Indian Institute of Space Science and Technology

Thiruvananthapuram

M.Tech. Aerodynamics and Flight Mechanics
Curriculum and Syllabus

(Effective from 2019 Admission)

Department of Aerospace Engineering

Program Educational Objectives (PEO)

1. To establish strong foundations of fundamental knowledge with analytical and experiment skills in Aerospace Engineering.
2. To cultivate the practice of independent academic research along with innovation in aerodynamics and flight mechanics.
3. To promote academic research based on the contemporary technological needs of the industry and society.
4. To inculcate the process to be effective in technical communication and work as team.

Program Outcomes (PO)

1. An ability to independently carry out research /investigation and development work to solve practical problems.
2. An ability to write and present a substantial technical report/document.
3. Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program.
4. Capability to Innovate, design and analyze components related to aerospace engineering. Ability to perform multidisciplinary analysis involving aerodynamics, flight dynamics and control design for aerospace applications.
5. Ability to perform experimental and numerical simulations for modeling of aerospace systems.
6. Guidance to upkeep professional ethics in all scientific and engineering practices.

SEMESTER I

CODE	TITLE	L	T	P	C
AE601	Mathematical Methods in Aerospace Engg.	3	0	0	3
AE602	Compressible Flow	3	0	0	3
AE611	Aerodynamics	3	0	0	3
AE612	Atmospheric Flight Mechanics	3	0	0	3
AE613	Spaceflight Mechanics	3	0	0	3
E01	*Elective I*	3	0	0	3
	Total	18	0	0	18

SEMESTER II

CODE	TITLE	L	T	P	C
AE614	Flight Dynamics and Control	3	0	0	3
E02	*Elective II*	3	0	0	3
E03	*Elective III*	3	0	0	3
E04	*Elective IV*	3	0	0	3
E05	*Elective V*	3	0	0	3
AE801	Aerodynamics and Flight Mechanics Lab	0	0	6	2
	Total	15	0	6	17

SEMESTER III

CODE	TITLE	L	T	P	C
AE851	Seminar	0	0	0	1
AE852	Project Work – Phase I	0	0	0	17
	Total	0	0	0	18

SEMESTER IV

CODE	TITLE	L	T	P	C
AE852	Project Work – Phase II	0	0	0	17

LIST OF ELECTIVES

CODE	TITLE
AE701	Linear Algebra and Perturbation Methods
AE702	Numerical Methods for Scientific Computing
AE711	Experimental Aerodynamics
AE712	Aeroacoustics
AE713	Hypersonic Aerothermodynamics
AE714	Turbulence in Fluid Flows
AE715	Computational Methods for Compressible Flows
AE716	Navigation Guidance and Control
AE717	Optimal Control Theory
AE718	Space Mission Design
AE719	High Temperature Gas Dynamics
AE720	Multidisciplinary Design Optimization
AE721	Boundary Layer Theory
AE722	Introduction to Flow Instability
AE723	Applied Aerodynamics
AE724	Modern Aircraft Control Design
AE725	Modeling and Simulation of Aerospace Vehicles

Note: Electives from other streams may also be credited after approval

SEMESTER–WISE CREDITS

Semester	I	II	III	IV	Total
Credits	18	17	18	17	70

SEMESTER I

AE601 MATHEMATICAL METHODS IN AEROSPACE ENGINEERING (3 – 0 – 0) 3 Credits

Review of Ordinary Differential Equations: analytical methods, stability – Fourier series, orthogonal functions, Fourier integrals, Fourier transform – Partial Differential Equations: first-order PDEs, method of characteristics, linear advection equation, Burgers' equation, shock formation, Rankine-Hogoniot jump condition; classification, canonical forms; Laplace equation, min-max principle, cylindrical coordinates; heat equation, method of separation of variables, similarity transformation method; wave equation, d'Alembert solution – Calculus of Variations: standard variational problems, Euler-Lagrange equation and its applications, isoperimetric problems, Rayleigh-Ritz method, Hamilton's principle of least action.

