fins.
4	**Texts/References**	1. M N Ozisik, Heat Conduction, 2nd ed, John Wiley & Sons, 1993. 2. Kakaç, S., Yener, Y., Heat Conduction, 3rd edition, Taylor & Francis, 1993. 3. F P Incropera and D P Dewitt, Introduction to Heat Transfer, 3rd ed, John Wiley & Sons, 1996. 4. W. M. Kays and E. M. Crawford, Convective Heat and Mass Transfer, Mc Graw Hill,1993. 5. Adrian Bejan, Convective Heat Transfer, John Wiley and Sons, 1995. 6. M F Modest, Radiative Heat Transfer, McGraw-Hill, 1993. 7. R Siegel and J R Howell, Thermal Radiation Heat Transfer, 3rd ed, Taylor & Francis, 1992.

1	**Title of the course (L-T-P-C)**	**Introduction to Turbulence and its Modelling (3-0-0-6)**
2	**Pre-requisite courses(s)**	ME203 Fluid Mechanics.
3	**Course content**	• **Introduction to Turbulence**: Nature of turbulence, origin of turbulence, laminar and turbulent boundary layers, diffusion of turbulence, concept of eddy viscosity • **Statistics of Turbulence**: Statistical aspects of turbulence, scales in turbulence, spectrum of turbulence, energy cascade in isotropic turbulence, Kolmogorov hypotheses • **Mathematical Theory of Turbulence**: The Reynolds equation, Reynolds decomposition, equations for the mean flow, Reynolds stress, mixing length model, turbulent heat transfer, limitations of mixing length theory • **Dynamics of Turbulence**: Dynamics of turbulence, Taylor microscale, Reynolds stress and vorticity, the vorticity equation • **Boundary-free and Wall-bounded Turbulence**: Turbulent wakes, turbulent jets and mixing layers, turbulent flows in pipes and channels, experimental techniques for turbulence characteristics • **Introduction to Turbulence Modelling**: Turbulence modelling and closure problem, algebraic models, modern variants of the mixing length model, one equation models, k-□ and k-□ models, Spalart–Allmaras turbulence model • **Introduction to Numerical Techniques for Turbulence**: Direct numerical simulations (DNS), large eddy simulations (LES) and Reynolds averaged Navier-Stokes (RANS) modelling techniques, spectral methods and particle based methods for turbulence
4	**Texts/References**	**TEXTBOOKS** 1. Tennekes H. and Lumley J., A first course in turbulence, M.I.T. Press. 2. Tritton D.J., Physical Fluid Dynamics, Oxford University Press. 3. Davidson P.A., Turbulence: An Introduction for Scientists and Engineers, Oxford Uni Press. 4. Townsend A.A., The structure of turbulent shear flow, Cambridge University Press., 1980. 5. Wilcox D.C., Turbulence modeling for CFD, DCW Industries, Incorporated, 1994.

<table>
<tr><td>1</td><td>Title of the course
(L-T-P-C)</td><td>Advanced Finite Element Methods
(3-0-0-6)</td></tr>
<tr><td>2</td><td>Pre-requisite courses(s)</td><td>Finite Element Methods</td></tr>
<tr><td>3</td><td>Course content</td><td>FEM formulation for time dependent problems (16 hours)
- Transient heat transfer problems
- Structural dynamics problem
- Explicit and Implicit methods of solutions
- stability, accuracy and convergence study of solution methods

Introduction to reduced order modelling technique: (6 hours)
- Introduction to reduced order modeling
- Methods of reduced order modeling
o Static condensation,
o mode superposition,
o component mode synthesis,
o Krylov subspace technique.

Nonlinear Finite Element Method (18 hours)
- Introduction to Nonlinear FEM
- FEM for geometric nonlinearity and forcing nonlinearity,
- FEM for elastic-plastic analysis
o Strain hardening model
o Kinematic hardening model
- Methods to solve nonlinear problems
o Newton Raphson method
o Secant method
o Continuation method
- Convergence of nonlinear solutions
o Force convergence
Displacement convergence</td></tr>
<tr><td>4</td><td>Texts/References</td><td>1. J.N. Reddy, Introduction to Finite Element Method, Tata McGraw-Hill, 2006
2. J. N. Reddy, An Introduction to Nonlinear Finite Element Analysis, Oxford University Press, 2004.
3. K. J. Bathe, Finite Element Procedures, PHI Learning Pvt. Ltd., 1996
4. T. J. R. Hughes, The Finite Element Method: Linear Static and Dynamic Finite Element Analysis, Dover Publications, 2000
5. Zu-Qing Qu, Model Order Reduction Techniques with Applications in Finite Element Analysis, Springer, 2004</td></tr>
</table>

<table>
<tr><td>1</td><td>Title of the course
(L-T-P-C)</td><td>Multiphase Flow
(3-0-0-6)</td></tr>
<tr><td>2</td><td>Pre-requisite courses(s)</td><td>None</td></tr>
<tr><td>3</td><td>Course content</td><td>
• Introduction and overview : History, Motivation and Application
• Transport phenomena : Introduction, Reynolds transport theorem, Continuity equation, Momentum equation
• Fluid mechanics with interface : Interfacial tension and its role in multiphase flow, Surface energy and capillary forces, Measurement of surface tension, Laplace pressure and Young's law, Curvature computation, Capillary rise, Capillary force on floating bodies, Wetting, Wetting of a rough surface, Contact angle hysteresis, Singularities
• Boundary conditions in multiphase flows : Kinematic and dynamic boundary conditions, Stress conditions at fluid interfaces, Stress on deforming surfaces
• Scaling analysis : Introduction, Buckingham's theorem and dimensionless numbers for multiphase flow systems, Dimensional analysis and physical similarity, Self-similarity
• Introduction of asymptotic analysis : Asymptotic expansion, Pulsatile flow : Analytical and asymptotic solution, Domain perturbation method
• Lubrication model/Thin film approximation : Derivation of basic equation of lubrication theory, Thin film approximation with free surfaces : Derivation of governing equations and boundary conditions, Self-similar solution, Application of lubrication theory
• Flow instabilities: Fluid jets, Rayleigh-Plateau Instability, Fluid sheets, Rupture of soap film and derivation of Taylor-Culick velocity, Rayleigh-Taylor Instability, Kelvin-Helmholtz instability
• Numerical solution of Navier-Stokes equation: Time integration, Spatial discretization, Marker and Cell method, Boundary conditions
• Advection of fluid interfaces: Fundamentals, Numerical definition of interface, Heaviside function, Advection of color function, Volume of fluid method, Level set method, Numerical model of surface tension driven flows
• Applications: Bubbly flows, drop collision and splashing, Breakup and Atomization
</td></tr>
<tr><td>4</td><td>Texts/References</td><td>
<u>TEXTBOOKS</u>
1. L. Gary Leal, Advanced Transport Phenomena, First Edition, 2007, CUP.
2. G. Tryggvason, R. Scardovelli, and S. Zaleski, Direct numerical simulations of gas-liquid multiphase flows, First Edition, 2011, Cambridge University Press
<u>REFERENCE</u>
1. P.G. de Gennes, F. Brochard-Wyart and D. Quéré, Capillarity and Wetting Phenomena : Drops, Bubbles, Pearls, Waves, First Edition, 2003, Springer Publication
2. E. J. Hinch, Purterbation Methods, First Editions, 1991, Cambridge University Press
3. G. I. Barenblatt, Scaling, First Edition, 2003, Cambridge University Press.
4. J. Eggers & M.A. Fontelos, Singularities: Formation, structure & propagation, 1st Ed., 2015, CUP
</td></tr>
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1	**Title of the course** (L-T-P-C)	**Additive and Forming Manufacturing Processes** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	
3	**Course content**	**Module 1:** Introduction to Smart manufacturing, various Smart Manufacturing Technologies, Smart foundry, Reverse engineering, Traditional manufacturing, Rapid Tooling, Rapid Manufacturing; Indirect Processes - Indirect Prototyping, Indirect Tooling, Indirect Manufacturing. Introduction to Additive Manufacturing (AM): Overview of Additive Manufacturing (AM), Introduction to flexible manufacturing processes **Module 2:** AM technologies, classification of AM processes: Sheet Lamination, Material Extrusion, Photo- polymerization, Powder Bed Fusion, Binder Jetting, and Direct Energy Deposition, Popular AM processes. Additivemanufacturing of different materials **Module 3:** Advance in welding techniques, Robotic welding, characterization, Non-traditional Manufacturing processes, **Module 4:** Introduction: CAD/CAM, NC/CNC, CNC machines, Industrial applications of CNC, economic benefits of CNC. CNC Machine Tools, CNC tooling: Qualified and pre-set tooling, tooling systems, tool setting, automatic tool changers, work holding and setting. Programming: Part programming language, programming procedures, proving part programmes, computer aided part programming **Module 5:** Metal forming: Bulk and sheet metal forming processes, Fundamentals of plasticity, yield and flow, anisotropy, instability, yield criterion for isotropic materials, plastic stress strain relations for isotropic materials. Force equilibrium method and its application to metal forming processes. Introduction to incremental sheet and bulkmetal forming **Module 6:** Industry 4.0 cases studies of manufacturing
4	**Texts/References**	1. Gibson, D. W. Rosen, and B. Stucker, Additive Manufacturing Technologies: Rapid Prototypingto DirectDigital Manufacturing. Springer, 2014. 2. C. K. Chua and K. F. Leong, Rapid Prototyping: Principles and Applications in Manufacturing.WorldScientific, 2003. 3. Theory of Plasticity by J. Chakrabarty, McGrawHill Book Co., InternationalEdition, 19874. 4. Messler, R. W. (2008). Principles of Welding: Processes, Physics, Chemistry, and Metallurgy.Germany:Wiley. 5. Ibrahim Zaid, R. Sivasubramanian, CAD/CAM: Theory and Practice. McGraw Hill Education,2nd edition,2009. 6. M. P. Groover, E. W. Zimmers, CAD/CAM: Computer-aided design and manufacturing.Pearson, 2013.

