COURSE CONTENTS

OF THE

M.TECH. PROGRAM

OF

AEROSPACE ENGINEERING DEPARTMENT

IIT BOMBAY

(Updated 26th December, 2022)

Title of the course	**AE 402 Smart Materials and Structures**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction to smart materials. Concepts and examples of smart systems and structures. Properties and mechanism of piezoelectric materials, shape memory alloys, electro-rheological/magneto-rheological fluids. Introduction to modeling. Modeling of smart structures. Applications of smart materials as sensors and actuators. Vibration control. Structural health monitoring.
Texts/References	1. A. V. Srinivasan and D. M. McFarland, Smart Structures, Analysis and Design, Cambridge University Press, 2002 2. M. V. Gandhi and B. D. Thompson, Smart Materials and Structures, Springer, 1992 3. P. Gaudenzi, Smart Structures: Physical behavior, mathematical modeling and applications, Wiley, 2009 4. R. Vepa, Dynamics of Smart Structures, Wiley, 2010

Title of the course	**AE 604 Advanced Topics in Aerospace Structures**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	The course focuses on advanced topics in structural dynamics and aeroelasticity. The emphasis is on aspects of rotary wing aeroelasticity and hypersonic aerothermoelasticity. A selection of topics is listed below. The actual coverage will depend on the precise background and interests of the students. Rotary wing topics: A. Structural dynamics of rotating structures (beams); B. Approximate unsteady aerodynamic models for rotary wing applications; C. Introduction of helicopter aeromechanics Topics in aerothermoelasticity: A. Structural dynamics of thermoelastic structures (beams); B. Approximate aerothermal load models for high speed applications; C. Numerical considerations and coupling strategies
Texts/References	1. R. L. Bielawa, Rotary Wing Structural Dynamics and Aeroelasticity, AIAA Education Series, 2nd ed., 2006 2. G. Leishman, Principles of Helicopter Aerodynamics, Cambridge Aerospace Series, 2006 3. W. D. Hayes and R. F. Probstein, Hypersonic Inviscid Flow, Dover Publications, 2004 4. W. Nowacki, Thermoelasticity, Pergamon Press, 2nd ed., 1986

Title of the course	**AE 607 Aerospace Propulsion Lab.**
Credit Structure	0-0-4-4
Prerequisite	Nil
Course Content	Study of aircraft engine models, basic measurement techniques in thermal, mechanical and fluid systems. Experimentation related to aerodynamics and performance of turbomachinery (in axial flow fan set-up and in two-dimensional compressor/turbine cascades), fuel systems, combustion and heat transfer (convective heat transfer to geometries typical of aerospace propulsion applications) in aerospace propulsion systems. Experiments on performance characteristics of gas turbine/jet propulsion systems.
Texts/References	1. P. Hill and C. Peterson, Mechanics and thermodynamics of propulsion, Pearson Education, 2009 2. Laboratory Manual, Propulsion Laboratory, Dept. of Aerospace Engg, IIT Bombay, 2007

Title of the course	**AE 611 Aerodynamics Lab.**
Credit Structure	0-0-4-4
Prerequisite	Nil
Course Content	Types of wind tunnels and their characteristics, wind tunnel corrections. Flow past bluff and a streamlined bodies and measurement of pressure drag.

	Wall shear flows, free shear flows, development of boundary layer on flat plate with and without pressure gradient, free shear layer in a jet, estimation of drag by wake survey method. Flow in a variable area duct and experimental determination of mass flow coefficient. Flow visualization methods, surface flow methods and color die injection method. Measurement of unsteady flow using hot-wire and Laser Doppler Velocimeter
Texts/References	1. R. J. Goldstein, Fluid Mechanics Measurements, Taylor and Francis, 1996 2. A. Pope and K. W. Goin, High Speed Wind Tunnel Testing, John Wiley & Sons, 1985 3. J. B. Barlow, W. H. Rae and A. Pope, Low-Speed Wind Tunnel Testing, 3rd ed., Wiley-Interscience, 1999

Title of the course	**AE 616 Gas Dynamics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Basic equation of motion. Small perturbation methods in subsonic and supersonic flows. Similarity rules in high speed flows. Transonic flows. Normal and oblique shocks. Conical flow. Flow in ducts of variable cross section. Method of characteristics and design of supersonic nozzles. Viscous effects in compressible flow. Hypersonic flows.
Texts/References	1. H. W. Liepmann and A. Roshko, Elements of Gas Dynamics, John Wiley, 1958 2. A. H. Shapiro, Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. I and II, Ronald Press Co., 1957

Title of the course	**AE 617 Numerical Methods for Conservation Laws**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Scalar conservation laws. Burger's equation. Weak solutions, shocks, entropy conditions, linear hyperbolic systems, Linearization of nonlinear systems. Riemann problem, Hugoniot laws, rarefaction waves, integral curves, contact discontinuities, solution of Riemann problem for Euler equations. Numerical schemes for linear equations, CFL condition, upwind methods, conservative methods, Lax-Wendroff theorem, Godunov's method, approximate Riemann solver, Roe's solver, High resolution methods TVD schemes, flux limiters, multidimensional upwinding.
Texts/References	1. R. J. Leveque, Numerical Methods for Conservation Laws, BirkhauserVerlag, 1990 2. G. Whitham, Linear and Nonlinear Waves, Wiley, 1974 3. C. Hirsch, Numerical Computation of Internal and External Flows, Vol. II, Wiley, 1988

Title of the course	**AE 619 Nonlinear Systems Analysis**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Preliminaries: state and state space of a system, vector fields and their flows, ordinary differential equations as vector fields, examples of 1D and 2D flows, flows of linear systems. Nonlinear Phenomena: nonexistence and non-uniqueness of solutions, finite-escape time, isolated multiple equilibria, limit cycles, chaos. Mathematical Foundations: normed linear vector spaces, completeness, Lp spaces, contraction mapping principle, existence, uniqueness, continuity and differentiability of solutions of ordinary differential equations. Stability Theory: types of stability, Lyapunov stability, attractivity, asymptotic stability, Lyapunov's direct method for Lyapunov stability, asymptotic stability and instability, invariance principle and the Krasovskii-LaSalle theorem. Applications of Lyapunov Theory: estimation of domains of attraction, the comparison principle and estimation of rate of convergence, stability in the presence of perturbations, stability of linear systems, Lyapunov's indirect (linearization) method, the Lur'e problem. Input-Output Stability: BIBO stability, relation between BIBO stability and Lyapunov stability, small gain theorem. Special Topics: topological methods (Poincare-Bendixon theorem, index theory, Brockett's theorem), centre manifold theory, Poincare normal forms, methods of averaging and singular perturbations, existence and stability of periodic solutions, chaos.

Texts/References	1. M. Vidyasagar, Nonlinear Systems Analysis, Prentice-Hall, 1993 2. S. Sastry, Nonlinear Systems: Analysis, Stability and Control, Springer-Verlag New York, 1999 3. H. K. Khalil, Nonlinear Systems, Prentice-Hall, Upper Saddle River, NJ, 1996 4. V. I. Arnold, Ordinary Differential Equations, MIT Press, 1973

Title of the course	**AE 621 Inelasticity Theory**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Inelastic behavior in materials: an introduction. Thermodynamics of inelastic materials: Governing balance laws and state variables; Entropy and the equation of state; Free energy and the rate of dissipation. Elastoplastic beams: Modeling of a thermo-elasto-plastic beam; Formulation of the solution strategy; Statically indeterminate problems/general beam problems. Introduction to small deformation plasticity: Rigid-plasticity model; Elasto- plasticity model; Hardening and the plastic arc length; Finding the response of the material. The boundary value problem for plasticity: The governing equations – 3-D case, compatibility, equations; Plane problems – plane strain and plane stress; Airy's stress function and the equations of compatibility; Boundary conditions for the stress function; Numerical solution. Numerical solutions of boundary value problems: Integration of the plastic flow equations; Numerical examples of boundary value problems.
Texts/References	1. A. Khan and S. Huang, Continuum Theory of Plasticity, Wiley-Interscience, 1995 2. J. Lubliner, Plasticity Theory, Macmillan Publications, 1990 3. A. R Srinivasa and S. M. Srinivasan, Inelasticity of Materials, Series on Advances in Mathematics for Applied Sciences, World Scientific, 2009 4. J. C. Simó and T. J. R. Hughes, Computational Inelasticity, Springer, 1998

Title of the course	**AE 622 Computing of High Speed Flows**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Review of basics – gas dynamics, hypersonic flows, turbulence modelling, computation fluid dynamics. CFD topics – grid refinement and convergence, explicit and implicit time-integration, grid aspect ratio and stretching, flow initialization and development, boundary conditions. Research topics – re-entry capsule: bow shock, stagnation region, heat transfer, chemical reactions; inlet and nozzle flows: laminar and turbulent boundary layer, turbulence models, show-turbulent layer, flow reattachment; base flows: pressure drag, wake flow, transition to turbulence; jet exhaust plumes: under and over-expanded jets; shock-shock interaction: classification based on shock patterns.
Texts/References	1. C. Hirsch, Numerical computation of internal and external flows, John Wiley, 1990 2. D. C. Wilcox, Turbulence modelling for CFD, DCW Industries, 2000 3. J. D. Anderson, Hypersonics and high temperature gas dynamics, McGraw Hill, 1989

Title of the course	**AE 623 Computing of Turbulent Flows**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Basic fluid mechanics processes: convection, viscous diffusion, dissipation, heat conduction, conservation equations, tensor form, constitutive relations. Turbulent flows: examples, comparison with laminar flows, mean properties and fluctuations, correlation between fluctuations. Direct numerical simulation: grid resolution for a range of length scales, DNS results for turbulent statistics, DNS data used for model evaluation. Large eddy simulation: filtered conservation equations, subgrid scale stresses, SGS models, computational requirement. Reynolds averaged Naveir Stokes simulation: temporal, spatial and ensemble averaging, Reynolds averaged conservation equations, flow processes: convection, viscous diffusion, turbulent diffusion.

	Reynolds stress tensor: physical interpretation, closure problem, eddy viscosity model, non-linear models, model calibration. Turbulent kinetic energy: exact transport equation, modelled conservation equation, physical processes: production, dissipation, molecular and turbulent diffusion. Turbulent boundary layer: viscous sublayer, log layer and defect layer, displacement and momentum thickness. Compressible free shear layers: convective Mach number, growth rate, compressibility corrections. Shock-boundary layer interaction: turbulence amplification by shock, limitation of existing models, shock-unsteadiness effects, comparison with DNS. Applications: scramjet inlets, rocket nozzles, wing-body junctions.
Texts/References	1. White, F. M., Viscous fluid flow, 3rd ed., McGraw- Hill, 2006 2. Pope, S. B., Turbulent flows, Cambridge University Press, 2000 3. Tennekes, H. and Lumley, J. L., A first course in turbulence, The MIT Press (Cambridge), 1974 4. Smits, A. J. and Dussauge, J.-P., Turbulent shear layers in supersonic flow, 2nd ed., Springer, 2005. 5. Gatski, T. B. and Bonet J.-P., Compressibility, turbulence and high speed flows, Elsevier, 2009

Title of the course	**AE 624 Hypersonic Flow Theory**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Characteristics of hypersonic flows, Basic hypersonic shock relation, Hypersonic similarity parameter, Hypersonic expansion wave relations, Newtonian flow, Modified Newtonian law, Centrifugal force corrections to Newtonian theory, Local surface inclination methods, Hypersonic inviscid flow fields, Governing equations, Mach number independence principle, Hypersonic small disturbance equations, Hypersonic similarity, Hypersonic equivalence principle and blast wave theory, Thin shock layer theory, Hypersonic transition, Hypersonic turbulent boundary layer, Hypersonic aerodynamic heating, Entropy layer effects in heating, Hypersonic viscous interactions, Strong and weak interactions, Shock wave-boundary layer interactions, Hypersonic experimental facilities.
Texts/References	1. J. D. Anderson, Hypersonic and High Temperature Gas Dynamics, McGraw-Hill, 1989 2. J. J. Bertin, Hypersonic Aerothermodynamics, AIAA Education Series, 1994