References:

1. Brown, J. W. and Churchill, R. V., *Fourier Series and Boundary Value Problems*, 8th ed., McGraw-Hill, (2012).
2. Bleecker, D. D. and Csordas, G., *Basic Partial Differential Equations*, Van Nostrand Reinhold (1992).
3. Myint-U, T. and Debnath, L., *Linear Partial Differential Equations for Scientists and Engineers*, 4th ed., Birkhauser (2006).
4. Strauss, W. A., *Partial Differential Equations: An Introduction*, 2nd ed., John Wiley (2008).
5. Kot, M., *A First Course in the Calculus of Variations*, American Math Society (2014).
6. Gelfand, I. M. and Fomin, S. V., *Calculus of Variations*, Prentice Hall (1963).
7. Arfken, G. B., Weber, H. J., and Harris, F. E., *Mathematical Methods for Physicists*, 7th ed., Academic Press (2012).
8. Greenberg, M. D., *Advanced Engineering Mathematics*, 2nd ed., Pearson (1998).

Course Outcomes (COs):

CO1: Develop a general understanding of linear algebra in terms of vector spaces and its application to differential equations and Fourier analysis.

CO2: Ability to use Fourier analysis techniques for solving PDE and for signal analysis.

CO3: Formulate physical problems in terms of ODE/PDE and obtain analytical solutions.

CO4: Use commercial/open-source math packages for solving ODE and performing signal analysis.

AE602 COMPRESSIBLE FLOW (3 – 0 – 0) 3 Credits

1-D Gas Dynamics: governing equations – isentropic flow with area change, area-Mach number relations – R-H equations – normal shocks. 1-D Wave Motion: wave propagation – simple and finite waves – Reimann shock tube problem – 2-D waves, governing equations – oblique shocks, charts, shock polar and pressure deflection diagrams – Prandtl–Meyer expansion waves – reflection and interaction of waves – supersonic free jets. Linearized Flow: subsonic flow – Goethert's and Prandtl-Glauert rules – hodograph methods – supersonic flow – supersonic thin airfoils – 2-D airfoils – method of characteristics, the compatibility equation – applications, supersonic nozzle design – generalised one-dimensional flow: working equations – influence coefficients – combined friction and heat transfer

– combined friction and area change – conditions at sonic point – transonic flow – measurements in compressible flows.

References:

1. Shapiro, A. H., *Dynamics and Thermodynamics of Compressible Fluid Flow*, Vol. 1 & 2, Wiley & Sons (1953).
2. Liepmann, H. W. and Roshko, A., *Elements of Gasdynamics*, Dover Publications (2001).
3. Thompson, P. A., *Compressible Fluid Dynamics*, McGraw-Hill (1972).
4. Saad, M. A., *Compressible Fluid Flow*, 2nd ed., Prentice Hall (1993).
5. John, J. E. A. and Keith, T., *Gas Dynamics*, 3rd ed., Prentice Hall (2006).
6. Rathakrishnan, E., *Gas Dynamics*, 2nd ed., Prentice Hall (2009).

Course Outcomes (COs):

CO1: A clear understanding of thermodynamics and fluid dynamics of high-speed flows.

CO2: A clear perspective of the physics of various high-speed flow physics.

CO3: Capability to perform numerical examples-oriented tutorial/assignments in various high-speed flow physics.

CO4: Analysis and estimates of one dimensional flow situations.

CO5: Analysis and synthesis of isentropic flow with area change, normal shocks, Fanno flow and Rayleigh flow.

CO6: Analysis and synthesis of isentropic flow with normal/oblique shocks and expansion waves in propulsion systems.

CO7: Perform experiment/simulation/theoretical analysis of practical applications are envisaged through curse project.

AE611 **AERODYNAMICS** (3 – 0 – 0) 3 Credits

Introduction to tensors – Kinematics – Governing equations – Kelvin's theorem – Potential flow – Uniqueness and Kutta condition – Foundations of panel methods – Airfoils – Thin Airfoil Theory: Forces and moments on airfoil, flaps – Finite Wings: Prandtl lifting line theory, Induced drag, Elliptic lift distribution – 3D panel methods – Viscous Incompressible Flows: Prandtl boundary layer equation, Similarity solutions, Flow separation and stall – Introduction to turbulence – Turbulent boundary layer – Viscous-inviscid coupling – High lift devices – Swept wing – Delta wing.

