Indian Institute of Technology Kanpur

COURSES OF STUDY

2025

Indian Institute of Technology Kanpur
KANPUR-208016

AEROSPACE ENGINEERING

Template for BT Program in Aerospace Engineering

Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
SCHEME-1 (9) ELC111/ELC112/ELC113 *	ETH111 (3)	SCHEME-2 EME (9-11)	SCHEME-3 HSS-I (9-11)	SCHEME* HSS-II (9)	SCHEME* HSS-II (9)	DE-1 (9)	SCHEME* HSS-II (9)
MTH 111 (6)	MTH 113 (6)	ESO202 (11)	ESC201 (14)	AE311 (9)	AE341 (11)	AE463 (3)	AE462 (4)
MTH 112 (6)	MTH 114 (6)	ESO204 (11)	ESO201(11)	AE321 (9)		AE461 (7)	AE421 (3)
PHY 115 (11)	PHY 112 (11)	TA 211 (3)§	AE211 (9)		AE351 (3)	AE451 (3)	OE-5 (9)
PHY 111 (3)	CHM 111 (3)	AE201M (5)	AE233M (5)	AE333 (9)	AE322 (9)	DE-2 (9)	UGP-2 /DE-3
TA 111 (9)	ESC 111 (7)	MSO202M	AE252M (4)	OE-1 (9)	AE334 (9)	UGP-1 (5)	UGP-3 /OE-6
CHM 112 (4)	ESC 112 (7)	MSO203M	TA212 (3) §	OE-2 (9)		OE-3 (9)	
CHM 113 (4)	LIF111 (6)	AE209 (8)			AE 312 (9)	OE-4 (9)	
PE111 (3)	PE112 (3)						
55	52	59-61	55-57	54	50	54	43

Remarks:

- At least 9 credits of DE must be taken from Basket-A as below.
- Basket-A: AE641 [9], AE662 [9], AE673 [9], AE747 [9], and AE777 [9]

Credit Table for BT Program in Aerospace Engineering		
Course type	Allowable Credit range	Credit in the department template
Institute Core (IC)	112	112
E/SO	18-45	51*
Department requirements	144-179	151 (124 DC + 27 DE)
Open electives (OE)	51-57	54
SCHEME	54-58	54-58
Total for 4-year BT/BS	391-420	422-426*

Template for the BTH program in Aerospace Engineering

Template for 3rd to 8th semester for BTH program in Aerospace Engineering					
Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
SCHEME-2 EME (9-11)	SCHEME-3 HSS-I (9-11)	SCHEME* HSS-II (9)	SCHEME* HSS-II (9)	DE-1 (9)	SCHEME* HSS-II (9)
ESO202 (11)	ESC201 (14)	AE311 (9)	AE341 (11)	AE463 (3)	AE462 (4)
ESO204 (11)	ESO201(11)	AE321 (9)		AE461 (7)	AE421 (3)
TA 211 (3)	AE211 (9)		AE351 (3)	AE451 (3)	UGP-2 (9)
AE201M (5)		AE333 (9)	AE322 (9)	DE-2 (9)	OE-4 (9)
MSO202M (6)	AE233M (5)	OE-1 (9)	AE334 (9)	UGP-1 (5)	OE-5 (9)

MSO203M (6)	AE252M (4)	OE-2 (9)	DEH-1	OE-3 (9)	UGP-3 /OE-6 (9)
AE209 (8)	TA212 (3)		AE 312 (9)	DEH-2	DEH-3 (9)
59-61	55-57	54	59	54	61

For BTH, students should take UGP-2 and 27 credits of DEH courses which are DEs at 6 or 7 level.

CPI criteria for BTH: 8.0

Template for the BTM program in Aerospace Engineering

Template for 3rd to 8th semester for BTM program in Aerospace Engineering					
Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
SCHEME-2 EME (9-11)	SCHEME-3 HSS-I (9-11)	SCHEME* HSS-II (9)	SCHEME* HSS-II (9)	MTB-1 (9)	SCHEME* HSS-II (9)
ESO202 (11)	ESC201 (14)	AE311 (9)	AE341 (11)	AE463 (3)	AE462 (4)
ESO204 (11)	ESO201(11)	AE321 (9)		AE461 (7)	AE421 (3)
TA 211 (3)	AE211 (9)		AE351 (3)	AE451 (3)	MTB-4 (9)
AE201M (5)		AE333 (9)	AE322 (9)	MTB-2 (9)	MTB-5 (9)
MSO202M (6)	AE233M (5)	OE-1 (9)	AE334 (9)	UGP-1 (5)	MTB-6 (9)
MSO203M (6)	AE252M (4)	OE-2 (9)		MTB-3 (9)	
AE209 (8)	TA212 (3)		AE 312 (9)	OE-3 (9)	
59-61	55-57	54	50	54	43

Template for five year dual-degree program in Aerospace Engineering

Template for 3rd to 10th semester of dual-degree program in Aerospace Engineering (Category-A)							
Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
SCHEME-2 EME (9-11)	SCHEME-3 HSS-I (9-11)	SCHEME* HSS-II (9)	SCHEME* HSS-II (9)	DE-1 (9)	SCHEME* HSS-II (9)	Thesis (36)	Thesis (36)
ESO202 (11)	ESC201A (14)	AE311 (9)	AE341 (11)	AE463 (3)	AE462 (4)		
ESO204 (11)	ESO201 (11)	AE321 (9)		AE461 (7)	AE421 (3)		
TA 211 (3)	AE211 (9)		AE351 (3)	AE451 (3)	OE-3 (9)		
AE201M (5)		AE333 (9)	AE322 (9)	DE-2 (9)	UGP-2 /DE- 3 (9)		

MSO202M (6)	AE233M (5)	OE-1 (9)	AE334 (9)	PG-1 (9)	PG-4 (9)		
MSO203M (6)	AE252M (4)	OE-2 (9)		PG-2 (9)	PG-5 (9)		
AE209(8)	TA212 (3)		AE 312 (9)	PG-3 (9)	PG-6 (9)		
59-61	55-57	54	50	58	61	36	36

Minimum Credit Requirement in MT part:

- PG Component: 54 credits
- Thesis Component: 72

credits

Remarks:

- UGP-1 and up to 27 OE credits from the BT minimum requirements may be used to fulfil requirements of the PG course component of the MT part.
- 18 credits of PG DE courses may be substituted from the PG course basket (below) for Category-A Dual Degree students.

PG course basket:

ME641, ME642, ME671, ME674, ME685, ME723, ME728, ME763, EE650, EE653, EE654, EE705/EE651; AE674/CHE614; AE617/CHE614; AE621/ME647; AE614/ME631; AE604/ME630; AE622/ME630; AE605/ME634; AE615/ME634; AE696/ME649;
AE653/ME617; AE663/ME643; AE754/ME745 (/ means any one of the two courses only)

Template for 7th to 10th semester of dual-degree program in Aerospace Engineering (Category B)			
Semester 7	Semester 8	Semester 9	Semester 10
AE601 (9)	PG-3 (9)	Thesis (36)	Thesis (36)
PG-1 (9)	PG-4 (9)	PG-6 (9)	
PG-2 (9)	PG-5 (9)		
27	27	45	36

Minimum Credit Requirement in MT part:

- PG Component: 63 credits
- Thesis Component: 72 credits

Remarks:

Up to 36 OE credits may be waived from the parent department's BT/BS graduation requirements to fulfil the PG requirements of Dual Degree.

Template for double major: second major in Aerospace Engineering

Double Major – Aerospace Engineering	
Pre-Requisites (33)	
ESO201(11)*	
ESO202(11)*	
ESO204(11)*	
AE Mandatory Courses (85)	
Odd Semester (45)	Even Semester (40)
AE209(8)*	AE211 (9)
AE311(9)	AE252 (4)
AE321(9)	AE341 (11)
AE333(9)	AE351 (3)
AE451(3)	AE322 (9)
AE461(7)	AE462 (4)

Remarks:

- *Other equivalent courses may be considered in consultation with AE DUGC
- Up to 36 OE credits may be waived from the parent department BT/BS graduation requirements to fulfil requirements of Double Major
- Pre-requisite courses are mandatory to complete DM

Minors in Aerospace Engineering

Minor – Aerospace Engineering	
AE Compulsory Course	
AE201M (5)	
Any THREE:	Pre-Requisites
AE211 (9)	ESO204 OR ME231
AE321 (9)	NONE
AE333 (9)	NONE
AE341 (11)	AE311
32-34	

Department of AE			
Course ID	**Course Title**	**Credits L-T-P-D-[C]**	**Content**
AE100	INTRODUCTION TO PROFESSION	1-0-2-0-0	History of aviation, space flight. Aerodynamic shape, generation of forces. Aerodynamics of airfoils. Atmosphere. Performance, stability & control. Structural layout. Power plants. Instruments & navigational aids. Materials. Aircraft systems. Missiles, spaceships, helicopters, airships & hovercrafts. Trips to wind tunnel facilities, flight, structural, propulsion and high -speed aerodynamic laboratories together with demonstrative experiments.
AE201M	INTRODUCTION TO AEROSPACE ENGINEERING	3-0-0-0-5	Fixed wing vehicles: History of Aviation, introduction to fixed wing vehicles, configuration and layout, propulsion, lift generation mechanism, balance of forces and moments, control mechanisms. Rotary wing vehicles: History of rotary wing vehicles, configuration and layout, propulsion, lift generation mechanism, balance of forces and moments, control mechanisms. Space Vehicles: History, configuration and layout, propulsion, lift generation mechanism, balance of forces and moments, navigation. Demo flights in motorized gliders. Introduction to Flight. **Pre-requisites**: None **Course Reference**: J.D. Anderson, Jr., McGrawHill International Editions.
AE209	DYNAMICS	2-1-0-0-8	Introduction to coordinate system, vectors, tensors, particles and rigid bodies, rotation and coordinate transformation (Euler angles), concept of angular velocity, dynamics of particles (Newton's laws of motion), work-energy, impulse-momentum, general planar motion, dynamics of systems of particles (including impulse-momentum relations), steady mass flow and variable mass (ropes, chains and rocket propulsion) problems, kinematics of rigid bodies: non-Newtonian reference frames, kinetics of rigid bodies: Newtonian-Eulerian mechanics, general 3-D motions (tops, gyroscopes, rotor in space, introduction to dynamics of aerial vehicles etc.) **Pre-requisites**: None **Course Reference**: J. L. Meriam and L. G. Kraige,

			Engineering Mechanics: Dynamics, 6/7/8th edition, 2015, Wiley
AE211	INCOMPRESSIBLE AERODYNAMICS	3-0-0-0-9	Introduction to aerodynamics, review of NS eqns, BL approximations. Atmosphere (ISA) and its stability, dynamic similarity. Aerofoil nomenclature, forces and moments, incompressible irrotational flow. Complex potential, singularities and superposition, axisymmetric potential flow, Blasius theorem, method of images. Circulation, Robins Magnus effect and Kutta- Joukowski theorem. Conformal mapping and Joukowski airfoil, Kelvin's circulation theorem. Thin airfoil theory, Helmholtz theorems, finite wing theory. Low aspect ratio wings and slender body theory. Flow separation & dynamic stall. Flow control & wing design. Wing flutter. **Pre-requisites**: ESO204 **Course Reference**: 1. Fundamental of Aerodynamics, J. D. Andersson, Jr, McGraw-Hill. 2. Aerodynamics for Engineering Students by E.L. Houghton, P.W. Carpenter. 3. Theoretical and computational aerodynamics, by T. K. Sengupta, Willey, 2015. 4. Physical Fluid Dynamics by D.J. Tritton, Oxford Science Publication. 5. An Introduction to Fluid Dynamics by G.K. Batchelor, Cambridge University Press. 6. An Introduction to Theoretical and Computational Aerodynamics by Jack Moran, Dover.
AE233M	INTRODUCTIONS TO VIBRATIONS	3-0-0-0-5	Single degree of freedom system, Free and forced vibrations (harmonic and general forcing), Duhamel's integration, types of damping, two degree of freedom system, modal analysis, diagonalization, eigensystem, response calculations for general excitation, proportional damping, principle of virtual work, Lagrange's equation. **Pre-requisites**: AE209 **Course Reference**: 1. Theory of Vibration with Applications. WT Thomson, MD Dahlen (5th Edition) Pearson Education. 2. Fundamentals of Vibrations. L Meirovitch (Mc Graw Hill Intl. Edition)
AE251A	EXPERIMENTS IN AEROSPACE ENGINEERING-I	2-0-2-0-8	Content Principles of measurement Introduction Description of Measuring Instruments Performance Characteristics of Instruments, Calibration, Accuracy, Precision, Bias, Dynamic response Virtual Instrumentation and Data acquisition Introduction to VI Graphical programming using LABView: Vis and sub Vis, loops ,arrays, clusters, file I/O Data acquisition: ADC, DAC, DIO, serial

			and GPIB communication Motion control system Sensors Strain Gage Motion Force, Torque, Power Pressure and Sound Temperature and Heat Flux Flow Error analysis and data reduction Uncertainties in measurements Probability distributions Propagation of errors Estimates of Mean and Errors Curve fits Advanced Optical Measurements (PIV, LDV,etc.). **Pre-requisites**: None **Course Reference**:1. Measurement Systems Application and Design, E. O. Doebelin; 2. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington and D. K. Robinson; 3. Experimental Stress Analysis, James W. Dally, William F. Riley; 4. Mechanical Behavior of Materials, Norman E. Dowling
AE252M	EXPERIMENTS IN AEROSPACE ENGINEERING-I	2-0-2-0-4	Principles of measurement: Introduction, Description of measuring instruments, Performance characteristics of instruments, calibration, accuracy, precision, bias, dynamic response. Introduction to VI based data acquisition. Sensors: Strain gage, Motion, Force, Torque, Power, Pressure and Sound, Temperature and Heat Flux, Flow. Error analysis and data reduction: Uncertainties in measurements, probability distributions, propagation of errors, estimation of mean errors, curve fits. Measurement Technique: thermal anemometry. **Pre-requisites**: None **Course Reference**: 1. Measurement Systems Application and Design, E. O. Doebelin. 2. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington and D. K. Robinson. 3. Experimental Stress Analysis, James W. Dally, William F. Riley. 4. Mechanical Behavior of Materials, Norman E. Dowling
	COMPRESSIBLE AERODYNAMICS	3-0-0-0-9	Review of thermodynamics. Governing equations of compressible flow. Isentropic flow, Area Mach number relation. Speed of sound, Mach cone, Flow regimes in terms of Mach number. Stationary and moving normal shock, Rankine Hugoniot relations. Oblique shock, Prandtl Meyer expansion. Reflection, intersection of shocks and expansion waves. Converging diverging nozzle, supersonic wind tunnel. 1D unsteady flow: Riemann problem. Method of characteristics. Small perturbations applied to, subsonic & supersonic airfoils, slender bodies. Similarity rules and area rule. Curved shock and Croccos Theorem. Shock Boundary layer interaction. Transonic small perturbation (TSP) equations. Transonic full potential equations. Rayleigh & Fanno flow. Experimental techniques. Introduction to hypersonics. **Pre-requisites**: ESO201, ESO204

