DEPARTMENT OF AEROSPACE ENGINEERING, IIT MADRAS

ELECTIVES

AS 5300  Physical Gas Dynamics  3003

Introductory Kinetic theory (definition of pressure and temperature from microscopic viewpoint, mean free path transport processes). Equilibrium kinetic theory (Maxwell’s distribution, collision rate). Chemical equilibrium (Effective collision rate, Law of mass action, activation energy). Chemical thermodynamics (Gibb’s relations, Mixture of perfect gases, van’t Hoff’s relation). Statistical thermodynamics ( Macroscopic and microscopic descriptions, Quantum energy states, energy modes of molecules, Boltzman’s relation, contribution of internal structure). Equilibrium gas properties (Ideally dissociating gas, Ionisation equilibrium, Collision cross sections). Flow with translational non-equilibrium (Bhatnagar-Gross-Krook model for translational non-equilibrium, Chapman-Enskog solution, Transport properties as nonequilibrium phonomena, Linearised Couette flow).

AS 5310 Object Oriented Programming for Scientists and Engineers  3003


OOP applications to numerical analysis – find epsilon of the machine, interval analysis and interval class. A matrix class. Solutions to differential equations – ODEs and PDEs using grid point class, finite volume class and finite element class. Simple graphics and visualization. Random number generators, Monte-Carlo methods, Random walk, discrete event simulation.

Object oriented design and its implications to problem formulation and solution.

AS 5320  Boundary Layer Theory  3003


AS 5330  Computational Aerodynamics  3003

Introduction to computation methods. Examples: Method of steepest descent, numerical integration, interpolation, etc. Relaxation methods applied to subsonic and

**AS 5340     Advanced Flight Mechanics**


**AS 5350     Transonic Aerodynamics**


**AS 5360     Advanced Aerodynamics**


**AS 5370     Helicopter Aerodynamics**

AS 5375  Dynamics and Control of Rotorcraft


AS 5380  Flight Testing and Performance Reduction


AS 5390  Numerical Methods in Gas Dynamics


AS 5400  Theory and Computation of Vortex Dominated Flows


AS 5410 Grid Generation 3003


AS 5420 Introduction to CFD 3003


AS 5430 Stability of Shear Flows 3003


AS 5440 Hydrodynamic Stability, transition and Flow control 3003

Introduction to linear instability and transition. Recent developments in instability methods: transient growths, global analysis, optimization and feedback mechanisms. Routes to turbulence, factors affecting different mechanisms and re-laminarization. Methods to achieve transition delay, lift augmentation, separation prevention, turbulence suppression, noise abatement and other flow control strategies. Transition control: Wall heating and cooling, wall motion, suction and blowing etc. Separation control: Velocity profile modifiers, shaping, heat transfer, turbulators, etc. Drag reduction: reduction of near-wall momentum, Toms effect, etc. Recent developments in flow control.

Basics of rotor dynamics, flapping equation with and without hinge offset, flapping equation with gravity, effects of yaw, introduction to stability and control. Basics of fatigue analysis. Effects of Turbulence, autocorrelation and cross-correlation, vonKarman spectrum, Taylor’s frozen turbulence hypothesis, turbulence seen in rotating frame, turbulence loading on wind turbines. Unsteady Aerodynamics, Theodorsen function, dynamic stall Introduction to acoustics, design aspects.

Classification of PDEs – elliptic, hyperbolic and parabolic; discrete representation of PDE using Finite difference Method: accuracy, consistency and stability of discretized PDE; dissipation and dispersion errors, stability analysis using von Neumann and matrix methods; finite volume method: basic concept; Linear model equation: 1-D (wave) advection equation – exact solution, notion of wave speed and characteristic, numerical solution using FDM and FVM; upwinding methods Non-linear model equation: Burgers’ equation – numerical solution to Burgers’ equation; Godunov’s scheme; shocks and centered expansions; shock speed System of linear equations: linear acoustics equations (1D), wave speeds / Eigen values and Eigen vectors, characteristic variables, Riemann problem and its solution, upwinding methods for system of equations; System of non-linear equations: Euler equations, conservation and quasi-linear form, flux Jacobian matrix, Eigen values and Eigen vectors, characteristic variables; Flux reconstruction methods for the Euler equation: flux- vector splitting schemes – van Leer, AUSM and LDFSS schemes; flux difference splitting scheme: Roe’s method; Higher order interface state reconstruction: MUSCL scheme with limiters; Higher order time integration: Runge-Kutta methods;

Airfoils and wings in steady motion. Analytical methods for the unsteady aerodynamic behaviour of oscillating airfoils and wings. 2D unsteady thin airfoil theory. 3D unsteady wing theory. Airfoils and wings undergoing arbitrary motion. Gust. Time domain and frequency domain analysis of unsteady flows. Kelvin impulse and apparent mass concept in unsteady flows. Aerodynamics of flapping and hovering bio-mimetic
flights. Numerical techniques for unsteady potential flows. Unsteady flow-field of natural invertebrates and aquatic animals and flapping-type MAVs. Discussion on 3D and Re effects.