References:

1. Anderson, J. D., *Fundamentals of Aerodynamics*, 5th ed., McGraw-Hill (2010).
2. Kuethe, A. M. and Chow, C.-Y., *Foundations of Aerodynamics*, 5th ed., John Wiley (1997).
3. Katz, J. and Poltkin, A., *Low-Speed Aerodynamics*, 2nd ed., Cambridge Univ. Press (2001).
4. Kundu, P. K., Cohen, I. M., and Dowling, D. R., *Fluid Mechanics*, 5th ed., Academic Press (2011).
5. White, F. M., *Viscous Fluid Flow*, 3rd ed., McGraw-Hill (2006).
6. Schlichting, H. and Gersten, K., *Boundary Layer Theory*, 8th ed., Springer (2001).
7. Karamcheti, K., *Principles of Ideal-Fluid Aerodynamics*, 2nd ed., Krieger Pub. Co. (1980).

Course Outcomes (COs):

CO1: Identify and formulate the correct set of assumptions and boundary conditions for aerodynamic force calculations for incompressible flow.

CO2: Apply analytical methods based on potential flow theory to estimate the aerodynamic force on finite wings in incompressible flow.

CO3: Develop numerical algorithms based on panel methods for aerodynamic analysis of simple configurations.

CO4: Use boundary layer theory to estimate viscous drag on simple configurations and apply corrections to potential flow based methods.

AE612 ATMOSPHERIC FLIGHT MECHANICS (3 – 0 – 0) 3 Credits

Overview of aerodynamics – propulsion – atmosphere and aircraft instrumentation – Aircraft Performance: range, endurance, gliding, climbing flight, pull-up, pulldown, take-off, landing, accelerating climb, turning flight, V-n diagrams – optimal cruise trajectories – Static Stability & Control: frames of reference (body axis, wind axis) static longitudinal, directional, lateral stability and control, stick fixed and stick free stability, hinge moments, trim-tabs, aerodynamic balancing.

References:

1. Anderson, J. D., *Aircraft Performance and Design*, Tata McGraw-Hill (1998).
2. Nelson, R. C., *Flight Stability and Automatic Control*, 2nd ed., Tata McGraw-Hill (1997).
3. Phillips, W. F., *Mechanics of Flight*, 2nd ed., John Wiley (2010).
4. Hull, D. G., *Fundamentals of Airplane Flight Mechanics*, Springer (2010).
5. Perkins, C. D. and Hage, R. E., *Airplane Performance Stability and Control*, John Wiley (1949).
6. McCormick, B. W., *Aerodynamics, Aeronautics, and Flight Dynamics*, 2nd ed., Wiley (1994).
7. Etkin, B. and Reid, L. D., *Dynamics of Flight: Stability and Control*, 3rd ed., Wiley (1996).
8. Smetana, F. O., *Flight Vehicle Performance and Aerodynamic Control*, 3rd ed., AIAA (2001).

Course Outcomes (COs):

CO1: Formulate the equations of motion for aircraft in various flight phases under equilibrium conditions with appropriate assumptions.

CO2: Define and derive the performance and stability attributes of aircraft in terms of the design variables for both jet and propeller propulsion units.

CO3: Develop the competency to evaluate out the performance and stability characteristics of any given aircraft.

CO4: Identify and evaluate the aircraft design parameters.