AE311			**Course Reference**: 1. Elements of gasdynamics: Leipmann and Roshko, John Wiley & Sons. 2. The dynamics and thermodynamics of compressible flows: A. H Shapiro, John Wiley & Sons.
AE312	SHEAR FLOW	3-0-0-0-9	Tensor: Review of tensor algebra. Fundamental equations: Detailed derivation of stress tensor, Navier Stokes equation & energy equation. Some exact solutions: Exact solutions of NS equations: Hagen-Poiseuille flow with heat transfer, lubrication theory, Stokes 1st & 2nd problems, Jeffrey-Hammel flow, unsteady pipe flow. Boundary layer flows: Boundary layers: von Karman's momentum integral method, Thwait's method, similarity solutions: Blasius & Falkner-Skan solutions. Introduction to axisymmetric boundary layers, Mangler's transformation. Boundary layer control techniques. Free shear flows: mixing layers, jets and wakes. Transition to turbulence: Introduction to flow transition, stability, Rayleigh & Orr-Sommerfeld eqns. Introduction to turbulence. **Pre-requisites**: AE211 **Course Reference**: 1. Fluid Mechanics by Kundu and Cohen. 2. Incompressible flow by R Panton. 3. Viscous Fluid Flows by F. M. White. 4. Boundary Layer Theory by H. Schlichting.
	FLIGHT MECHANICS	3-0-0-0-9	Standard atmosphere Definition of altitude, relation between geopotential and geometric altitudes, pressure, temperature, density altitudes Airfoil nomenclature, Airfoil data, infinite vs finite wings, critical mach number, drag divergence mach number, wave drag, swept wings. Aerodynamic properties of wings and components Airplane drag estimation for subsonic and supersonic flight regime for fuselage, wings, tail and other components of aircraft Flaps mechanism of high lift, estimation of CL, CD, CL/CD, for different flaps at various configurations. Aircraft power plants Introduction to drag polar, equations of motion, thrust required for level and unaccelerated flight, thrust available and maximum velocity, power required for level and unaccelerated flight, power available and maximum velocity (reciprocating engine propeller combination, jet engine), altitude effects on power required and available. Rate of climb, gliding flight, absolute and service ceiling, time to climb, range and endurance propeller driven airplane, range and endurance jet airplane, take off and landing performance, turning flight and the Vn diagram, accelerated rate of climb (energy method), special consideration for supersonic airplane Optimal performance of airplanes Introduction to performance estimation of fixed wing unmanned aerial vehicles. **Pre-requisites**: AE201M, AE209

AE321			**Course Reference**: 1. Introduction to Flight: J.D. Anderson, McGraw Hill International Editions. Miele, A; 2. Flight Mechanics Theory of Flight Paths, Vol.I AddisonWesley, Reading, MA. Tewari, A; 3. Atmospheric and Space Flight Dynamics, Birkhauser, Boston, 2006; Mechanics of Flight: Warren F. Phillips. John Wiley and Sons, Inc
AE322	AIRCRAFT CONTROL SYSTEMS	3-0-0-0-9	Definition of stability and control static stability and dynamicstability. Moments on an airplane. Definition of pitch angle, flightpath angle and angle of attack. Criteria for longitudinal and static stability Aerodynamic model (longitudinal mode), Longitudinal staticstability and control, contribution of the wing, tail, fuselage to total moment about CG of aircraft. Equations of longitudinal staticstability. Calculation of elevator angle to trim in stick fixed vsstick free longitudinal static stability, estimation of neutral point (both stick fixed and stick free), estimation of static margin, estimation of maneuvering point (both stick fixed and stick free). Directional static stability, lateral static stability, estimation ofstatic margin, estimation of trim condition Equations of airplane motion Concept of stability and control derivatives Longitudinal and lateral directional dynamic modes Airplane response to controls Introduction to flying qualities and stability augmentation system. **Pre-requisites**: AE321 **Course Reference**: 1. Flight Stability and Automatic Control: R. Nelson, McGraw Hill Education. 2. Introduction to Flight: J.D. Anderson, McGraw Hill International Editions. Etkin, B., 3. Dynamics of Flight: Stability and Control 3rd ed., Wiley, New York, 1995*. 4. Mechanics of Flight: Warren F. Phillips. John Wiley and Sons, Inc
AE331	EXPERIMENTS IN STRUCTURES	1-0-3-0-3	Loads on an aircraft. Elements of Linear Theory of Elasticity for Idealization of Aerospace Structure; 1. Stress Resultant; 2. Extension bending of nonhomogenous Euler Bernoulli, Bending shear stress (open closed SE422 solid) St. Venant torsion of arbitrary crosssection 3. Shear flow; Thin Walled beams: Single celled and multi celled box beams. Shear center for open and closed section. Tapered beams Beam Column Euler Buckling Principle of virtual work **Course Reference**: 1. Theory and analysis of flight structures: R.M. Rivello.No. of lectures; 2, Aircraft Structures for Engineering Students (Fourth edition): T.H.G. Megson, Elsevier Aerospace Engineering Series; 3. Analysis of Aircraft Structures (second edition): B.K. Donaldson, Cambridge Aerospace Series.
AE333	AEROSPACE STRUCTURES - I	3-0-0-0-9	Introduction to flight vehicle structures: Fixed wing, rotary, launch vehicles and space structures;

			discussion on Cessna airframe with visit to Flight Lab.; introduction to FAR and MIL standards; loads on an aircraft. Elements of theory of elasticity: 3D-thermoelasticity equations, boundary-conditions, generalized Hooke's Law, material matrices for orthotropic, transversely isotropic and isotropic materials with examples of usable materials; plane stress and strain approximations, yielding and failure of materials. Mechanics of slender, hollow, stiffened structures: Concept of stress resultants, general picture of resultants on a cross-section; generalized beam theory for combined bending and axial response of metallic components; bending deflection analysis (using energy method also); post-processing for transverse shear, shear flow for hollow sections; open sections, shear centre for open sections. Torsion of hollow members of arbitrary cross-section: Review of torsion of circular cross-section; extension to non-circular sections, warping, Prandtl stress function; torsion of open and closed sections; shear flow in multi-celled sections including idealized sections for semi-monocoque construction. Combined bending-torsion: Shear flow, combined state of stress, prediction of yielding, introduction to fatigue models, design demands (fail safe, safe life and damage tolerant design). **Pre-requisites**: ESO202 **Course Reference**: 1. Aircraft Structures for Engineering Students (Fourth edition): T.H.G. Megson, Elsevier Aerospace Engineering Series. 2. Theory and analysis of flight structures: R.M. Rivello. 3. Analysis and design of flight vehicle structures: E. F. Bruhn.
AE334	AEROSPACE STRUCTURES - II	3-0-0-0-9	Introduction to aerospace structures: Review of concepts from Aerospace Structures I; plate and shell-like structures as part of airframe; discussion on design and certification of airframe components. Mechanics of thin plates and shells: Introduction to classical plate theory; boundary-conditions, solution of the plate problem; extension to laminated structures; extension of classical plate theory to shells; state of stress. Energy, variational and finite element method: Weak formulation, principle of virtual work, variational formulation from total potential energy; series solutions for beams, shafts, plates and shells of simple geometry; applicable finite element method for simple problems. Structural stability: Buckling as a design requirement; buckling of slender beams; example of bending-torsion coupling for I-section beams; buckling of plates; need and effect of stiffeners on plate buckling; discussion on buckling

			of shells with focus on fuselage and launch-vehicle structure. Summary of airframe design: Air-worthiness requirements, classic failures, airframe design evolution. **Pre-requisites**: ESO202 **Course Reference**: 1. Aircraft Structures for Engineering Students (Fourth edition): T.H.G. Megson, Elsevier Aerospace Engineering Series. 2. Theory of Plates and Shells: Timoshenko and Young. 3. Analysis and design of flight vehicle structures: E. F. Bruhn.
AE341	AEROSPACE PROPULSION	3-1-0-0-11	Introduction- Principle of propulsion & middot; Air-breathing and rocket propulsion · Reading assignment and home work on basic fluid mechanics, thermodynamics and compressible flows. Aero-thermodynamics of gas turbine engines · Introduction: Type of air-breathing jet engines; Performance of gas turbine engines (Thrust, efficient, range). Cycle analysis of air-breathing jet engines (ideal and actual cycles); Ramjet; Scramjet; Turbojet; Turbofan; Turboprop; Turboshaft. Jet engines (ideal and actual cycles); Ramjet; Scramjet; Turbojet; Turbofan; Turboprop; Turboshaft. Introduction to turbo-machinery; Types of turbomachinery; Conservation of angular momentum. Centrifugal compressors; Principle of operation; Stage dynamics and cascade; Efficiency and losses; Compressor characteristics; Rotating stall and surge. Axial compressors; Principle of operation; Stage dynamics · Multi staging; Radial equilibrium; Efficiency and characteristics. Axial turbines · Elementary theory; Stage dynamics; Efficiency and losses; Blade cooling; Compressor-turbine matching. Gas turbine combustors and after-burners. **Pre-requisites**: AE311
AE345	SPACECRAFT GUIDANCE NAVIGATION AND CONTROL	3-0-0-0-9	Attitude dynamics and stability of three axis stabilized, singlespin, dualspin, and multibody spacecraft with alticulated antennas, sensors, and solar arrays. Design of control of three axis stabilized spacecraft in orbit using reaction wheels, thrusters, magnets, single and double gimbaled control moment gyros Large angle three axis attitude maneuver controllers using reaction wheels and thrusters Control of spinning spacecraft in transfer orbit during delta_ v firing and in operational orbits around the Earth, and design of active nutation control Attitude stabilization of bias momentum spacecraft using magnets and thrusters Dynamics and control of dualspin spacecraft Precision pointing and tracking controllers for tracking landmarks, moving objects, and other satellites for crosslink communication Solar array controllers for tracking the Sun;

			determining the arrays orientation with sun sensors Modeling of dynamics of flexible solar arrays, its interaction with spacecraft dynamics and control systems Attitude determination with gyros, star trackers, sun sensors, and horizon sensors using algorithms such as TRIAD and QUEST (quaternion estimator); sensors error characteristics; and Kalman filtering Guidance and navigation for spacecraft rendezvous The above control techniques will be related with the control of Indian communication, remote sensing, and other special purpose satellites (Ca1tosat, Edusat, telemedicine). **Course Reference**: 1. Hughes, P.C., Spacecraft Attitude Dynamics, John Wiley, 1986; 2.Sidi, M.J., Spacecraft Dynamics and Control, Cambridge University Press, 1997 Noton, M;, 3. Spacecraft Navigation and Guidance, Springer 1998; 4.Kaplan, M.H., Modern Spacecraft Dynamics and Control, John Wiley, 1976; 5. Agrawal, B., Design of Geosynchronous Spacecraft, Prentice Hall, 1986; 6. Bryson, A.E., Control of Spacecraft and Aircraft, Princeton University Press, 1994; 7.Pocha, J.J., An Introduction to Mission Design for Geostationary Satellites, D. Reidel,1987; 8. Mara[, G., and Bousquet, M., Satellite Communications Systems, Fourth Edition, John Wiley, 2006; 9.Wie, B., Space Vehicle Dynamics and Control, AIAA Education Series, 1998.
AE351A	EXPERIMENTS IN AEROSPACE ENGINEERING -II	0-0-4-1-5	Dimensional analysis, Wind tunnels, Basic Experiments with different sensors, Material characterization, Flow Visualization. About 12 experiments will be conducted in the course. The breakup of the experiments will be as follows: Aerospace Structures: 4- Low Speed Aerodynamics: 4 -Aerospace Propulsion: 2- High speed Aerodynamics: 2-List of Experiments: Aerospace Structures:1. Bending of beams; 2. Shear centre estimation;3. Estimation of Principal Axes; 4. Torsion; 5. UTM (static tests) Low Speed Aerodynamics:1. Laser light flow visualization; 2. Smoke flow visualization; 3. Hot wire anemometry (calibration + test); 4. Force balance calibration; 5. Calibration of low speed tunnel6. Flow past airfoil/circular cylinder Cp distribution. Aerospace Propulsion:1. Calibration and use of pressure sensors; 2. Calibration and use of thermocouples High Speed Aerodynamics:1. Schlieren + shadowgraphy; 2. Estimation of Mach number from static pressure measurement in supersonic tunnel. **Pre-requisites**: AE251A **Course Reference**: 1. Measurement Systems Application and Design, E. O. Doebelin; 2. Data Reduction and Error Analysis for Physical

			Sciences, P. R. Bevington and D. K. Robinson; 3. Experimental Stress Analysis, James W. Dally, William F. Riley; 4. Mechanical Behavior of Materials, Norman E. Dowling
AE351	EXPERIMENTS IN AEROSPACE ENGINEERING -II	0-0-3-0-3	List of Experiments: 1. Flow visualization in the smoke tunnel ,Hele-Show Bow and flow over delta wing. 2. Pressure distribution measurement over airfoil (static and dynamic stall) 3. Hot-wire moment-calibration nel velocity and frequency 4. Experimentally of wave propagation in a shock tube & Experiments in hypersonic flow 5. Calibration of pressure sensor and its application in flow measurements 6. Experimental investigation on pre mixed LPG-Air flume. 7. Calibration of supersonic wind tunnel. 8. Supersonic flow visualization 9. Load cell fabrication and testing (Demonstration) 10. Uniaxial tensile test to determine elastic constants. 11. Torsion test to determine elastic constants. 12. Beam bending test to verify Euler-Bernoulli beam theory. **Pre-requisites**: AE252M **Course Reference**: 1. Measurement Systems Application and Design, E. O. Doebelin; 2. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington and D. K. Robinson; 3. Experimental Stress Analysis, James W. Dally, William F. Riley; 4. Mechanical Behavior of Materials, Norman E. Dowling
AE371	UG PROJECT I (UGP-I)	----	(Optional/Extra Credits) To learn about a topic through independent study under the guidance of a faculty member from the department.
AE401A	TECHNICAL COMMUNICATION	0-0-2-2-2	Selection of topic of research or review; development of presentation material; preparation of technical report; technical presentations.
AE421M	EXPERIMENTS IN FLIGHT MECHANICS	1-0-2-0-3	Introduction to fliaht testing and instrumentation 1. Techniques and data reduction methods, Error analysis 2. Calibration of flight and special flight test instruments: Evaluation of cruise and climb performance of a small airolane. Determination of static and maneuver stability and control characteristics. Observations of airplane dynamic modes and stall characteristics: Introduction to

			flight testing and instrumentation. Techniques and data reduction methods, Error analysis. Calibration of flight and special flight test instruments. Evaluation of cruise and climb performance of a small airplane. Determination of static and maneuver stability and control characteristics. Observations of airplane dynamic modes and stall characteristics. **Pre-requisites**: AE321
AE441A	ROCKET PROPULSION	3-0-0-0-5	Rocket propulsion & ndash; Introduction, Single and multi-stage rockets. Performance of chemical rockets- Principles of combustion, Estimation of adiabatic flame temperature, Thrust coefficient, Characteristic velocity, Types of nozzles, efficiencies, cooling, heat transfer. Non-chemical rockets.
AE451A	EXPERIMENTS IN AEROSPACE ENGINEERING III	0-0-3-2-5	List of Experiments: Low Speed Aerodynamics Lab:1. Turbulence measurement ;2.0 Boundary Layer. measurement3. Aerodynamic characterization of a model aircraf t High Speed Aerodynamics Lab:1. Characterization of supersonic jets; 2. Forces and moments on a projectile at supersonic speeds Structures Lab:I. Experiments in photoelasticity; 2. Experiments in vibration; 3. Dynamic characterization of elastomeric materials; 4. Inertia measurement Propulsion Lab:I. Characterization of intake; 2. Experiments in compressor/turbine cascades; 3. Performance analysis of 2stage axial fan; 4. Performance of gas turbine engine; 5. Experiments in continuous combustion unit. **Pre-requisites**: AE351A **Course Reference**: 1. Measurement Systems Application and Design, E. 0. Doebelin; 2. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington and D. K. Robinson; 3. Experimental Stress Analysis, James W. Dally, William F. Riley; 4. Mechanical Behavior of Materials, Norman E. Dowling
AE451	EXPERIMENTS IN AEROSPACE ENGINEERING III	0-0-3-0-3	List of Experiments: 1. Experiments using PIV technique. 2. Force measurement on a generic aircraft model using six-component force balance. 3. Hot wire measurements-turbulence measurements. 4. Mach distribution inside a Jet using, visualization of Shock-cell structure & measurement of sound pressure levels emitting from a round free jet. 5. Characterization of intake. 6. Experiments in compressor/ turbine cascades