AS 5540 Space Flight Dynamics

Conic Sections, Kepler’s Laws, Fundamentals of orbits, co-ordinate systems and transformations, Governing equations for two body system, Orbit representation in 3D, Keplerian orbital elements, Dynamics of rotating frames, Orbit determination - Laplace, Gauss, Lambert, and Gibbs methods, Orbit Perturbations, Orbit Manoeuvres, Restricted circular 3-body problem, Interplanetary mission design.

AS 5545 Dynamic and Control of Space Craft

To introduce students to spacecraft attitude dynamics, rigid and multi-body dynamic equations, spacecraft stabilization concepts, attitude determination and control design strategies etc.

Satellite dynamics as rigid body: Fundamentals of Equations of Rigid spacecraft Motion, using Newton, Lagrange and Hamiltonian approaches. Types of Satellite Stabilizations, Spin, gravity-gradient, Dual-spin, Momentum biased, zero-momentum biased concepts; Dynamics and control of spinning spacecraft, characteristics of spin dynamics — stability, precession and nutation; Dual spin concept and equations of motion. Dynamics and stability of bias-momentum and zero-momentum three-axis stabilized spacecraft; spacecraft dynamics as rigid multi-body with articulated antennas, rotating solar panels etc., methods of dynamical analysis. Modeling spacecraft perturbations / disturbance torques in orbit and torque-free attitude motion.


Control of Spacecrafts: spin-axis attitude and control. Control using dual-spin concept, problems and solutions, control using two momentum wheels configurations, with magnets and thrusters. Design of control system for three-axis stabilized spacecraft: using reaction wheels, thrusters etc. Estimation of spacecraft attitude states from sensor measurements, Kalman filters, mechanization of Kalman Filters for attitude estimation, PI, PID, PD controllers, spacecraft attitude maneuvers design, guidance
aspects, rest-to-rest attitude maneuvers, rate-to-rest and rest-to-rate attitude maneuvers.

**AS 5550  Aerospace Systems Control and Estimation  3003**

Frequency domain and state space technique; control law design using Nyquist diagrams and Bode plots; state feedback, state estimation, design of dynamic control laws; elementary analysis of non-linearities and their impact on control design, basic applications of control theory to aerospace systems, navigation, guidance.

**AS 5560  Dynamical Systems Stability and Bifurcations  3003**

Introduction to dynamical systems, existence and uniqueness of solutions, concepts of steady states and stability, stability theorem, 1-dimensional parameterized systems, fixed points, stability, and bifurcations, normal forms, 2-dimensional parameterized systems, nullclines, index theory, fixed points, periodic attractor, stability, and bifurcations, normal forms, Poincare'-Bendixson theorem, higher-dimensional systems, fixed points, stability, and bifurcations, chaos via bifurcations of steady states, periodic attractor, strange attractor, 2-dim iterative maps for 3-dim systems and their treatment, Iterative maps representing dynamical systems, periodic solutions, stability, Floquet multiplier, fractal dimensions.

**AS 5610  Rocket Propulsion  3003**

Chemical rocket performance: Thermochemical calculations. Liquid propellant rockets: Droplet combustion, feed system and ignition, injector design, combustion chamber geometry and cooling, nozzle design, thrust vector control. Solid propellant rockets: Combustion mechanisms, grain design, two phase flow, case fabrication problems. Combustion instability.

**AS 5615  Spacecraft Electric Propulsion  3003**

Basic orbital mechanics and astrodynamics, Introduction to rocket propulsion and rocket performance, comparison of chemical rockets and electrical rockets, introduction to electrodynamics, kinetic theory and non-equilibrium flows, basic plasma physics, electro-thermal propulsion (arcjets and resistojets), electrostatic propulsion (Hall thrusters, ion thrusters), electromagnetic propulsion (MPD thrusters, PPT thrusters).

**AS 5620  Theory and Design of Gas Turbines  3003**

**AS 5630 Performance of Gas Turbines**


**AS 5640 Combustion, Explosion and Detonation**


**AS 5650 Multiphase Flow**

Historical review: Need for such a study, various flow regimes, fundamental notations, definitions and experimental correlations. Basic relations: Homogeneous, separated and continuum mixture approaches for governing equation derivations.