Title of the course	**AE 625 Particle Methods for Fluid Flow Simulation**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Brief introduction to vortex dynamics and the basic laws of vorticity. Introduction to inviscid vortex methods for 2D simulation with applications to a few sample problems, including the numerical simulation of vortex sheet rollup. Brief introduction to panel methods and their applications in the context of vortex methods. Overview of various viscous vortex methods and their application in simulating 2D, incompressible, viscous fluid flow problems. Introduction to the Fast Multipole Method (FMM) and other fast algorithms for particle simulation. 3D vortex methods: vortex filaments and vortex particles. Introduction to the method of Smoothed Particle Hydrodynamics (SPH). Applications of the SPH. An introduction to the Direct Simulation Monte-Carlo method and its applications.
Texts/References	1. R. W. Hockney and J. W. Eastwood, Computer Simulation Using Particles, Taylor & Francis, 1988 2. G.-H. Cottet and P. D. Koumoutsakos, Vortex methods: Theory and Practice, Cambridge University Press, 2000 3. G. R. Liu and M. B. Liu, Smoothed Particle Hydrodynamics: A Mesh-free Particle method, World scientific, 2003 4. G. A. Bird, Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford University Press, 1994

Title of the course	**AE 626 Spacecraft Attitude Dynamics and Control**
Credit Structure	3-0-0-6
Prerequisite	AE 308 / AE 775
Course Content	3-axis Spacecraft attitude dynamics and control: Attitude dynamics and stability of three-axis stabilized, single-spin, dual-spin, and multi-body spacecraft with articulated antennas, sensors, and solar arrays; design of control system for three-axis stabilized spacecraft in orbit using reaction wheels, thrusters, magnets, single- and double-gimbaled control moment gyros; large-angle three-axis attitude manoeuvre controllers using reaction wheels and thrusters. Control of spinning spacecraft: Control of attitude during ΔV-firing in transfer orbits and operational orbits around the Earth, Rhumb-line manoeuvre of spinning spacecraft; Attitude control of bias momentum spacecraft using magnets and thrusters Dynamics and control of dual-spin spacecraft Precision pointing and tracking controllers: Controllers for tracking landmarks, moving objects for surveillance, and other satellites for crosslink communication; solar array controllers for tracking the Sun, determining the array's orientation with sun sensors; modelling of attitude dynamics of spacecraft with flexible solar arrays, its interaction with spacecraft dynamics and control systems. Attitude determination: Gyros, star trackers, sun sensors, and horizon sensors; attitude determination using TRIAD and QUEST (quaternion estimator) algorithms; sensors error characteristics, Kalman filtering for attitude estimation and covariance analysis. Note: The above techniques will be illustrated with the control of Indian communication and remote sensing satellites (Oceansat, Cartosat, Edusat, telemedicine); Matlab and Simulink will be used to simulate the controllers.
Texts/References	1. P. C. Hughes, Spacecraft Attitude Dynamics, John Wiley, 1986. 2. M. J. Sidi, Spacecraft Dynamics and Control, Cambridge University Press, 1997 3. M. H. Kaplan, Modern Spacecraft Dynamics and Control, John Wiley, 1976 4. B. Agrawal, Design of Geosynchronous Spacecraft, Prentice Hall, 1986 5. A. E. Bryson, Control of Spacecraft and Aircraft, Princeton University Press, 1994 6. B. Wie, Space Vehicle Dynamics and Control, AIAA Education Series, 1998 7. J. R. Wertz, Spacecraft Attitude Determination and Control, D. Reidel, 1978 8. G. Maral, and M. Bousquet, Satellite Communications Systems, 4th ed., John Wiley, 2006. 9. G. F. Franklin, J. D. Powell, and A. Emami-Naeini, Feedback Control of Dynamic Systems, 6th ed., Prentice Hall, 2010 10. R. C. Dorf and R. H. Bishop, Modern Control Systems, 12th ed., Prentice Hall, 2011 11. Technical papers by Landis Markley and others

Title of the course	**AE 639 Continuum Mechanics**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Continuum mechanics: an introduction. Mathematical Preliminaries: Vector spaces; Index notations; Tensor algebra; Tensor calculus. Kinematics: Motion of a body – referential and spatial descriptions; The deformation gradient; Stretch, strain and rotation; Spin, circulation and vorticity; Deformation of volume and area; Discussion on frames of reference. Basic Thermo-mechanical Principle: Conservation of mass; Surface tractions, body forces and stress tensor; Conservation of linear and angular momentum; Conservation of energy; Clausius-Duehm inequality. Constitutive Relations: Principle of material objectivity; Thermoelastic materials – isotropic, transversely isotropic and orthotropic; Inviscid fluids; Viscous fluids. Typical boundary value problems: Bending of beams, Torsion of a circular cylinder, Fluid flow –Poiseuille flow and Couette flow.
Texts/References	1. Y. C. Fung, First Course in Continuum Mechanics, Prentice Hall, 1977 2. W. M. Lai, D. Rubin and E. Krempl, Introduction to Continuum Mechanics, Pergamon Press, 1993 3. M. E. Gurtin, Introduction to Continuum Mechanics, Academic Press, 1981 4. A. J. M. Spencer, Continuum Mechanics, Dover Publications, 2004

Title of the course	**AE 641 Introduction to Navigation and Guidance**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction: fundamentals of navigation, historical perspective and stellar navigation concept. Basic navigation strategies: radio and radar based navigation systems, inertial navigation system (INS). Modern navigation methods: Global Positioning System (GPS) based navigational aids, INS-GPS based navigation and other specialized navigation systems, comparison of the various navigational aids, case studies on navigation in aircraft, missiles, launch vehicles and spacecraft. Concept of guidance: fundamentals of guidance, concepts of intercept geometry, line of sight and collision triangle. Basic guidance strategies: proportional navigation & guidance (PNG) and determination of miss distance, augmented PNG and its comparison with PNG. Advanced guidance methods: command to LOS & beam rider guidance, pulsed and Lambert`s guidance. Special topics: tactical vs. strategic considerations in guidance, impact of noise on guidance, target maneuver and evasion, case studies on guidance methods in aircraft, missiles, launch vehicles and spacecraft.
Texts/References	1. E. W. Anderson, The Principles of Navigation, Hollis & Carter, London, 1966 2. M. Kayton, Navigation: Land, Sea, Air, Space, IEEE Press, 1990 3. B. E. Parkinson and J. J. Spilker, Global Positioning System: Theory and Applications, Vol.1, Progress in Aeronautics and Astronautics Series, Vol.163, AIAA Publication, 1996 4. P. Zarchan, Tactical & Strategic Missile Guidance, Progress in Aeronautics and Astronautics Series, Vol.176, 3rd ed., AIAA Publication, 1997 5. D. J. Biezad, Integrated Navigation and Guidance Systems, AIAA Education Series, AIAA Publication, 1999 6. J. L. Farrell, Integrated Aircraft Navigation, Academic Press, 1976 7. P. Misra and P. Enge, Global Positioning System, 2nd ed., Ganga-Jamuna Press, 2001

Title of the course	**AE 647 Introduction to Plasmas for Engineering**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Background, Plasma definition, parameters, Collisions, Quasi-neutrality, Debye-shielding, Magnetization, Generation of plasmas, Review of Thermodynamics and Electrodynamics, Continuum, Phase space & Configuration space, Kinetic & Fluid equations, Collisions, Transport Coefficients, Temperature, Specific Heat, Entropy, Behaviour of gases at high temperatures, Ionization (collisions/external fields), Maxwell Equations, Lorentz Force, Charged particle drifts under EM fields, collisions, mean free path, Plasma Fluid Theory – Governing Equations, Partially ionized gases, Plasma sheath/Plasma material boundary, Modeling for computations, Ideal MHD, Magnetic tension and pressure, Equilibrium, Flux freezing, Waves, Shocks, Plasma thrusters, Non-ideal MHD, Resistivity, Ohm's Law, Internal & External flows: Duct/Channel flows and Boundary layers, Plasma actuators for flow control, Space Plasmas, Stellar plasma, Solar wind and Earth`s outer atmosphere, Solar weather and spacecraft
Texts/References	1. A. Piel, Plasma Physics, Springer, 2010 2. G. W. Sutton and A. Sherman, Engineering Magneto-hydrodynamics, Dover Publications, 2006 3. M. G. Kivelson, and C. T. Russell (eds.), Introduction to Space Physics, Cambridge University Press, 1997

Title of the course	**AE 648 Energy Methods in Structural Mechanics**
Credit Structure	3-0-0-6
Prerequisite	Nil

Course Content	General concepts and principles of mechanics and energy theorems: Mechanical systems; Generalized coordinates; First law of thermodynamics; Principle of virtual work; Generalized force; Potential energy; Properties of conservative systems; Potential energy of a system of particles; Stability. 2. Elastic beams and frames: Strain energy of beams, columns and shafts; Beam columns analysed by Fourier series; Curved beams and pin-jointed trusses. Methods of the calculus of variations: Introduction using a simple cantilever beam example; Euler's equation and notation; Derivation of beam equation, curved cantilever beam; Isoperimetric problems and auxiliary differential equations; First variation of a double integral; First variation of a triple integral; The Rayleigh-Ritz method. Deformable bodies: Deformation of a body, stress and strain; First law of thermodynamics applied to a deformation process; Stress-strain relations of elastic bodies; Complementary energy density; Hookean materials; Generalization of Castigliano's theorem of least work; Reissner variational theorem of elasticity; Principle of complementary energy; Unit load method and analysis of statically indeterminate structures by unit load method. Plate Theory – using variational approach: The Von Karman theory of flat plates; Small deflection theory of plates; Boundary conditions in the classical theory of plates; Simply supported rectangular plates; Shear deformation of plates. 6. Theory of buckling: Introduction; Post-buckling behaviour of a simple column; Buckling of conservative systems with enumerable degrees of freedom; Buckling of simply supported compressed rectangular plates; Lateral buckling of beams; Torsional-flexural buckling of columns.
Texts/References	H. L. Langhaar, Energy Methods in Applied Mechanics, John Wiley & Sons Inc., 1962

Title of the course	**AE 649 Finite Element Method**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Basics of finite element method; The standard discrete system; Variational methods of approximation: Rayleigh-Ritz method and Method of Weighted Residuals; Problems in Linear Elasticity; Variational Forms and Weak Forms of Finite Element Approximation: 1-D Problems (bar, Euler-Bernoulli beam, Timoshenko beam); Discussion on shear locking problem; Constraint equations; Standard 2- and 3 dimensional finite elements; Isoparametric elements; Nonconforming elements; Numerical integration; Reduced integration; Numerical errors and convergence; Introduction to finite element method in dynamics and vibrations; Computer implementation of the finite element models.
Texts/References	1. R. D. Cook, Concepts and Application of Finite Element Analysis: A Treatment of the Finite Element Method as Used for the Analysis of Displacement, Strain, and Stress, 2nd ed., John Wiley, New York, 1974 2. O. C. Zienkiewicz and R. L. Taylor, Finite Element Method, 4th ed., McGraw-Hill, UK, 1989 3. J. N. Reddy, Introduction to Finite Element Method, Mc-Graw Hill, New York, 1985 4. K. J. Bathe, Finite Element Procedures, Prentice Hall, New York, 1995

Title of the course	**AE 650 Mini Project**
Credit Structure	0-0-6-6
Prerequisite	Nil
Course Content	This is a supervised learning program whereby the student is expected to solve a problem of practical interest using modern tools. The availability of supervised learning units depends upon offerings by individual faculty members.