			7. Performance analysis of 2 stage axial fan. 8. Performance of gas turbine engine. 9. Experiments in continuous combustion unit. 10. Fabrication of laminated composites (Demonstration). 11. Characterizing impact induced failure in beam/plate specimens. 12. Characterizing vibration in beam/plate specimens. 13. Full field stress analysis by optical method. **Pre-requisites**: AE351 **Course Reference**: 1. Measurement Systems Application and Design, E. 0. Doebelin; 2. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington and D. K. Robinson; 3. Experimental Stress Analysis, James W. Dally, William F. Riley; 4. Mechanical Behavior of Materials, Norman E. Dowling.
AE461	AIRCRAFT DESIGN - I	1-0-2-2-7	Conceptual design based on preliminary mission requirements Survey of existing vehicular configurations (in similar category); lofting (preliminary layout sketches); preliminary weight estimation Selection of wing loading; thrust loading; wing section and plan form Fuselage layout and weight balance. Estimation of aerodynamic characteristics and performance evaluation Design of tail areas and control surfaces Estimation of span wise load distributions on wing and tail TOTAL LABORATORY OF THE COURSE Conceptual design based on preliminary mission requirements; survey of existing vehicular configurations (in similar category); lofting (preliminary layout sketches); preliminary weight estimation; selection of wing loading; thrust loading; wing section and plan form; fuselage layout and weight balance; estimation of aerodynamic characteristics and performance evaluation; design of tail areas and control surfaces; estimation of span wise load distributions on wing and tail. **Pre-requisites**: None **Course Reference**: Aircraft Design: A Conceptual Approach, D. Raymer (4th Ed.), AIAA Press, 2006.
AE462	AIRCRAFT DESIGN - II	1-0-1-0-4	Concepts of structural design; Vn diagram; airworthiness requirements Stress resultants for swept and unswept wings; application of modified beam theory Methods for wing stress analysis; yielding based design Buckling (of columns, panels and stiffened panels) based design of thin structures Rib spacing; sizing and preliminary layout of wing; margin of safety; advanced analysis

			(using FEM based commercial/open source software) for full wing. Total Laboratory component of the course: Topic Concepts of structural design; Vn diagram; airworthiness requirements; stress resultants for swept and unswept wings; application of modified beam theory; methods for wing stress analysis; yielding based design; buckling (of columns, panels and stiffened panels) based design of thin structures; rib spacing; sizing and preliminary layout of wing; margin of safety; advanced analysis (using FEM based commercial/opensources oftware) for full wing. **Pre-requisites**: None **Course Reference**: 1. Analysis and design of Flight Vehicle Structures: E.F. Bruhn; 2. Airframe Structural Design: M. Niu; 3. Aircraft Design: A Conceptual Approach, D. Raymer (4th Edition), AIAA Press,2006.
AE463	AEROMODELLING DESIGN & FABRICATION	0-0-3-0-3	Design and fabrication of aero models/components; Balsa, Styrofoam, wood, parchment, composites-based model making; model upgradation; design, fabrication and testing of components; use of flight simulator, RC devices. **Pre-requisites**: None **Course Reference**: 1. Introduction to Flight: J.D. Anderson, Jr. McGrawHill International Editions. *Handouts. *Internet resources.
AE471	UG PROJECT II (UGP- II)	0-0-0-0-9	Registration for project with the selection of topic & getting started on the design, fabrication work, algorithm etc.
AE472	UG PROJECT III (UGP- III)	0-0-0-0-9	Continuation of the project work initiated as a part of UGP-II and completion.
AE473	UG PROJECT IV (UGP-IV)	----	(Optional/Extra Credits) May be taken in the summer after 8th semester to continue the project work of UGP-III.
AE481	BOUNDARY LAYER THEORY	3-0-0-0-9	Conclusions from small BL thickness, BL eqns, exact & similar solns: Blasius, Howarth & Merk. Methods: continuation & integral conditions, Polhausen, Walz, Weighardt. Axisymm BL. Mangler transformation, elementary 3D BL., Transition, turb BL. Walz integral method. BL control.
AE601	INTRO TO AEROSPACE ENGG.	3-0-0-0-4	History of aviation. History of spaceflight. Earths atmosphere and gravitational field. Anatomy of Flight vehicles. Bluff bodies v/s streamlined body, airfoil. Lift generation, significance of L/D ratio. Aerodynamic forces. Propulsion. Spacecrafts. Aircraft performance. Aerospace materials. Structural layout. Flight envelope and Vn diagrams. Instruments and navigational aids. Exposure to flight testing.
AE601A	INTRO TO AEROSPACE	3-0-0-0-9	History of aviation. History of spaceflight. Earths

	ENGG.		atmosphere and gravitational field. Anatomy of Flight vehicles. Bluff bodies v/s streamlined body, airfoil. Lift generation, significance of L/D ratio. Aerodynamic forces. Propulsion. Spacecrafts. Aircraft performance. Aerospace materials. Structural layout. Flight envelope and Vn diagrams. Instruments and navigational aids. Exposure to flight testing.
AE602	MATHEMATICS FOR AEROSPACE ENGG.	3-0-0-0-4	Matrices, determinants, vector spaces, linear transformation, eigen systems, linear equations, introduction to ordinary differential equations, homogeneous linear equations of second order, nonhomogeneous linear equations of second order, free and forced oscillation problems, problems with variable coefficients, systems of equations, Fourier series, Fourier transform, Laplace transform, introduction to differencing methods; basic concepts of partial differential equations, classification of second order equations, wave propagation in one dimension, parabolic equations, higher dimensional problems, Laplace equation, series solutions, transform methods, elements of complex variables.
AE602A	MATHEMATICS FOR AEROSPACE ENGG.	3-0-0-0-9	differential equations, homogeneous linear equations of second order, nonhomogeneous linear equations of second order, free and forced oscillation problems, problems with variable coefficients, systems of equations, Fourier series, Fourier transform, Laplace transform, introduction to differencing methods; basic concepts of partial differential equations, classification of second order equations, wave propagation in one dimension parabolic equations, higher dimensional problems, Laplace equation, series solutions, transform methods, elements of complex variables.
AE603	INTRODUCTION TO SCIENTIFIC COMPUTING	2-0-1-0-4	Basics of Computing & Discretization, Errors: Different types of error, Interpolation and extrapolation, Root finding: Polynomials; Newton Raphson Method, Secant Method, ODE and their computations, Stiff ODEs & parasitic error, Solution of IVP (ODE), Linear Algebra & BVP(ODE), Solution of Linear System, Finding eigenvalue/eigenvector **Course Reference**: 1. Computational Fluid Dynamics: Charles Hirsch, Wiley, Chichester, U.K. (1990); 2. Computational Fluid Dynamics and heat transfer: J.C. Tannehill, D.A. Anderson and R.H. Fletcher, Taylor and Francis (1997); 3. Numerical Recipes in Fortran 77, W.H. Press, S. Teukolsky, W, Vetterling and B. Flannery, Cambridge Univ. Press (1992); 4. Foundation of CFD: Tapan K. Sengupta, University Press Hyderabad, India (2009).

AE603A	INTRODUCTION TO SCIENTIFIC COMPUTING	2-0-1-0-7	Basics of Computing & Discretization, Errors: Different types of error, Interpolation and extrapolation, Root finding: Polynomials; Newton Raphson Method, Secant Method, ODE and their computations, Stiff ODEs and parasitic error, Solution of IVP (ODE), Linear Algebra & BVP(ODE), Solution of Linear System, Finding eigenvalue/eigenvector. **Course Reference**: 1. Computational Fluid Dynamics: Charles Hirsch, Wiley, Chichester, U.K. (1990); 2. Computational Fluid Dynamics and heat transfer: J.C. Tannehill, D.A. Anderson and R.H. Fletcher, Taylor and Francis (1997); 3. Numerical Recipes in Fortran 77, W.H. Press, S. Teukolsky, W, Vetterling and B. Flannery, Cambridge Univ. Press (1992); 4. Foundation of CFD: Tapan K. Sengupta, University Press Hyderabad, India (2009).
AE604	COMPUTATIONAL FLUID MECHANICS	3-0-1-0-5	Basics of Governing Equations, Spacetime discretization for PDE, Classification of PDE, Grid Generation, Waves and disturbances in fluid flow, Spacetime scales in fluid flow, Classical methods for solving parabolic PDEs, Methods for solving elliptic PDEs, High accuracy methods, Time Discretization, Error analysis: DNS, LES, Solution of Navier Stokes equations. **Course Reference**: 1. Computational Fluid Dynamics: C. Hirsch, Wiley (1998); 2. Computational Fluid Flow and Heat Transfer, Tannehill, Anderson, Pletcher; 3. High Accuracy Computing Method: Fluid flow and wave phenomena: Tapan K. Sengupta, Cambridge University Press (2013); 4. Foundation of CFD: Tapan K Sengupta, Universities Press, Hyderabad, India (2004)
AE604A	COMPUTATIONAL FLUID MECHANICS	3-0-0-0-9	Basics of Governing Equations, Spacetime discretization for PDE, Classification of PDE, Grid Generation, Waves and disturbances in fluid flow, Spacetime scales in fluid flow, Classical methods for solving parabolic PDEs, Methods for solving elliptic PDEs, High accuracy methods, Time Discretization, Error analysis: DNS, LES, Solution of Navier Stokes equations. **Course Reference**: 1. Computational Fluid Dynamics: C. Hirsch, Wiley (1998);2. Computational Fluid Flow and Heat Transfer, Tannehill, Anderson, Pletcher; 3. High Accuracy Computing Method: Fluid flow and wave phenomena: Tapan K. Sengupta, Cambridge University Press (2013); 4. Foundation of CFD: Tapan K Sengupta, Universities Press, Hyderabad, India (2004)
AE605	ADVANCED COMPUTATIONAL FLUID	3-0-1-0-5	Issues of spacetime Resolution, Computing time averaged unsteady problem, Defference type of

	MECHANICS		high Modeling RANS, URANS, LES, DES, DNS, Generalized transformation: Orthogonal/ Nonorthogonal grid, Chimera Technique, Basis of FDM, FVM, EEM, FDM and FVM: High accuracy methods. **Course Reference**: 1. Computational Fluid Dynamics: Charles Hirsch, Wiley, Chichester, U.K. (1990); 2. Computational Fluid Dynamics and heat transfer: J.C. Tannehill, D.A. Anderson and R.H. Fletcher, Taylor and Francis (1997); 3. Foundation of CFD: Tapan K. Sengupta, University Press Hyderabad, India (2009).
AE605A	ADVANCED COMPUTATIONAL FLUID MECHANICS	3-0-0-0-9	Issues of space time Resolution, Computing time averaged unsteady problem, Defference type of high Modeling RANS, URANS, LES, DES, DNS, Generalized transformation: Orthogonal/Nonorthogonal grid, Chimera Technique, Basis of FDM, FVM, EEM, FDM and FVM: High accuracy methods. **Course Reference**: 1. Computational Fluid Dynamics: Charles Hirsch, Wiley, Chichester, U.K. (1990); 2. Computational Fluid Dynamics and heat transfer: J.C. Tannehill, D.A. Anderson and R.H. Fletcher, Taylor and Francis (1997); 3. Foundation of CFD: Tapan K. Sengupta, University Press Hyderabad, India (2009).
AE606A	UNSTEADY GAS DYNAMICS		To be procured
AE608	HEAT TRANSFER IN AEROSPACE APPLICATIONS		To be procured
AE608A	HEAT TRANSFER IN AEROSPACE APPLICATIONS		To be procured
AE610	AERODYNAMICS-I	3-0-0-0-4	Basic fluid mechanics Navier stokes equation, vorticity kinematics, Basic potential flows viscous flows including boundary layer theory, turbulence(introduction)
AE610A	AERODYNAMICS-I	3-0-0-0-9	Basic fluid mechanics Navier stokes equation, vorticity kinematics, Basic potential flows viscous flows including boundary layer theory, turbulence(introduction)
AE611	MEASUREMENTS IN FLUID MECHANICS	3-0-0-0-4	Introduction to measurement, Wind Tunnels and Water Tunnels, Flow visualization techniques, Measurement of Pressure and volume flow rate, Force Measurements, Temperature Measurements, Hotwire Measurements, Data Acquisition, Processing and uncertainty analysis, Static and dynamic response of measuring systems, PIV Measurements, Integral optical measurement techniques: Shadowgraph, Schlieren & Interferometers, LDV Measurements, LIF

			Measurements. Measurement of Wall Shear Stress. **Course Reference**: 1. Fluid Mechanics Measurement, by Richard J. Goldstein Springer Verlng. 1983; 2. Experimental Methods for Engineers by J.P. Holman McGrawHill 2008; 3. Measurement in Fluid Mechanics by Stavros Tavoularis. Cambridge 2005; 4. Particle Image Velocimetry: A Practical Guide by M. Raffel, C. Willert & J. Kompenhans. Springer, 1998; 5. Instrumentation, Measurements, and Experiments in Fluids, by E Rathakrishnan, CRCPress, 2007; 6. The Laser Doppler Technique, by L. E. Drain, John Wiley & Sons 1980; 7. Hotwire anemometry, by Perry A. E. Oxford University Press, 1982; 8. Particle Image Velocimetry, by Ronald J. Adrian and Jerry Westerweel Cambridge Aerospace Series, 2010.
AE611A	MEASUREMENTS IN FLUID MECHANICS	3-0-0-0-9	Introduction to measurement, Wind Tunnels and Water Tunnels, Flow visualization techniques, Measurement of Pressure and volume flow rate, Force Measurements, Temperature Measurements, Hotwire Measurements, Data Acquisition, Processing and uncertainty analysis, Static and dynamic response of measuring systems, PIV Measurements, Integral optical measurement techniques: Shadowgraph, Schlieren & Interferometers, LDV Measurements, LIF Measurements. Measurement of Wall Shear Stress. **Course Reference**: 1. Fluid Mechanics Measurement, by Richard J. Goldstein Springer Verlng. 1983; 2. Experimental Methods for Engineers by J.P. Holman McGrawHill 2008; 3. Measurement in Fluid Mechanics by Stavros Tavoularis. Cambridge 2005; 4. Particle Image Velocimetry: A Practical Guide by M. Raffel, C. Willert & J. Kompenhans. Springer, 1998; 5. Instrumentation, Measurements, and Experiments in Fluids, by E Rathakrishnan, CRCPress, 2007; 6. The Laser Doppler Technique, by L. E. Drain, John Wiley & Sons 1980; 7. Hotwire anemometry, by Perry A. E. Oxford University Press, 1982; 8. Particle Image Velocimetry, by Ronald J. Adrian and Jerry Westerweel Cambridge Aerospace Series, 2010.
AE612	AERODYNAMICS II	3-0-0--4	Thin aerofoil theory, finite wing theory, basic thermodynamics, one and two- dimensional flows, isentropic flows, waves (shock, expansion, characteristics etc.), potential flows, perturbation equation, subsonic flows similarities Fanno and Rayleigh flows.
AE612A	AERODYNAMICS II	3-0-0-0-9	Thin aerofoil theory, finite wing theory, basic thermodynamics, one and two-dimensional flows,

			isentropic flows, waves (shock, expansion, characteristics etc.), potential flows, perturbation equation, subsonic flows similarities Fanno and Rayleigh flows.
AE614	VISCOUS FLOWS	3-0-0--4	Basic concepts of BL theory; similar flows: generalized techniques of solving BL eqns. for incompressible fluids: thermal BL. BL control. Intro. to turbulent hear flows.
AE614A	VISCOUS FLOWS	3-0-0-0-9	Basic concepts of BL theory; similar flows: generalized techniques of solving BL eqns. for incompressible fluids: thermal BL. BL control. Intro. to turbulent shear flows.
AE615	ADVANCED COMPUTATIONAL METHODS IN CFD	3-0-0--4	Main issues of space time resolution: Computing time averaged and unsteady problems. Discretization with operators. Problems in physical and transformed plane: Jacobians and flux vector splitting. Generalized transformation and grid generation techniques: Orthogonal and Chimera grids application to FIV/aero elasticity problems. Spectral tools of analysis for discrete schemes: FDM, FVM& FEM. High order and high accuracy schemes of FDMs and FVMs. Design of Dispersion Relation Preservation schemes. Aliasing error and its alleviation. High accuracy methods for DN Sand LES. SGS models for LES and their connection to higher order up winding. Computing equations with discontinuous solutions and Gibbs phenomenon. Applications to incompressible viscous and compressible flows. DNS of turbulence and acoustic problems.
AE615A	ADVANCED COMPUTATIONAL METHODS IN CFD	3-0-0-0-9	Main issues of space time resolution: Computing time averaged and unsteady problems. Discretization with operators. Problems in physical and transformed plane: Jacobians and flux vector splitting. Generalized transformation & grid generation techniques: Orthogonal & Chimera grids application to FIV/aero elasticity problems. Spectral tools of analysis for discrete schemes: FDM, FVM& FEM. High order and high accuracy schemes of FDMs and FVMs. Design of Dispersion Relation Preservation schemes. Aliasing error & its alleviation. High accuracy methods for DN Sand LES. SGS models for LES and their connection to higher order up winding. Computing equations with discontinuous solutions and Gibbs phenomenon. Applications to incompressible viscous and compressible flows. DNS of turbulence and acoustic problems.
AE617	BOUNDARY LAYER INSTABILITY AND TRANSITION	3-0-0--4	Navier Stokes eqn. and its various forms, thin shear layer approxn. Various types of flows. Instabilities in laminar flows. Relationship of instability theory with transition to turbulence. Transition prediction. Receptivity for two and three-