Basic parameters and interactions. Transport properties and boundary condition. One-dimensional waves: Continuity and dynamic waves. Pipe flow sedimentary flow, boundary layer motion, flow over body and flat plates, cyclone separators, fluidized beds, gasification and combustion of coal, pneumatic transporters.

**AS 5660 Hypersonic Airbreathing Propulsion**

Introduction to hypersonic flight in the atmosphere and the propulsion requirements thereto. Thermodynamic, fluid mechanical, gas dynamic, and thermochemical background for supersonic combustion ramjets. Overall performance considerations of hypersonic propulsion systems and the need for supersonic combustion. Hypersonic airbreathing engine performance analysis. Component performance in inlets, combustors and exhaust nozzles. Other hypersonic airbreathing propulsion concepts, such as the detonation wave engines.

**AS 5670 Transport Processes in Reacting Flows**

**AS 5680  High Temperature Gas Dynamics**

Review of equilibrium gas properties, non-equilibrium and non-equilibrium kinetic theory. Equilibrium flow (Steady shocks, nozzle flow, Prandtl-Meyer flow, Frozen flow) Vibrational and Chemical rate processes (Vibrational rate equation, chemical rate equation, local relaxation times, small departures from equilibrium). Flow with Vibrational and chemical non-equilibrium (Equilibrium and frozen flow, non-linear equations, acoustical equations, speed of sound, sound propagation, small departures from uniform flow, linearised normal shock wave, dispersed shock wave, nozzle flow, MOC). Flow with translational non-equilibrium (transport properties, Bulk viscosity, structure of shock wave, linearised Couette flow). Radiative transfer in gases (Equation of radiative transfer, radiative equilibrium, radiation-solid surface interaction, Emission and absorption of radiation). Flow with radiative non-equilibrium (Basic non-linear equations, grey gas, 1D equations, normal shock wave).

**AS 5690  Radiation Heat Transfer**

Physics of thermal radiation, methods for evaluation of view factor, radiation exchange between gray, diffuse and partly specular solid surfaces, basic equations for radiation heat transfer in absorbing, emitting and scattering media, radiative properties of molecular gases, spectral models for radiative heat transfer (Narrow Band models, Wide Band models), approximate methods for radiation heat transfer in participating media (optically thick limit, optically thin limit, PN approximation, SN approximation), treatment of non gray gases. Radiation heat transfer application in space propulsion, microgravity combustion and re-entry problems.

**AS 5810  Theories of Modern Plate Structures**

Variational formulation of the classical theory of isotropic plates and counterparts for anisotropic, sandwich and layered plates and plates made up of functionally graded or piezoelectric materials. Combined bending and stretching.

Shear Deformation Theories: First-order Theory and Higher-order Theories based on global approximation and discrete layer approaches. Three-dimensional analysis.

Comparison of various theories for simple rectangular plate/strip problems.
AS 5820  Analysis of Plates and Shells  3003

Classical bending theory of thin flat rectangular and circular plates and with various edge conditions and loading.

Membrane and bending theories of thin shells of revolution. Analysis of circular cylindrical shells.

AS 5830  Approximate Methods in Structural Analysis  3003


AS 5840  Thermal Stress Analysis  3003

The basic equations of two-dimensional and three-dimensional thermoelasticity. Application of two-dimensional problems of elasticity, thermal stresses in beams, membranes and plates. Thermal buckling.

AS 5850  Finite Element Analysis  3003


AS 5860  Composite Structures  3003

AS 5870  Energy Methods in Structural Analysis 3003

The variational principle and the derivation of the governing equations of static and dynamic systems. Different energy methods: Rayleigh-Ritz, Galerkin etc. Application: Problems of stress analysis, determination of deflection in determinate and indeterminate structures, stability and vibrations of beams, columns and plates of constant and varying cross-sectional area.

AS 5880  Mechanics of Damage Tolerance 3003

Basics of Damage Tolerance: Strength vs. Damage Tolerance, Historic introduction and Molecular Interpretation.

Mathematical preliminaries: Vectors and Tensors, Complex Variables & Functions, Taylor’s and Laurent’s Series Expansions, Poles & Residues, Contour Integration.


Stress Analysis of Cracked Bodies: Stress Concentration in Circular and Elliptic Holes, Stress Intensity Factor, Fracture Modes, Other Analytical, Numerical and Experimental methods.


AS 5900  Elasticity 3003

Field equations of three dimensional elasticity; Theory of stress and strain, Generalised Hooke’s law, compatibility conditions, boundary conditions.