1	**Title of the course** (L-T-P-C)	**Nonlinear Solid Mechanics for Finite Element Method** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Solid Mechanics and Finite Element is recommended
3	**Course content**	**1. Introduction to Tensors:** Overview of conventions & mathematical identities in vector calculus and tensor algebra **2. Review of Linear Elasticity:** Linear strain tensor, compatibility conditions, stress tensor, equilibrium equation **3. Kinematics of Deformation:** Material and spatial derivatives, Deformation gradient, Strain tensor, Velocity gradients, Spin tensor, Lie time derivatives **4. Concept of Stress:** Cauchy stress theorem, Piola transformation, First Piola-Kirchhof (PK) stress, Principal directions, Alternative stress definitions such as Second PK stress, Biot stress, Corrotated cauchy stress tensors **5. Balance Principals and Constitutive relation:** Conservation of mass, Reynolds' Transporttheorem, Principals of Momentum and Energy balance **6. Hyperelasticity:** Various strain-energy constitutive formulations - invariant based model, isotropic model, incompressible model, composite material model, examples from the field of soft tissue biomechanics and tyre industry **7. Viscoelasticity:** Generalized Maxwell Model, Relaxation time **8. Finite Element for Non-linear material:** Variational Principles, Objective stress rates, Linear Consistent Tangent Modulus, numerical challenge due to incompressibility
4	**Texts/References**	**Text-books: 1.** Gerhard A. Holzapfel, *Non-linear Solid Mechanics- A continuum approach for engineering,* John Wiley and Sons Ltd. 2000. **References: 1.** J. Bonet, RD. Wood, *Non-linear Continuum Mechanics for Finite Element Analysis* (2^{nd} Ed), Cambridge University Press., 2008. **2.** LA. Taber, *Non-linear Theory of Elasticity – Applications in Biomechanics*, World Scientific Publishing, 2004. **3.** Rene de Borst, Mike A. Crisfield, Joris J.C. Remmers, and Clemens V. Verhoosel, *Non-linear Finite Element Analysis of Solid and Structures,* (2^{nd} Edition), John Wiley and Sons Ltd., 2012.

1	**Title of the course** (L-T-P-C)	**Advanced Solid Mechanics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	--
3	**Course content**	**Module 1: Analysis of Stress:** Concept of traction, Cauchy Stress formula: Traction on arbitrary planes, Equality of cross-shears, Principal stresses and Principal Planes, Stress invariants, State of Stress Referred to Principal Axes – Octahedral stresses, Mohr's Circles for 3D State of Stress, Equations of equilibrium – Cartesian and Cylindrical coordinate systems. **Module 2: Analysis of Strain:** Displacement field, Deformation gradient, Change in length of a linear element andits linearization and physical interpretation, State of Strain at a point, Change in thedirection of a linear element, cubical dilatation, change in the angle between two linear elements – shear strain, Principal axes of strain and Principal strains, Strains in cylindrical coordinate systems, compatibility of linear strains. **Module 3: Stress-strain Relations – Linear Elastic Solids:** Generalized Hooke's Law, Material Symmetry Planes – Monoclinic, Orthotropic and Isotropic, Lames's constants, Bounds on moduli. **Module 4: Formulations, General theorems and Solution Strategies:** Stress formulation – Beltrami-Michell Compatibility relations, Navier-Lame Equations of equilibrium, Strain Energy Concept, Saint Venants principle, Principle of Superposition, Uniqueness theorem; General Solution strategies. **Module 5: Plane elasticity:** Plane stress, Pane strain, 2D stress formulation in Cartesian and Polar Coordinates: Airy stress function. **Module 6: 2D Problems:** Cartesian coordinate Problems: Using Polynomials and Fourier series , Polar coordinateProblems: Axisymmetric problems - Lame, Rotating Disk, curved beams under pure moments, Infinite/Semi-infinitebody subjected to concentrated loads – Kelvin and Flamant problems, Stress concentration in an infinite plate with a small hole – Kirsch problem. **Module 7: Extension, Flexure and Torsion of Prismatic bars:** Extension formulation; Torsion formulation: SaintVenants semi-inverse approach, Prandtl's stress function approach, Membrane analogy, Solution using Fourier series, Torsion of thin-walled tubes – Bredt-Batho formula; Flexure formulation without twist.
4	**Texts/References**	**Text-books: 1.** M.H.Sadd,"Elasticity: Theory, Applications and Numerics",Academic Press, 2013. **2.** J. R. Barber, Elasticty, Springer, 2010. **3.** L.S.Srinath,"Advanced Mechanics of Solids" Tata McGraw Hill, 2007. **References: 1.** S.P. Timoshenko and J.N. Goodier, "Theory of Elasticity," McGraw-Hill, Third Ed., New York,1970. 2. Allan F. Bower, Applied mechanics of Solids.. CRC press, 2009. 3. Adel S. Saada , Elasticity: Theory andApplications, Second Edition, Revised & Updated.. J. Ross Publishing, ,2009. 4. Robert William Soutas-Little,Elasticity, Courier Corporation, 2012.

<table>
<tr><td>1</td><td>Title of the course
(L-T-P-C)</td><td>Advanced Mechanisms and Dynamics ofMechanical Systems
(3-0-0-6)</td></tr>
<tr><td>2</td><td>Pre-requisite courses(s)</td><td>--</td></tr>
<tr><td>3</td><td>Course content</td><td>
Review of Grashof criterion and its derivation
Synthesis of Mechanisms - Four bar linkage and Slider crank mechanisms
Two position Double rocker design
Two position motion generation
Three position motion generation
Function Generation
Synthesis of crank-rocker for a specified rocker amplitude
Path synthesis -- practical Approaches
Roberts Cognate Theorem
Review of Special Mechanisms
Straight Line generating mechanisms
Ackermann Steering Mechanism
Pantograph Mechanism and its derivation
Brief introduction to spatial linkages
Serial Chain
Closed loop linkages
Review of Dynamics of particles
Newton's laws, Impulse Momentum
Moment of a force and Angular Momentum, Work and Energy
System of particles
Fundamentals of Analytical Mechanics
Degrees of freedom and generalized coordinates
Systems with constraints
The stationary value of a function and a definite integral
The principle of virtual work
D' Alembert's principle
Hamilton's principle
Lagrange's equation of motion
Lagrange's equations for impulsive forces
Conservation laws
Routh's method for ignoration of coordinates
Rayleigh's dissipation Function
Hamilton's equations
</td></tr>
<tr><td>4</td><td>Texts/References</td><td>TEXTBOOKS
1. "Kinematics Dynamics and Design of Machinery", Kenneth Waldron and Gary L. KInzel,Second Edition, John Wiley and Sons.
2. "Analytical Dynamics", Leonard Meirovitch, First Edition, McGraw Hill.</td></tr>
</table>

1	**Title of the course** (L-T-P-C)	**Advanced Fluid Mechanics and Heat Transfer** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	-----
3	**Course content**	Boundary layer theory: fundamentals, derivation of N-S equations, exact solutions of N-S equations,Boundary-layer equations in plane flow, coupling of thermal boundary layers and velocity field of the temperature field, internal flows Potential flow and flow past immersed bodies Turbulence: high Re flows, energy-transfer concepts, turbulent boundary layers, free-shear flows like jets, wakes, andmixing layers, turbulence modelling Compressible flows: energy equation, assumptions, compressible flows, stagnation properties, speed of sound, isentropic and non-isentropic flows, potential and rotational flows, effect of area change, shaft work, heat addition, mass addition and friction on flow states in a compressible (channel) flow. Pool Boiling: Nukiyama curve, boiling regimes, correlations, enhancement of boiling heat transfer Two phase flow and heat transfer: liquid-vapor interface, contact angle hysteresis, bubble formation,flow regimes,flow models, condensation. Radiation: Intensity, radiosity, irradiance, view factor geometry and algebra, radiative heat transfer equation, extinctionand scattering properties of gases and aerosols, overview of solution methods and applications. Radiation in Enclosures – Gas Radiation – Diffusion and Convective Mass Transfer – Combined Heat and Mass Transfer
4	**Texts/References**	**Texts:** 1. Hermann Schlichting, and Klaus Gersten. Boundary layer theory. 9th edition. Springer, 2017. 2. Tennekes, Hendrik, and John L. Lumley. A first course in turbulence. MIT press, 2018. 3. Anderson, John D. Modern compressible flow. Tata McGraw-Hill Education, 2003. 4. Carey, Van P. Liquid-vapor phase-change phenomena: an introduction to the thermophysics ofvaporizationand condensation processes in heat transfer equipment. CRC Press, 2018. 5. Incropera, Frank P., et al. Fundamentals of heat and mass transfer. Wiley, 2007. 6. Modest, Michael F. Radiative heat transfer. Academic press, 2013. **References:** 7. Davidson, Peter Alan. Turbulence: an introduction for scientists and engineers. Oxford universitypress, 2015. 8. Pope, Stephen B. "Turbulent flows." (2001): 2020. 9. Bejan, Adrian. Convection heat transfer. John wiley & sons, 2013. 10. Kays, William Morrow. Convective heat and mass transfer. Tata McGraw-Hill Education,2011.