			dimensional problems.
AE617A	BOUNDARY LAYER INSTABILITY AND TRANSITION	3-0-0-0-9	Navier Stokes eqn. and its various forms, thin shear layer approxn. Various types of flows. Instabilities in laminar flows. Relationship of instability theory with transition to turbulence. Transition prediction. Receptivity for two and three -dimensional problems.
AE618	FINITE ELEMENT METHODS FOR FLUID DYNAMICS	3-0-0--4	Fundamental concepts; strong form, weak form, Galerkins approximation; matrix eqns, element and global point of view; numerical integration Guassian quadrature; termporal discretization generalized trapeziodal rule; compressible and incompressible flows; implementation of the methods; issues related to high performance computing.
AE618A	FINITE ELEMENT METHODS FOR FLUID DYNAMICS	3-0-0-0-9	Fundamental concepts; strong form, weak form, Galerkins approximation; matrix eqns, element and global point of view; numerical integration Guassian quadrature; termporal discretization generalized trapeziodal rule; compressible and incompressible flows; implementation of the methods; issues related to high performance computing.
AE621	TURBULENCE	3-0-0--4	Origin, examples and character of turb, Reynolds stress, energy relations, closure problem, phenomenology, eddy viscosity. Staistics. spectra, space time correlations, macro & micro scales, stat. theory of turb, locally isotropic turb, Kolmogorovs hypothesis, correlation method, spectral method, turb. diffusion. Experimental techniques.
AE621A	TURBULENCE	3-0-0-0-9	Origin, examples and character of turb, Reynolds stress, energy relations, closure problem, phenomenology, eddy viscosity. Staistics. spectra, space time correlations, macro & micro scales, stat. theory of turb, locally isotropic turb, Kolmogorovs hypothesis, correlation method, spectral method, turb. diffusion. Experimental techniques.
AE622	COMPUTATIONAL FLUID DYNAMICS	3-0-0--4	Eqns of fluid dynamics & its classifications. Boundary conditions. Stability analysis & concept of feedback. Various explicit & implicit schemes. Grid generation. Solving parabolic, elliptic PDEs by explicit, implicit, accelerated techniques. Solving advection equation. Integral representation of Navier Stokes equation; LES and DNS.
AE622A	COMPUTATIONAL FLUID DYNAMICS	3-0-0-0-9	Equations of fluid dynamics and its classifications. Boundary conditions. Stability analysis and concept of feedback. Various explicit & implicit schemes. Grid generation. Solving parabolic, elliptic PDEs by explicit, implicit, accelerated techniques. Solving advection equation. Integral representation of

			Navier Stokes equation; LES & DNS.
AE625	TRANSITION AND TURBULENCE	3-0-0--4	Elements of viscous flows and thin shear layer approximation. Different types of TSL flows. Instabilities in flows. Rayleigh Taylor, Kelvin Helmholtz mechanisms. Thin shear layer instabilities: for parallel and nonparallel flows. Temporal and spatial instabilities in boundary layers. convective/absolute, local/global instabilities of boundary layers, wakes, jets and free shear layers. Primary and secondary instabilities and relationship of instability theories to transition. Receptivity of shear layers for 2 and 3D flows. Bypass transition in different flows. Classified views of turbulent flows. Scales, spectra and closure of turbulent flows. Vorticity dynamics and other kinematic tools of turbulence. Role of stretching and dispersion in small scale turbulence. Route to turbulence: Chaos via nonlinearity, instabilities and bifurcation. Coherent structures in turbulence: Universality of transitional and turbulent flows. Study of turbulence via chaos dynamics and proper orthogonal decomposition (POD). DNS, LES and other closure schemes of turbulence **Course Reference**: 1. Drazin. P.G. & Reid W.H.: Hydrodynamic Stability 1981, (CUP); 2. Davidson. P.A.: Turbulence (2003) (OUP);3. Lmdahl. M.T. & Mollo Christcnsen: Turbulence & Random Processes in Fluid Mechanics 1992 (CUP); 4. Holmes. P., Lumley, J.L. & Bcrkooz G: Turbulence, Coherent structures. Dynamical systems and Symmetry. 1996 (CUP); 5. Sagaut. P.: Large Eddy Simulation for Incompressible Flows. 2000 (Springer); 6. Sengupta T.K.: Foundation of CFD, 2004 (Univ. Press)
AE625A	TRANSITION AND TURBULENCE	3-0-0-0-9	Elements of viscous flows and thin shear layer approximation. Different types of TSL flows. Instabilities in flows. Rayleigh Taylor, Kelvin Helmholtz mechanisms. Thin shear layer instabilities: for parallel and nonparallel flows. Temporal and spatial instabilities in boundary layers. convective/absolute, local/global instabilities of boundary layers, wakes, jets and free shear layers. Primary and secondary instabilities and relationship of instability theories to transition. Receptivity of shear layers for 2 and 3D flows. Bypass transition in different flows. Classified views of turbulent flows. Scales, spectra and closure of turbulent flows. Vorticity dynamics and other kinematic tools of turbulence. Role of stretching and dispersion in small scale turbulence. Route to turbulence: Chaos via nonlinearity, instabilities and bifurcation. Coherent structures in turbulence: Universality of transitional and turbulent flows. Study of turbulence via chaos dynamics ans

			proper orthogonal decomposition (POD). DNS, LES and other closure schemes of turbulence **Course Reference**: 1. Drazin. P.G. & Reid W.H.: Hydrodynamic Stability 1981, (CUP); 2. Davidson. P.A.: Turbulence (2003) (OUP);3. Lmdahl. M.T. & Mollo Christcnsen: Turbulence & Random Processes in Fluid Mechanics 1992 (CUP); 4. Holmes. P., Lumley, J.L. & Bcrkooz G.: Turbulence, Coherent structures. Dynamical systems and Symmetry. 1996 (CUP); 5. Sagaut. P.: Large Eddy Simulation for Incompressible Flows. 2000 (Springer); 6. Sengupta T.K.: Foundation of CFD, 2004 (Univ. Press)
AE628	CONTINUUM HYPERSONIC AERODYNAMICS	3-0-0--4	Continuum hypersonics in entry flight. Gen features, Mach no. Small disturb theory, similitude. Large diflecn similitude; wedge, cone, wing. Unified similitude. Lighthill & other piston analogies, Newton Busemann theory, thin shock layers, viscous inviscid interaction. Real gas. Frozen flow. Non equillibrium flow.
AE628A	CONTINUUM HYPERSONIC AERODYNAMICS	3-0-0-0-9	Continuum hypersonics in entry flight. Gen features, Mach no. Small disturb theory, similitude. Large diflection similitude; wedge, cone, wing. Unified similitude. Lighthill & other piston analogies, Newton Busemann theory, thin shock layers, viscous inviscid interaction. Real gas. Frozen flow. Nonequilibrium flow.
AE629	ADVANCES IN WIND ENERGY CONVERSION	3-0-0--4	Earths atmosphere & rotation, Coriolis force, geotrophic winds. Terrain, mettheories, measuring technique. Wind power site. Atmospheric BL. Aerodynamics in wind power. Sails, airscrews. Vertical & horizontal axis wind turbines. Actuator disc, momentum, and vortex theories. Control of wind turbines.
AE629A	ADVANCES IN WIND ENERGY CONVERSION	3-0-0-0-9	Earth’s atmosphere & rotation, Coriolis force, geotrophic winds. Terrain, mettheories, measuring technique. Wind power site. Atmospheric BL. Aerodynamic in wind power. Sails, airscrews. Vertical & horizontal axis wind turbines. Actuator disc, momentum, and vortex theories. Control of wind turbines.
AE630A	AUTONOMOUS UNMANNES AERIAL SYSTEMS		To be procured
AE633A	MISSILES GUIDANCE AND DYNAMICS		To be procured
AE640	AUTONOMOUS NAVIGATION	3-0-0-0-4	Course introduction, basic definition, notion, guidance, navigation, and control loops. Review to linear algebra. Coordinated frames, kinematics and dynamics, trim conditions. Linear control and autopilot design. Introduction to probability and random processes. Accelerometer, rate gyros,

			pressure sensors, magnetometers, inertial measurement units (IMUs), global positioning systems (GPS). State estimation: Kalman filter (KF), Extended Kalman filter (EKF), Unscented Kalman filter (UKF), Cubature Kalman filter (CKF), Information filters, GPS aided navigation. Path planning and path following algorithms. Controllability, observability, vision guided navigation. Cooperative control **Course Reference**: 1. D. P. Bertsekas and J. N. Tsitsiklis, Introduction to Probability, Athena Scientific, 2008; 2. S. Thrun, W. Burgard, and D. Fox, Probabilistic Robotics, MIT Press, 2005; 3. S. M. LaValle. Planning Algorithms. Cambridge University Press, Cambridge, U.K., 2006.
AE640A	AUTONOMOUS NAVIGATION	3-0-0-0-9	Course introduction, basic definition, notion, guidance, navigation, and control loops. Review to linear algebra. Coordinated frames, kinematics and dynamics, trim conditions. Linear control and autopilot design. Introduction to probability and random processes. Accelerometer, rate gyros, pressure sensors, magnetometers, inertial measurement units (IMUs), global positioning systems (GPS). State estimation: Kalman filter (KF), Extended Kalman filter (EKF), Unscented Kalman filter (UKF), Cubature Kalman filter (CKF), Information filters, GPS aided navigation. Path planning and path following algorithms. Controllability, observability, vision guided navigation. Cooperative control. **Course Reference**: 1. D. P. Bertsekas and J. N. Tsitsiklis, Introduction to Probability, Athena Scientific, 2008; 2. S. Thrun, W. Burgard, and D. Fox, Probabilistic Robotics. Cambridge University Press, Ca, MIT Press, 2005; 3. S. M. LaValle. Planning Algorithms mbridge, U.K., 2006.
AE641	SPACE DYNAMICS-I	3-0-0-0-4	Introduction, performance of single and multistage rockets, central force motion, two body problem, ballistic trajectories, trajectory transfer, rendezvous and interception, Eulers eqns, satellite attitude dynamics, stabilization through gravity gradient, spin and dual spin, effect of energy dissipation on stability.
AE641A	SPACE DYNAMICS-I	3-0-0-0-9	Introduction, performance of single and multistage rockets, central force motion, two body problem, ballistic trajectories, trajectory transfer, rendezvous and interception, Eulers eqns, satellite attitude dynamics, stabilization through gravity gradient, spin and dual spin, effect of energy dissipation on stability.
AE645	SPACECRAFT GUIDANCE NAVIGATION AND CONTROL	3-0-0--4	Attitude dynamics and stability of three axis stabilized, single spin, dual spin, and multi body spacecraft with a1ticulated antennas, sensors, and

			solar arrays. Design of control of three axis stabilized spacecraft in orbit using reaction wheels, thrusters, magnets, single and double gimbaled control moment gyros Large angle three axis attitude maneuver controllers using reaction wheels and thrusters Control of spinning spacecraft in transfer orbit during delta_ v firing and in operational orbits around the Earth, and design of active nutation control Attitude stabilization of bias momentum spacecraft using magnets and thrusters Dynamics and control of dual spin space craft Precision pointing and tracking controllers for tracking landmarks, moving objects, and other satellites for crosslink communication Solar array controllers for tracking the Sun; determining the arrays orientation with sun sensors Modeling of dynamics of flexible solar arrays, its interaction with spacecraft dynamics and control systems Attitude determination with gyros, star trackers, sun sensors, and horizon sensors using algorithms such as TRIAD and QUEST (quaternion estimator); sensors error characteristics; and Kalman filtering Guidance and navigation for spacecraft rendezvous The above control techniques will be related with the control of Indian communication, remote sensing, and other special purpose satellites (Ca1tosat, Edusat, telemedicine). **Course Reference**: 1. Hughes, P.C., Spacecraft Attitude Dynamics, John Wiley, 1986; 2. Sidi, M.J., Spacecraft Dynamics and Control, Cambridge University Press, 1997; 3. Noton, M., Spacecraft Navigation and Guidance, Springer 1998; 4. Kaplan, M.H., Modern Spacecraft Dynamics and Control, John Wiley, 1976; 5. Agrawal, B., Design of Geosynchronous Spacecraft, Prentice Hall, 1986; 6. Bryson, A.E., Control of Spacecraft and Aircraft, Princeton University Press, 1994; 7. Pocha, J.J., An Introduction to Mission Design for Geostationary Satellites, D. Reidel,1987; 8. Mara[, G., and Bousquet, M., Satellite Communications Systems, Fourth Edition, JohnWiley, 2006; 9. Wie, B., Space Vehicle Dynamics and Control, AIAA Education Series, 1998
AE645A	SPACECRAFT GUIDANCE NAVIGATION AND CONTROL	3-0-0-0-9	Course Details: Attitude dynamics and stability of three axis stabilized, single spin, dual spin, and multibody spacecraft with a1ticulated antennas, sensors, and solar arrays. Design of control of there axis stabilized spacecraft in orbit using reaction wheels, thrusters, magnets, single and double gimbaled control moment gyros Large angle three axis attitude maneuver controllers using reaction wheels and thrusters Control of spinning spacecraft in transfer orbit during delta_ v firing and in operational orbits around the Earth,

			and design of active nutation control Attitude stabilization of bias momentum spacecraft using magnets and thrusters Dynamics and control of dualspin spacecraft Precision pointing and tracking controllers for tracking landmarks, moving objects, and other satellites for crosslink communication Solar array controllers for tracking the Sun; determining the arrays orientation with sun sensors Modeling of dynamics of flexible solar arrays, its interaction with spacecraft dynamics and control systems Attitude determination with gyros, star trackers, sun sensors, and horizon sensors using algorithms such as TRIAD and QUEST (quaternion estimator); sensors error characteristics; and Kalman filtering Guidance and navigation for spacecraft rendezvous The above control techniques will be related with the control of Indian communication, remote sensing, and other special purpose satellites (Ca1tosat, Edusat, telemedicine). **Course Reference** : 1. Hughes, P.C., Spacecraft Attitude Dynamics, John Wiley, 1986; 2. Sidi, M.J., Spacecraft Dynamics and Control, Cambridge University Press, 1997; 3. Noton, M., Spacecraft Navigation and Guidance, Springer 1998; 4. Kaplan, M.H., Modern Spacecraft Dynamics and Control, John Wiley, 1976; 5. Agrawal, B., Design of Geosynchronous Spacecraft, Prentice Hall, 1986; 6. Bryson, A.E., Control of Spacecraft and Aircraft, Princeton University Press, 1994; 7. Pocha, J.J., An Introduction to Mission Design for Geostationary Satellites, D. Reidel,1987; 8. Mara[, G., and Bousquet, M., Satellite Communications Systems, Fourth Edition, JohnWiley, 2006; 9. Wie, B., Space Vehicle Dynamics and Control, AIAA Education Series, 1998
AE647	FLIGHT DYNAMICS	3-0-0-0-4	Fundamentals of vectors. Transformation of coordinates. Particle kinematics. Rigid body kinematics. Force equations in a moving frame. Moment equations in a moving frame. Atmospheric flight Dynamics. Space flight dynamics. Gyrodynamics.
AE647A	FLIGHT DYNAMICS	3-0-0-0-9	Fundamentals of vectors. Transformation of coordinates. Particle kinematics. Rigid body kinematics. Force equations in a moving frame. Moment equations in a moving frame. Atmospheric flight Dynamics. Space flight dynamics. Gyrodynamics.
AE648	FLIGHT STABILITY AND CONTROL	3-0-0-0-4	Linearized equations of aircraft motion for small perturbations in stability axes. Stability analysis of linearized equations of motion. Airplane longitudinal motion. Airplane lateral motion. Airplane handling qualities. Missile and launch vehicle stability and control. Qualitative discussion