AE613 SPACEFLIGHT MECHANICS (3 – 0 – 0) 3 Credits

Dynamics of Particles: reference frames and rotations, energy, angular momentum – Two Body Motion: equations of motion, Kepler laws, solution to two-body problem, conics and relations, vis-viva equation, Kepler equation, orbital elements – orbit determination: Lambert problem, satellite tracking, different methods of solution to Lambert problem – Non-Keplerian Motion: perturbing acceleration-earth aspherical potential, oblateness, third body effects, atmospheric drag effects, application of perturbations – Orbit Maneuvers: Hohmann transfer, inclination change maneuvers, combined maneuvers, bi-elliptic maneuvers – Lunar/Interplanetary Trajectories: sphere of influence, methods of trajectory design, restricted three body problem, Lagrangian points – Rigid Body Dynamics: attitude control of spinning and non-spinning spacecrafts.

References:

1. Howard, D. C., *Orbital Mechanics for Engineering Students*, 2nd ed., Elsevier (2004).
2. Chobotov, V. A., *Orbital Mechanics*, 3rd ed., AIAA (2002).
3. Weisel, W. E., *Spaceflight Dynamics*, 3rd ed., McGraw-Hill (2010).
4. Brown, C. D., *Spacecraft Mission Design*, 2nd ed., AIAA (1998).
5. Escobal, P. R., *Methods of Orbit Determination*, Krieger Pub. Co. (1976).
6. Tewari, A., *Atmospheric and Spaceflight Dynamics: Modeling and Simulation with MATLAB and Simulink*, Birkhauser (2007).

Course Outcomes (COs):

CO1: Apply the basic conservation laws and concepts of orbital mechanics for problem solving.
CO2: Design, evaluate and select required orbits for spacecrafts around earth.
CO3: Evaluate and determine suitable orbital transfers needed for space mission design.

E01 ELECTIVE I (3 – 0 – 0) 3 Credits

- Refer list of electives

SEMESTER II

AE614 **FLIGHT DYNAMICS AND CONTROL** (3 – 0 – 0) 3 Credits

Equations of Motion: rigid body dynamics, coordinate transformation, Euler angle & quaternion formulation – Dynamics of Generic Fixed Wing Aircraft: 6-DoF equations of motion, linearized equations of motion, linearised longitudinal & lateral equations, aerodynamic derivatives – LTI system basics – Stability of Uncontrolled Motion: linearized longitudinal & lateral dynamics, modes of motion – Response to Control Inputs: transfer function, step response & frequency response characteristics – Feedback Control: stability augmentation, PID control, root-locus technique for controller design – Introduction to modern control theory.

References:

1. Etkin, B. and Reid, L. D., *Dynamics of Flight: Stability and Control*, 3rd ed., Wiley (1996).
2. Phillips, W. F., *Mechanics of Flight*, 2nd ed., John Wiley (2009).
3. Nelson, R. C., *Flight Stability and Automatic Control*, 2nd ed., Tata McGraw-Hill (1997).
4. Cook, M., *Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control*, 3rd ed., Elsevier (2012).
5. Stevens, B. L. and Lewis, F. L., *Aircraft Control and Simulation*, 2nd ed., Wiley (2003).
6. Stengel, R. F., *Flight Dynamics*, Princeton Univ. Press (2004).

Course Outcomes (COs):

CO1: Formulate the 6 DOF nonlinear and linearized equations of a conventional aircraft in flight about the equilibrium states.

CO2: Develop the competency to infer the stability and control derivatives of any given aircraft.

CO3: Deduce and analyze the longitudinal and lateral-directional modes.

CO4: Assess the handling qualities of a conventional aircraft.

CO5: Derive the transfer functions for aircraft motion for different control inputs.

CO6: Implement stability augmentation system and Autopilot for a conventional aircraft the using classical and modern control techniques.

E02 **ELECTIVE II** (3 – 0 – 0) 3 Credits

- Refer list of electives

E03 **ELECTIVE III** (3 – 0 – 0) 3 Credits

- Refer list of electives

E04 **ELECTIVE IV** (3 – 0 – 0) 3 Credits

- Refer list of electives

E05 ELECTIVE V (3 – 0 – 0) 3 Credits

- Refer list of electives

AE801 AERODYNAMICS AND FLIGHT MECHANICS LAB (0 – 0 – 6) 2 Credits

Basic Experiments in Low Speed Wind Tunnels – Measurement of Aerodynamic Forces and Moments – Measurements of Pressure and Velocity – Flow Visualisation Techniques – Transient Flows: Shock Waves, Detonation – Experiments in Supersonic Flows – Optical Flow Visualisation Methods – Measurement of Flow Generated Sound.