1	**Title of the course** (L-T-P-C)	**Compressible Flow and Gas Dynamics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	● **Introduction**: Gas dynamics, review of basic mass, momentum and energy conservation lass for compressible flows, speed of sound, wave equation, regimes of Mach number, shocks, wave propagation, sound speed, Mach number, isentropic flow, static and stagnation properties ● **One-dimensional flow**: Governing equations for one dimensional flow, Converging-diverging nozzles, shock waves, moving and reflected waves, blast waves, wind tunnels, supersonic engines, 1D equations for stationary normal shock, Entropy change across a normal shock, Crocco's theorem, Hugoniot equation, moving normal shock and reflected shock waves ● **Two Dimensional Flow**: Oblique shock wave theory, conical oblique shock waves, concepts of attached and detached shock waves, Prandtl-Mayer expansion fans, supersonic inlets and diffusers. ● **Compressible Pipe Flow**: Fanno-Line flow, Rayleigh pipe flow, natural gas flow in pipelines ● **Compressible Potential Flow**: Method of characteristics, supersonic nozzle design ● **Introduction to Hypersonic Flows.** **Introduction to Numerical Solutions**: Characteristic relations and Riemann invariants, representative model problems, convection-diffusion equation, Burgers' equation, Riemann problems, Roe's approximate Riemann solver for the Euler equations
4	**Texts/References**	● J.D. Anderson, Modern Compressible Flow, McGraw-Hill, (3rd Edition), 2017 ● S.M. Yahya. Fundamentals Of Compressible Flow With Aircraft And Rocket Propulsion, New Age International Publishers; 6th Edition, 2018. ● Doyle D. Knight, Elements of Numerical Methods for Compressible Flows, Cambridge Aerospace Series, Cambridge University Press, 2012. ● Hodge & Koenig, Compressible Fluid Dynamics, PEI, 1st edition, 2015. ● H.W. Liepmann and A. Roshko, Elements of Gas Dynamics, Dover Pub., 2013. ● Shapiro, Ascher H., Dynamics and thermodynamics of compressible fluid flow, John Wiley 1953.

1	**Title of the course** (L-T-P-C)	**Design of Heat Exchangers** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Fluid Mechanics and Heat Transfer
3	**Course content**	Classification of heat exchangers, Basic design methods of heat exchangers Single phase heat exchangers: Forced Convection Correlations for the Single-Phase Side of Heat Exchangers, Design of double pipe heat exchangers, shell and tube heat exchangers, compact heat exchangers Fundamentals of two phase flow, Essentials for the design of two phase heat exchangers, Design Correlations for Condensers and Evaporators, Design of evaporators and condensers
4	**Texts/References**	1. Ramesh K. Shah, Dusan P. Sekulic, Fundamentals of Heat Exchanger Design, John Wiley and Sons, USA, 2003, ISBN:9780471321712, First Edition 2. Sadik Kakac, Hongtan Liu, Anchasa Pramuanjaroenkij, Heat Exchangers: Selection, Rating, and Thermal Design, CRC Press, 2020, ISBN 9781138601864, Fourth Edition 3. W.M. Kays and A.L. London, Compact heat exchangers, McGrawhill Book Company, 1984, ISBN: 9780070334182, Third Edition 4. Arthur P Fraas, Heat Exchanger Design, John Wiley and Sons, 1989, ISBN: 978-0-471-62868-2. Second Edition

1	**Title of the course** (L-T-P-C)	**Tribology** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	**Introduction – Materials and surfaces:** Tribology — Historical perspective, Industrial Significance, Economic considerations; Solid structure and properties — Atomic Structure, Bonding and Coordination, Disorders in Solid Structures, Elastic and Plastic Deformation, Fracture and Fatigue, Time Dependent Viscoelastic & Viscoplastic Deformation. Surfaces — Nature of surfaces, Characteristics of Surface Layers, Surface texture, Surface parameters, Measurement of surface parameters, Statistical properties of surfaces, Analysis of Surface Roughness. **Contacts:** Analysis of Contacts — Single Asperity, Multiple Asperity Contacts, Measurement of the Real Area of Contact, Stress distribution, Displacements due to loading, Hertzian and non-Hertzian contacts, Rough surfaces in contact, Deformation mode, Thermal effects; Adhesion — Solid–Solid Contact, Contact with liquid mediation. **Friction:** Friction — Measurement, Causes, Theories, Plastic interaction of surface asperities, Ploughing effect, Elastic hysteresis losses, Solid–Solid Contact, Liquid-Mediated Contact, Friction of Materials; Rolling Motion — Free rolling, Microslip in rolling, Tyre-road contacts. **Wear:** Wear — Definitions, Mechanisms, Wear Debris, Wear of Materials, Indentation cracking, Factors affecting wear, Experimental considerations, Wear control, Application of wear in design, Characteristics of friction induced vibrations. **Lubrication:** Lubricants — Viscosity, Measurement of viscosity, Lubricating oils, Greases; Lubrication — Regimes of Fluid Film Lubrication, Viscous Flow and Reynolds Equation, Hydrostatic Lubrication, Hydrodynamic Lubrication, Elasto- hydrodynamic Lubrication.
4	**Texts/References**	1. Introduction to Tribology, Bharat Bhushan, John Wiley & Sons. 2. Principles of Tribology, Halling, J. (Ed), Macmillan, 1975.

1	**Title of the course** (L-T-P-C)	**CNC & Part Programming** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Manufacturing processes
3	**Course content**	**Module: 1** Introduction: NC/CNC, CNC machines, Industrial applications of CNC, economic benefits of CNC. CNC Machine Tools (6 hr) **Module: 2** Classification of machine tools, CNC machines tool design, control systems (8 hr) **Module: 3** Position control, velocity control and machine tool control, Interpolation and electronics. Data Input: Punched tape, manual data input, tape punch, reader error checking (8 hr) **Module: 4.** CNC tooling: Qualified and pre-set tooling, tooling systems, tool setting, automatic tool changers, work holding and setting. Programming: Part programming language, programming procedures, proving part programmes, computer aided part programming (9 hr) **Module: 5.** Advances: Advances in CNC programming, integration with CAD, material handling in CNC machines, manufacturing systems (9 hr)
4	**Texts/References**	1) Warren S. Seames, Computer numerical control: concepts and programming, Thomson Learning, 2001 2) William W. Luggen, Computer numerical control: a first look primer, Thomson Publishing, 1996 3) Learning Barry Leatham - Jones, Introduction to Computer Numerical Control, Pitmans, London, 1988. 4) T.K. Kundra, P.N. Rao and N.K. Tewari, Numerical control and Computer Aided Manufacturing, Tata McGraw Hill Publishing Company Limited, New Delhi

1	**Title of the course** (L-T-P-C)	**Linear Viscoelasticity** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	**Concepts of Viscoelasticity** – Force-extension equations of the simple models, Creep and relaxation behaviour, Complex modulus and compliance, Stored and dissipated energies, Creep and relaxation behaviour of some real materials. **Fundamental Aspects of Viscoelastic Response** – Introduction, Nature of Amorphous Polymers, Mechanical Response of Viscoelastic Materials, Energy Storage and Dissipation, Glass Transition and Regions of Viscoelastic Behavior, Aging of Viscoelastic Materials. **Constitutive Equations in Hereditary Integral Form** – Boltzmann's Superposition Principle, Principle of Fading Memory, Closed-Cycle Condition, Relationship Between Modulus and Compliance, Alternate Integral Forms, Work and Energy. **Constitutive Equations in Differential Operator Form** – Fundamental Rheological Models, Rheological Operators, Construction of Rheological Models, Simple Rheological Models, Generalized Models, Composite Models. **Constitutive Equations for Steady-State Oscillations** – Steady-State Constitutive Equations from Integral Constitutive Equations, Steady-State Constitutive Equations from Differential Constitutive Equations, Limiting Behavior of Complex Property Functions, Energy Dissipation. **Structural Mechanics** – Bending, Torsion, Column Buckling, Viscoelastic Evens, Elastic– Viscoelastic Correspondence, Mechanical Vibrations. **Thermoviscoelasticity** – Thermodynamical Derivation of Constitutive Relations, Restrictions and Special Cases, Time Temperature Superposition, Relationship to Nonnegative Work Requirements, Formulation of the Thermoviscoelastic Boundary Value Problem, Temperature Dependence of Mechanical Properties, Thermorheologically Simple Materials, Phenomenology of the Glass Transition, Glass Transition Criterion, Effect of Pressure on the Glass Transition Temperature, Hygrothermal Strains, Heat Conduction.
4	**Texts/References**	1. Engineering Viscoelasticity, Gutierrez-Lemini, Danton, Evener, 2014. 2. Theory of Viscoelasticity, R. M. Christensen, 2nd Edition, Dover Civil and Mechanical Engineering. 3. The Theory of Linear Viscoelasticity, D. R. Bland, Dover Books on Physics. 4. Viscoelasticity of Engineering Materials, Haddad, Y.M., Evener, 1995.