			of automatic flight control systems
AE648A	FLIGHT STABILITY AND CONTROL	3-0-0-0-9	Linearized equations of aircraft motion for small perturbations in stability axes. Stability analysis of linearized equations of motion. Airplane longitudinal motion. Airplane lateral motion. Airplane handling qualities. Missile and launch vehicle stability and control. Qualitative discussion of automatic flight control systems
AE649	AUTOMATIC CONTROL OF AIRCRAFT ROCKETS AND SPACECRAFT	3-0-0--4	1. Introduction to Automatic Control Systems.(Plant Models, Control Algorithms, Sensors, Actuators, Control Systems Classification.); 2. Introduction to Rigid Body Dynamics and Flight Models; 3. Linear Systems (Analog and Digital Systems, Transfer Function and Frequency Response, State Space Representations, Stability, Performance, and Robustness); 4. Single Variable Linear Control(Proportional, Integral, Derivative Control, Rate and Rate Integrating Gyros, Single Input Regulation by Pole Placement, Linear Observers, SISO Compensation and Tracking, Single Axis Attitude Control, Aircraft Heading Autopilot, Aircraft Speed Autopilot, Roll Autopilots for Aircraft, Rockets, and Entry Vehicles, Planar Tracking Systems for Rockets and Entry Vehicles, Pitch Stabilization of Gravity Gradient Spacecraft, Spacecraft Single Axis Maneuvers); 5. Multivariable Linear Optimal Control(Linear Optimal Control, Linear Quadratic Regulator, Kalman Filter, Optimal Compensation and Multivariable Tracking, Longitudinal Autopilots for Aircraft, Bank to turn Missiles, and Entry Vehicles, Lateral Directional Autopilots for Atmospheric Flight Vehicles, Attitude Stabilization of Spacecraft, Reaction Wheel Control Systems, Magnetic Torquer/Reaction Wheel Control Systems, Control Moment Gyroscopes ,Variable Speed Control Moment Gyroscopes, Thrust Vectoring Attitude Control of Rockets); 6. Terminal Time Weighted Linear Optimal Control (Time Varying Tracking Systems, Guidance and Control of Rockets and Entry Vehicles, Automated Orbital Rendezvous); 7. Digital Implementation of Linear Flight Control Systems. **Course Reference**: 1. Tewari, A, Modern Control Design with MATLAB and Simulink, John Wiley & Sons, Chichester, 2002; 2. Tewari, A, Atmospheric and Space Flight Dynamics, Springer (Birkhauser), Boston, 2006.
AE649A	AUTOMATIC CONTROL OF AIRCRAFT ROCKETS AND SPACECRAFT	3-0-0-0-9	1. Introduction to Automatic Control Systems.(Plant Models, Control Algorithms, Sensors, Actuators, Control Systems Classification.); 2. Introduction to Rigid Body Dynamics and Flight Models; 3. Linear Systems(Analog and Digital Systems, Transfer Function and Frequency Response, State Space

			Representations, Stability, Performance, and Robustness); 4. Single Variable Linear Control(Proportional, Integral, Derivative Control, Rate and Rate Integrating Gyros, Single Input Regulation by Pole Placement, Linear Observers, SISO Compensation and Tracking, Single Axis Attitude Control, Aircraft Heading Autopilot, Aircraft Speed Autopilot, Roll Autopilots for Aircraft, Rockets, and Entry Vehicles, Planar Tracking Systems for Rockets and Entry Vehicles, Pitch Stabilization of Gravity Gradient Spacecraft, Spacecraft Single Axis Maneuvers); 5. Multivariable Linear Optimal Control(Linear Optimal Control, Linear Quadratic Regulator, Kalman Filter, Optimal Compensation and Multivariable Tracking, Longitudinal Autopilots for Aircraft, Banktoturn Missiles, and Entry Vehicles, Lateral Directional Autopilots for Atmospheric Flight Vehicles, Attitude Stabilization of Spacecraft, Reaction Wheel Control Systems, Magnetic Torquer/Reaction Wheel Control Systems, Control Moment Gyroscopes ,Variable Speed Control Moment Gyroscopes, Thrust Vectoring Attitude Control of Rockets); 6. Terminal Time Weighted Linear Optimal Control (Time Varying Tracking Systems, Guidance and Control of Rockets and Entry Vehicles, Automated Orbital Rendezvous); 7. Digital Implementation of Linear Flight Control Systems. **Course Reference**: 1. Tewari, A, Modern Control Design with MATLAB and Simulink, John Wiley & Sons, Chichester, 2002; 2. Tewari, A, Atmospheric and Space Flight Dynamics, Springer (Birkhauser), Boston, 2006.
AE650	FUNDAMENTAL OF AEROSPACE PROPULSION - I	3-0-0-0-4	Introduction to propulsion, conservation equations, basic thermodynamics, dynamics and thermodynamics of 1 D flows, 1 D isentropic flows, normal and oblique shocks, compressible flows, Rayleigh flow, Fanno flow, elements of combustion, thermochemistry, adiabatic flame temperature, premixed flames, diffusion flames, rocket propulsion, thrust equation, solid rockets, liquid rockets, hybrid rockets, gas turbine cycles.
AE650A	FUNDAMENTAL OF AEROSPACE PROPULSION - I	3-0-0-0-9	Introduction to propulsion, conservation equations, basic thermodynamics, dynamics and thermodynamics of 1 D flows, 1 D isentropic flows, normal and oblique shocks, compressible flows, Rayleigh flow, Fanno flow, elements of combustion, thermochemistry, adiabatic flame temperature, premixed flames, diffusion flames, rocket propulsion, thrust equation, solid rockets, liquid rockets, hybrid rockets, gas turbine cycles.
AE652	AIRCRAFT PROPULSION	3-0-0-0-4	Gas turbine engines, performance analysis, subsonic and supersonic diffusers, centrifugal and axial compressors, stage dynamics, compressor

			stall, axial turbines, compressor turbine matching, gas turbine combustors and after burners, nozzles, ramjets, scramjets.
AE652A	AIRCRAFT PROPULSION	3-0-0-0-9	Gas turbine engines, performance analysis, subsonic and supersonic diffusers, centrifugal and axial compressors, stage dynamics, compressor stall, axial turbines, compressor turbine matching, gas turbine combustors and after burners, nozzles, ramjets, scramjets.
AE653	THERMAL TURBOMACHINERY	3-0-0--4	Axial compressors, stage dynamics, degree of reaction, pressure rise limitations, secondary flows, performance: design and off design, starting problems, centrifugal compressors; inlet flow, slip, sweep, diffuser design. Axial turbines: stage dynamics, three dimensional flows, loss estimation, blade cooling.
AE653A	THERMAL TURBOMACHINERY	3-0-0-0-9	Axial compressors, stage dynamics, degree of reaction, pressure rise limitations, secondary flows, performance: design and off design, starting problems, centrifugal compressors; inlet flow, slip, sweep, diffuser design. Axial turbines: stage dynamics, three dimensional flows, loss estimation, blade cooling.
AE654	COMBUSTION PROBLEMS IN ROCKET PROPULSION		To be procured
AE654	COMBUSTION PROBLEMS IN ROCKET PROPULSION		To be procured
AE654A	COMBUSTION PROBLEMS IN ROCKET PROPULSION		To be procured
AE657	AIRBREATHING MISSILE PROPULSION	3-0-0-0-4	Introduction and overview. Comparison of ramjet propulsion with other types of missile propulsion. Types of ram propulsion. Specific impulse. Propellants. Ramjet air induction system for missile application. Ducted rocket performance with single and multiple inlet systems. Engine and airframe integration for ramjet and ram rocket powered missiles. Ramjet with solid fuel. Solid propellant ram rockets. Supersonic combustion ramjet. Inlet, combustor and nozzle analysis.
AE657A	AIRBREATHING MISSILE PROPULSION	3-0-0-0-9	Introduction and overview. Comparison of ramjet propulsion with other types of missile propulsion. Types of ram propulsion. Specific impulse. Propellants. Ramjet air induction system for missile application. Ducted rocket performance with single and multiple inlet systems. Engine and airframe integration for ramjet and ram rocket powered missiles. Ramjet with solid fuel. Solid propellant ramrockets. Supersonic combustion ramjet. Inlet, combustor and nozzle analysis.
AE658	NUMERICAL MODELING OF CHEMICALLY REACTING FLOWS	3-1-0-0-5	Introduction, Governing equations, Modeling of laminar premixed and nonpremixed flames, Modeling of turbulent premixed and nonpremixed

			flames, Advanced modeling aspect. Introduction (3 hrs) Motivation and aim Governing equations for reacting flows Modeling of Laminar Premixed flames (7 hrs) Introduction Conservation equations and numerical solutions Steady 1 D flames Theoretical solution methods Calculation of flame speed, thickness and stretch Modeling of Laminar non premixed flames (6 hrs) Non premixed flame configuration Theoretical tools Flame structure for irreversible infinite fast chemistry and solutions Theory of other flame structures Modeling of turbulent premixed flames (10 hrs) Phenomenological description Premixed turbulent combustion regime RANS modeling LES modeling DNS modelling Modeling of turbulent non premixed flames (10 hrs) Phenomenological description Turbulent non premixed combustion regime RANS modeling LES modeling DNS modelling Advanced modeling aspect (4 hrs) Combustion in two phase flows Boundary conditions Flame/wall interactions Flame/acoustics interaction. **Course Reference**: 1. Peters, N., Turbulent Combustion, Cambridge University Press, 2000; 2. Warnatz, J., Mass, U., Dibble, R.W., Combustion: Physical and Chemical Fundamentals, Modeling and Simulation, Experiments, Pollutant Formation, Springer, 4111 Edition, 2006; 3. Kuo, Kenneth, Principles of Combustion, John Wiley and Sons, Inc, Edition,2005; 4. Chung, T. J., Computational Fluid Dynamics, Cambridge University Press, 2002; 5. Law, C. K., Combustion Physics, Cambridge University Press, 2006.
AE658A	NUMERICAL MODELING OF CHEMICALLY REACTING FLOWS	3-0-0-0-9	Introduction, Governing equations, Modeling of laminar premixed and nonpremixed flames, Modeling of turbulent premixed and nonpremixed flames, Advanced modeling aspect. Introduction (3 hrs) Motivation and aim Governing equations for reacting flows Modeling of Laminar Premixed flames (7 hrs) Introduction Conservation equations and numerical solutions Steady 1 D flames Theoretical solution methods Calculation of flame speed, thickness and stretch Modeling of Laminar non premixed flames (6 hrs) Non premixed flame configuration Theoretical tools Flame structure for irreversible infinite fast chemistry and solutions Theory of other flame structures Modeling of turbulent premixed flames (10 hrs) Phenomenological description Premixed turbulent combustion regime RANS modeling LES modeling DNS modelling Modeling of turbulent non premixed flames (10 hrs) Phenomenological description Turbulent nonpremixed combustion regime RANS modeling LES modeling DNS modelling Advanced modeling aspect (4 hrs) Combustion in two phase

			flows Boundary conditions Flame/wall interactions Flame/acoustics interaction. **Course Reference**: 1. Peters, N., Turbulent Combustion, Cambridge University Press, 2000; 2. Warnatz, J., Mass, U., Dibble, R.W., Combustion: Physical and Chemical Fundamentals, Modeling and Simulation, Experiments, Pollutant Formation, Springer, 4111 Edition, 2006; 3. Kuo, Kenneth, Principles of Combustion, John Wiley and Sons, Inc, 2nd Edition,2005; 4. Chung, T. J., Computational Fluid Dynamics, Cambridge University Press, 2002; 5. Law, C. K., Combustion Physics, Cambridge University Press, 2006.
AE660	PRELIMINARY DESIGN OF HELICOPTER	2-0-3-0-4	1. Introduction to: design process, design goals, types of rotorcraft (2 Lec.); 2. Understanding mission requirements, use of Analytical Hierarchy Process in configuration selection (2 Lec.) (1 Lab.); 3. Concept selection methodology: collection of statistical data, Pughs method, key performance indices, life cycle costs (2 Lec.) (1 Lab.); 4. Generating design alternatives: preliminary sizing using Tischenkos Method, preliminary weight estimation, rotor propulsive efficiency, Lift/Drag ratio, engine performance, main rotor blade weight estimation, rotor hub and swash plate (3 Lec.) (1 Lab.); 5. Performance: power required for hover, climb, level flight, maximum level speed, speed forbest endurance, best range, autorotative performance (3 Lec.) (2 Lab.); 6. Main rotor configuration design: rotor structural and aerodynamic design (number of blades, rotor diameter, blade chord, rotor inertia, blade twist, blade taper, blade tip shape, sweep, root cutout, tip speed, hinge offset, air foils, frequency placement, material selection) (5 Lec.) (3 Lab.); 7. Rotor component design: hub design, control power, helicopter stability considerations (3 Lec.) (2 Lab.); 8. Tail rotor/ antitorque systems: diameter, tip speed, disk area, number of blades, pusher vstractor (2 Lec.) (1 Lab.); 9. Fuselage and landing gear design (4 Lec.) (2 Lab.); 10. Vibration sources, vibration reduction (2 Lec.) (1 Lab.); 11. Life cycle cost estimation: environmental cost, purchase cost. operating cost (2 Lec.) (1 Lab.); 12. Leishman, J. G., Principles of Helicopter Aerodynamics, Cambridge Aerospace Series,2000. **Course Reference**: 1. Prouty, R. W., Helicopter Performance, Stability, and Control, Krieger Publishing Company, Florida, 1986; 2. Stepniewski, W. Z., and Keys, C. N., Rotary Wing Aerodynamics, Dover, New York,1984; 3. Venkatesan, CLecture Notes on Helicopter Technology; Department of Aerospace Engineering, IiT Kanpur, 2000; 4. Filippone, A.,

			Flight Performance of Fixed and Rotary Wing Aircraft, AIAA Education Series, 2006.
AE660A	PRELIMINARY DESIGN OF HELICOPTER	2-0-3-0-9	1. Introduction to: design process, design goals, types of rotorcraft (2 Lec.); 2. Understanding mission requirements, use of Analytical Hierarchy Process in configuration selection (2 Lec.) (1 Lab.); 3. Concept selection methodology: collection of statistical data, Pugh's method, key performance indices, life cycle costs (2 Lec.) (1 Lab.); 4. Generating design alternatives: preliminary sizing using Tischenko's Method, preliminary weight estimation, rotor propulsive efficiency, Lift/Drag ratio, engine performance, main ro tor blade weight estimation, rotor hub and swash plate (3 Lec.) (1 Lab.); 5. Performance: power required for hover, climb, level flight, maximum level speed, speed forbest endurance, best range, autorotative performance (3 Lec.) (2 Lab.); 6. Main rotor configuration design: rotor structural and aerodynamic design (number of blades, rotor diameter, blade chord, rotor inertia, blade twist, blade taper, blade tip shape, sweep, root cutout, tip speed, hinge offset, air foils, frequency placement, material selection) (5 Lec.) (3 Lab.); 7. Rotor component design: hub design, control power, helicopter stability considerations (3 Lec.) (2 Lab.); 8. Tail rotor/ antitorque systems: diameter, tip speed, disk area, number of blades, pusher vstractor (2 Lec.) (1 Lab.); 9. Fuselage and landing gear design (4 Lec.) (2 Lab.); 10. Vibration sources, vibration reduction (2 Lec.) (1 Lab.); 11. Life cycle cost estimation: environmental cost, purchase cost. operating cost (2 Lec.) (1 Lab.) **Course Reference :** 1. Leishman, J. G., Principles of Helicopter Aerodynamics, Cambridge Aerospace Series,2000; 2. Prouty, R. W., Helicopter Performance, Stability, and Control, Krieger Publishing Company, Florida, 1986; 3. Stepniewski, W. Z., and Keys, C. N., Rotary Wing Aerodynamics, Dover, New York,1984; 4. Venkatesan, C.,;Lecture Notes on Helicopter Technology; Department of Aerospace Engineering, IiT Kanpur, 2000; 5. Filippone, A., Flight Performance of Fixed and Rotary Wing Aircraft, AIAA Education Series, 2006.
AE662	ROCKET ENGINE DESIGN	2-0-3--4	Introduction to rocket propulsion, Types of rocket engines, Elements of combustion, Chemical propellants and their burning characteristics, Aero thermodynamic design analysis of solid propellant rocket engine, Liquid propellant rocket engine, Design ofthrust chamber, Design of cooling system; Design of rocket Nozzle. **Course Reference**: 1. Sutton G.P and Ross D. M.; Rocket Propulsion Elements;, John Wiley &