Title of the course	**AE 651 Aerodynamics of Compressors and Turbines**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Axial Flow Compressor: Work done, Pressure-rise, Losses and efficiency, The blade shape, stagger and solidity; Incidence and deviation angles; Transonic/Supersonic blades - shock structures; Blade design on a meridional plane; Vortex Laws - radial distribution; Blade element method of design

	of stage; Characteristic plots; Multistaging and Matching of stages. Centrifugal Compressor: Flow pattern in Impellers; work done, losses and efficiency; Slip factor and degree of reaction; Design choices for impeller vanes: Backward, Forward curved and Radial; Vaned / Vaneless Diffuser, Axial Flow Turbine: Work extraction; Loading limits, Stator and Rotor - subsonic and supersonic profiles; Reaction and radial variation; Blade cooling techniques; Blade element method of design of stage; Radial Flow Turbine: Work done in impeller; Loading - temperature limits; Losses and efficiency.
Texts/References	1. N. A. Cumpsty, Compressor Aerodynamics, Longman Scientific & Technical, 1989 2. J. H. Horlock, Axial Flow Turbine, R. E. Krieger Pub. Co., 1968 3. Gas Turbine Engine Design: (with Video Cassette) - ASME/IGTI, 1989

Title of the course	**AE 653 Engineering Mathematics**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Basics of vectors and matrices: definition of vector spaces; dimension of spaces, matrices as transformations between coordinate spaces. System of linear equations: rank, range and null space, eigenvalues, eigenvectors. Data analysis: mean, variance, standard deviation, auto/cross-correlation, probability distribution functions, moments. Fourier series, transform, I & II order ordinary differential equations (ODEs), simple partial differential equations: hyperbolic (wave equation, I & II-order), parabolic (1-D transient conduction), elliptic (1-D, 2-D steady-state conduction). Systems of differential equations: basic concepts and theory, phase plane, critial points, stability. Basic vector calculus: operators, Gauss and Stokes theorems, etc., gradient, divergence operators in cylindrical and spherical coordinates. Fixed-point iteration, root-finding, interpolation, curve-fitting (least-squares), numerical differentiation (finite differences), quadrature. Numerical solution of ODEs: Euler, Runge-Kutta methods, stability limits. Finite difference and finite volume approaches to solving PDEs (heat equation).
Texts/References	1. E. Kreyszig, Advanced Engineering Mathematics, 10th ed., Wiley India Pvt. Ltd., 2003 2. J. Bird, Higher Engineering Mathematics, 6th ed., Routledge, 2010 3. J. W. Dettman, Introduction to Linear Algebra and Differential Equations, Courier Co., 2012 4. K. F. Riley, M. P. Hobson and S. J. Bence, Mathematical Methods for Physics and Engineering, Cambridge University Press, 1999 5. B. S. Grewal, Higher Engineering Mathematics, 43rd ed., Khanna Publishers, 2014

Title of the course	**AE 656 Aviation Fuels and their Combustion**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction, Various fuels, solid, liquid and gaseous fuels, Aviation fuels requirements and specifications. Chemical thermo dynamics, Laws of thermodynamics applied to reacting systems. Equilibrium composition, Adiabatic flame temperature. Chemical kinetics, Reaction rates, Gas phase reactions, Surface reactions. Combustion: Premixed and diffusion flames, Laminar and turbulent flames, Flame velocities, Flame propagation theories, Diffusion flame, Droplet Combustion. Application to gas turbine combustor and rocket engine.
Texts/References	1. K. K. Kuo, Principles of Combustion, Wiley International, 1986. 2. S. P. Sharma and C. Mohan, Fuels and Combustion, Tata McGraw Hill, 1984. 3. F. A. Williams, Combustion Theory, John Wiley, 1965 4. A. G. Gaydon and H. G. Wolfhard, Flames, Their Structure, Radiation, and Temperature, Chapman Hall, 1979

Title of the course	**AE 658 Design of Powerplants for Aircraft**
Credit Structure	3-0-0-6
Prerequisite	AE 605

Course Content	Preliminary cycle optimization. Design requirements and specifications. Matching of powerplant components. Propellers: elements of propellers, representative blade element theory, vortex theory, momentum theory, propeller characteristics, performance graphs, propeller design criteria. Propo-fans. Intakes, Various intake configurations, intake design criteria, intake flow analysis. Exhaust nozzles, various nozzle configurations, Convergent - Divergent nozzles, Critical, supercritical and Subcritical operations, variable geometry nozzle, vectored thrust nozzle, future propulsion systems for passenger aircraft and military aircraft. Powerplant component testing, engine testing and performance evaluation.
Texts/References	1. D. O. Dommasch, S. S. Sherby and T. L. Connolly, Airplane Aerodynamics, Pitman, 1967 2. J. Seddon and E. L. Goldsmith, Intake Aerodynamics, Collins, 1985 3. J. Chauvin, Supersonic Turbojet Propulsion Systems and Components, AGARD-AG-120, 1969

Title of the course	**AE 660 Interfacial Phenomena in Liquid Atomization**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Review of combustion fundamentals; Droplet evaporation and combustion model; Importance of atomization in liquid fuel combustion. Atomization – definition, Introduction, Characteristic parameters: breakup length, spray penetration, drop size distribution, patternation. Basics of Interfacial tension, capillarity, Young-Laplace Equation, surface energy. Stability theory of liquid jets, liquid sheets, Theory of droplet formation by primary breakup of liquid jets and sheets; planar sheets, curved sheets. Secondary breakup of liquid droplets; Effect of liquid properties and non-dimensional numbers. Types of atomization techniques used in IC engines, gas turbine engines and liquid rocket engines; Pressure atomizers, swirl atomizers, twin-fluid atomization, impinging jet atomizers. Experimental and numerical techniques for analysis of atomization: High speed imaging, optical diagnostics, introduction to numerical approaches, level set method, VOF.
Texts/References	1. A. H. Lefebvre and V. G. McDonell, Atomization and Sprays, CRC Press, 2nd ed., 2017 2. N. Ashgriz (ed.), Handbook of Atomization and Sprays: Theory and Applications, Springer 2011 3. S. P. Lin, Breakup of Liquid Sheets and Jets, Cambridge University Press, 2003 4. L. Bayvel and Z. Orzechowski, Liquid Atomization, Taylor and Francis, 1993

Title of the course	**AE 662 Applied Optimal Control**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Motivation and Overview; Mathematical Preliminaries; Unconstrained Optimization and Constrained Optimization; Differentials in Optimal Control; Calculus of Variations; Numerical Techniques for Optimal Control/Trajectory Optimization: Gradient Method, Shooting Method; Infinite-time and Finite-time Linear Quadratic Regulator (LQR); Infinite-time and Finite-time State Dependent Riccati Equation (SDRE); Dynamic Programming and Approximate Dynamic Programming; Neighboring Optimal Control; Constrained Optimal Control; Singular Optimal Control; Generation of Optimal Trajectories: Pseudospectral Method, Model Predictive Static Programming (MPSP), Generalized MPSP; Time Optimal Control; Linear Quadratic (LQ) Observer and Kalman Filter; Linear Quadratic Gaussian (LQG) Design; Solutions of Practical Problems
Texts/References	1. D. S. Naidu, Optimal Control Systems, CRC Press, 2002 2. D. E. Kirk, Optimal Control Theory: An Introduction, Prentice Hall, 1970 3. A.E. Bryson and Y.-C. Ho, Applied Optimal Control, Taylor and Francis, 1975 4. B. D. O. Anderson and J. B. Moore, Linear Optimal Control, Prentice-Hall, 1971 5. D. G. Hull, Optimal Control Theory for Applications, Springer-Verlag New York, Inc., 2003

	6. I. M. Ross, A Primer on Pontryagin's Principle in Optimal Control, Collegiate Publishers, 2015 7. J. L. Crassidis and J. L. Junkins, Optimal Estimation of Dynamic Systems, CRC Press, 2004

Title of the course	**AE 663 Software Engineering for Engineers and Scientists**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Using Unix command line tools to carry out common (mostly text processing) tasks. Automating typical tasks using basic shell-scripting. The effective use of version control for collaborating on code and documents. The use of LaTeX and other markup languages to generate professional documents. Use of the Python programming language to carry out typical engineering/numerical computations such as those that involve (basic) manipulation of large arrays in an efficient manner. Generating 2D and simple 3D plots. Understanding the impact of coding style and readability on quality. Debugging programs using a standardized approach, Understanding the importance of tests and the philosophy of Test Driven Development. Writing unit tests and improve the quality of code.
Texts/References	1. A. Scopatz and K. D. Huff, Effective Computation in Physics: Field Guide to Research with Python, O'Reilly Media, 2015 2. G. Wilson, Software carpentry – material available at http://software-carpentry.org, 2010 3. H. P. Langtangen, Python Scripting for Computational Science, Springer-Verlag, 2004 4. H. P. Langtangen, A Primer on Scientific Programming with Python, Springer-Verlag, 2009

Title of the course	**AE 664 Lighter-Than-Air Systems**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction to LTA Systems, Historical Developments, Key Subsystems and Components of LTA Systems. Static Lift Prediction, Effect of ambient conditions on Static Lift, Climb, Descent and Pressure Height, Methodology for airship conceptual design, Aerodynamics & Stability analysis of Airships, Ground Handling and Mooring systems, Case Studies in Airship Operations, Design & Development of Remotely Controlled Airships, Methodology for sizing of Aerostat sub-systems, Equilibrium and Stability analysis of aerostats, Design and Development of Tethered Aerostats, Challenges in design of LTA Systems, Hybrid LTA Systems, Stratospheric Airships, Current Trends and Recent Developments
Texts/References	1. R. S. Pant, Course Material for Design and Development of LTA systems, Curriculum Development Program, IIT Bombay, 2010 2. J. A. Taylor, Principles of Aerostatics, The Theory of Lighter-Than-Air Aircraft, CreateSpace Independent Publishing Platform, 2014 3. G. Khoury (ed.), Airship Technology, 2nd ed., Cambridge Aerospace Series, Cambridge University Press, 2012 4. G. E. Carichner, and L. M. Nicolai, Fundamentals of Aircraft and Airship Design, Vol. 2 – Airship Design and Case Studies, AIAA Education Series, 2013

Title of the course	**AE 665 Aircraft Stealth Technology**
Credit Structure	2-1-0-6
Prerequisite	AE 714
Course Content	Air-power, Air-superiority, Air-supremacy & role of Aircraft Stealth Capabilities (with examples of actual warfare, including surgical strike with precision weapons). Low Observables – Camouflage (merge with background), Conceal (hide), Deception (role of Electronic Warfare & Electronic Countermeasures). Classification of Aircraft Stealth Technology – Active vs. Passive Signatures [Signatures - Radar, Infrared (IR), Acoustic, Visual, & Miscellaneous]

	Effectiveness of Air Combat & Advantage of Low Observable Aircraft (Mission Attainment Measure, Survival Rate, Measure of Mission Success). Probabilities – Survivability, Susceptibility, Vulnerability, & their inter-relation (Probability of Kill, Blast-Kill Radius). Radar – Surveillance & Tracking bands, Radar Range Equation, Radar Cross-Section (RCS) (Rayleigh, Resonance, Optical Regimes). Monostatic Radar – Backscatter RCS, RCS – Estimation & Reduction [Countermeasures = Shaping, Radar Absorbent Material, Jamming (Burn-through Range)]. Aircraft IR-Signatures – Detection in Atmospheric Windows, Lock-On & Lethal Range [IR bands = 2-3, 3-5, 8-12 μm; IRCM = Suppression & Management (decoys - flares)]. Estimation - Sources of IR-signature in Aircraft & Background IR-Radiance [Internal (Jet-Nozzle, Plume, Aerodynamic Heating) & External (Earthshine, Sunshine)].
Texts/References	1. D. C. Aronstein and A. C. Piccirillo, Have Blue & the F-117A, Evolution of the Stealth Fighter, AIAA Education Series Inc., 1997 2. D. C. Aronstein, M. J. Hirschber and A. C. Piccirillo, Advanced Tactical Fighter to F-22 Raptor: Origins of the 21st Century Air Dominance Fighter, AIAA Education Series Inc., 1998 3. D. Richardson, Stealth Warplanes: Deception, Evasion, and Concealment in the Air, Zenith Press, 2001 4. R. E. Ball, The Fundamentals of Aircraft Combat Survivability: Analysis & Design, 2nd ed., AIAA Education Series Inc., 2003 5. K. Zale, Stealth Aircraft Technology, Create-Space Independent Publishing Platform, 2016 6. G. A. Rao and S. P. Mahulikar, Integrated Review of Stealth Technology and its Role in Airpower, Aeronautical Journal, 106(1066) 629-641, 2002 7. S. P. Mahulikar, H. R. Sonawane and G. A. Rao, Infrared Signature Studies of Aerospace Vehicles, Progress in Aerospace Sciences, 43(7-8) 218-245, 2007