1	**Title of the course** (L-T-P-C)	**Mechanics of Composite Materials** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Mechanics of Materials
3	**Course content**	**Module 1: Basic Concepts, Materials, Processes and Characteristics**: Conventional materials and composite materials; Terminologies definition; composite materials Classification; Scales of analysis and basic lamina properties; Constituent Materials Manufacturing methods**Module 2: Lamina's elastic and strength behaviour - Micromechanics**: Micromechanics model; Longitudinal and transverse elastic properties of continuous fibers; In-plane shear modulus; Longitudinal properties of discontinuous fibers or short fibers – Shear lag analysis; Strength – longitudinal tensile and compressive behaviour, transverse tensile and compressive behaviour, in- plane shear, pout-of-plane behaviour**Module 3: Lamina's elastic and strength behaviour - Macromechanics**: Stress-strain relation – Anisotropic; orthotropic, transversely isotropic and isotropic; Stress-strain relations for a lamina; Transformations- stress, strain elastic moduli in 2D and 3D; Failure theories – Maximum stress, maximum strain, Tsai-Hill; Failure-mode-based theories.**Module 4: Multi-directional Laminate's elastic and strength behaviour**: Strain-displacement relations; Stress-strain relation; Laminate's stiffness/compliance; Types of laminates – symmetric, balanced, orthotropic and quasi-isotropic laminates; Determination of elastic parameters for uni- directional and angle-ply laminates; Modified lamination theory for transverse shear; Strength – types of failure, stress analysis and strength component for first-ply failure of symmetric laminates; Extension to multidirectional laminates; Carpet plots**Module 6: Bending, Buckling, And Vibration Of Laminated Plates**: governing equations for bucklion, vending and vibrations; flexural deflection of simply supported laminated plates; buckling of simply supported laminated plates; vibration of simply supported laminated plates**Module 7: Hygrothermal effects**: Introduction, CoTE (thermal expansion) and CoME (Moisture- expansion) for a lamina; Load-deformation relations in hygrothermalelasticity; COTE and COME for multi-directional laminates; Warpage and residual stresses; Effect on strength of mechanical and hygrothermal loading on multi-directional laminates.**Module 8: Experimental characterisation and testing of Composite materials:** Characterisation of constituent materials; Determination of tensile/compressive and shear properties of uni-directional laminae; Through thickness properties; Biaxial testing; Stress concentration characterization and structural testing
4	**Texts/References**	**Text-books: 1**. I. M. Daniel and O. Shai, Engineering Mechanics of Composite Materials, 2nd ed., Oxford University Press. **2.** R. M. Jones, Mechanics of Composite Materials, 2nd Ed., CRC Press. **References: 1.** A. Kaw, Mechanics of Composite Materials, 2nd Ed., CRC Press., **2.** V.V. Vasilievand E.V. Morozov, Mechanics And Analysis Of Composite Materials, , Elsevier, 2001. **3.** R.M. Christensem, Mechanics of Composite Materials, Dover**, 4.** H. Altenbach, J. Altenbach, W. Kissing, Mechanics of Composite Structural Elements, Springer-Verlag Berlin Heidelberg, 2004*Reference:* *(1) Parameterized Complexity, R. G. Downey, and M. R. Fellows. Springer Science and Business Media. 2012*

1	**Title of the course** (L-T-P-C)	**Mechanical Vibrations** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	
3	**Course content**	**Module 1:** Concepts of Vibrations: Harmonic motion and definitions and terminology, Harmonic analysis, Fourier series expansion, Importance of vibration, Basic concepts of vibration, Classification of Vibration, Vibration analysis procedure; Discrete System Components – Springs, Dampers and Masses. **Module 2:** One DOF systems: Free Vibrations, Harmonic Oscillator, Types of damping, Viscously Damped Single DOF Systems, Measurement of Damping, Coulomb Damping – Dry Friction. Forced Vibrations – Response of Single DOF System to Harmonic Excitations, Response to Periodic Excitations, Response of Single DOF systems to Nonperiodic Excitations. **Module 3:** Two DOF Systems: System Configuration, Equations of Motion of 2 DOF Systems, Free Vibration of Undamped Systems Natural Modes, Response to Initial Excitations, Coordinate Transformations – Coupling, Orthogonality of Modes - Natural Coordinates, Beat Phenomenon, Response of Two-Degree-of-Freedom Systems to Harmonic Excitations, Undamped Vibration Absorbers. **Module 4:** Vibrations of Continuous Systems: Vibrating String, Longitudinal vibrations of Bar, Torsional vibrations of Rod. Lateral vibrations of Beam. Analytical Dynamics: Degrees of Freedom and Generalized Coordinates, Principle of Virtual Work, Principle of D'Alembert, Hamilton's Principle, Lagrange's Equations. **Module 5:** Multi-Degree-of-Freedom Systems: Equations of Motion for Linear Systems; Flexibility, Stiffness Influence Coefficients and Mass Coefficients; Lagrange's Equations; Linear Transformations; The Eigenvalue Problem; Orthogonality of Modal Vectors; Systems Admitting Rigid-Body Motions; Decomposition of the Response in Terms of Modal Vectors; Response to Initial Excitations by Modal Analysis;Eigenvalue Problem in Terms of a Single Symmetric Matrix; Geometric Interpretation of the Eigenvalue Problem; Rayleigh's Quotient and Its Properties; Response to Harmonic External Excitations; Response to External Excitations by Modal Analysis – Undamped systems, Systems with proportional damping; Systems with Arbitrary Viscous Damping; Discrete-Time Systems. .
4	**Texts/References**	**Text-books: 1.** S S Rao, Mechanical Vibrations, Pearson Education, 5 th Edition, 2004. **References: 1.** W T Thomson, M D Dahleh and C Padmanabha, Theory of Vibration with applications, Pearson Education, 2008. **2.** Leonard Meirovitch, Fundamentals of Vibrations, McGraw-Hill, 2000. **3.** Den Hartog, Mechanical Vibrations, Dover Publications, 4 th Edition.

1	**Title of the course** (L-T-P-C)	**Fundamentals of Acoustics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Exposure to Fluid Mechanics
3	**Course content**	**Review of classical acoustics**: review of classical acoustics, linearized equations of motion, classical wave equation. Speed of sound, harmonic waves, acoustic energy/intensity, decibel scale. Acoustic impedance and admittance, reflection and transmission at the interface of two media, Impedance tube technique. **Sound propagation:** plane and spherical waves, Travelling and standing waves, boundary conditions, Eigen frequency and Eigen modes. Effects of area variation, reflection and transmission of waves in pipes. Acoustic wave propagation in homogeneous and inhomogeneous media; **Models for acoustic sound sources:** point sources, monopoles, dipoles and quadrupoles, Aero-acoustic sources: Lighthill's acoustic analogy, integral solutions and far-field approximations; effect of solid surface; **Losses:** Viscous and thermal conduction losses, absorption coefficient, sound absorption in pipes **Measurement** of sound signals, microphones, time series analysis using Fast Fourier Transform, Discrete Fourier Transform, Transfer function, and Bode plots. Solving numerical problems. **Applications to engineering problems**: Aero-acoustic jet noise, Thermoacoustic instability, fan/rotor noise and numerical evaluation
4	**Texts/References**	1.Lawrence E. Kinsler, Austin R. Frey, and Alan B. Coppens, 2000. Fundamentals of acoustics. 4th edn. John-Wiley & Sons, Inc. 2.Pierce, Allan D. Acoustics: an introduction to its physical principles and applications. Springer, 2019. 3.Munjal, M. L. (1987). Acoustics of ducts and mufflers with application to exhaust and ventilation system design. John Wiley & Sons. 4.Tim C. Lieuwen, 2012. Unsteady combustor physics. 1st edn. Cambridge University Press.

1	**Title of the course** (L-T-P-C)	**Turbomachinery Aerodynamics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Thermodynamics, Fluid Mechanics during UG
3	**Course content**	**Introduction to Turbomachineries** **Axial flow compressors and Fans:** Introduction; Aero-Thermodynamics of flow through an Axial flow Compressor stage; Losses in axial flow compressor stage; Losses and Blade performance estimation; Secondary flows (3-D); Tip leakage flow and scrubbing; Simple three dimensional flow analysis; Radial Equilibrium Equation; Design of compressor blades; 2-D blade section design: Airfoil Data; Axial Flow Track Design; Axial compressor characteristics; Multi-staging of compressor characteristics; Transonic Compressors; Shock Structure Models in Transonic Blades; Transonic Compressor Characteristics; 3-D Blade shapes of Rotors and Stators; Instability in Axial Compressors; Loss of Pressure Rise; Loss of Stability Margin; Noise problem in Axial Compressors and Fans **Axial flow turbines:** Introduction; Turbine stage; Turbine Blade 2-D(cascade) analysis Work Done; Degree of Reaction; Losses and Efficiency; Flow Passage; Subsonic, transonic and supersonic turbines, Multi-staging of Turbine; Exit flow conditions; Turbine Cooling; Turbine Blade design – Turbine Profiles: Airfoil Data and Profile construction. **Centrifugal Compressors:** Introduction; Elements of centrifugal compressor/ fan; Inlet Duct Impeller; Slip factor; Concept of Rothalpy; Modified work done; Incidence and lag angles; Diffuser; Centrifugal Compressor Characteristics; Surging; Choking; Rotating stall; Design **Radial Turbine:** Introduction; Thermodynamics and Aerodynamics of radial turbines; Radial Turbine Characteristics; Losses and efficiency; Design of radial turbine. Use of CFD for Turbomachinery analysis and design.
4	**Texts/References**	1. Dixon, S. Larry, and Cesare Hall, "Fluid mechanics and thermodynamics of turbomachinery," Butterworth-Heinemann, 2013. 2. Lakshminarayana, Budugur, "Fluid dynamics and heat transfer of turbomachinery," John Wiley & Sons, 1995. 3. Cumpsty, Nicholas A., "Compressor aerodynamics," Longman Scientific & Technical, 1989. 4. Hill, Philip G., and Carl R. Peterson, "Mechanics and thermodynamics of propulsion," AW (1992). 5. Johnsen, Irving A., and Robert O. Bullock, eds., "Aerodynamic Design of Axial-Flow Compressors," NASA SP-36, 1965. 6. Glassman, Arthur J., ed., "Turbine design and application," NASA-SP-290, 1975.