			Sons,New York, 1985; 2. Barrere M, Jaumotte A and Vandenkerckhove 1; Rocket Propulsion, Elsevier Publishing Company, New York, 1960; 3. Hill, P.G. and Peterson C.R.,; Mechanics and Thennodynamics of Propulsion Addison Wesiey Publishing Company, 1965; 4. Oater G.C, ; Aero-thermodynamics of Gas Turbine and Rocket Propulsion, 3rdEdition, AIAA education Seria, 1998; 5. Mishra D.P.; Fundamental of Combustion Prentice Hall oflndia, New Delhi; 6. Kuo K. K. and Summerfield,; Fundamentals Of Solid Propellant, combustion;progress in Astronautics and Aeronautics, Vol. 90, AIAA New York.
AE662A	ROCKET ENGINE DESIGN	2-0-3-0-9	Introduction to rocket propulsion, Types of rocket engines, Elements of combustion, Chemical propellants and their burning characteristics, Aerothermodynamic design analysis of solid propellant rocket engine, Liquid propellant rocket engine, Design ofthrust chamber, Design of cooling system; Design of rocket Nozzle.
AE663A	FUNDAMENTALS OF COMBUSTION	3-0-0-0-9	Introduction, Combustion and Thermochemistry: Motivation and objective, Property relations, Thermodynamic laws, Reactant & Product mixtures, Adiabatic flame temperature, Chemical equilibrium and equilibrium products Kinetics and Mechanism: Introduction, Global versus elementary reactions, Rates of reaction for multistep mechanisms Conservation equations: Simplified governing equations, Momentum, energy, mass conservation, Multi component diffusion, Concept of conserved scalar Laminar Premixed and Non premixed flames: Physical description, Simplified and detailed analysis, Flame speed, thickness, quenching, flammability limits, Flame stabilization, Nonremixed flames, laminar jets, Droplet Combustion, Solid fuel Combustion
AE664	APPLIED COMPRESSIBLE FLOWS		To be procured
AE664A	APPLIED COMPRESSIBLE FLOWS		To be procured
AE665	FINITE VOLUME METHODS IN HEAT MASS & MOMENTUM TRANSFER		To be procured
AE665A	FINITE VOLUME METHODS IN HEAT MASS & MOMENTUM TRANSFER		To be procured
AE666A	COMBUSTION DIAGNOSTICS		To be procured
AE667A	NANO-PARTICLE AEROSOL DYNAMICS		To be procured
AE670	AEROSPACE STRUCTURAL ANALYSIS - I	3-0-0-0-4	Free body diagram, equilibrium equations, examples from three-dimensional truss problems;

			bending moment, shear force. Introduction to theory of elasticity, stress, strain, stress strain relations, constitutive relations, basic equations of elasticity. Bending of beams, symmetrical and unsymmetrical sections, temperature effects, nonhomogeneous materials, modulus weighted sectional properties, thin walled sections. Deflection of beams. Torsion of circular and noncircular sections, thin walled sections, single and multiple closed cell sections. Shear in thin walled sections, shear center, single and multiple cell sections, combined bending and torsion. Plane strain and plane stress problems in elasticity. Eulers bucklingof columns.
AE670A	AEROSPACE STRUCTURAL ANALYSIS - I	3-0-0-0-9	Free body diagram, equilibrium equations, examples from three-dimensional truss problems; bending moment, shear force. Introduction to theory of elasticity, stress, strain, stress strain relations, constitutive relations, basic equations of elasticity. Bending of beams, symmetrical and unsymmetrical sections, temperature effects, nonhomogeneous materials, modulus weighted sectional properties, thin walled sections. Deflection of beams. Torsion of circular and noncircular sections, thin walled sections, single and multiple closed cell sections. Shear in thin walled sections, shear center, single and multiple cell sections, combined bending andtorsion. Plane strain and plane stress problems in elasticity. Eulers buckling of columns.
AE672	SOLID MECHANICS	3-0-0--4	Introduction. Material behaviour of idealized bodies, mathematical preliminaries, tensor analysis, partial derivatives, etc. Analysis of stress and strain measures. Laws of conservation, eqn. of motion, conservation of energy. Thermodynamic and mechanical equilibrium. Constitutive laws: viscoelastic materials.
AE672A	SOLID MECHANICS	3-0-0-0-9	Introduction. Material behaviour of idealized bodies, mathematical preliminaries, tensor analysis, partial derivatives, etc. Analysis of stress and strain measures. Laws of conservation, eqn. of motion, conservation of energy. Thermodynamic and mechanical equilibrium. Constitutive laws: visco-elastic materials.
AE673	ROCKET AND MISSILE STRUCTURES	3-0-0--4	Mission analysis, design approaches, analytical techniques, rocket grain analysis, structural types and optimization, honeycomb and sandwich construction, structural materials, aeroelasticity of cylindrical and conical shells, re-entry problems, ablation analysis, design examples, future trends, inflatable and expandable structure.
AE673A	ROCKET AND MISSILE STRUCTURES	3-0-0-0-9	Mission analysis, design approaches, analytical techniques, rocket grain analysis, structural types

			and optimization, honeycomb and sandwich construction, structural materials, aeroelasticity of cylindrical and conical shells, re-entry problems, ablation analysis, design examples, future trends, inflatable and expandable structure.
AE675	INTRODUCTION TO FINITE ELEMENT METHODS	3-0-0--4	Discussion on mathematical models, reliability of computer aided engineering analysis. Model problem of linear elastostatics in one dimension, principle of minimum potential energy, beam bending problem. Finite element discretisation in one dimension. One dimensional h/p code, Finite Element Formulation and development of two-dimensional code. Convergence analysis in two dimensions. Characterizational of solution smoothness, rate of convergence in energy norm, a posteriori error estimation. Direct computation of stresses and strains, postprocessing, superconvergent extraction techniques, nonlinear and time dependent problems.
AE675A	INTRODUCTION TO FINITE ELEMENT METHODS	3-0-0-0-9	Discussion on mathematical models, reliability of computer aided engineering analysis. Model problem of linear elastostatics in one dimension, principle of minimum potential energy, beam bending problem. Finite element discretisation in one dimension. One dimensional h/p code, Finite Element Formulation and development of two-dimensional code. Convergence analysis in two dimensions. Characterizational of solution smoothness, rate of convergence in energy norm, a posteriori error estimation. Direct computation of stresses and strains, post processing, superconvergent extraction techniques, nonlinear and time dependent problems.
AE676	AEROELASTICITY	3-0-0--4	Influence coefficients and function. Formulation of static and dynamic aeroelastic equations. Static aeroelasticity; divergence, aileron reversal & control effectiveness, solutions by matrix and energy methods. Unsteady aerodynamics, oscillating airfoil in incompressible flow, experimental methods, Dynamic aeroelasticity, flutter calculation, panel flutter.
AE676A	AEROELASTICITY	3-0-0-0-9	Influence coefficients and function. Formulation of static and dynamic aeroelastic equations. Static aeroelasticity; divergence, aileron reversal & control effectiveness, solutions by matrix and energy methods. Unsteady aerodynamics, oscillating airfoil in incompressible flow, experimental methods, Dynamic aeroelasticity, flutter calculation, panel flutter.
AE678	THEORY OF VIBRATIONS	3-0-0--4	Introd. Hamilton’s principles, Lagranges eqn, Eigenvalue problem (EVP), discrete& continuous system. Boundary value problem formulation. General EVP, positive definite system, self adjoint

			property. Vibration of strings, rods, beams, membranes and plates. Rayleighs quotient. Integral formulation of EVP, natural modes of vibration, approximate methods. Response to excitation.
AE678A	THEORY OF VIBRATIONS	3-0-0-0-9	Introd. Hamiltons principles, Lagranges eqn, Eigenvalue problem (EVP), discrete& continuous system. Boundary value problem formulation. General EVP, positive definite system, self adjoint property. Vibration of strings, rods, beams, membranes and plates. Rayleighs quotient. Integral formulation of EVP, natura modes of vibration, approximate methods. Response to excitation.
AE681	COMPOSITE MATERIALS	3-0-0--4	Introduction, Definition, classification, behaviors of unidirectional composites: prediction of strength, stiffness, factors influencing strength & stiffness, failure modes, analysis of lamina; constitutive classical laminate theory, thermal stresses. Design consideration, analysis of laminates after initial failure, interlaminar stresses, fracture mechanics, joints, experimental characterization. Performance under adverse environment.
AE681A	COMPOSITE MATERIALS	3-0-0-0-9	Introduction, Definition, classification, behaviors of unidirectional composites: prediction of strength, stiffness, factors influencing strength and stiffness, failure modes, analysis of lamina; constitutive classical laminate theory, thermal stresses. Design consideration, analysis of laminates after initial failure, interlaminar stresses, fracture mechanics, joints, experimental characterization. Performance under adverse environment.
AE682A	ANALYSIS & COMPOSITE STRUCTURES		To be procured
AE683	RANDOM VIBRATIONS	3-0-0--4	Introduction to probability theory, random process. Excitation response relations forstationary random processes single and multidegree of freedom system with linear and nonlinear characteristics, continuous systems. Failure due to random vibration, application to aero, civil & mechanical systems.
AE683A	RANDOM VIBRATIONS	3-0-0-0-9	Intro. to probability theory, random process. Excitation response relations for stationary random processes single and multidegree of freedom system with linear and nonlinear characteristics, continuous systems. Failure due to random vibration, application to aero, civil & mechanical systems.
AE684	AIRCRAFT MATERIALS AND PROCESSES	3-0-0--4	Definition of various terms used for classification of materials. Mechanical properties. Testing of aircraft materials. Classification of alloys of aluminium, steel, titanium etc. High temperature problems;

			aerodynamic heating, design considerations, ceramic coating etc. Plastics, fibre reinforced composites, transparent materials.
AE684A	AIRCRAFT MATERIALS AND PROCESSES	3-0-0-0-9	Definition of various terms used for classification of materials. Mechanical properties. Testing of aircraft materials. Classification of alloys of aluminium, steel, titanium etc. High temperature problems; aerodynamic heating, design considerations, ceramic coating etc. Plastics, fibre reinforced composites, transparent materials.
AE685	DETERMINISTIC & RANDOM VIBRATION	3-0-0--4	Free and forced vibration of discrete multidegree of freedom systems with and without viscous damping; impulse and frequency response methods. Continuous systems; natural modes, free & forced vibration. Random vibrations: intro. To probability theory, random variables & processes, properties of random processes, response of system to random excitations
AE685A	DETERMINISTIC & RANDOM VIBRATION	3-0-0-0-9	Free and forced vibration of discrete multidegree of freedom systems with and without viscous damping; impulse and frequency response methods. Continuous systems; natural modes, free & forced vibration. Random vibrations: intro. To probability theory, random variables & processes, properties of random processes, response of system to random excitations
AE686	HELICOPTER THEORY: DYNAMICS AND AEROELASTICITY	3----4	Historical development, configurations of helicopters, rotor system, flight control mechanism, momentum theory and blade element theory in hover, vertical flight and forward flight. Idealization of rotor blades, Flaplag and torsional dynamics of the blade. Trim and equilibrium analysis, aeroelastic stability of rotor blades. Flappitch, lagpitch and flaplag coupling, simple model of rotor fuselage dynamics, longitudinal and lateral stability and control of helicopters.
AE686A	HELICOPTER THEORY: DYNAMICS AND AEROELASTICITY	3-0-0-0-9	Historical development, configurations of helicopters, rotor system, flight control mechanism, momentum theory and blade element theory in hover, vertical flight and forward flight. Idealization of rotor blades, Flaplag and torsional dynamics of the blade. Trim and equilibrium analysis, aeroelastic stability of rotor blades. Flappitch, lagpitch and flaplag coupling, simple model of rotor fuse lage dynamics, longitudinal and lateral stability and control of helicopters.
AE687	AEROSPACE STRUC ANALYSIS II	3-0-0--4	General loads on aircraft, load factor, Vn diagram, effect of gust loading. Energy principles, potential and complementary potential; deflection analysis, indeterminate structures. Analysis of plates, Kirchhoff and first order shear deformation plate theories, buckling of plates, buckling of stiffened plates, local buckling of composite shapes.

AE687A	AEROSPACE STRUC ANALYSIS II	3-0-0-0-9	General loads on aircraft, load factor, Vn diagram, effect of gust loading. Energy principles, potential and complementary potential; deflection analysis, indeterminate structures. Analysis of plates, Kirchhoff and first order shear deformation plate theories, buckling of plates, buckling of stiffened plates, local buckling of composite shapes.
AE688	DYNAMICS AND VIBRATION	3-0-0--4	Rigid body dynamics: Newtons second law, impulse and momentum, moment of a force and angular momentum, work and energy, system of particles, rigid bodies, Eulers equations. Analytical mechanics: degrees of freedom, generalized coordinates, virtual work, Hamiltons principle, Lagranges equations. Linear system theory: frequency response, transform methods, transfer function, transition matrix, Eigen value problem, Modal analysis. Lumped parameter systems: single degree of freedom system, two degrees of freedom system, multiple degrees of freedom system. Continuous system: introduction, longitudinal, transverse and torsional vibrations of slender members.
AE688A	DYNAMICS AND VIBRATION	3-0-0-0-9	Rigid body dynamics: Newtons second law, impulse and momentum, moment of a force and angular momentum, work and energy, system of particles, rigidbodies, Eulers equations. Analytical mechanics: degrees of freedom, generalized coordinates, virtual work, Hamiltons principle, Lagranges equations. Linear system theory: frequency response, transform methods, transfer function, transition matrix, Eigen value problem, Modal analysis. Lumped parameter systems: single degree of freedom system, two degrees of freedom system, multiple degrees of freedom system. Continuous system: introduction, longitudinal, transverse and torsional vibrations of slender members.
AE689	INTRODUCTION TO THE THEORY OF SMART STRUCTURES	3-0-0-0-4	Introduction to smart materials, piezo, pyro and ferro electric effects; hysteresis effects: electric field in solids: fundamentals of continuum mechanics; basic conservation laws; thermodynamic principles; constitutive modelling for smart materials; electrothermoelastic formulation and analysis of smart structures; control of smart structures; applications to aerospace vehicles.
AE689A	INTRODUCTION TO THE THEORY OF SMART STRUCTURES	3-0-0-0-9	Introduction to smart materials, piezo, pyro and ferro electric effects; hysteresis effects: electric field in solids: fundamentals of continuum mechanics; basic conservation laws; thermodynamic principles; constitutive modelling for smart materials; electrothermoelastic formulation and analysis of smart structures;

			control of smart structures; applications to aerospace vehicles.
AE690	HIGH TEMPERATURE GAS DYNAMICS	3-0-0--4	Nature of high temperature flows, perfect and real gas, Gibbs free energy and entropy production, microscopic description of gases, thermodynamic properties, equilibirum properties kinetic theory, inviscid high temp. equilibrium and nonequilibrium flow, transport properties
AE690A	HIGH TEMPERATURE GAS DYNAMICS	3-0-0-0-9	Nature of high temperature flows, perfect and real gas, Gibbs free energy and entropy production, microscopic description of gases, thermodynamic properties, equilibirum properties kinetic theory, inviscid high temp. equilibrium and nonequilibrium flow, transport properties
AE692	MECHANICS OF HIGHLY DEFORMABLE STRUCTURES	3-0-0-0-4	Definition of large deformation of structures as large deflection, large rotation with small strains. Linear and nonlinear structural responses. Theory of elastica with exact and numerical solutions. Elements of large deformation mechanics: Reference and deformed configurations, Lagrange strain, Cauchy and Piola Kirchoff stress, work conjugate stress and strain measures. Governing equations in strong and weak form. Hyperelastic material constitutive law. Incremental numerical solution of large deformation boundary value problems: tangent stiffness, explicit and implicit methods, Newton Raphson method. Elastic and geometric stiffness. Total Lagrangian method. Corotational scheme. **Course Reference**: 1. JamesF. Doyle. Nonlinear analysis of thin walled structures. Springer Verlag. 2001; 2. M. A. Crisfield. Nonlinear finite element analysis of solids and structures. Vols. I and II. JohnWiley& Sons. 1991; 3. M.A. Biot. Mechanics of incremental deformations. John Wiley& Sons. 1965. 25-JUL-2013
AE692A	MECHANICS OF HIGHLY DEFORMABLE STRUCTURES	3-0-0-0-9	Definition of large deformation of structures as large deflection, large rotation with small strains. Linear and nonlinear structural responses. Theory of elastica with exact and numerical solutions. Elements of large deformation mechanics: Reference and deformed configurations, Lagrange strain, Cauchy and Piola Kirchoff stress, work conjugate stress and strain measures. Governing equations in strong and weak form. Hyper elastic material constitutive law. Incremental numerical solution of large deformation boundary value problems: tangent stiffness, explicit and implicit methods, Newton Raphson method. Elastic and geometric stiffness. Total Lagrangian method. Corotational scheme. **Course Reference:** 1. JamesF. Doyle. Nonlinear analysis of thin walled structures. Springer Verlag.