Title of the course	**AE 666 Adaptive and Learning Control Systems**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction and Overview; Mathematical Preliminaries: Matched and Unmatched Conditions, Mathematical Norms, Comparison Functions, Small Gain Theorem; Stability: Autonomous, Non-autonomous and Nonlinear Systems, Barbalat's Lemma, Ultimate Boundedness Theorem; Model Reference Adaptive Control (MRAC): Direct MRAC, Indirect MRAC, Predictor based MRAC; Robustness Modifications: σ-Modification, e-Modification, Parameter Projection, Q-Modification; Update Law Modification: Gradient Method; Concurrent Learning Adaptive Control; Frequency Selective Learning Adaptive Control; Higher-Order Adaptive Control; $\mathcal{L}1$ Adaptive Control: From MRAC to $\mathcal{L}1$, $\mathcal{L}1$ Reference System, Closed-Loop Control Structure; Solutions of Practical Problems.
Texts/References	1. K. S. Narendra and A. M. Annaswamy, Stable Adaptive Systems, Dover Publications Inc., 1989. 2. K. Aström and B. Wittenmark, Adaptive Control, 2nd ed., Addison-Wesley, Readings, 1995 3. P. Ioannou and J. Sun, Robust Adaptive Control, Prentice Hall Inc., NJ, 1996 4. G. Tao, Adaptive Control Design and Analysis, Wiley, New York, USA, 2003 5. E. Lavretsky and K. Wise, Robust and Adaptive Control with Aerospace Applications, Ser. Advanced Textbooks in Control and Signal Processing. London: Springer-Verlag, 2013 6. N. Hovakimyan and C. Cao: $\mathcal{L}1$ Adaptive Control Theory: Guaranteed Robustness with Fast Adaptation, Advances in Design and Control, SIAM, Philadelphia, PA, 2010 7. G. Chowdhary and E. Johnson: Concurrent Learning Adaptive Control of Linear Systems with Exponentially Convergent Bounds, International Journal of Adaptive Control and Signal Processing, 27(4), 280–301, 2012 8. A. Maity, L. Höcht, and F. Holzapfel, Higher-order Direct Model Reference Adaptive Control with Generic Uniform Ultimate Boundedness, International Journal of Control, 88(10), 2126–2142, 2015

	9. L. Höcht, A. Maity, and F. Holzapfel, Frequency Selective Learning Model Reference Adaptive Control, IET Control Theory & Applications, 9(15), 2257–2265, 2015 10. K. Y. Volyanskyy: Adaptive and Neuroadaptive Control for Nonnegative and Compartmental Dynamical Systems, Ph.D. Dissertation, Aerospace Engineering, Georgia Institute of Technology, USA, 2010 11. H. J. Marquez, Nonlinear Control Systems Analysis and Design, Wiley, New Jersey, 2003 12. H. K. Khalil, Nonlinear Systems, 3rd ed., Prentice Hall Inc., New Jersey, 2002

Title of the course	**AE 667 Rotary Wing Aerodynamics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction (importance, challenges, definition of terms); Hover prediction methods (momentum theory, blade element theory, blade element momentum theory, vortex theory); Vertical descent of rotors, Coning angle & Lock number; Forward flight prediction methods (performance, blade dynamics); Helicopter performance prediction (endurance, range, speed, power); Advanced topics (reverse flow, dynamic Stall, compound helicopters)
Texts/References	1. W. Johnson, Helicopter Theory, Courier Corporation, 2012 2. G. J. Leishman, Principles of Helicopter Aerodynamics, Cambridge University Press, 2006

Title of the course	**AE 668 Reduced Order Strategies for Structures and Fluids**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Mathematical preliminaries and background: Structural and fluid governing equations, solution methodologies, and method of snapshots. Order reduction techniques: Normal modes; Eigenvalue realizations and operating deflection shapes; Principal component analysis, dynamic mode decomposition, and sparse coding approach; Static and implicit condensation; Response surface methodology; Kriging; Volterra and Weiner kernels. Applications: Beams, plates, steady state and dynamic solutions for representative fluid systems.
Texts/References	1. A. Forrester and A. Sobester and A. Keane, Engineering Design via Surrogate Modelling: A Practical Guide, John Wiley & Sons, 2008 2. J. N. Kutz, S. L. Brunton, B. W. Brunton, and J. L. Proctor, Dynamic Mode Decomposition: Data-Driven Modeling of Complex Systems, SIAM, 2016 3. M. P. Mignolet, A. Przekop, S. A. Rizzi, and S. M. Spottswood, A Review of Indirect/Non-Intrusive Reduced Order Modeling of Nonlinear Geometric Structures, Invited Paper, Journal of Sound and Vibration, 332(10), 2437–2460, 2013 4. D. J. Lucia, P. S. Beran, and W. A. Silva, Reduced-Order Modeling: New Approaches for Computational Physics, Progress in Aerospace Sciences, 40, 51–117, 2004

Title of the course	**AE 669 Machine Learning Based Uncertainty Quantification for Composites**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Overview of uncertainty quantification, Sources of uncertainty in engineering structures, Uncertainty modelling, propagation and quantification, Probabilistic/ non-probabilistic methods, Intrusive/non-intrusive methods, Monte Carlo Simulation/ Perturbation Techniques/Expansion methods/Surrogate modelling approach, Machine learning based approach for uncertainty quantification, Uncertainty quantification in laminated composite structures, Random variable model, Layer-wise random variable model, Random field model, Sensitivity analysis, Stochastic characterization of global responses of composite structures, Introduction to reliability analysis methods, Simple computational exercise related to uncertainty quantification and reliability analysis

Texts/References	1. S. Dey, T. Mukhopadhyay and S. Adhikari, Uncertainty quantification in laminated composites: A meta-model based approach, CRC Press, Taylor & Francis Group, 2018 2. R. Smith, Uncertainty Quantification: Theory, Implementation, and Applications, Computational Science and Engineering, SIAM, 2013 3. R. M. Jones, Mechanics of Composite structures, Taylor & Francis, Philadelphia, PA, 1999 4. J. N. Reddy, Mechanics of Laminated Composite Plates and Shells: Theory and Analysis, Second Edition, CRC Press, 2003 5. S. Naskar, T. Mukhopadhyay and S. Sriramula, Probabilistic micromechanical spatial variability quantification in laminated composites, Composites Part B: Engineering. Elsevier Publication, 151, 291–325, 2018 6. S. Naskar, T. Mukhopadhyay and S. Sriramula, Spatially varying fuzzy multi-scale uncertainty propagation in unidirectional fibre reinforced composites, Composite Structures. Elsevier Publication, 209, 940–967, 2019 7. S. Naskar, T. Mukhopadhyay, S. Sriramula and S. Adhikari, Stochastic natural frequency analysis of damaged thin-walled laminated composite beams with uncertainty in micromechanical properties. Composite Structures. Elsevier Publication, 160, 312–334, 2017

Title of the course	**AE 673 Fiber Reinforced Composites**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Polymer matrix composites in aerospace structures. Fibers and polymeric matrix materials. Fabrication processes. Introduction to anisotropic elasticity. Unidirectional composites. Micromechanics interfaces and interphases in polymer composites. Laminates and lamination theory. Damage characteristics of laminated composites. Delamination in composites. Interlaminar stresses and free edge effects. Hygrothermal stresses in composites. Short fiber composites. Experimental characterization of composites. Introduction to metal matrix, ceramic matrix and carbon-carbon composites. Laminated plates under lateral load. Transverse shear effects.
Texts/References	1. R. F. Gibson, Principles of Composite Material Mechanics, McGraw-Hill, 1994 2. I. M. Daniel and O. Ishai, Engineering Mechanics of Composite Materials, Oxford University Press, 1994 3. G. Lubin, Handbook of Composites, Van Nostrand Reinhold, 1982

Title of the course	**AE 676 Elastic Analysis of Plates and Laminates**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Assumptions of Love-Kirchhoff thin plate theory, governing equation and boundary conditions of thin plates. Rectangular plates with various boundary conditions; Navier's and Levy's solutions; bending of circular and annular plates. Plates under combined action of lateral and in-plane loads. Classical laminated plate theory for anisotropic laminated plates. Deformation of shells without bending. General theory of cylindrical shells; shells having the form of a surface of revolution and axi-symmetrically loaded; spherical shells, conical shells. Approximate methods of analysis for plates and shells.
Texts/References	S.P. Timoshenko and S. Winowsky-Krieger, Theory of Plates and Shells, 2^{nd} ed., McGraw-Hill, 1975.

Title of the course	**AE 678 Aeroelasticity**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction to static and dynamic aeroelastic phenomena. Divergence of a lifting surface, two-dimensional and three-dimensional analysis. Analysis of divergence, aeroelastic loads of tapered and swept wings. Loss and reversal of control two and three dimensional analysis. Assumed

	modes and matrix formulations. Aeroelastic efficiency and flexible aerodynamic derivatives. Fundamentals of flutter analysis. Quasi-steady and unsteady aerodynamic forces on airfoils. Two-dimension and three-dimensional flutter analysis - modal formulation, generalised unsteady airloads. Flutter of tapered and swept cantilever wings. Flutter computation methods. Buffeting and stall flutter. Galloping and Vortex-induced vibrations of structures. Aeroelastic testing techniques.
Texts/References	1. Y. C. Fung, An Introduction to the Theory of Aeroelasticity, Dover, 1969 2. B. L. Bisplinghoff, H. Ashley and R. L. Halfman, Aeroelasticity, Addison-Wesley, 1972 3. C. H. Scanlan and R. Rosenbaum, Aircraft Vibration Flutter, Dover, 1968 4. E. H. Dowell, A Modern Course in Aeroelasticity, Kluwer Academic Publishers, 1994

Title of the course	**AE 679 Advanced Guidance and Control**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Fundamentals of guidance and control for autonomous aerospace vehicles. Mathematical Preliminaries: Basics concepts on dynamical systems and their stability Review of basic guidance concepts Performance analysis: Method of Adjoints Modern guidance: Linear and nonlinear control-based guidance strategies. Terminal constrained guidance: Different approaches for impact angle, impact time, impact angle and impact time guidance, maximizing impact velocity. Variants of classical guidance, such as biased PNG, multi-phase PNG, etc. Cooperative guidance: Simultaneous interception of target Aircraft defense: Active and passive approaches, various approaches to cooperative aircraft defense, different levels of cooperation. Unmanned aerial vehicle: Path planning, trajectory following, formation flying. Guidance and control strategies: Two-loop and integrated approaches. Trajectory shaping approach for terminal constrained guidance, field-of-view (FOV) constrained guidance. Guidance design with obstacle and collision avoidance. Tactical and strategic considerations, Lambert guidance, guidance of ballistic trajectories
Texts/References	1. P. Zarchan, Tactical and Strategic Missile Guidance**,** AIAA Progress in Astronautics and Aeronautics, 6th ed., 2013 2. N. A. Shneydor, Missile Guidance and Pursuit: Kinematics, Dynamics and Control, Woodhead Publishing, 1998 3. G. M. Siouris, Missile Guidance and Control Systems, Springer-Verlag New York, 2004 4. R. W. Beard and T. W. McLain, Small Unmanned Aircraft: Theory and Practice, Princeton University Press, 2012

Title of the course	**AE 681 Combustion of Solid Propellants**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction: Solid propellants, Solid rocket motors and their classification, Rocket performance parameters. Characterization of solid propellants: (a) Properties of basic ingredients, mixing and processing of solid propellants (b) combustion characteristics of solid propellants: burn rate law, temperature sensitivity, LPDL, effect of various parameters, (c) Experimental techniques: Measurement of burn rate, temperature sensitivity, specific impulse, combustion efficiency and thrust. Challenges in measurements under hostile conditions. (d) Mechanical properties of solid propellants, sensitivity and handling. Solid rocket motor operation: Time evolution of pressure and web thickness, various grain shapes, incremental analysis to predict pressure-time curve, Analysis of motors with head end / aft end fynocyl configuration and their pressure time curve.