1	**Title of the course** (L-T-P-C)	**Metal Forming and Plasticity** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Exposure to Manufacturing Science
3	**Course content**	**Introduction:** Different metal forming processes, importance of plasticity in the course. **Module 1:** Analysis of stress: transformation relations, principal stresses and directions, maximum normal and shear stresses, invariants, hydrostatic and deviatoric parts; Analysis of (infinitesimal) strain: transformation relations, principal strains, invariants, hydrostatic and deviatoric parts; (Infinitesimal) rotation, Stress strain relations for isotropic, linearly elastic material. **Module 2:** Experimental observations on plasticity: yielding, strain hardening, visco plasticity, temperature softening, Baushinger effect, hysteresis, incompressibility of plastic deformation, anisotropy, plastic instability. **Module 3:** Yield criterion for isotropic materials: von Mises and Tresca yield criterion, their geometric interpretation, convexity of the yield surfaces, experimental validation. **Module 4:** Incremental and rate forms of the measures of plastic deformation: linear incremental strain tensor, strain rate (i.e. the rate of deformation) tensor and their relation, incremental rotation tensor and spin tensor. **Module 5:** Change in yield criteria due to isotropic hardening: strain hardening and work hardening hypotheses, experimental validation of the hypotheses. **Module 6:** Plastic stress strain relations for isotropic materials: plastic potential and associated flow rule, incremental and rate forms of elastoplastic stress strain relations, simplifications for non- hardening and rigid plastic materials (Prandtl Reuss and Levy-Mises relations), Objective measures of stress rate and incremental stress.
4	**Texts/References**	1. The Mathematical Theory of Plasticity by R. Hill, Oxford University Press 2. Theory of Plasticity by J. Chakrabarty, Butterworth-Heinemann, 3rd edition 3. Metal Forming Mechanics and Metallurgy, William F. Hosford, Robert M. Caddell Cambridge University Press; 4th edition

1	**Title of the course** (L-T-P-C)	**Sustainable Energy for Transportation** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	None for M. Tech SSM. For others, instructor consent is required
3	**Course content**	**Introduction**: Introduction to conventional energy for transportation, Internal combustion (IC) engines and Gas Turbine Engines, Emission formation and Environmental issues; Hydrocarbon fuels and Sustainability. **Battery operated vehicles**: Introduction, Types, Batteries, Accessories; Hybrid vehicles: Introduction, Classification, Advantages and disadvantages; Different types of sustainable electricity production: Solar, Wind, Hydro renewable energy, Direct Energy Conversion: thermionic and thermoelectric converters, photovoltaic generators, MHD generators, Integrated Gasification Combined Cycle (IGCC), Clean Coal Technologies, Geological CO_2 sequestering. **Fuel cells**: Introduction, Fuel cell system, Classification, Thermo dynamics and performance of fuel cells and their applications. Operational issues; **Hydrogen Energy**: General introduction to hydrogen production, storage, dispensing and utilization. Hydrogen Utilization in I.C. Engines, gas turbines, and marine applications. Hydrogen fuel quality, performance, COV, emission and combustion characteristics of Spark Ignition engines for hydrogen, back firing, knocking, volumetric efficiency, hydrogen manifold and direct injection, fumigation, NO_x controlling techniques, dual fuel engine, durability studies. Hydrogen Safety. **Bioenergy**: Introduction to bioenergy; characterization of biomass feedstock (physico-chemical properties, ultimate, proximate, compositional, calorific value, thermogravimetric, differential thermal and ash fusion temperature analyses); classification of biomass feedstock: first, second and third generation biofuels; hybrid biofuels, basic principles of chemical thermodynamics; carbon neutral fuels. utilization of biofuels in gas turbine, internal combustion engines and fuel cells; **Alternative fuels for ground transportation**: Alternative fuels -liquid and gaseous fuels, Physico- chemical characteristics, Alcohol fuels: ethanol & methanol, fuel composition, Fuel induction techniques, Applications to engines and automotive conversions, Biodiesel formulation techniques, Transesterification, Application in diesel engines, Dimethyl ether (DME), properties fuel injection consideration general introduction to Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG), Compressed natural gas (CNG), Biogas, Producer gas and their characteristics, System development for engine application. **Plasma trusters**: Thermal, non-thermal plasmas; Aerospace, Plasma thrusters, Micro-satellite application, Collection and removal of fine particles in plasma chambers; Hazardous waste problem.
4	**Texts/References**	**1.** Moran M.J., H.N. Shapiro., Fundamentals of Engineering Thermodynamics, 3rd Ed., Wiley, 1995. **2.** Rand D.A. J., Woods R. & Dell R.M., Batteries for Electric Vehicles, Research Studies Press (1998). **3.** Linden D. & Reddy T.S., Handbook of Batteries, 3rd Edition, McGraw-Hill, (2002).**4.** Nikolai Khartekenko, Advanced Energy Systems, Taylor & Francis (1988). **5.** Angrist S. W., Direct Energy Conversion, Pearson, 1982. **6.** Bagotsky V.S., Fuel Cell Problems and Solutions, John Wiley & Sons, 2009. **7.** Ball M. and Wietschel M., The Hydrogen Economy Opportunities and Challenges, CPU (2009). **8.** Mukunda, H. S., Understanding Clean Energy and Fuels from Biomass, Wiley, 2011. **9.** Babu M.K.G., Subramanian K.A. Alternative Transportation Fuels: Utilization in Combustion Engines, CRC Press (2013). **10.** Bechtold R.L., Alternate Fuels-Transportation Fuels for Today and Tomorrow, Society of Automotive Engineers (SAE), 2002.

<table>
<tr><td>1</td><td>Title of the course
(L-T-P-C)</td><td>Mechanical Engineering Experimental Laboratory
(1-0-3-5)</td></tr>
<tr><td>2</td><td>Pre-requisite courses(s)</td><td>--</td></tr>
<tr><td>3</td><td>Course content</td><td>Theory: Design of Experiments: Types of Experiments, Experiment Design Factors, Experiment Planning, Static and Dynamic Calibration. General Data Acquisition System, Signal Conditioning, Data Transmission, Analog-to-Digital and Digital-to-Analog Conversion, Data Storage and Display, Causes and Types of Experimental Errors, Evaluation of Uncertainties. Error Propagation, Central limit theorem, 95% confidence interval, Pressure Measurement, Measurement of Temperature, Thermal and Transport-Property Measurements. Pitot and static tubes, Intrusive and non-intrusive flow measurements. Probability Density Function, Auto- and Cross-correlations, Correlation functions and their use in experiments, Inverse techniques, Digital image analysis.

• Exp. 1. CNC part programming, Job preparations, tool setting, job setting, fundamentals of part programming, path generation.
• Exp. 2. Effect of process parameters on weld bead geometry, Characterization
• Exp. 3. 3D printing of simple to composite material, path planning, STL processing, post planning composite and tensile testing
• Exp. 4. Sheet metal formability test; Erichsen cupping test
• Exp. 5.Tensile (MS and Al), Compression and 3-point bend test on 100 kN machine
• Exp. 6. Determination of ductile to brittle transition temperature of Mild Steel and Aluminum using Impact Testing Machine.
• Exp. 7. Fatigue Tests and Endurance limit
• Exp. 8. Hertzian apparatus, stress and strains in membrane and Measurement of stress concentration factor in a specimen with holes using photo-elasticity method.
• Exp. 9. Observation of mode shapes and measurement of natural frequencies of cantilever (damped and undamped)
• Exp. 10. Measurement of Mode I fracture toughness using a compact tension (CT) specimen
• Exp. 11: Wind tunnel experiments: measurement of static, dynamic pressure and forces acting on cylinder, symmetric and asymmetric airfoils at different Reynolds numbers
• Exp. 12: Measurement of flow through anemometer, DAQ and its components, low-pass, high-pass filters and spectrum analysis
• Exp. 13: Turbulent jets and plumes, flow visualization and analysis
• Exp. 14: Experiments on Boiling and Condensation</td></tr>
<tr><td>4</td><td>Texts/References</td><td>1. Springer Handbook of Experimental Solid Mechanics, Sharpe, 2008. 2. Flow Visualization, Wolgang Merzkirch, Academic Press, 3. Mechanical Measurements, Beckwith and Buck, Addison-Wesley, 1982., 4. Measurement Science for Engineers, Regtein, 2004., 5. Experimental Methods for Engineers, J P Holman, McGraw-Hill, 2011., 6. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, J R Taylor, University Science Books, 1997.</td></tr>
</table>

1	**Title of the course** (L-T-P-C)	**Practicum** **(0-0-3-3)**
2	**Pre-requisite courses(s)**	None for M. Tech SSM. For others, instructor consent is required
3	**Course content**	Pre-mid semester: 1. Overview on components, subsystems in EV 2. Reverse Engineering: a. Two/Three/Four Wheel EV, b. Conventional IC Vehicle 3. Site visits to testing and manufacturing centers or colloquium with Industry experts Post-mid semester: 1. Hands-on on fabrication, manufacturing, machining and metrology a. Sheet metal b. Welding processes c. Machining processes d. 3D Printing e. Material characterization; static and dynamic loading f. Impact tests
4	**Texts/References**	TEXTBOOKS a. Elements of Workshop Technology Vol. 1 (2015), S. K. Hajra Choudhary, A. K. Hajra Choudhary and Nirjhar Roy, Media Promoters and Publishers Pvt. Ltd. b. W. A. J. Chapman, Workshop Technology, Vol. 1 (2006), Vol 2 (2007), and (1995), CBS Publishers. c. Handbooks of Convenctional IC Engine Vehicle and EV vehicles