AS 5930  Elastic Stability 3003


Introduction to post-buckling of columns and plates, snap buckling of shallow arches and shells.
AS 5950  Continuum Mechanics  3003

Tensor Algebra, tensor Calculus, Kinematics of Deformation and Motion, Fundamental Laws and Equations (Conservation of mass, conservation of momentum, conservation of energy, restrictions of elastic materials by second law of thermodynamics, constitutive equations), Linear Elasticity, Kinematics of Fluid Motion, Classical Fluids, Linear Viscoelasticity, Non-linear Elasticity.

AS 5960  Advanced Strength of Materials  3003

Analysis of indeterminate beams: Clapeyron's equation for continuous beams - Analysis of frames and rings - Analysis of curved beams - Composite beams. Wide beams - Torsion of noncircular solid and thin-walled crosssections, Warping function.

AS 5970  Structural Dynamics and Aeroelasticity  3003

Review of vibration of discrete and continuous systems-Aspects of nonlinear dynamical system behaviour and solution techniques, some examples like Vander Pol oscillator, Duffing and Mathieu systems - Introduction to some advanced topics like coupled oscillations, rotating beams, random vibrations, unsteady aerodynamics.

Static aeroelasticity, wind tunnel models, divergence instability and aileron reversal - Aeroelastic flutter, stability characteristics and aeroelastic analysis of a typical section, classical flutter analysis and engineering solutions - introduction to nonlinear aeroelasticity.

AS 5980  Contacts Mechanics and Tribology  3003


AS 5990  Micromechanics  3003

Effective properties of composites: effective elastic properties of heterogeneous media, bounds on effective modulii: Voigt, Reuss and Hashin-Shtrikman bounds, self-consistent and Mori-Tanaka averaging methods. Comparison of different averaging methods, composite cylinders and composite spheres models for effective modulii, computational methods for periodic microstructures.

Elements of nanomechanics: types of defects in crystals, Fick’s laws of diffusion, elastic fields of dislocations, introduction to discrete methods in solid mechanics, molecular dynamics and discrete dislocation dynamics simulation methods.

AS 6000 Basic Concepts in Aerospace Engineering

Classification of Airplanes, Principles of flight, Flight Controls, Basic Instruments and aircraft systems, Helicopters.
Introduction to Wing and fuselage construction: functions of structural components; Structural idealization: Shear centre; Bending, shear and torsion of closed and open tubes; Multi-cell tubes; Brief discussion of buckling and postbuckling.

Basic equations of fluid flow: Generalized conservation law - integral form; Conservation of mass, momentum, energy - specialization to potential flow. Thin airfoil theory, effect of viscosity, finite wings, Prandtl’s lifting line theory. Area rule, sweep; Aircraft stability and control - maneuvers, longitudinal stability.

One-dimensional isentropic flow, Mach wave, flow with shocks, heat, and friction, oblique shocks, Prandtl-Meyer expansion, two-dimensional linearized subsonic flow. Introduction to air breathing engines: piston engine + Propeller, turbojet, turboprop, turbofan, ramjet, scram jet, and pulse jet. Introduction to non-air breathing engines: Solid propellant rockets, liquid propellant rockets, hybrid propellant rockets and other rockets. Introduction to hybrid engines: ducted ram rocket, solid fuel ram jet.

AS 6010 Hypersonic Flow Theory


AS 6015 Aerodynamics of Missiles and Launch Vehicles

Introduction to missiles and launch vehicles, bodies of revolution, non-circular shapes, lifting surfaces, low Aspect Ratio characteristics, wing - body - tail interference,
prediction of overall characteristics of body dominated configurations and lifting surface dominated configurations, high angle of attack aerodynamics, dynamic derivatives, boundary layer, shock wave - boundary layer interactions, aerodynamic heating, intake aerodynamics, engine-airframe integration, airframe flexibility effects on aerodynamics. Stage separation dynamics. Configuration design methodology of tactical missiles. Design methodology of multistage vehicles.

AS 6020 Introduction to Turbulent Flows and their Predictions 3003


AS 6030 Experimental Methods in Aero/Gas Dynamics 3014


AS 6040 Turbulent Flows and their computation 3003

1. Tensors functions and analysis
2. Random data analysis
3. Homogeneous Isotropic Turbulence
4. Homogeneous Anisotropic turbulence
5. Spectral Analysis and Navier Stokes Equations
6. Turbulence Modeling
7. Second order (Reynolds Stress) Modeling
8. DNS of Turbulent Flows
9. LES of Turbulent Flows
11. Dynamical Systems approach to Turbulent Flows

AS 6050 Dynamic Fluid Structure Interaction 3003

**AS 6060  Shockwave Dynamics**

**Unsteady 1-D flows:** Governing equations for non-stationary flows, Riemann invariants, finite amplitude waves, rarefaction and compression waves.