	Steady state solid propellant combustion: Governing equations, Interface boundary conditions, Combustion of Mono-propellants: Ammonium Perchlorate (AP), effect of additives, Combustion of double base propellants, Combustion of composite solid propellants. Combustion of non-aluminized solid propellants, particle size effect of AP, plateau and dual plateau compositions, effect of additives, Combustion of aluminized propellants and two phase losses. Sandwich propellants: Introduction, combustion of sandwich propellants, Thick vs thin sandwiches, Pressure dependence of sandwich propellants. Erosive burning: Theoretical aspects, empirical and semi-empirical theories, Measurement of erosive burning. Ignition and extinction of solid propellants: Types of igniter, Operation of igniter, charge composition, igniter performance, Theoretical analysis of ignition, Extinction analysis of solid rocket motor, Methods of extinction, Rapid depressurization. Combustion Instability: Theoretical analysis, admittance and energy growth rate, Pressure and velocity coupled response, Damping mechanisms in solid rocket motor. Special solid propellants: Gun Propellants, Fuel Rich Propellants (FRP), Gas generator (GG) propellants, High energy materials (HEMs) and their applications.
Texts/References	1. F.A. Williams, M. Barrere and N.C. Huang, Fundamental Aspects of Solid Propellant Rockets, Publication: Technivision Services Slough, England, AGARD, 1989 2. N. Kubota, Propellants and Explosives, Wiley, 2007 3. H S Mukunda, Understanding Aerospace Chemical Propulsion, Interline Publishing, 2004 4. J. P. Agrawal, High Energy Materials, Wiley, 2010 5. G. P. Sutton and Oscar Biblarz, Rocket Propulsion Elements, Wiley, 2016

Title of the course	**AE 682 Introduction to Thermoacoustics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Basic acoustic theory: derivation of wave equation, specific and characteristic impedance, admittance, acoustic energy intensity and power, spherical waves, quantitative measures of sound, open and closed boundary condition, reflection and transmission at an interface, monopoles, dipoles and quadrupoles. Practical thermoacoustic devises and models: Rijke tube, premixed flames, G-equation, diffusion flames, acoustic instabilities in solid rocket motors, vortex impingement models for combustion instability. Techniques to analyze experimental data: fast fourier transform, phase space reconstruction, recurrence analysis, Poincare maps, Hurst exponent analysis.
Texts/References	6. A. D. Pierce, Acoustics: An Introduction to its Physical Principles and applications, Acoustical Society of America, 1994 7. F. E. C. Culick, Unsteady Motions in Combustion Chambers for Propulsion Systems, AGARDograph, NATO/RTO-AG-AVT-039, 2006 8. T. C. Lieuwen, Unsteady Combustor Physics, Cambridge University Press, 2012

Title of the course	**AE 690 Control System Design Techniques**
Credit Structure	3-0-0-6
Prerequisite	AE 695 and AE 775
Course Content	Introduction: design problem definition, selection of design specifications and basic design objectives, review of PID controller and lag-lead design methodologies, linear state feedback control review. 2-DOF PID Controllers: concept of PI-D and I-PD forms, two-loop and 2-DOF generalization of PID controllers, feedforward control option, multi-loop structures, zero placement technique for 2-DOF PID design. Non-unity Feedback Control: feedback path control concept, rate and acceleration feedback based design methodology, role of sensors and filters in feedback path. Optimal & Robust Classical Design: performance parameter based optimal design solutions, integrated error based optimal controllers, concept of close loop robustness and sensitivity analysis, uncertainty models and Quantitative Feedback Theory (QFT) for robust design. Classical Control of Non-linear Systems: types of nonlinear behaviour and their

	classification, gain scheduled controllers, concept of describing function for modelling nonlinear behaviour. Discrete Domain Control Design: discrete representation of signals and systems, concept of z-domain and z-transform, discrete system response attributes and control design strategies. State Estimators & Filters: state estimation in noisy environment, recursive least-squares filters, Kalman filter in continuous and discrete domains. Optimal &Robust State Feedback Control: the separation principle, Linear Quadratic Gaussian (LQG), optimal tracking control design, design for discrete time systems, H_∞ norm based robust control design. Non-linear & MIMO Systems: feedback linearization & non-linear dynamic inversion (NDI) based techniques, concept of MIMO control, eigenspace assignment technique for linear systems.
Texts/References	1. J. J. D'Azzo and C. H. Houpius, Feedback Control System Analysis & Synthesis, 2nd ed., McGraw-Hill, NY, 1966 2. H. Kwakernaak and R. Sivan, Linear Optimal Control Systems, Wiley Interscience, 1972 3. B. Friedland, Control System Design: An Introduction to State-Space Methods, McGraw-Hill, New York, 1987 4. W. A. Wolovich, Automatic Control Systems: Basic Analysis and Design, Saunders College Publishing, 1994 5. D. K. Fredrik, Computer Programmes for Simulation and Design of Control Systems, Academic Press, 1984 6. J. J. D'Azzo and C. H. Houpius, Linear Control System Analysis and Design: Conventional and Modern, 4th ed., McGraw-Hill, New York, 1995 7. B. Friedland, Advanced Control System Design, Prentice Hall, New Jersey, 1996 8. P. Zarchan, and H. Musoff, Fundamentals of Kalman Filtering: A Practical Approach, 2nd ed., Progress in Aerospace Sciences Vol. 208, AIAA, 2005

Title of the course	**AE 695 State-Space Methods for Flight Vehicles**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction: Time domain representation of dynamical systems, basics of time response of higher order linear systems, algebraic perspective for dynamical system response. Vector Algebra: Vector spaces, concept of linear independence, basis vectors and dimension, linear transformations. Solution Spaces: solution of linear algebraic systems, concept of kernel and image spaces, concept of eigenvalues, eigenvectors and eigenspace. System Forms: Diagonal and Jordan forms, characteristic equation, operator form of linear dynamical systems, analytic functions of square matrices and Cayley-Hamilton theorem. Basics of State-space: Dynamical system response in a vector space, representation of linear dynamical systems in the state-space, various canonical forms. System Solution Space: Concept of fundamental matrix and state transition matrix, solution of homogeneous and nonhomogeneous systems, evaluation of matrix exponential. Stability Analysis: Energy based stability hypothesis, Lyapunov's theorem of stability, concept of phase plane and state-trajectory based stability analysis. Control Concepts: Controllability of dynamical systems, regulator problem and full state feedback control structure, pole placement design technique, tracking control structures, optimal control system using Linear Quadratic Regulator (LQR), output feedback control concept. State Observers: Concept of observability and its role in control, full and reduced order observers, observer controllers
Texts/References	1. K. Ogata, State Space Analysis of Control Systems, Prentice Hall, USA, 1967 2. T. Kailath, Linear Systems, Englewood Cliff: Prentice Hall, 1980 3. B. Friedland, Control System Design: An Introduction to State-Space Methods, McGraw-Hill, New York, 1986 4. J. H. Blakelock, Automatic Control of Aircraft & Missiles, 2nd ed., 1991 5. A. E. Bryson, Control of Spacecraft and Aircraft, Princeton University Press, 1994 6. J. J. D'Azzo and C. H. Houpius, Linear Control System Analysis & Design: Conventional and Modern, 4th ed., McGraw-Hill, New York, 1995 7. B. Etkin, Dynamics of Flight: Stability and Control, 3rd ed., John Wiley & Sons, 1996 8. K. Ogata, Modern Control Engineering, 5th ed., Prentice Hall India, 2010

Title of the course	**AE 699 Control Systems Lab**
Credit Structure	0-0-4-4
Prerequisite	AE 775
Course Content	Reinforcement of basic control concepts: Proportional, integral and velocity feedback applied to simple control systems such as servo control, temperature control, gyroscope, and flexible shafts, rectilinear spring-mass systems and rotary inertia driven systems. Real system effects: Effect of friction, backlash, resistance, loading and transport lag on the control system behavior. Frequency response: Experimental generation, application to closed loop system stability analysis.
Texts/References	1. Ogata, K., Modern control engineering, 5th ed., Prentice Hall India, Eastern Economy Edition, 2010. 2. User Manuals of the various experimental setups

Title of the course	**AE 700 Guidance and Control of Unmanned Autonomous Vehicles**
Credit Structure	2-1-0-6
Prerequisite	Nil, but desired background is basic concepts of Control Theory and Differential Equations
Course Content	• Fundamentals of unmanned autonomous vehicles, types of vehicles, aerial vehicles: fixed wing, multirotors, etc.; ground vehicles: wheeled, tracked, etc.; underwater vehicles: surface vessels and submerged vehicles; and associated subsystems, applications of unmanned autonomous vehicles • Coordinate frames, transformation matrices, direction cosine matrix, Euler angles, quaternions • Kinematics and dynamics, forces and moments, general rigid body dynamics, rigid body dynamics for fixed wing, rotary wing vehicles, multi-rotors, underwater and ground vehicles • Path planning: schemes for path planning, smooth trajectory generation, waypoint following • Guidance: basic concepts of guidance theory, guidance design for trajectory following and tracking • Control: Design of autopilots, integrated and separate control subsystems design, constraints imposed by different types of vehicles • Common sensors for unmanned autonomous vehicles, vision-guided navigation • Course project using specific vehicle and applying above concepts
Texts/References	1. R. Beard and T. W. McLain, Small Unmanned Aircraft: Theory and Practice, Princeton University Press, 2012 2. B. L. Stevens, E. N. Johnson, and F. L. Lewis, Aircraft Control and Simulation: Dynamics, Controls Design, and Autonomous Systems, 3rd ed., Wiley Publications, 2016 3. T. I. Fossen, Marine control systems: guidance, navigation and control of ships, rigs and underwater vehicles, Trondheim, Norway: Marine Cybernetics, 2002 4. K. P. Valavanis and G. J. Vachtsevanos, Handbook of Unmanned Aerial Vehicles, Springer, 2014 5. B. Siciliano and O. Khatib, Handbook of Robotics, 2nd ed., Springer, 2016 6. P. Zarchan, "Tactical and Strategic Missile Guidance", 7th ed., AIAA Progress in Astronautics and Aeronautics, 2019 7. N. A. Shneydor, "Missile Guidance and Pursuit: Kinematics, Dynamics and Control", 1st ed., Woodhead Publishing, 1998

Title of the course	**AE 702 Advanced Flight Dynamics**
Credit Structure	3-0-0-6
Prerequisite	AE 717
Course Content	Introduction to nonlinear dynamics, bifurcation theory and continuation methods. Problem of inertia coupling in rapid rolls and its solution. Flight dynamics at high angles of attack, Normal and Large-amplitude wing rock. Wing rock of delta wings, Topological methods. Nonlinear dynamics of missiles and projectiles, Roll lock-in, Catastrophic yaw.
Texts/References	G. L. Hancock, An Introduction to the Flight Dynamics of Rigid Airplanes, Ellis Horwood, 1995

Title of the course	**AE 705 Introduction to Flight**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Nomenclature of aircraft components. Standard atmosphere. Basic aerodynamics: Streamlines, steady fluid motion, incompressible flow, Bernoulli's equation, Mach number, Pressure and airspeed measurement, Boundary layer, Reynolds number, Laminar and Turbulent flow. Airfoils and Wings: Pressure coefficient and lift calculation, Critical Mach number, Wave drag, Finite wings, Induced drag, Swept wings, Aircraft Performance: Steady level flight, Altitude effects, Absolute ceiling, Steady climbing flight, Energy methods, Range and Endurance, Sustained level turn, Pull-up, V-n diagram, Take-off and landing. Longitudinal static stability and control, Neutral point.
Texts/References	1. J. D. Anderson, Introduction to Flight, McGraw Hill 1989 2. J. F. Hale, Introduction to Aircraft Performance, Selection and Design, John Wiley, 1984 3. R. H. Barnard and D. R. Philpot, Aircraft Flight, Longman, 1989

Title of the course	**AE 706 Computational Fluid Dynamics**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Basic equations of fluid dynamics and levels of approximation. Mathematical nature of the flow equations and their boundary conditions. Grids and transformations. Basic discretization techniques applied to model equations and system of equations: finite difference, finite volume and finite element methods. Analysis of numerical schemes: concept of consistency, stability and convergence. Error and stability analysis. Some applications.
Texts/References	1. C. Hirsch, Numerical Computation of Internal and External Flows, Vol. I, John Wiley, 1990 2. J. D. Anderson, Computational Fluid Dynamics, McGraw Hill, 1995 3. D. A. Anderson, J. C. Tannehill and R. H. Pletcher, Computational Fluid Dynamics and Heat Transfer, McGraw Hill, 1984

Title of the course	**AE 707 Aerodynamics of Aerospace Vehicles**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Potential flow, Circulation and lift generation, Kutta condition. Thin airfoil theory, Source, Vortex and doublet panel methods. Subsonic compressible flow over airfoils, Prandtl-Glauert Compressibility correction. Supersonic flow over air- foils, Ackeret Theory. Oblique shocks and expansion waves, shock expansion method. Potential flow over finite wings, lifting-line theory, Vortex lattice method. Supersonic flow over finite wings, subsonic / supersonic leading edge. Linearized theory, Supersonic vortex lattice method. Slender Body Theory: Introduction to Transonic flows, Conical flows, Hypersonic flow and high-temperature flows.
Texts/References	1. J. D. Anderson, Fundamentals of Aerodynamics, McGraw Hill, 1991 2. J. J. Bertin and M. C. Smith, Aerodynamics for Engineers, Prentice Hall, 1989 3. A. M. Kuethe and C. Chow, Foundations of Aerodynamics, John Wiley, 1986 4. H. Ashley and M. T. Landahl, Aerodynamics of Wings and Bodies, Addison Wesley, 1965