1	**Title of the course** (L-T-P-C)	**Introduction to Statics and Dynamics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	None for M. Tech SSM. For others, instructor consent is required
3	**Course content**	• Recapitulation of concepts of Units system, Vectors, Force, Moments, Couples, the concept of free body diagram; Equivalent systems for a system of forces - reducing a system of forces to a single force and couple, wrench; First moment of area, second moment of area, mass moment of inertia; • **Equilibrium conditions** for a particle, a rigid body, system of rigid bodies (structures - truss, frames), Friction - Columb laws, Applications of friction: Journal bearing, belt drives • **Energy and stability**: Principle of virtual work for a particle, rigid body and system of rigid bodies,; Potential Energy - linear springs and gravitational potential energy; Stability - stable, unstable and neutral equilibrium, conditions for the stability. • **Kinetics & Kinematics** of particles - Motion in 3D - Recap of vector calculus, Path coordinates system - tangential and normal coordinate system, Radial coordinate system, Relative motion - translating and rotating frame of references. • Introduction to the **deformable bodies**, **concepts of stress** - normal and tangential,
4	**Texts/References**	<u>TEXTBOOKS</u> 1. Beer, Johnston, Cornwell, Sanghi - Vector Mechanics for Engineers: Statics and Dynamics, 10th Edition, McGraw-Hill, 2017 2. Crandall, Dahl, Lardner, Shivkumar - An Introduction to Mechanics of Solids, 3rd Edition, McGrraw-Hill, 2017 3. Norton RL, Machine Design – An Integrated Approach, 4th Edition, Pearson Education, 2010 4. Norton RL, Kinematics & Dynamics of Machinery, 1st Edition, McGraw-Hill, 2010 <u>REFERENCE</u> 1. Richard Budynas, Keith Nisbett , Shigley's Mechanical Engineering Design, 10th Edition, McGraw-Hill, 2014

1	**Title of the course** (L-T-P-C)	**Smart manufacturing and material selection (3-0-0-6)**
2	**Pre-requisite courses(s)**	None for M. Tech SSM. For others, instructor consent is required
3	**Course content**	• Introduction to Smart manufacturing, various Smart Manufacturing Technologies, Smart foundry, Reverse engineering, Traditional manufacturing, Rapid Tooling, Rapid Manufacturing; Indirect Processes - Indirect Prototyping • Materials and design, Evolution of Engineering Materials and their Properties, Materials selection charts, Selection of Engineering materials and shape, Selection of Manufacturing Processes, Examples and Case studies. • Introduction to Additive Manufacturing, classification of AM processes: Sheet Lamination, Material Extrusion, Photo-polymerization, Powder Bed Fusion, Binder Jetting, and Direct Energy Deposition, Popular AM processes functional material. • Introduction: NC/CNC, CNC machines, Industrial applications of CNC, economic benefits of CNC. CNC Machine Tools • Surface coating, painting, Industry 4.0, Robotics and automation in manufacturing.
4	**Texts/References**	1. Gibson, D. W. Rosen, and B. Stucker, Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing. Evener, 2014 2. C. K. Chua and K. F. Leong, Rapid Prototyping: Principles and Applications in Manufacturing. World Scientific, 2003. 3. Lu, L., Fuh, J., Wong, YS., 2001, Laser Induced Materials and Processes for Rapid Prototyping, Kluwer. 4. Michael F. Ashby, Materials selection in mechanical design, Elsevier 5. G Boothroyd, P Dewhurts W A Knight, Product Design for Manufacture and Assembly, CRC press, Taylor and Francis

1	**Title of the course** (L-T-P-C)	**Design of Mechatronic Systems** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	
3	**Course content**	Introduction: Elements of mechatronics system: Sensor, actuator, plant, and controller. Applications of mechatronics system. Systems like CDROM, scanner opened to see whats there inside and why?. Integrated mechanical-electronics design philosophy. Examples of real life systems. Smart sensor concept and utility of compliant mechanisms in mechatronics. Microprocessor building blocks, combinational and sequential logic elements, memory, timing and instruction execution fundamentals with example of primitive microprocessor. Microcontrollers for mechatronics: Philosophy of programming interfaces, setting sampling time, and Getting started with TIVA programming Microcontroller programming philosophy emphasis on TIVA, programming different interfaces PWM, QEI etc. Mathematical modeling of mechatronic systems, Modeling friction, DC motor, Lagrange formulation for system dynamics. Dynamics of 2R manipulator, Simulation using Matlab, Selection of sensors and actuators. Concept of feedback and closed loop control, mathematical representations of systems and control design in linear domain, Basics of Lyapunov theory for nonlinear control, notions of stability, Lyapunov theorems and their application Trajectory tracking control development based on Lyapunov theory, Basics of sampling of a signal, and signal processing Digital systems and filters for practical mechatronic system implementation. Research example/ case studies of development of novel mechatronics system: 3D micro-printer, Hele Shaw system for microfabrication.
4	**Texts/References**	• Devdas Shetty, Richard A. Kolk, "Mechatronics System Design," PWS Publishing company • Boukas K, Al-Sunni, Fouad M "Mechatronic,Systems Analysis, Design and Implementation," Springer, • Sabri Cetinkunt, "Mechatronics with Experiments," 2nd Edition, Wiley • Janschek, Klaus, "Mechatronic Systems Design," Springer

1	**Title of the course (L-T-P-C)**	**Modeling of Metal Plasticity: Discrete and Continuum approaches (3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	Introduction: Importance of Metal Plasticity, Plasticity as multiscale phenomenon, Different approaches to model plasticity Plasticity at discrete dislocation level Module 1 Fundamentals of dislocation mechanics: Classification of defects, line defects, Dislocation and its Characteristics, classification of dislocations, Dislocation as source of plasticity Module 2 Discrete Dislocation Dynamics method: Stress field of a dislocation, Volterra construction, Dislocation motion, Driving force on a dislocation, Evaluation of dislocation velocity, Discretization and adaptive remeshing of dislocation lines, Time integration of equations of motion, Dislocation reactions Module 3 Dislocation dynamics code and examples: Introduction to ParaDis, Simulation procedure, Basic simulation examples (Frank-Read source, Strain Hardening simulation, dislocation relaxation) Plasticity at Continuum scale Module 4 Structure and Properties of Metals and Introductory Mechanics: Crystal structure, slip systems, elastic and plastic deformation, anisotropy Stress and strain tensors, principle stresses, Yield criteria Module 5 Small and Large deformation theory: Infinitesimal strain theory, Kinematics, Deformation gradient, Different stress and strain measures, Velocity gradient, Elastoplastic decomposition, Mechanical Equilibrium, Finite element method as a solver Module 6 Different continuum plasticity models: Constitutive modeling (Yield condition, flow rule, hardening law), Phenomenological crystal plasticity model, Dislocation density based models, Microstructure based modeling, Dislocation based constitutive laws, Integration of other deformation mechanisms (Mechanical Twinning, Phase transformation) Module 7 Crystal plasticity modeling procedure and examples: Abaqus UMAT, DAMASK, FreeFem++, Time integration, Pre-processing, Running Crystal plasticity simulation, Post-processing of simulation results, Virtual Tension tests, Indentation and Micro-bending Simulations
4	**Texts/References**	Ryan B. Sills, William P. Kuykendall, Amin Aghaei, Wei Cai, Fundamentals of Dislocation Dynamics Simulations, Multiscale Materials Modeling for Nanomechanics. Vol. 245. Springer Franz Roters, Philip Eisenlohr, Thomas R. Bieler, Dierk Raabe Crystal Plasticity Finite Element Methods: In Materials Science and Engineering, John Wiley & Sons, 2011 Ellad B. Tadmor, Ronald E. Miller, Modeling Materials - Continuum, Atomistic and Multiscale Techniques, Cambridge University Press, 2011

1	**Title of the course** (L-T-P-C)	**Fracture Mechanics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Theory of Elasticity or equivalent
3	**Course content**	**Module 1: Background** Kinds of Failure; Historical Aspects; Brittle and Ductile Fracture; Modes of Fracture Failure **Module 2: LEFM** Griffith's Theory of Brittle Fracture; Irwin-Orowan Modification; Stress Intensity Factor (SIF) Approach; Concepts of Strain Energy and Potential Energy Release Rates; Determination of Crack-Tip Stress and Displacement Field - Airy Stress Function Approach, Westergaard Stress Function Approach, Williams' Eigenfunction Expansion. Determination of Stress Intensity Factors: Analytical Methods, Numerical and Experimental Methods. Mixed Mode Brittle Fracture: Theory based on Potential Energy Release Rates, Maximum Tangential Stress Criterion, Maximum Tangential Principal Stress Criterion, Strain Energy Density Criterion **Module 3: Anelastic Deformation at Crack Tip** Irwin Plastic Zone Size Correction; Dugdale-Barenblatt Model for Plastic Zone Size; Crack-Tip Mode I, II and III Plastic Zone Shape; Thickness Dependence of Fracture Toughness KC; Crack Opening Displacement; Rice's Path-Independent Integral J; Resistance Curve; Stability of Crack Growth **Module 4: Elastic Plastic Fracture Mechanics** Crack Opening Displacement Criterion; Mode I Crack-Tip Field - Rice-Rosengren Analysis, Hutchinson's Analysis; Crack-Tip Constraints: T Stress and Q Factor; Crack Propagation and Crack Growth Stability **Module 5: Fatigue Crack Growth** Fatigue Crack Growth Rate under Constant Amplitude Loading; Factors Affecting Fatigue
4	**Texts/References**	**Text-books:** 1. T. L. Anderson, Fracture Mechanics: Fundamentals and Applications, 4th ed. – Boca Raton 2017. 2. D. Broek, Elementary Engineering Fracture Mechanics, 3rd Revised Edition, Springer Netherlands, 1982, 3. Maiti S.K, Fracture Mechanics: Fundamentals and Applications. – 1st Edition, Delhi: Cambridge University Press, 2015. **References:** 1. Prashant Kumar, Elements of Fracture Mechanics, Tata McGraw-Hill. Education, 2009, 2. CT Sun, Fracture Mechanics, Academic press, 2012, 3. T. Kundu, Fundamentals of Fracture Mechanics, CRC Press, 2008.