**Shock tube flows:** Wave systems in a shock tube - hot and cold gas regions, reflection of shock and rarefaction waves, collision of shockwaves, collision of rarefaction and shockwaves. Open end flows-spherical blast waves, various shock structures. Contact discontinuities-refraction of shock and rarefaction waves at a contact surface, Richtmeyer-Meshkov instability.

**Shock-boundary layer interactions (SBLI):** Physical background - structure of boundary layer flow-boundary layer response to a rapid pressure variation. Basic SBLI in 2-D flows - boundary layer-shock pressure jump competition. SBLI with and without separation.

**AS 6320  Acoustic Instabilities in Aerospace Propulsion**

Introduction to Acoustics; Derivation of the wave equation in both cartesian and polar co-ordinates, applications to problems. Fundamentals of Combustion Instability; Basic principles, instability in solid and liquid rockets and ramjets, passive and active control of combustion instability, pulse combustors. Theoretical Analysis of Combustion Instability. Measurement techniques.
AS 6330  Aeroacoustics


AS 6340  Combustion and Flow Diagnostics

Fundamentals of digital data acquisition, Dynamic transducers for transient measurements; Fundamentals of digital image processing, Lasers and laser safety: Principle and application of Particle Image Velocimetry (PIV) and Laser Doppler Velocimetry (LDV); Fundamentals of spectroscopy; Rayleigh scattering; Raman Scaterring, Laser Induced Fluorescence, and their application in species concentration and temperature measurements. Digital Background oriented Schlieren; Optical patternation for spray diagnostics

AS 6342  Spectroscopic Reactive Flow Diagnostics

Introduction to electromagnetic spectrum, review of quantum mechanics concepts. Absorption, emission, fluorescence, scattering processes. Planck's law, Beer's law, spectra and spectral lines, optical density; line position, line strengths and line shapes of spectral transitions; broadening mechanisms (natural, collision, Doppler, stark, instrument), line shape functions (Gaussian, Lorentzian, Voigt), line shifting mechanisms (pressure and Doppler shifts). Atomic and molecular spectra (diatomic & polyatomic); electric dipole moment (IR), induced polarization (Raman), elastic (Rayleigh) scattering; rotational (MW), vibrational (IR), ro-vibrational, electronic (UV & VIS) spectra; Rayleigh & Raman spectra. Quantitative emission and absorption, radiative transfer equation, spectral absorption coefficient, temperature dependence; pressure, temperature and species concentration measurements. Diagnostic techniques for gaseous flow and combustion: LIF, PLIF, Rayleigh scattering, spontaneous Raman scattering, coherent anti-Stokes Raman spectroscopy, cavity ring-down spectroscopy, laser absorption spectroscopy, TDLAS, LIBS, FTIR spectroscopy, LII. Spectroscopic softwares (HITRAN, LIFBASE).

AS 6510  Experimental Techniques in Structural Mechanics

Strain gauges : Mechanical, electrical, acoustic, pneumatic and other types of strain gauges. Associated circuits for electrical resistance strain gauges.

Analogies: Membrane, electrical analogies. Transducers; Pick-ups to measure displacement, velocity, acceleration and forces.

**AS 6520 Mathematics for Aerospace Engineers**


Review of basic Probability theory, Random variables, discrete and continuous distributions.

**ID 5040 Engineering Plasticity**

Phenomenon of plasticity, experimental facts, lumped parameter models, 1-D elasto-plastic problems - bending and torsion, three dimensional isotropic plasticity, yield criteria, flow rules, hardening laws, governing equations for small strain elasto-plasticity, integration algorithms, intro to finite deformation plasticity.

**ID 6080 Impact Mechanics**

Rigid body impact: Low-speed impact of rigid bodies, collinear impact, Two dimensional impact.
Impact of deformable bodies: Hertz contact problem, Elasto-plastic analysis of contact region, Elastic wave propagation during impact
Material response under high strain rate: Review of popular material models used for materials undergoing high strain rate (Elasto-plastic models, Johnson Cook Models etc.)
Experimental methods for impact analysis: Drop hammer tests, Split Hopkinsons bar experiment
Numerical methods for impact analysis: FEM models for high impact simulation, Review of case studies of specific applications such as, Vehicle crash analysis and Bird impact analysis