Title of the course	**AE 708 Aerospace Propulsion**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Introduction, Various propulsive devices used for aerospace applications, Classifications of rockets: Electrical, Nuclear and Chemical rockets, Applications of rockets. Nozzle design: Flow through nozzle, Real nozzle, Equilibrium and frozen flow, Adaptive and non-adaptive nozzles, Thrust vector controls, Rocket performance parameters. Solid propellant rockets, Grain

	compositions, Design of Grain. Liquid propellant rockets, Injector design, cooling systems, Feed Systems: Pressure feed and turbo-pump feed system. Heat transfer problems in rocket engines.
Texts/References	1. G. C. Oates, Aerothermodynamics of Gas Turbine and Rocket Propulsion, AIAA, 1998 2. S. M. Barrere et al, Rocket Propulsion, Elsevier, 1956 3. S. P. Sutton, Rocket Propulsion Elements, John Wiley, 1954

Title of the course	**AE 709 Aerospace Structures**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Thin-walled stiffened structures in aerospace vehicles, basic components and assemblages. General formulation for thin-walled beams. Bending and torsion of thin-walled beams of arbitrary closed and open cross-sections, shear flow and shear centre calculations for general cross-sections, warpless cross-sections. Bending and torsion of multi-cell thin-walled beams - warping, shear flow and shear centre, stresses in thin walled beams of variable depth, effect of taper. Effect of warp restraint in thin-walled beams, axial constraint stresses, effect of warp restraint in open section beams. Buckling of thin walled beams, torsional instability, introduction to the instability of flat sheets, local buckling of composite shapes, buckling of stiffened sheets, effective width concept, design charts and formulae. Diagonal tension and semi-tension field beams.
Texts/References	1. T. H. G. Megson, Aircraft structures for engineering students, 2nd ed. Edward Arnold, London, 1990 2. E. F. Bruhn, Analysis and Design of Flight Vehicle Structures, Tri-State Offset Co., Cincinnati, Ohio, USA, 1965 3. D. Williams, Introduction to the Theory of Aircraft Structures, Edward Arnold, London, 1960 4. B. E. Gatewood, Virtual Principles in Aircraft Structures, Vols.1 & 2, Kluwer Academic Publishers, 1989

Title of the course	**AE 710 Aeroacoustics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Background and definition of aeroacoustics; Linearity of acoustics; Aspects of classical acoustic theory: Governing equations for acoustics, Special solutions; Sources of aeroacoustic sound and their resultant fields: Introduction to generalized functions and Green's theory for solution of partial differential equations, as required in acoustics, Sound field due to various multipole sources, Analysis of sound due to moving sources; Kirchhoff's formula of linear acoustics in the presence of surfaces; Lighthill's theory and application to jet noise; Ffowcs-Williams and Hawkings' formulation of nonlinear acoustics in the presence of surfaces; Scattering of sound at an edge, as applicable to airfoil noise; Study of current literature on various topics of aeroacoustics
Texts/References	1. M. E. Goldstein, Aeroacoustics, McGraw-Hill, 1976 2. D. G. Crighton, Basic Principles of Aerodynamic Noise Generation, Prog. Aerospace Sci., 16(1), 31–96, 1975 3. A. P. Dowling and J. E. Ffowcs-Williams, Sound and Sources of Sound, Ellis Horwood Publishers, 1983

Title of the course	**AE 711 Aircraft Propulsion**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Introduction to various aircraft propulsive devices: Piston-prop, Turbo-prop,Turbojet, Turbofan, Turboshaft, Ramjet, Vectored-thrust, Lift engines. Gas Turbine Cycles and cycle based performance analysis; 1-D and 2-D analysis of flow through gas turbine components - Intake, Compressors, Turbines, Combustion Chamber, Afterburner, and Nozzle. Compressor and Turbine blade shapes; cascade theory; radial equilibrium theory; matching of compressor and Turbine.

	Turbine cooling. Single spool and Multi- spool engines. Powerplant performance with varying speed and altitude.
Texts/References	1. H. G. Cohen, F. C. Rogers and H. I. H. Saravanamuttoo, Gas Turbine Theory, Longman, 1987 2. G. C. Oates, Aerothermodynamics of Gas Turbine and Rocket Propulsion, AIAA, 1998

Title of the course	**AE 712 Flight Dynamics and Control**
Credit Structure	3-0-0-6
Prerequisite	AE 695, AE 775 and AE 717
Course Content	Introduction. Review of aircraft flight dynamics, Aircraft missions. Flight envelope as a mission statement, effect of flight conditions on linearized aircraft dynamic models, flying (or handling) quality requirements and the design objectives for the flight control systems. Stability augmentation systems, longitudinal and lateral autopilots e.g. displacement autopilot, pitch attitude controller, altitude and glide path hold controllers including instrument landing system, speed hold autopilot, yaw damper and roll control systems, automatic flare controller using model following, dutch roll damping augmentation, turn compensation & automatic lateral beam guidance system. Eigen structure assignment based longitudinal pitch controller, linear quadratic regulator (LQR) based lateral control systems, normal acceleration based stability augmentation system, LQR based pitch rate controller, yaw orientation controller incorporating servo dynamics, design of lateral autopilots under physical constraints, Controllers for noisy & uncertain aircraft dynamics. Robust pitch rate controllers to handle wind gust and unmodelled dynamics, Case studies. Typical control law designs for civilian, military and unmanned aircraft.
Texts/References	1. D. McLean, Automatic Flight Control Systems, Prentice Hall, 1990 2. J. H. Blakelock, Automatic Control of Aircraft and Missiles, Wiley-Interscience, 1991 3. B. L. Stevens and F. L. Lewis, Aircraft Control and Simulation, John Wiley and Sons, 1992 4. B. Etkin and L. D. Reid, Dynamics of flight – stability and control, Wiley India, 1996 5. R. C. Nelson, Flight Stability and Automatic Control, 2^{nd} ed., McGraw Hill, 1998 6. R. S. Stengel, Flight Dynamics, Princeton University Press, 2004; Overseas Press, 2009

Title of the course	**AE 713 Spaceflight Dynamics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction: Space missions, Historical Perspective. Ascent Mission: Ascent mission objectives, mathematical models governing ascent mission, rectilinear and gravity turn ascent trajectories, effect of aerodynamic drag and gravity. Multi-stage Launch Vehicles: Concept of multi-staging, staging solution, series and parallel staging, optimal staging solutions. Launch Vehicle Attitude Motion: Short period attitude motion. Basic Orbital Solution: Two-body Problem, Keppler`s laws & equation, classical orbital elements, orbit determination, position and velocity predictions, different types of orbits, perturbation due to earth oblateness and solar radiation pressure, non-Keplerian formulation and restricted 3-body problem, sphere of activity. Satellite Operations: Orbit raising manoeuvre, Hohmann and low thrust transfers, orbit inclination & perigee change maneuvers, launch to orbit and docking, launch window concept. Spacecraft Motion: Interplanetary motion, departure and arrival solutions, gravity assist trajectories. Descent Mission: Orbit decay solution, concept of re-entry mission, ballistic and other mechanisms. Spacecraft Attitude Motion: Torque-free motion models, effect of energy dissipation on stability of rotational motion.
Texts/References	1. J. W. Cornelisse, H. F. R. Schoyer and K. F. Wakker, Rocket Propulsion and Spaceflight Dynamics, Pitman, London, 1979 2. W. T. Thompson, Introduction to Space Dynamics, Dover Publications, New York, 1986 3. V. L. Pisacane and R. C. Moore, Fundamentals of Space Systems, Oxford University Press, 1994 4. W. E. Wiesel, Spaceflight Dynamics, 2^{nd} ed., McGraw-Hill, 1997 5. B. Wie, Space Vehicle Dynamics and Control, AIAA Education Series, 1998 6. R. X. Meyers, Elements of Space Technology for Aerospace Engineers, Academic Press, 1999

Title of the course	**AE 714 Introduction to Aircraft Design**
Credit Structure	**3-0-0-6**
Prerequisite	Nil
Course Content	Overview of engineering design process, Phases in aircraft design, type of civil and military aircraft. Aircraft Configuration and Layout, Unconventional aircraft configurations. Initial sizing, Constraint analysis. Lift and drag coefficient, design loads, component mass breakdown, acquisition cost, direct operating cost. Range-payload diagram, V-n diagram, noise and emission levels, special considerations in design such as stealth, survivability, maintainability. Supersonic aircraft design, very large aircraft, morphing aircraft.
Texts/References	1. D. P. Raymer, Aircraft Design - A Conceptual Approach, AIAA Educational Series, 5^{th} ed., 2012 2. S. A. Brandt, R. J. Stiles, J. J. Bertin and R. Whitford, Introduction to Aeronautics: A Design Perspective, AIAA Education Series, 3^{rd} ed., 2015 3. L. M. Nicolai and G. E. Carichner, Fundamentals of Aircraft and Airship Design, Vol. 1 – Aircraft Design, 2010 4. J. Fielding, Introduction to Aircraft Design, Cambridge Aerospace Series, Cambridge University Press, 1999

Title of the course	**AE 715 Structural Dynamics**
Credit Structure	2-1-0-6
Prerequisite	Nil
Course Content	Elements of analytical dynamics, generalised coordinates, Principle of Virtual Work, Hamilton's principle, Lagrange's equations, applications. Discrete systems with multiple degrees of freedom, elastic and inertia coupling, natural frequencies and modes, free vibration response, orthogonality of natural modes, modal analysis, forced vibration response, special and general cases of damping, matrix formulations, solution of the eigenvalue problem. Vibration of continuous systems, differential equations and boundary conditions, longitudinal, flexural and torsional vibrations of one-dimensional structures, approximate methods-Ritz series, assumed modes, Galerkin and integral formulations, vibration analysis of simplified aircraft and launch vehicle structures, structural damping, free and forced response of continuous systems, modal truncation. Special formulations for large systems.
Texts/References	1. L. Meirovitch, Elements of Vibration Analysis, 2^{nd} ed. McGraw-Hill Book Co., 1988 2. W. Weaver, S.P. Timoshenko and D.H. Young, Vibration Problems in Engineering, 5^{th} ed., John Wiley & Sons, 1990 3. L. Meirovitch, Computational Methods in Structural Dynamics, Sitjhoff & Noordhoff, 1980 4. R. W. Clough and J. Penzien, Dynamics of Structures, McGraw-Hill, 1975 5. R.L. Bisplinghoff, H. Ashley and R.L. Halfman, Aeroelasticity, Addison-Wesley, 1965

Title of the course	**AE 717 Aircraft Flight Dynamics**
Credit Structure	3-0-0-6
Prerequisite	AE 705
Course Content	Frames of reference: Inertial frame, body frame, definitions of α and β, wind axes, notation and sign convention for forces, moments and motion variables, nondimensional parameters – stability derivatives, control surfaces and control derivatives, dynamic derivatives. Equations of motion of rigid body: Euler angles & Quaternions. Aircraft dynamics: equations in wind axes, aerodynamic, propulsive, gravity forces and moments for an aircraft, 12^{th} order non-linear ODEs, 9^{th} order ODEs, 8^{th} order ODEs. Simulations: trim analysis. Stability analysis: linearization with respect to equilibrium, decoupling into longitudinal and lateral/directional dynamics. Longitudinal dynamics: mode shapes, short period and phugoid –frequency and damping, time to double/half. Lateral /directional dynamics: mode shapes, Dutch roll, roll subsidence & spiral mode –frequency and damping, time to double/half. Effect of winds: gust response.