1	**Title of the course** (L-T-P-C)	**Advanced CAM** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	None
3	**Course content**	**Geometric modeling:** ***Representation of curves*****:** wireframe models, wireframe entities, analytic curves, synthetic curves - cubic splines, Bezier curves, B-Spline curves. ***Representation of surfaces*****:** surface models, surface entities, analytic surfaces, synthetic surfaces ***Representation of solids*****:** solid models, solid entities, fundamentals of solid modeling, boundary representation (B-rep), constructive solid geometry (CSG) . CAD/CAM data exchange: evolution of data exchange formats, STL, IGES, STEP formats Numerical control: principles of numerical control, numerical control systems, NC controllers. NC part programming: manual part programming, computer assisted part programming, sculptured surface machining/forming/deposition, path verification. **Digital manufacturing science**: system of digital manufacturing science, manufacturing informatics, intelligent manufacturing, key technology in digital manufacturing, impact of digital manufacturing in industrial transformation. **Digital twins:** concept of digital twin, digital twin modeling, digital twin driven smart manufacturing, cyber physical fusion in digital twin, digital twin and big data. **Industry 4.0 cases studies of manufacturing.**
4	**Texts/References**	**Textbook:** 1. Ibrahim Zeid, R. sivasubramanian. CAD/CAM theory and practice, 2nd edition, McGrawHill , 2019 2. TS chang. Computer aided manufacturing, 3rd edition, Pearson Prentice Hall 2005 3. Zude Zhou, Shane Xie, Deju Chen. Fundamentals of digital manufacturing science, Springer series in advanced manufacturing, SpringerLink, 2013 4. A.Y.C. Nee, Fei Tao, Meng Zhang. Digital twin driven digital manufacturing, 1st edition, Academic press, 2019

1	**Title of the course** (L-T-P-C)	**Design and Manufacturing of Composites** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	
3	**Course content**	**Design:** Micromechanics of Composites: Density; Mechanical properties – Prediction of elastic constants, Micromechanical approach, Halpin-Tsai equations, Transverse stresses; Thermal properties – COTE for composites, Thermal conductivities, Hygral and thermal stresses; Mechanics of load transfer from matrix to fibre. Macromechanics of composites - Elastic constants of an isotropic material and lamina, Variation of lamina properties with orientation; Laminated composites; Stresses and strains in laminated composites, Interlaminar stresses and edge stresses; Monotonic strength and Fracture: Tensile strength of uni-direction FRC; Max strain theory, Tsai-Hill criterion, Quadratic interaction. Fatigue and Creep: S-N curves-FCP tests, Fatigue of composites. Creep **Traditional and Additive Manufacturing**: Thermosets and Thermoplastic; Fiber Reinforcement, Lay-up processes, Spray up process; Fiber placement process and Traditional Manufacturing of composites. Various Additive Manufacturing technologies for composites and comparison, Thermoforming Metal and ceramic matrix composites: **Composites for Industrial Applications:** Material requirements for applications, Aerospace applications, Automotive and Road transportation applications, Architectural / building applications, Wind energy applications, Marine transportation and ship building applications, Defence applications, Advancements in composites, New Technologies.
4	**Texts/References**	**Textbook:** 1) Krishan K. Chawla, Composite Materials Science and Engineering· Springer International Publishing, 2016 2) M. Balasubramanian, Composite Materials and Processing, 1st edition CRC Press 3) T. W. Clyne, D. Hull, An Introduction to Composite Materials,3rd edition Cambridge University Press. **References:** 1. Krishan Chawla, Fibrous materials, Cambridge university press, 2016. 2. Krishan Chawla, Ceramic matrix composites, Springer Science & Business Media, 2013

1	**Title of the course** (L-T-P-C)	**Energy for Transportation** **(3-0-0-3)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	Introduction: Introduction to conventional energy for transportation, Internal combustion (IC) engines and Gas Turbine Engines, Emission formation and Environmental issues; Hydrocarbon fuels and Sustainability. Battery operated vehicles: Introduction, Types, Batteries, Accessories; Hybrid vehicles: Introduction, Classification, Advantages and disadvantages; Different types of sustainable electricity production: Solar, Wind, Hydro renewable energy, Direct Energy Conversion: thermionic and thermoelectric converters, photovoltaic generators, MHD generators, Integrated Gasification Combined Cycle (IGCC), Clean Coal Technologies, Geological CO2 sequestering. Fuel cells: Introduction, Fuel cell system, Classification, Thermodynamics and performance of fuel cells and their applications. Operational issues; Hydrogen Energy: General introduction to hydrogen production, storage, dispensing and utilization. Hydrogen Utilization in I.C. Engines, gas turbines, and marine applications. Hydrogen fuel quality, performance, COV, emission and combustion characteristics of Spark Ignition engines for hydrogen, back firing, knocking, volumetric efficiency, hydrogen manifold and direct injection, fumigation, NOx controlling techniques, dual fuel engine, durability studies. Hydrogen Safety.
4	**Texts/References**	1. Moran M.J., H.N. Shapiro., Fundamentals of Engineering Thermodynamics, 3rd Ed., Wiley, 1995. 2. Rand D.A. J., Woods R. & Dell R.M., Batteries for Electric Vehicles, Research Studies Press (1998). 3. Linden D. & Reddy T.S., Handbook of Batteries, 3rd Edition, McGraw-Hill, (2002). 4. Nikolai Khartekenko, Advanced Energy Systems, Taylor & Francis (1988). 5. Angrist S. W., Direct Energy Conversion, Pearson, 1982. 6. Bagotsky V.S., Fuel Cell Problems and Solutions, John Wiley & Sons, 2009. 7. Ball M. and Wietschel M., The Hydrogen Economy Opportunities and Challenges, CPU (2009).

1	**Title of the course** (L-T-P-C)	**Fatigue and Fracture Mechanics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Exposure to Strength of Materials/Mechanics of Materials (& Theory of Elasticity)
3	**Course content**	Module 1(10 hours): Introduction and historical overview, Types of fatigue – low cycle fatigue, highcycle fatigue, very high cycle (giga cycle) fatigue, Fatigue test methods and equipment, Totallife approaches based on cyclic stress and cyclic strain, Cyclic hardening and softening in single crystals and polycrystals. Module 2(10 hours): Crack initiation and propagation, Mechanisms, Macro-structural and microstructural aspects, Use of fracture mechanics in fatigue Module 3(10 hours): Local strain approach, effect of different factors on fatigue – Stress concentration, Size, Surface, Temperature, Frequency, Environment, Microstructure, Residual stresses, Fretting, Creep-fatigue interaction, Multiaxial stresses, Thermomechanical loading, Variable amplitude loading, Load sequence, Crack closure Module 4(10 hours): Fatigue behaviour of different materials – Metallic materials and weldments, Ceramics, Polymers, Composites, Metallic glasses, Shape memory alloys, Ultrafine grained materials, Nanocrystalline materials, Biomaterials, Metallic foams, Case studies on fatigue failures, Design considerations, Methods for fatigue life improvement
4	**Texts/References**	1. Fatigue of Materials, Suresh, Cambridge India, 2015 2. Fracture Mechanics, Fundamentals and Applications, T.L. Anderson, CRC Press 2017

1	**Title of the course** (L-T-P-C)	**Functional Materials Manufacturing for Energy and Biomedical Applications (1-0-0-2)**
2	**Pre-requisite courses(s)**	--
3	**Course content**	1. **Introduction to Functional Materials** a. Crystal structures b. Morphology and Microstructure c. Defects, dislocation and microcracks d. Thermal Treatment and Recovery Mechanisms 2. **Magnetic Materials** a. Types of Magnetic Materials b. Permanent Magnets as Magnetic Field Source c. Magnetoelastic Materials d. Magnetocaloric Materials 3. **Ferroelectric Materials** a. Types of Ferroelectric Materials b. Piezoelectric Materials for Energy Harvesting c. Piezoelectric Polymers 4. **Fabrication of Nanostructured Functional Materials** a. Thin Films: Pulsed Laser Deposition and Atomic Layer Deposition b. Nanoparticles: High Energy Ball Milling, Hydrothermal Reactions 5. **Additive Manufacturing of Functional Materials** a. Review of AM Technologies Suitable for Functional Materials b. Anisotropy Consideration Towards Tuning Functional Properties c. Compositional Grading 6. **Functional Additive Manufacturing Case Studies and applications** a. Magnetocaloric Regenerators **b.** Brain Phantoms **c.** Transcranial Magnetic Stimulation Coils
4	**Texts/References**	**Text Books**: None **Reference Books:** 1. D. C. Jiles, Introduction to Magnetism and Magnetic Materials, CRC Press, Tylor & Francis Group, 2015, 2. A. Kitanovski, J. Tušek, U. Tomc, U. Plaznik, M. Ozbolt, and A. Poredoš, Magnetocaloric Energy Conversion: From Theory to Applications. Springer International Publishing, 2015. 3. H. Huang and J. F. Scott, *Ferroelectric Materials for Energy Applications*. John Wiley & Sons, 2019. 4. Ian Gibson, David Rosen, Brent Stucker, Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing. **Resources from Peer-Reviewed Research Journals:** 1. H. Magsood and R. L. Hadimani, "Development of anatomically accurate brain phantom for experimental validation of stimulation strengths during TMS," *Materials Science and Engineering: C*, p. 111705, 2020, doi: 10.1016/j.msec.2020.111705. 2. H. Hou *et al.*, "Fatigue-resistant high-performance elastocaloric materials made by additive manufacturing," *Science*, vol. 366, no. 6469, pp. 1116–1121, Nov. 2019, doi: 10.1126/science.aax7616. 3. C. V. Mikler *et al.*, "Laser Additive Manufacturing of Magnetic Materials," *JOM*, vol. 69, no. 3, pp. 532–543, Mar. 2017, doi: 10.1007/s11837-017-2257-2.