			2001; 2. M. A. Crisfield. Nonlinear finite element analysis of solids and structures. Vols. I and II. JohnWiley & Sons. 1991; 3. M.A. Biot. Mechanics of incremental deformations. John Wiley& Sons. 1965.
AE693A	AIRCRAFT SRUCTURAL INTEGRITY		To be procured
AE694A	ACOUSTICS IN FLUIDS	3-0-0-0-9	Introduction to the course. Fundamentals of acoustics: Derivation of wave equation, speed of sound, harmonic waves, acoustic energy/intensity, decibel scale, acoustic impedance, reflection and transmission at the interface of two media. Wave propagation: Rectangular and circular ducts, cutoff frequency, free field propagation. Acoustics of resonantors: Travelling and standing waves, boundary conditions, eigen frequency and eigenmodes, effects of area variation, reflection and transmission of waves in pipes. Acoustic sources: Inhomogeneous wave equation, acoustic sources: monopole, bipole & quadrupole sources, acoustic reciprocity, aeroacoustic analogies. Attention of sound: Viscous and thermal conduction losses, absorption coefficient, sound absorption in pipes. Application of principles of acoustics: Aeroacoustic jet noise, combustion instability noise. **Course Reference**: 1. Lawrence E. Kinsler, Austin R. Frey, and Alan B. Coppens, 2000. Fundamentaals of acoustics, 4th edn. JohnWiley & Sons, Inc. 2. Philip M. Morse and K. Uno Ingard, 1986. Fundamentals of acoustics. 1st edn. Priceton University Press. 3. S.W. Rienstra & A. Hirschberg, 2000. An introduction to acoustics. http://www.win.tue.nl/sjoerder/papers/boek.pdf 4. S.W. Rienstra & A. Hirschberg, 2004. An introduction to aeroacoustics. http://www.win.tue.nl/sjoerder/papers/lesswrmh.pdf 24-MAR-15
AE696	INSTRUMENTATION, MEASUREMENTS AND EXPERIMENTS IN FLUIDS	3----4	Need and objective, fundamentals of fluid mechanics, wind tunnels, visualization, HWA, pressure and noise measurements, temperature, wall shear stress, flow measurements, geophysical flows, spin up and spin down, data acquisition and processing, uncertainty analysis.
AE696A	INSTRUMENTATION, MEASUREMENTS AND EXPERIMENTS IN FLUIDS	3-0-0-0-9	Need and objective, fundamentals of fluid mechanics, wind tunnels, visualization, HWA, pressure and noise measurements, temperature, wall shear stress, flow measurements, geophysical flows, spin up and spin down, data acquisition and processing, uncertainty analysis.
AE698	INTRO TO VIRTUAL INSTRUMENTATION	2-0-3-0-4	Introduction to VI, typical applications, functional systems, graphical programming, data flow techniques, advantages of VI techniques. VI

			programming techniques; VIs and subVIs, loops and charts, arrays, clusters and graphs, case and sequence structures, formula nodes, string and file I/O, DAQ methods, code interfacenodes and DLL links. Sensors, transducers and signal conditioning; common transducers for displacement, temperature, load, pressure, flow etc. Single ended, floating and differential inputs, grounding, noise and filtering. Data acquisition basics; AD DAC, DIO, counters and timers, PC Hardware structure, timing, interrupts, DMA, operating system, PCI buses. Bus based instrumentation; instrumentation buses, GPIB, RS232C.
AE698A	INTRO TO VIRTUAL INSTRUMENTATION	2-0-3-0-9	Introduction to VI, typical applications, functional systems, graphical programming, data flow techniques, advantages of VI techniques. VI programming techniques; VIs and subVIs, loops and charts, arrays, clusters and graphs, case and sequencestructures, formula nodes, string and file I/O, DAQ methods, code interfacenodes and DLL links. Sensors, transducers and signal conditioning; common transducers for displacement, temperature, load, pressure, flow etc. Singleended, floating and differential inputs, grounding, noise and filtering. Dataacquisition basics; AD DAC, DIO, counters and timers, PC Hardware structure, timing, interrupts, DMA, operating system, PCI buses. Bus based instrumentation; instrumentation buses, GPIB, RS232C.
AE698B	MECHANICS OFHIGHLY DEFORMABLE STRUCTURES		To be procured
AE699	M TECH THESIS	0-0-0-0-0	Units: As arranged
AE699.	M TECH THESIS (FOR DUAL DEGREE ONLY)	0-0-0--9	M TECH THESIS (FOR DUAL DEGREE ONLY)
AE701	NONLINEAR FINITE ELEMENT METHOD	3-0-0--4	Overview of nonlinear problems in structural analysis geometric and material nonlinearities, nonlinear forces and boundary conditions; nature of forced eflectioncurves, critical points. Single degree of freedom system withgeometric nonlinearity Incremental solution, iterative solution using directand Newton Raphson approaches; combined incremental and iterative solution with full or modified Newton Raphson or initial stress method. One dimensional continuum problem: Axial bar under compression, variousstrain measures, weak and variational formulations based on Green strain measure. I D Finite element formulation: Total and Updated Lagrangian approaches: derivation of stiffness and tangent stiffness matrices, limitpoint and bifurcation; traversal of critical points. Two dimensional problems: Strain measures in two and three

			dimensions, stress measures (Cauchyand Piola Kirchhoff), objectivity, Updated Lagrangian formulation stress increments. 2D Incremental formulation with updates, derivation ofstiffness and tangent stiffness matrices. Advanced Solution Procedures: Line search, arc length quasi Newton and Secant methods. Nonlinear Dynamics: Direct Integration techniques: explicit and implicit solution techniques. Stability of time integration schemes. Newmarks scheme. The method; energy conserving and automatic time stepping methods. (1) Nonlinear finite element analysis of solids and structures, Vols. I and II, M.A. Crisfield, John Wiley and Sons (1994).(2) Finite Element Procedures, K.J. Bathe, Prentice Hall (1996).(3) Suggested journal papers
AE701A	NONLINEAR FINITE ELEMENT METHOD	3-0-0-0-9	Overview of nonlinear problems in structural analysis geometric and material nonlinearities, nonlinear forces and boundary conditions; nature of forced eflection curves, critical points. Single degree of freedom system with geometric nonlinearity Incremental solution, iterative solution using directand Newton Raphson approaches; combined incremental and iterative solution with full or modified Newton Raphson or initial stress method. One dimensional continuum problem: Axial bar under compression, variousstrain measures, weak and variational formulations based on Green strainmeasure. I D Finite element formulation: Total and Updated Lagrangian approaches: derivation of stiffness and tangent stiffness matrices, limitpoint and bifurcation; traversal of critical points. Two dimensional problems: Strain measures in two and three dimensions, stress measures (Cauchy and Piola Kirchhoff), objectivity, Updated Lagrangian formulation stress increments. 2D Incremental formulation with updates, derivation ofstiffness and tangent stiffness matrices. Advanced Solution Procedures: Line search, arc length quasi Newton and Secant methods. NonlinearDynamics: Direct Integration techniques: explicit and implicit solutiontechniques. Stability of time integration schemes. Newmarks scheme. The method; energy conserving and automatic time stepping methods. **Course Reference:** 1. Nonlinear finite element analysis of solids and structures, Vols. I and II, M.A. Crisfield, John Wiley and Sons (1994); 2. Finite Element Procedures, K.J. Bathe, Prentice Hall (1996); 3. Suggested journal papers
AE704	DEFORMATION AND FRACTURE		To be procured
AE704A	DEFORMATION AND FRACTURE		To be procured

AE708	OPTICAL METHODS IN SOLID MECHANICS		To be procured
AE708A	OPTICAL METHODS IN SOLID MECHANICS		To be procured
AE747	MOLECULAR GAS DYNAMICS	3-0-0-0-4	The molecular model; binary elastic collisions: basic kinetic theory; reference states & boundary conditions; collisionless flow; transition regime flows. Directsimulation Monte Carlo method. One dimensional flow of a simple monatomicgas. Measurements in low density flows.
AE747A	MOLECULAR GAS DYNAMICS	3-0-0-0-9	The molecular model; binary elastic collisions: basic kinetic theory; reference states and boundary conditions; collisionless flow; transition regime flows. Direct simulation Monte Carlo method. One dimensional flows of a simple monatomic gas. Measurements in low density flows.
AE751	FUNDAMENTALS OF LIQUID ATOMIZATION	3-0-0-0-4	Introduction to atomization, Physical processes in atomization, Types of atomizers, Classical Theories of atomization, Numerical modeling of atomization process, Theory of multiphase flows, Atomizer design: Single Fluid and Twin Fluid, SprayCharacterization Measurement techniques in Spray Characterization, Applications of Atomizers Metal forming Chemical Industry Combustion.
AE751A	FUNDAMENTALS OF LIQUID ATOMIZATION	3-0-0-0-9	Course Details: Introduction to atomization, Physical processes in atomization, Types of atomizers, Classical Theories of atomization, Numerical modeling of atomization process, Theory of multiphase flows, Atomizer design: Single Fluid and Twin Fluid, Spray Characterization Measurement techniques in Spray Characterization, Applications of Atomizers Metal forming Chemical Industry Combustion.
AE752	PRINCIPLES OF ACOUSTICSV	3-0-0-4-4	Wave theory of sound: Plane waves, Harmonic waves and complex Algebra, Speed ofsound, Energy, Intensity and Power, Spherical wavesb. Quantitative measurement of sound: Frequency content and bands, Decibel scale, Multiple frequency signals, coherence, Frequency domain representation of transientsignalsc. Propagation of Plane waves: Reflection from a rigid surface, Propagation in a tube, Radiation due to waves on the wall, Oblique reflection and transmission at a planar interfaced. Radiation from Vibrating Bodies: Oscillating spheres, Monopoles and Multipoles.
AE752A	PRINCIPLES OF ACOUSTICSV	3-0-0-0-9	Wave theory of sound: Plane waves, Harmonic waves and complex Algebra, Speed ofsound, Energy, Intensity and Power, Spherical wavesb. Quantitative measurement of sound: Frequency content and bands, Decibel scale, Multiple frequency signals, coherence, Frequency domain representation of transient signals. Propagation of

			Plane waves: Reflection from a rigid surface, Propagation in a tube, Radiation due to waves on the wall, Oblique reflection and transmission at a planarinterfaced. Radiation from Vibrating Bodies: Oscillating spheres, Monopoles and Multipoles.
AE753	THEORY OF COMBUSTION	3-0-0-0-4	Introduction to combustion: Types of flames, role of chemical kinetics Chemical Kinetics: Formulation of chemical kinetics equations, reaction mechanisms, steady state approximation, Arrhenius Law: Formulation of Arrhenius law, Microscopic consideration of reaction rates. Explosions: Thermal explosions, Chain branching explosions, Chemical equilibrium Conservation equations for reacting flows: Shvab Zeldovich formulation. Laminar premixed combustion: Flame speed Thermal theory (Mallard and Le Chatellier), DiffusionTheory (Zeldovich, Frank Kamenstakii and Semenov), Flame stabilization, Quenching and Flammability limits micro combustion. Detonation and Deflagration: Chapman Hugoniot relations, Chapman Jouguet points Liminarnon premixed conbustion: Burke Schuman Analysis, Phenomenological Analysis Ignition, Extinction and Flammability. Turbulet premixed combustion: Theories, Time and length scales, thin flame approach, stirred reactor. Turbulent nonpremixed combustion: Conserved scalar approach, two variable approach, flamelet model, direct closure.
AE753A	THEORY OF COMBUSTION	3-0-0-0-9	Introduction to combustion: Types of flames, role of chemical kinetics Chemical Kinetics: Formulation of chemical kinetics equations, reactionmechanisms, steady state approximation, Arrhenius Law: Formulation of Arrhenius law, Microscopic consideration of reaction rates. Explosions: Thermal explosions, Chain branching explosions, Chemical equilibrium Conservation equations for reacting flows: Shvab Zeldovich formulation. Laminar premixed combustion Flame speed Thermal theory (Mallard and Le Chatellier), Diffusion Theory (Zeldovich, Frank Kamenstakii and Semenov), Flame stabilization, Quenching and Flammability limits micro combustion. Detonation and Deflagration: Chapman Hugoniot relations, Chapman Jouguet points Liminarnon premixed conbustion: Burke Schuman Analysis, Phenomenological Analysis Ignition, Extinction and Flammability. Turbulet premixed combustion: Theories, Time and length scales, thin flame approach, stirred reactor. Turbulent nonpremixe combustion: Conserved scalar approach, two variable approach, flamelet model, direct closure.
AE754	TURBULENT COMBUSTION	3-0-0-0-4	Introduction, Governing equations, Statistical description of turbulence, Turbulent scales and correlations, Reynold saveraged equations, Mixing,

			Flows with premixed and nonpremixed reactants, Numerical and experimental methods for reacting flows. Introduction Motivation and objective Governing equationsTurbulence Introduction Turbulent scales Spatial and temporal correlations Reynold saveraged equations Wall bounded shear flows Free shear flows Statistical description. Turbulence modeling and Mixing Introduction Turbulence modeling Molecular mixing Turbulent mixing Reaction diffusion systemsFlows with premixed and nonpremixed reactants Introduction to premixed and nonpremixed mixtures Moment methods Wellstirred reactor Conserved scale methodsNumerical and experimental methods for Reacting flows Combustion CFD Numerical solvers for stiff differential equations General concepts about experimental methods Measurement techniques. **Course Reference**: 1. A first course in Turbulence, Tennekes and Lumley; 2. An introduction to combustion, Stephen Turns; 3. Turbulent Combustion, N. Peters; 4. Combustion Theory, F. Williams; 5. Theoretical and Numerical Combustion, Poinsot and Veynante
AE754A	TURBULENT COMBUSTION	3-0-0-0-9	Introduction, Governing equations, Statistical description of turbulence, Turbulent scales and correlations, Reynold saveraged equations, Mixing, Flows with premixed and nonpremixed reactants, Numerical and experimental methods for reacting flows. Introduction Motivation and objective Governing equationsTurbulence Introduction Turbulent scales Spatial and temporal correlations Reynold saveraged equations Wallbounded shear flows Free shear flows Statistical description. Turbulence modeling and Mixing Introduction Turbulence modeling Molecular mixing Turbulent mixing Reaction diffusion systems Flows with premixed and nonpremixed reactants Introduction to premixed and nonpremixed mixtures Moment methods Wellstirred reactor Conserved scale methods Numerical and experimental methods for Reacting flows Combustion CFD Numerical solvers for stiff differential equations General concepts about experimental methods Measurement techniques. **Course Reference**: 1. A first course in Turbulence, Tennekes and Lumley; 2. An introduction to combustion, Stephen Turns; 3. Turbulent Combustion, N. Peters; 4. Combustion Theory, F. Williams; 5. Theoretical and Numerical Combustion, Poinsot and Veynante
AE777	OPTIMAL SPACE FLIGHT CONTROL	3-0-0-0-4	1. Control Systems (Basic definitions, notation, tracking systems.); 2. Guidance and navigation (Basic concepts, linear regulation and tracking,