Texts/References	1. J. Roskam, Flight Dynamics of Rigid and Elastic Airplanes, University of Kansas Press, 1972 2. B. Etkin and L. D. Reid, Dynamics of Flight – Stability and Control, Wiley India, 1996 3. R. C. Nelson, Flight Stability and Automatic Control, 2nd ed., McGraw Hill, 1998 4. R. S. Stengel, Flight Dynamics, Princeton University Press, 2004; Overseas Press, 2009

Title of the course	**AE 718 Hydrodynamic Stability Analysis**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction and motivation: relevance of hydrodynamic stability theory in transition to turbulence, coherent structures in turbulence, flow control, acoustics, etc. Review of equations of fluid mechanics, numerical differentiation, complex analysis and Fourier-Laplace theory. Linear stability and normal modes; temporal, spatial and spatio-temporal problems. Kelvin Helmholtz instability of inviscid and viscous shear flows such as jets, wakes and boundary layers. Other canonical fluid instabilities – Rayleigh-Benard, Richtmeyer-Meshkov, Rayleigh-Taylor. Weakly non-linear stability theory. Weakly non-parallel theory (parabolized stability equations) and global stability analysis. Introduction to absolute instability theory. Introduction to non-normal (non-modal) stability theory.
Texts/References	1. P. G. Drazin, Introduction to Hydrodynamic Stability, Cambridge University Press, 2002 2. P. J. Schmid and D. S. Henningson, Stability and Transition in Shear Flows, Springer, 2001 3. P. G. Drazin and W. H. Reid, Hydrodynamic Stability, 2nd ed., Cambridge University Press, 2004

Title of the course	**AE 720 Advanced Numerical Methods for Compressible Flows**
Credit Structure	3-0-0-6
Prerequisite	AE 706, AE 616
Course Content	Governing equations for compressible fluid flows – differential and integral forms, equation of states for perfect and real gasses, Reynolds and Favre averaging to deal with turbulent flow modelling. Introduction to basics of hyperbolic partial differential equations - Characteristics, general solution and its application to linear hyperbolic system. Properties of 1D and 2D Euler equations, elementary wave solutions, Riemann problem for Euler equations and its solutions. Introduction to multi-dimensional finite volume method for Navier-Stokes equations – structured and unstructured grid formulations, cell centered and cell vertex approaches, static and moving grid formulations, evaluations of geometric quantities of control volume, data structures for unstructured grid computations, discretization of convective and viscous fluxes, temporal discretization, grid movement algorithms, stability conditions. Development of upwind methods based on flux difference splitting – approximate Riemann solvers for 1D Euler equations, rotational invariance property and extension of Riemann solvers for 2D finite volume formulations, concept of genuinely multidimensional Riemann solver. Higher order temporal and spatial discretizations in finite volume formulations; spurious oscillations, monotonicity, positivity, total variations diminishing, local extremum diminishing criteria, development of non-linear discretization techniques for non-oscillatory solutions. Numerical treatment of boundary conditions – inlet, outlet, symmetry, periodic, flat and curved solid wall boundaries. Challenges in high-speed flow computations – high temperature and real gas effect, numerical shock instabilities. Challenges in low Mach number flow computations – ill conditioning, cancellation error, lack of solution convergence, undesired numerical dissipation, pressure scaling, checkerboard pressure-velocity decoupling.
Texts/References	1. E. F. Toro, Riemann Solvers and Numerical Methods for Fluid Dynamics: A Practical Introduction, Springer, 2009

	2. D. D. Knight, Elements of Numerical Methods for Compressible Flows, Cambridge University Press, 2006 3. C. B. Laney, Computational Gas Dynamics, Cambridge University Press, 1998 4. R. J. Leveque, Finite Volume Methods for Hyperbolic Problems, Cambridge University Press, 2004 5. J. Blazek, Computational Fluid Dynamics: Principles and Applications, Elsevier, 2015

Title of the course	**AE 724 Experimental Methods in Fluid Mechanics**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Physical laws of Fluid Mechanics, Similarity analysis, inviscid incompressible flows, inviscid compressible flows, Viscous flows, Various measurable quantities. Flow facilities: Various types of Wind Tunnels, Water Tunnels, Towing Tank. Measurement of mean and fluctuating pressures: Various types of probes, Manometers, Transducers. Measurement of Temperature: Thermocouples, Measurement of Velocity: Mean velocity, Turbulence, Hot Wire Anemometer, LDV, PIV. Measurement of Skin Friction: Balance, Preston Tube; Unsteady Flow Measurements: Conditional sampling technique for periodic flows. Basics of aero-acoustics and its measurements. Calibration: Primary calibrators and traceability. Data analysis: Precision, accuracy, error.
Texts/References	1. R. J. Goldstom (ed.), Fluid Mechanics Measurements, Hemisphere Publishing, 1983

Title of the course	**AE 725 Air Transportation**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Historical development and nature of civil aviation; Aviation organisations and their functions; Air-transport regulations. The airline industry: Airline economics and planning; Operating costs and revenue; Fleet planning and route development; Aircraft operations and performance; Aircraft Systems. Introduction to ATC and Avionics, Aircraft characteristics related to Airport Design, Airport Layout and Configuration, Geometric design of the airfield, Airport Costing and Financing, Cost-benefit analysis of Airport development. Impact of Airline deregulation on the airline industry. Airtransport in developing countries, Modern trends and current issues in Air transportation.
Texts/References	1. N. Taneja, Introduction to Civil Aviation, 2nd ed. Lexington Books, 1988 2. W. E. O'Conner, An introduction to airline economics, Praeger Publishers, New York, 1995 3. R. Wilkinson, Aircraft Structures and Systems, Addison Wesley Longman, 1996 4. R. Horonjeff and F. McKelvey, Planning and Design of Airports, 4th ed. McGraw Hill, 1994 5. N. Ashford and C. Moore, Airport Finance, Van Nostrand Reinhold, 1992 6. G. Williams, The Airline Industry and the impact of Deregulation, 2nd ed., Avebury Aviation, 1994

Title of the course	**AE 726 Heat Transfer - Aerospace Applications**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction, Modes of Heat transfer and basic equations. Conduction: Simple steady and unsteady conduction, applications. Convection: Natural and forced convection, applications. Radiation: Stefan - Boltzmann Law, Planck's law, Absorptivity, Emmissivity shape factor, applications. Aerospace applications: Turbine blade cooling, Disk cooling, Combustion Chamber Cooling, Rocket Engine cooling systems - regeneratively cooled, dump cooling, ablation cooling, radiation shield.
Texts/References	1. J. P. Holman, Heat Transfer, McGraw Hill, 7th ed., 1992 2. S. P. Sukhatme, A Textbook on Heat Transfer, Orient Longman, 1979

Title of the course	**AE 727 Aircraft Structural Mechanics Lab**
Credit Structure	0-0-4-4
Prerequisite	Nil
Course Content	The aerospace structures laboratory includes experiments related to material aspects as well as structural mechanics. These experiments are largely based upon the syllabus covered in the courses on AE 227 Solid Mechanics and AE 238 Aerospace Structural Mechanics. A couple of experiments on vibrations and structural dynamics are also included for exposure. The experiments in this laboratory course cover the following: Fabrication of fibre reinforced composite laminate; tension, compression, interlaminar shear, impact and hardness testing for determination of elastic moduli and strength of material; coefficient of thermal expansion; strain measurement; inverse methods for material property determination (Poisson's ratio and Young's Modulus) using measured static and dynamic structural response in conjunction with simple structural models; shear centre of open section thin-walled beam, displacement and strain distribution in bending and torsion of twin-walled open and closed section beams; Buckling of beams/plates; measurement of natural frequency, natural modes and modal damping of beams.
Texts/References	Laboratory Manual, Aircraft Structures Lab., Dept. of Aerospace Engineering, IIT Bombay, 2007.

Title of the course	**AE 731 Multiscale Modelling of Materials**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Elements of Quantum Mechanics; Density Functional Theory; Elements of Classical and Statistical Mechanics; Introduction to Atomistic Modelling and Simulation - Molecular Statics, Molecular Dynamics, and Monte Carlo methods; Mesoscale physics – vacancies, dislocations, twinning, grain boundaries, alloys and precipitates; Discrete Dislocation Dynamics; Microstructure Evolution; Phase Field method; Continuum Modelling – Crystal Plasticity, Finite Element Method; Examples of Multiscale Modelling – Car Parinello Molecular Dynamics, Quasi-continuum Method, Atomistic-to-Continuum coupling techniques; Case studies – multiscale modelling of plasticity and fracture.
Texts/References	1. R. LeSar, Introduction to Computational Materials Science – Fundamentals to Applications, Cambridge University Press, 2013 2. R. Phillips, Crystals, Defects and Microstructures – Modeling across Scales, Cambridge University Press, 2001

Title of the course	**AE 736 Advanced Aeroelasticity**
Credit Structure	3-0-0-6
Prerequisite	AE 678
Course Content	Basic equations of motion of unsteady potential flow, small perturbation linearized theory. Boundary conditions and addition al physical considerations. Solution methodology, Accelerated flows. Unsteady lift and moments on oscillating two-dimensional thin airfoil and slender wing in incompressible flow and super- sonic flow, Piston Theory. Introduction to unsteady lifting surface theory. Divergence of swept, tapered wings. Aeroelastic loads and Aeroelastic efficiency computations. Flutter of wings. Modal formulation and assumed modes approaches. Generalised aerodynamic forces and modal unsteady airloads. Flutter solution methods. Transient motion of airfoils - Fourier superposition, Wagner and Kussner functions and gust response. Time domain modelling of modal unsteady aerodynamic forces. Subcritical response of wings. Exposure to practical aeroelastic analysis. Introduction to aero-servo-elastic modelling of aircraft.
Texts/References	1. R. L. Bisplinghoff, H. Ashley and R. L. Halfman, Aeroelasticity, Addison-Wesley, Massachusetts, 1955 2. Y. C. Fung, An Introduction to the Theory of Aeroelasticity, John Wiley & Sons, N.Y., 1955 3. R. L. Bisplinghoff and H. Ashley, Principles of Aeroelasticity, John Wiley & Sons, N.Y. 1962

	4. E. H. Dowell, H. C. Curtiss, R. H. Scanlan and F. Sisto, A Modern Course in Aeroelasticity, Sijthroff & Noordoff, 1978

Title of the course	**AE 738 Tensors for Engineers**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Vector space: Field, vector space, subspace, linear combination, span of subspace, linearly independent, basis, dimension, direct sum space. Linear transformation: Definition and examples, matrices, range space and null space, row space and column space, rank and nullity, geometrical aspects, singular cases, projection and invariants, dual basis, double dual, transpose, inverse, trace, determinant, cofactor, tensor product. Euclidean space: Scalar/inner product, general curvilinear coordinates, contravariant and covariant, geometric interpretation, metric tensor, orthonormal basis, Gram-Schmidt orthonormalization, tensor product representation with respect to basis, change in basis, special tensors(symmetric, skew symmetric, orthogonal), matrix representation of tensors. Spectral decomposition: Principal values and principal directions, positive definite tensor, polar decomposition, diagonal form of matrix, power and functions of matrices, spectral decomposition of second order symmetric and orthogonal and skew symmetric tensor, Cayley-Hamilton theorem, representation theorem. Fourth order tensor: Fourth order tensor as linear map, tensor product and representation, special operations, major/minor symmetry, special fourth order tensor. Tensor analysis in Euclidean space: Differentiation, gradient, covariant and contravariant derivatives, Christoffel symbols, representation of the covariant derivative, divergence and curl, tensor identities, examples in cylindrical and spherical coordinates. Analysis of tensor function: Tensor valued isotropic/anisotropic functions, structural tensor, derivative of tensor valued tensor functions, some mechanics applications.
Texts/References	1. M. Itskov, Tensor Algebra and Tensor Analysis for Engineers with Applications to Continuum Mechanics, Mathematical Engineering Series, 4th ed., Springer, 2015 2. I. S. Sokolnikoff, Tensor Analysis: Theory and Applications, 2nd ed., John Wiley & Sons, 1964

Title of the course	**AE 755 Optimization for Engineering Design**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Engineering design process. Problem formulation in design; Constraints; Objective function. Constrained and unconstrained optimization problems; Necessary and sufficient conditions for optimality; Kuhn-Tucker conditions; Post-optimality analysis. Numerical methods for unconstrained and constrained nonlinear optimizations; Direct search methods; Steepest descent; Conjugate gradient (Fletcher Reeves); Newton's, DFP & BFGS method; Random walk; Simulated Annealing; Genetic Algorithms; Penalty function approaches; Method of Lagrange multipliers. Introduction to multi criteria optimization (MCO); Decision variables; Integrated problem formulation; Pareto optimum and Min-Max optima; Solution methods based on function scalarisation. Introduction to Multidisciplinary Design Optimization (MDO); Definition; Examples; Decomposition; Approximations and System sensitivity analysis in MDO. Exposure to single level, concurrent subspace and collaborative optimization methods; System and discipline level functions and intercommunication.
Texts/References	1. J. S. Arora, Introduction to Optimum Design, McGraw-Hill, 1989 2. S. S. Rao, Engineering Optimisation - Theory and Applications, New Age International, New Delhi, 1998 3. K. Deb, Optimisation for Engineering Design: Algorithms and Examples, Prentice-Hall India, 1995 4. Osyczka, Multicriterion Optimization in Engineering, John Wiley & Sons, 1984 5. D. E. Goldberg, Genetic Algorithms in Search, Optimisation and Machine Learning, Addison Wesley, 1989