1	**Title of the course** (L-T-P-C)	**Combustion and Fire Dynamics** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	--
3	**Course content**	**Fundamentals** Motivation for studying combustion, Fuels and their combustion properties: diesel, gasoline, aviation fuels, natural gas, coal, Thermochemistry: the composition of a gas mixture: mass and mole fraction, Chemical reactions – theoretical and actual combustion processes, Enthalpy of formation and enthalpy of combustion, Adiabatic flame temperature, Introduction to mass transfer, Chemical equilibrium. Chemical kinetics – reaction rates, chemical time scales. **Flames** Conservation equations with chemical reaction, Laminar premixed flames – flame speed, governing equations, flammability limits, flame stability, Laminar diffusion flames – diffusive burning of liquids, stagnation layer model – pure convective burning, radiative convective burning, Droplet evaporation and burning – Spalding number. **Measurement in Fire** Measurement of temperature – thermocouples, plate thermometer for the measurement of temperature and heat flux, heat flux sensors, cone calorimetry, measurement of soot volume fraction, soot yield and spectral measurements.
4	**Texts/References**	1. Stephen R. Turns, An Introduction to Combustion: Concepts and Applications, Third edition, McGraw Hill Education (India) Private Limited, New Delhi, 2012. 2. James G. Quintiere, Fundamentals of Fire Phenomena, John Wiley and Sons, Wet Sussex, 2006. 3. The SFPE Handbook of Fire Protection Engineering, fourth edition, National Fire Protection Association (NFPA), Massachusetts, 2008.

1	**Title of the course** (L-T-P-C)	**Convective Heat Transfer** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	Nil
3	**Course content**	Flow classifications, mass momentum and energy relation in differential form Exact and approximate solution to convection in laminar and turbulent, internal and external flow. solution to natural convection problems.
4	**Texts/References**	1 kays w,, Crawford M, Wigand B., connective Heat and mass Transfer Fourth Edition McGraw Hill Education, 2017 2 sodic kakac and Yamane yenar, connective Heat Transfer, Second Edition, CRC Press 1994 3 Louis C Burmiester, connective Heat Trasfer Second Edition, john wily and sons 1993 4 Bejan A, connective Heat Transfer Third Edition, wily,2006 5 Kavinay M, Principles of connective heat transfer, second Edition springer,2001.

1	**Title of the course** **(L-T-P-C)**	**Satellite Attitude Dynamics and Control** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	None
3	**Course content**	**Review of Newtonian particle mechanics**. **Rigid-body Kinematics**: Direction cosines, Euler angles, Principal rotation vector, Euler parameters, Rodrigues parameters, Homogeneous transformations. **Rigid-body Dynamics**: Newton-Euler equation of motion, Torque-free rigid-body rotation. **Generalized methods of analytical dynamics**: Generalized coordinates, D'Alembert's principle, Lagrangian dynamics. . **Stability and control**: Stability of torque free rotation, Gravity gradient modeling and stabilization, Spin stabilized satellite, Satellite attitude control using reaction wheels and control moment gyros, Attitude stabilization using magnetic torquers and Lorentz force, Attitude Control using thrusters
4	**Texts/References**	References: 1. *Analytical Mechanics of Space Systems,* Hanspeter Schaub and John Junkins, American Institute of Aeronautics and Astronautics, 2003 2. *Spacecraft Attitude Dynamics*, Peter Hughes, Dover Publication, 2004 3. *Spacecraft Dynamics and Control - A practical engineering approach*, Marcel Sidi, Cambridge University Press, 2002

1	**Title of the course** (L-T-P-C)	**Applied Elasticity** **(2-1-0-6)**
2	**Pre-requisite courses(s)**	Mechanics of Materials
3	**Course content**	Equilibrium Equations, Relations in Curvilinear Cylindrical and Spherical Coordinates Deformation: Displacements and Strains (6 hrs) Small Deformation Theory, Strain Transformation, Principal Strains, Spherical and Deviatoric Strains, Strain Compatibility, Curvilinear coordinate system: Cylindrical, Spherical system relations Material Behavior: (3 hrs) Linear Elastic Materials—Hooke's Law Physical Meaning of Elastic Moduli, Thermoelastic Constitutive Relations, Anisotropy - Basic Concepts, Material Symmetry, Restrictions on Elastic Moduli, Strain Energy Formulation and Solution Strategies:(2 hrs) Stress Formulation, Displacement Formulation, Principle of Superposition, Saint-Venant's Principle, Uniqueness theorem, Reciprocal theorem Two-Dimensional Formulation: (9 hrs) Plane Strain, Plane Stress, Generalized Plane Stress, Airy Stress Function, Polar Coordinate Formulation, Cartesian Coordinate Solutions; Curvilinear coordinates; Complex Variable Methods: Complex Formulation of the Plane Elasticity Problem, Resultant Boundary Conditions, General Structure of the Complex Potentials: Extension, Torsion, and Flexure of Elastic Cylinders (6 hrs) Extension Formulation; Torsion, Flexure Formulations, Flexure Problems without Twist Thermoelasticity (2 hrs) General Uncoupled Formulation, Two-Dimensional Formulation, Displacement Potential Solution, Stress Function Formulation 3D Elasticity: Displacement Potentials and Stress Functions (4 hrs) Helmholtz Displacement Vector Representation, Lame´'s Strain Potential, Galerkin Vector Representation, Papkovich-Neuber Representation; Spherical Coordinate Formulations, Stress Functions.
4	**Texts/References**	**Texts:** 1. MH. Sadd, Elasticity: Theory, Applications, and Numerics, 3rd Edition, Academic Press, 2014. 2. J. R. Barber ,Elasticity, 3rd edition, Kluwer Academic, 2009. References: 1. S. P. Timoshenko, J. N. Goodier, Theory of Elasticity, 3rd Edition, McGraw Hill Pub. 1970. 2. ArthurP. Boresi, Ken Chong, James D. Lee, Elasticity in Engineering Mechanics, 2010, Wiley. 3. Allan F. Bower, Applied Mechanics ofSolids, 1st Edition, 2009, CRC Press. 4. R. W. Soutas-Little, Elasticity, DoverPublications, 1999 5. P Chou, N Pagano. Elasticity: Tensor, Dyadic and Engineering Approaches, DoverPub., 1992. 6. A. S. Saada, "Elasticity Theory and Applications", Cengage Learning, New Delhi, 2014. 7. Mark Kachanov,Igor Tsurkov, Handbook of Elasticity Solutions, Evener, 2003 8. W.S. Slaughter, The Linearized Theory of Elasticity, Birkhäuser, 2002 9. V. V. Novozhilov, Theory of Elasticity, Pergamon Press, 1961.

1	**Title of the course** (L-T-P-C)	**Automobile Engineering Fundamentals** **3-0-0-6**
2	**Pre-requisite courses(s)**	ATD, ToM
3	**Course content**	Introduction - Overview of automobile components, Classification of IC Engines, Engine components, Engine cycles, Engine performance, Turbocharging and Supercharging, Combustion in ICE, Fuel delivery systems – Carburetion and Fuel Injection systems, Engine emissions, Emission control systems, Automotive powertrain - Automotive clutch, Transmission, Manual transmission, Automatic transmissions, Powertrain analysis, Transmission matching, Brake system – Components of brake system, Drum brake, Disc brakes, Hydraulic brakes, Air brakes, Anti-lock-braking (ABS) systems, Braking analysis, Steering system, Manual steering systems, Power steering systems, Steering analysis, Wheel alignment, Suspension systems, Shock absorbers, Independent and dependent suspensions, Suspension analysis, Safety systems – Airbags, ABS, Electronic Brake Distribution (EBD), Electronic Stability Control (ESC) systems, Advanced Driver Assistance System (ADAS) Introduction to Electric and Hybrid Powertrains
4	**Texts/References**	**References:** 1. R. Stone and J. K. Ball, Automotive Engineering Fundamentals, SAE International, 2. D. B Astow, G. Howard and J. P. Whitehead, Car Suspension and Handling, SAE International, 3. K. Newton, W. Steeds and K. Garrett, The Motor Vehicle, Butterworths, 4. R. Limpert, Brake Design and Safety, SAE International, 5. V. Ganesan, Internal Combustion Engines, Tata McGraw Hill, 6. H. Heisler, Vehicle and Engine Technology, SAE International, 7. M. Ehsani, Y. Gao and A. Emadi, Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, 2nd Edition, CRC Press, 2009.

1	**Title of the course** (L-T-P-C)	**Nonlinear Oscillation** **(3-0-0-6)**
2	**Pre-requisite courses(s)**	None
3	**Course content**	Phase plane analysis: Classification of linear systems, Lyapunov stability, Structural stability Duffing Oscillator: Lindstedt's method van der Pol Oscillator: Method of averaging, Hopf Bifurcation, Homoclinic Bifurcations, Relaxation Oscillations Forced Duffing Oscillator: Two variable expansion method, Cusp Catastrophe Forced van der Pol Oscillator: Entrainment Mathieu's equation: Floquet Theory, Hill's equation, Harmonic Balance Coupled conservative oscillators: Nonlinear normal modes, Modal equation Center Manifolds
4	**Texts/References**	Text books: 1. Richard Rand. "Lecture Notes on Nonlinear Vibration" URL: [https://ecommons.cornell.edu/handle/1813/28989]. References: 1. Ali H. Nayfey, Dean T. Mook, "Nonlinear Oscillation", Wiley, 2008. 2. Chihiro Hayashi. "Nonlinear Oscillations in Physical Systems",Princeton University Press, 2014. 3. Vladimir I. Nekorkin , "Introduction to Nonlinear Oscillations", 2016.