			proportional navigation, crossproduct steering); 3. Optimal control techniques (Multivariable optimization, constrained minimization, optimal control of dynamic systems, Hamiltonian and the minimum principle, HamiltonJacobi Bellman formulation, end point constraints, EulerLagrange formulation, two point boundary value solution techniques, optimal terminal control with interior constraints, singular control, neighbouring extremals, linear optimal control, stochastic systems, Kalman filtering, LQG/LTR and Hinfinity robust optimal control.) 4. Optimal guidance and control of rocket flight (Terminal guidance of interceptors, nonplanar tracking systems (3DPN), Goddards problem, 2PBVP solutions for gravityturn trajectories, attitude autopilots, pitch maneuver control of launch vehicles.) 5. Optimal spacecraft navigation and control (Introduction to orbital mechanics, Hill Clohessey Wiltshire model, autonomous rendezvous and docking, minimum energy transfer, Lamberts problem, optimal guidance of reentry vehicles, nonplanar orbital regulation, optimal threeaxis control by thrusters, reaction wheels and control moment gyros.) **Course Reference**: 1. Tewari, A., Advanced Control of Aircraft, Spacecraft, and Rockets, John Wiley &Sons, Chichester, 2011; 2. Tewari, A., Atmospheric and Space Flight Dynamics, Birkhuser, Boston, 2006; 3. Bryson, A.E., Jr., and Ho, Y.C., Applied Optimal Control. Hemisphere, 1975; 4. Athans, M., and Falb, P.L., Optimal Control. Dover, 2007.
AE777A	OPTIMAL SPACE FLIGHT CONTROL	3-0-0-0-9	1. Control Systems (Basic definitions, notation, tracking systems.); 2. Guidance and navigation (Basic concepts, linear regulation and tracking, proportional navigation, crossproduct steering); 3. Optimal control techniques (Multivariable optimization, constrained minimization, optimal control of dynamic systems, Hamiltonian and the minimum principle, Hamilton Jacobi Bellman formulation, endpoint constraints, EulerLagrange formulation, twopoint boundaryvalue solution techniques, optimal terminal control with interior constraints, singular control, neighbouring extremals, linear optimal control, stochastic systems, Kalman filtering, LQG/LTR and Hinfinity robust optimal control.); 4. Optimal guidance and control of rocket flight (Terminal guidance of interceptors, nonplanar tracking systems (3DPN),Goddards problem, 2PBVP solutions for gravityturn trajectories, attitude autopilots, pitch maneuver control of launch vehicles.); 5. Optimal spacecraft navigation and control (Introduction to orbital mechanics, Hill Clohessey Wiltshire model,

			autonomous rendezvous and docking, minimum energy transfer, Lamberts problem, optimal guidance of reentry vehicles, nonplanar orbital regulation, optimal threeaxis control by thrusters, reaction wheels and control moment gyros.) **Course Reference**: 1. Tewari, A., Advanced Control of Aircraft, Spacecraft, and Rockets, John Wiley &Sons, Chichester, 2011; 2. Tewari, A., Atmospheric and Space Flight Dynamics, Birkhuser, Boston, 2006; 3. Bryson, A.E., Jr., and Ho, Y.C., Applied Optimal Control. Hemisphere, 1975; 4. Athans, M., and Falb, P.L., Optimal Control. Dover, 2007.
AE778A	NONLINEAR AND ADAPTIVE CONTROL		To be procured
ESO204	MECHANICS OF SOLIDS	3-1-0-1-4	Free body diagram with examples on modelling of typical supports and joints,Conditions for equilibrium in 3D and 2D, Friction: limiting and nonlimiting cases; Forcedisplacementrelationship and geometric compatibility (for small deformations) with illustrations through simpleproblems on axially loaded members and thinwalled pressure vessels; Concept of stress at a point,Plane stress case: transformation of stresses at a point, principal stresses and Mohr's circle, Displacement field, Concept of strain at a point, Plane strain case: transformation of strain at a point,principal strains and Mohr's circle, Strain Rosette; Discussion of experimental results on 1D material behaviour, Concepts of elasticity, plasticity, strainhardening, failure (fracture/yielding), Idealization of 1D stressstrain curve, Generalized Hooke's law (without and with thermal strains) for isotropic materials, Complete equations of elasticity; Force analysis (axial force, shear force, bending moment, and twisting moment diagrams) of slender members (singularity functions nat to be used); Torsion of circular shafts and thinwalled tubes (plastic analysis and rectangular shafts not to be discussed); Moment curvature relationship for pure bending of beams with symmetric crosssection, bending stress,shear stress (Shear centre and plastic analysis not to be discussed); Cases of combined stresses, Conceptof strain energy, Yield criteria; Deflection due to bending, Integration of the moment curvature relationship for simple boundary conditions, Method of superposition (singularity functions not to beused); Strain energy and complementary strain energy for simple structural elements (those under axialload, shear force, bending moment, and torsion), Castigliano theorems for deflection analysis and indeterminate problems; Concept of elastic instability,

			Introduction to column buckling, Euler formula(postbuckling behaviour not to be covered) **Course Reference**: 1. Crandall, S.H., Dahl, N.C., and Lardner, T. J., An Introduction to the Mechanics of Solids, McGrawHill,Second Ed. with 51 Units, 1978; 2. Beer, F.P, Johnston, E.R. and DeWolf, J.T., Mechanics of Materials, Tata McGrawHill Edition2004; 3. Meriam, J.L. and Kraige, L.G., Engineering Mechanics, Vol. 1: Statics, John Wiley,Second Ed. with 51 Units, 1980; 4. Popov, E.P., Engineering Mechanics of Solids, PrenticeHall, First Ed., 1990
ESO204A	FLUID MECHANICS AND RATE PROCESSES		FLUID MECHANICS: Introduction to fluids, Fluid statics; pressure as a scalar, manometry, forces on submerged surfaces (NO moments NOR center of pressure), Description of flows; field approach, Euler acceleration formula, streamlines, streaklines, etc., Reynolds transport theorem Conservation of mass; stream function, Linear (NOT angular) Momentum balance, Navier Stokes (NS) equation; elementary derivation; application; Poiseuille flow, Couette flow, Energy equation Bernoulli equation, applications including flow measurement (Pitot tube, Orifice meters); Pipe flows and losses in fittings; Similitude and modelling: using nondimensionalization of NS equations and boundary conditions, simplifications for cases without free surfaces and without cavitation (scale factor approach should NOT be done); High Re flow: Prandtls approximation; basic inviscid flow; need for boundary layer; Magnus effect (mathematical derivations be avoided), Boundary layerselementary results for flat plates. Separation, flow past immersed bodies (bluff, streamlined); physics of ballgames (qualitative) Heat Transfer: Introduction, rate law and conservation law, Conduction equation; nondimensionalization, various approximations, Steady state conductionconcept of resistances in series and of critical thickness of insulation, Unsteady conduction; significance of Biot and Fourier numbers, Heissler charts; Low Bi case;
SE371	FOUNDATION OF SCIENTIFIC COMPUTING	3-0-0--4	Basics of Computing: discretization and numerical errors. ODEs and their computations. Stiff ODEs & parasitic error, solving stiff equation via orthogonolization and compound matrix method. Governing PDEs for scientific computing and their classification. Wave mechanics: hyperbolic and dispersive waves. Dispersion relation and spacetime resolution. Finite difference methods for wave equation. Discretization of spatial derivatives by polynomial expansion and operator's explicit methods. Spectral theory of discrete computing: stability analysis; Theory of signal and error

			propagation; dispersion relation preservation (DRP) property. Finite difference methods (FDM) for wave equation. Designing high accuracy, high fidelity methods via error control as an optimization problem. Spectral method visvis discrete computing methods: Aliasing error and focusing; Capturing discontinuities and Gibbs phenomenon; qwavesin computing. Numerical Methods for Partial Differential Equations WF Ames Fundamentals of Computational Fluid Dynamics: T. K. Sengupta.Waves in Fluids M. J. LighthillComputational Aeroacoustics: M. J. Lighthill.Linear and Nonlinear Waves: G. B. Whitham. 17-SEP-14
SE422	FOUNDATION OF SCIENTIFIC COMPUTING	3-0-0-0-3	Basics of Computing: discretization and numerical errors. ODEs and their computations. Stiff ODEs & parasitic error, solving stiff equation via orthogonolization and compound matrix method. Governing PDEs for scientific computing and their classification. Wave mechanics: hyperbolic and dispersive waves. Dispersion relation and spacetime resolution. Finite difference methods for wave equation. Discretization of spatial derivatives by polynomial expansion and operator's explicit methods. Spectral theory of discrete computing: stability analysis; Theory of signal and error propagation; dispersion relation preservation (DRP) property. Finite difference methods (FDM) for wave equation. Designing high accuracy, high fidelity methods via error control as anoptimization problem. Spectral method visvis discrete computing methods: Aliasing error and focusing; Capturing discontinuities and Gibbs phenomenon; qwavesin computing. Numerical Methods for Partial Differential Equations WF AmesFundamentals of Computational Fluid Dynamics: **Course Reference**: 1. T. K. Sengupta.Waves in Fluids M. J. Lighthill; 2. Computational Aeroacoustics: M. J. Lighthill.Linear and Nonlinear Waves: G. B. Whitham. 17-SEP-14
IDC611	Parallel Computation of Sparse Matrix Systems	3-0-1-0 [10]	Objectives: Sparse Matrix systems in parallel environments are one of the widely used techniques in the scientific community and industry as well. This course aims to introduce students from interdisciplinary Engineering and science streams to the fundamentals of the sparse matrix systems. The students will learn about the basics of a sparse matrix, parallel programming, and solution techniques of the sparse matrix using a parallel environment. A sparse matrix is the outcome of discretized partial differential equations that represent the conservation laws to simulate fluid

			flow, heat transfer, and other related physical phenomena. Thereafter, the system of algebraic equations is solved to compute the values of the dependent variable for each of the elements to represent the physical processes. The course is targeted for all engineering and science disciplines to the emerging paradigm of quantum computing. Contents: considering the duration of each lecture is 50 minutes (preferably in the form of 5 to 10 broad titles):

S No.	Broad Title	Topics	No. of lectures
1	Basics of Matrix Computations	1) Subspaces, Bases, Orthogonality, Matrices, | 6 Computations Projectors, Norms. Floating point arithmetic. 2) Systems of linear equations. Solution of Systems of Linear Equations: matrix LU factorization. Special matrices: symmetric positive definite, banded. 3) Error analysis, condition numbers, operation counts, estimating accuracy. 4) Orthogonality, the Gram-Schmidt process. Classical and modified Gram-Schmidt. Householder QR factorization. Least-squares systems. 5) Eigenvalues, singular values. The Singular Value Decompo-	6

					sition. Applications of the SVD. 6) Eigenvalue problems: Background, Schur decomposition, perturbation analysis, power and inverse power methods, subspace iteration; the QR algorithm. 7) The Symmetric Eigenvalue Problem: special Properties and perturbation theory, Law of inertia, Min-Max theorem, symmetric QR algorithm, Jacobi method. Applications.	
			2	Sparse Matrices	1) Sparse matrices and their origin. Graph representation of sparse matrices, sparse graphs, Discretization of Partial Differential Equations. Electrical networks, Information retrieval. 2) Storage schemes for sparse matrices. Regular and irregular structures.	6
			3	Direct Solution methods of Sparse matrices	Direct solution methods; Variants of Gaussian Elimination; Permutations and orderings; Band and envelope methods; Cuthill-Mc Kee	3

					and reverse Cuthill-Mc Kee orderings; Graph representation. Elimination tree; The frontal and multifrontal approaches; Minimal degree and nested dissection orderings.	
			4	Iterative Solution Methods of Sparse matrices	Iterative methods; Projection methods; Onedimensional case: steepest descent, minimal residual methods; Krylov subspace methods; Conjugate gradient (CG) method; basic convergence theory; Connection to Lanczos tridiagonalization and orthogonal polynomials; The idea of preconditioning.	5
			5	Eigenvalue problems	Types of problems; Subspace iteration; Krylov methods; Arnoldi's method; The Lanczos algorithm; Nonsymmetric Lanczos.	3
			6	Basics of Parallel Programming	1) Introduction; Historical Perspective; Types of parallelism; Parallel algorithms and parallel computing. 2) Parallel computing platforms, Taxonomy, Pipelined-Vector-, superscalar. Examples of paral-	6

		lel platforms. 3) Memory and cache performance issues, Hierarchical memories, Latency, bandwidth, Caches. 4) Parallel algorithms, design. Parallel performance metrics (Efficiency, load balancing, scalability, ...)	
7	Parallel Programming Using OpenMP, MPI, and Open ACC	1) Programming shared memory machines -Open MP. 2) Programming GPUs, CUDA, open ACC. 3) Basic communication operations. Programming with MPI. 4) Programming distributed systems - MPI	6
8	Parallel toolkit	1) Parallel Scientific Libraries: BLAS, LAPACK, SCALAPACK, ARPACK, LIS libraries (only two or three of them will be covered) 2) PETSC	5

Recommended pre-requisites, if any (examples: a-PS0201A,or b- P.50201A orequivalent): Undergraduate/Graduate Mathematics, Linear Algebra, and Programming

Short summary for including in the Courses of StudyBooklet:
This course introduces parallel computing to

			sparse matrix systems and their applications. It covers parallel architectures, parallel algorithms, and their analysis in the context of sparse linear systems and eigenvalue problems. The course will start with a general discussion of sparse matrices, their origins, and how they are stored and exploited. Then it will briefly cover direct solution methods and iterative methods for solving sparse linear systems of equations and sparse eigenvalue problems. Further, it will discuss other topics related to sparsity, e.g., graph-based algorithms in machine learning, and basic nonlinear techniques. Finally, it will also introduce programming on parallel platforms. Along with the programming medium; OpenMP, MPI, and CUDA for the NVIDIA Graphics Processing Units (CPUs), will also be covered, in conjunction with a quick overview of openACC. The course blends theory with practical issues such as parallel architectures and parallel programming. Recommended text/reference books: 1) Introduction to Parallel Computing, 2nd edition, by V. Kumar, A. Grama, A. Gupta, and G. Karypis (2003). 2) Introduction to Parallel Programming by Peter S. Patcheco, Elsevier (2011). 3) Programming Massively Parallel Processors, Third Edition: A Hands-on Approach by David B. Kirk and Wen-mei W. Hwu. (2017). 4) Using MPI, Portable Parallel Programming with the Message-Passing Interface by William Gropp, Ewing Lusk, and Anthony Skjellum, Second Edition, MIT Press, 1999. 5) Matrix Computations, 4th edition by G. Golub and C. Van Loan. John Hopkins, 2015. 6) Numerical linear algebra by Lloyd N. Trefethen and David Bau, III. SIAM, 1997. 7) Iterative methods for sparse linear systems (2nd edition) by Yousef Saad 8) Direct methods for sparse linear systems by T. A. Davis, SIAM publishing, 2006.
AE631	Multidisciplinary Design Optimization	2-0-3-0 [9]	Objectives: The main objective of the course is to introduce students to Multidisciplinary Design Optimization (MDO) emphasizing its role in integrating multiple disciplines for effective design solutions. It further aims to engage them in hands-on projects to learn concepts and explore MDO principles using available software tools in Lab sessions.
AE632	Structural Vibration and Control	3-0-0-2 [9]	*Objectives:* The objective of this course is to enable the students to make the link between structural dynamics and vibrations, and control theory

			instead of studying these topics in isolation. The course begins with formulation of the eigen value problem, converting the vibration problem into the state space form, and then applying control theory for systems where instabilities (such as flutter, torsional vibrations under aerodynamic loads) can lead to catastrophic failures
AE651	System Identification Techniques for Aerial Vehicles	3-0-0-0 [9]	Objective: The objective of the course is to familiarize students with existing system identification techniques applied to flight vehicles. The focus will be on the applicability of various estimation techniques in different flight conditions and the quality of sensor data. This course will be beneficial for comprehensive analysis of flight vehicle’s performance, stability, and control

IDC611	Parallel Computation of Sparse Matrix Systems	3-0-1-0[10]	Objectives:Sparse Matrix systems in parallel environments are one of the widely used techniques in the scientific community and industry as well. This course aims to introduce students from interdisciplinary Engineering and science streams to the fundamentals of the sparse matrix systems. The students will learn about the basics of a sparse matrix, parallel programming, and solution techniques of the sparse matrix using a parallel environment. A sparse matrix is the outcome of discretized partial differential equations that represent the conservation laws to simulate fluid flow, heat transfer, and other related physical phenomena. Thereafter, the system of algebraic equations is solved to compute the values of the dependent variable for each of the elements to represent the physical processes. The course is targeted for all engineering and science disciplines to the emerging paradigm of quantum computing