	6. P. J. M. van Laarhoven, and E. H. L. Aarts, Simulated Annealing: Theory and Applications, Kluwer Academic, 1987 Research papers in MDO (AIAA papers)

Title of the course	**AE 759 Systems Engineering Principles**
Credit Structure	2-0-2-6
Prerequisite	Nil
Course Content	System definitions and conceptual system design. Introduction to engineering design and decision making; Requirements capture; Requirements analysis, functional decomposition; System architecture; Quality Function Deployment; Queuing theory; Design Options, Monte Carlo modeling, Utility theory, Forecasting. Engineering Systems modeling. Analysis of system; reliability; Maintainability, Serviceability, Disposability and Affordability. Cost and benefit analysis. Methods of decision analysis; State transition matrix models; modeling the research and development process; Information, System life-cycle modeling and optimization. Game theory; Management of Engineering systems design and operation; Programme management with case studies. Use of systems engineering software to capture the systems engineering process.
Texts/References	1. G. A. Hazelrigg, Systems Engineering: An Approach to Information-Based Design, Prentice Hall NJ,1996 2. B. A. Blanchard and W. J. Fabrycky, Systems Engineering and Analysis, 5th ed., Prentice Hall International Series, Industrial & Systems Engg., 2010 3. R. I. Faulconbridge and M. J. Ryan, System Engineering Practice, Argos Press, Canberra, Australia 2014 4. System Engineering handbook, A Guide for System Life Cycle Processes and Activities, INCOSE-TP-2003-002-03-2.1, International Council on Systems Engineering (INCOSE) January 2011 5. Systems Engineering - Application and Management of the Systems Engineering Process, ISO/IDC26702 IEEE Std 1220-2005, IEEE 2005 6. Systems and Software Engineering 302226 System life cycle process, ISO/IEC 15288 IEEE Std 15288-2. IEEE 2 7. BKCASE Editorial Board, 2. The Guide to the Systems Engineering Body of Knowledge (SEBok), v.1.3.2. Adcock (EIC), Hoboken, NJ; The Trustees of the Stevens Institute of Technology, Accessed 19th June 2, www.sebokwiki.org.

Title of the course	**AE 774 Special Topics in Aerodynamics and CFD**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	This course will cover special and advanced topics in aerodynamics and CFD. The course will typically consist of 2 or 3 modules taught by one or more instructors. Exact topics and coverage will depend on availability of instructors and background of students, and will be intimated in advance. The topics will be in the areas of Turbulence and turbulence modelling, Bluff body and vortex dominated flows, High speed and hypersonic flows, Advanced computational methods, Flow dynamics, stability and control, Industrial fluid mechanics, Aero acoustics and noise control.

Title of the course	**AE 775 System Modelling, Dynamics and Control**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction to System Modelling: Dynamic Models of Physical Systems: System Representation: Laplace transform and transfer function, block diagram representation and manipulation, signal flow graphs, Masons' gain formula. System Dynamics: Transient and steady state response of first and second order systems. Introduction to Control: Control situations & objectives, open-loop and closed-loop control concepts, various types of control structures, unity negative feedback control systems, basic control actions, 1st and 2nd order system on-off control. System Stability: Concept of system stability and connection with its response, asymptotic and

	bounded-input bounded output stability, role of characteristic roots in stability, Routh's stability criterion. Proportional Control Systems: concept of root locus and its application to proportional control system analysis. Frequency Response: Concept of frequency response & its representation using bode, Nyquist and Nichol's plots, closed loop system analysis using frequency response attributes, Nyquist stability analysis. Closed-loop Response Attributes: Transient and steady-state response concept, tracking control task and closed-loop error constants, integral control option for tracking, transient response and role of derivative action. Closed-loop Response Control Elements: PI controllers and lag compensators, PD controllers and lead compensators, PID controllers. Design of Closed-loop Control Systems:
Texts/References	1. K. Ogata, Modern Control Engineering, 5th ed., Prentice Hall India, Eastern Economy Edition, 2010 2. B. C. Kuo and F. Golnaraghi, Automatic Control Systems, 8th ed., John Wiley & Sons, 2003 3. J. J. D'Azzo and C. H. Houpis, Linear Control Systems Analysis and Design - Conventional and Modern, 4th ed., McGraw-Hill, 1995 4. N. S. Nise, Control Systems Engineering, 3rd ed., John Wiley & Sons, 2001 5. G. F. Franklin, J. D. Powell and A. Emami-Naeini, Feedback Control of Dynamic Systems, 5th ed., Pearson Prentice Hall, LPE, 2006 6. M. Gopal, Control Systems – Principles and Design, 3rd ed., Tata McGraw-Hill, 2008 7. R. C. Dorf and R. H. Bishop, Modern Control Systems, 12th ed., Prentice Hall, 2011 8. E. Bryson, Control of Spacecraft and Aircraft, Princeton University Press, 1994 9. B. Wie, Space Vehicle Dynamics and Control, AIAA Education Series, 2008 10. J. H. Blakelock, Automatic Control of Aircraft and Missiles, John Wiley, 1991

Title of the course	**AE 779 Optimization of Multidisciplinary Systems**
Credit Structure	3-0-0-6
Prerequisite	AE 755
Course Content	Introduction to Multidisciplinary Design Optimization (MDO) - need and importance, conceptual elements, examples. Coupled systems - analyser vs. evaluator, decomposition, system and discipline level design variables and constraints. Classification of MDO problem formulations - single vs. bi-level optimisation, nested analysis and design vs. simultaneous analysis and design. System and discipline level functions and intercommunication. MDO architectures based on these concepts. Concurrent subspace optimisation, collaborative optimisation and BLISS. Sensitivity analysis in MDO, global sensitivity equations, automatic differentiation, complex variable and adjoint methods. Approximation concepts and surrogate modelling, first and second order approximations, design of experiments and response surface methodology, krigging, design and analysis of computer experiments, multi-fidelity multi-point approximations. Software and IT issues in MDO - MDO frameworks.
Texts/References	1. P. Hajela and G. N. Vanderplaats, Optimal Design in Multi-disciplinary Systems, Notes of the three day professional course on Multi-disciplinary Design Optimization held at ADA, Bangalore, Jan. 5-7, 2001, CASDE Library, Dept. of Aerospace Engineering, IIT Bombay 2. I. Khuri and J. A. Cornell, Response Surfaces - Design and Analyses, 2nd ed., Marcel Dekker Inc., New York, 1996 3. D. C. Montgomery, Design and Analysis of Experiments, 5th ed., John Wiley & Sons, 2001 4. Selected AIAA Papers.

Title of the course	**AE 780 Computational Heat Transfer**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction, Governing equations for fluid flow and heat transfer. Solution to Partial Differential Equations - application to conduction, convection. Incompressible and compressible flow simulation, Laminar and Turbulent flows, Flow with chemical reactions.
Texts/References	1. S. V. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere Pub. Co., 1981 2. C. Hirsch, Numerical Computation of Internal and external flow, Vols. I & II, John Wiley, 1990

Title of the course	**AE 782 Flow Control**
Credit Structure	3-0-0-6
Prerequisite	Nil
Course Content	Introduction to flow control, history of flow control, governing equations, equations of motion at the wall, control goals, classification of flow control methods, active, passive and reactive flow control, wall bounded and free shear flows, coherent structures, control methods for laminar and turbulent flows, Reynolds number effects, transition control, compliant coatings, free-surface waves, flow separation, steady and unsteady separation, mechanics, characteristics and effects of flow separation, detection of flow separation, prevention and delay of separation, provocation of separation, control of flow separation by active and passive means, vortex generators and vortex generator jets, low-Reynolds number aerodynamics, separation bubble, drag reduction, drag reduction in automobiles, relaminarization, noise reduction, passive noise control, compliant coatings, jet noise, turbomachinery blades, secondary flows and its control, synthetic jets, micro-electro-mechanical systems in flow control, emerging trends in flow control.
Texts/References	1. M. Gad-el-Hak, Flow Control, Cambridge University Press, 2000 2. P. K. Chang, Control of Flow Separation, Hemisphere Publishing Corporation, 1976 3. G. V. Lachmann, Boundary Layer and Flow Control, Vols. 1 & 2, Pergamon Press, 1961

Title of the course	**AE 899 Communication Skills**
Credit Structure	1-2-0-6
Prerequisite	Nil
Course Content	**Context of communication**: Recognizing our capability and roles as professionals **Scientific Method**: Question and answer aspects of technical communication; Scientific Methodology and its relationship to technical communication; Surveying literature: Categories; reading and organizing scientific literature; search engines and tools. **Listening and Note-taking**: 5-R method and mind-mapping. **Technical writing**: Report organization; Journal selection; Introduction, conclusion, and abstract writing. **Speaking & Presentation skills**: Organization of presentation slides (number, content, and formatting); Oral presentations; Audience/context dependent practices; Nonverbal aspects: body language, eye-contact, personal appearance, facing large audience. **Elevator pitch**: Pitches for technical audience and policy makers **Workplace communication**: Sensitivity towards gender and diversity; Email communication and netiquettes. **Ethics in academic communication**: Intellectual Property, copyrights and plagiarism; Authorship; Data ethics; Biases and balanced criticism of literature; **Suggested additional topics relevant to disciplines**: Data representation, Group discussion and interviews; accessible scientific writing, report writing using LaTeX, Proofreading, etc.
Texts/References	1. Alley, M., The Craft of Scientific Presentations, Springer, 2003. 2. Booth, W. C., Colomb, G. G., and Williams, J. M., The Craft of Research, The University of Chicago Press, 3rd ed., 2008. 3. Keshav, S., How to read a paper. ACM SIGCOMM Comp. Commun. Rev., 37:83–84, 2007. 4. Monippally, M. M., Pawar, B. S., Academic Writing: A Guide for Management Students and Researchers, Response Books, 2010. 5. Purdue Online Writing Lab (OWL), https://owl.purdue.edu/ 6. William, S., Jr. and White, E. B., The Elements of Style, 4th ed., Longman, 1999. 7. Truss, L., Eats, Shoots & Leaves: The Zero Tolerance Approach to Punctuation, Gotham Books, 2006. 8. Whitesides, G. M., Whitesides' Group: Writing a Paper, Advanced Materials, 16(15):1375–77, 2004.

Title of the course	**AE 6102 Parallel Scientific Computing and Visualization**
Credit Structure	2-0-1-6
Prerequisite	Nil
Course Content	• Introduction to scientific computing with high-level languages. • Efficient use of arrays for vectorized computation. • Using modern tools for improved performance • Simple plotting and animation • Three dimensional plotting of scientific data • Using VTK and Mayavi for 3D visualization • Introduction to other popular visualization tools like ParaView • Basic OpenGL for simple but fast rendering • Basic debugging and profiling • High-level parallel computing on multi-core CPUs and GPUs • Programming using parallel primitives: map, reduce, and scans • Introduction to other high-level parallel computation packages • Brief introduction to distributed computing with MPI • Introduction to differentiable programming • Building simple UIs for scientific computing • Automation and reproducibility of scientific computing workflows • Case study of how these can be put together to build a modern, HPC package, and perform reproducible research The course will only introduce and make use of open source software. Many practical problem will be introduced and used throughout the course.
Texts/References	1. M. Gorelick and I. Ozsvald, High Performance Python: Practical Performant Programming for Humans, O'Reilly; 2nd ed., 2020 2. E. Forbes, Learning Concurrency in Python, Packt publishers, 2017 3. G. Hager and G. Wellein, Introduction to High Performance Computing for Scientists and Engineers, CRC Press, 2010

Document History

2022-12-26: Added contents of AE 623
2022-12-22: Added contents of AE 700
2022-07-29: Added contents of AE 6102
2021-07-29: Added contents of AE 681