Study of Pull Up - Pull Down Maneuver – Flight Simulator – Flight Controls of a Helicopter – Propeller Performance Testing – Measurement of Performance Parameters in Flight.

Course Outcomes (COs):

CO1: Explain the principles of aerodynamics and flight mechanics experiments.
CO2: Evaluate and select appropriate experimental techniques to understand the physics.
CO3: Collaborative with colleagues to perform aerodynamics and flight mechanics experiments.
CO4: Post processing and analyzing of experimental data.
CO5: Collaborative with colleagues to disseminate the findings in the form of reports and presentations.

SEMESTER III

AE851	**SEMINAR**	(0 – 0 – 0) 1 Credit

AE852	**PROJECT WORK — PHASE I**	(0 – 0 – 0) 17 Credits

SEMESTER IV

AE852	**PROJECT WORK — PHASE II**	(0 – 0 – 0) 17 Credits

Electives

AE701 LINEAR ALGEBRA AND PERTURBATION METHODS (3 – 0 – 0) 3 Credits

Vector Space, norm, and angle – linear independence and orthonormal sets – row reduction and echelon forms, matrix operations, including inverses – effect of round-off error, operation counts – block/banded matrices arising from discretization of differential equations – linear dependence and independence – subspaces and bases and dimensions – orthogonal bases and orthogonal projections – Gram-Schmidt process – linear models and least-squares problems – eigenvalues and eigenvectors – diagonalization of a matrix – symmetric matrices – positive definite matrices – similar matrices – linear transformations and change of basis – singular value decomposition.

Introduction to perturbation techniques – asymptotic approximations, algebraic equations – regular and singular perturbation methods – application to differential equations – methods of strained coordinates for periodic solutions – Poincaré–Lindstedt method.

References:

1. Strang, G., *Introduction to Linear Algebra*, 4^{th} ed., Cambridge Univ. Press (2011).
2. Strang, G., *Linear Algebra and its Applications*, 4^{th} ed., Cengage Learning (2007).
3. Lang, S., *Linear Algebra*, 2^{nd} ed., Springer (2004).
4. Golub, G. H. and Van Loan, C. F., *Matrix Computations*, 4^{th} ed., Hindustan Book Agency (2015).
5. Nayfe, A. H., *Introduction to Perturbation Techniques*, Wiley-VCH (1993).
6. Bender, C. M. and Orszag, S. A., *Advanced Mathematical Methods for Scientists and Engineers: Asymptotic Methods and Perturbation Theory*, Springer (1999).

AE702 NUMERICAL METHODS FOR SCIENTIFIC COMPUTING (3 – 0 – 0) 3 Credits

Mathematical review and computer arithmetic – numbers and errors; Nonlinear equations; Direct methods for linear systems; Iterative Methods for Linear Systems; Eigenvalues and Eigenvectors – power method, inverse power method, QR method; Approximation Theory – norms, orthogonalization, polynomial approximation, piecewise polynomial approximation, trigonometric approximation, rational approximation, wavelet bases; Numerical Differentiation; Numerical Integration- Romberg Integration, Gauss Quadrature, Adaptive Quadrature; Numerical Ordinary Differential Equations – single step and multi-step methods, Runge-Kutta method, predictor corrector method, stiffness, stability, shooting methods; Introduction to parallel programming system architectures, shared and distributed memory programming, performance.

References:

1. John, A. T., *Scientific Computing- Vol I, II, III*, Springer, (2010).
2. Parviz, M., Fundamentals of Engineering Numerical Analysis, Cambridge, (2010).
3. Steven, C. C, *Applied Numerical Methods*, McGraw Hill, (2012).
4. Walter, G., Martin, J. G., Felix K., *Scientific Computing*, Springer, (2010).

5. A.S. Ackleh, E.J. Allen, R.B. Hearfott, P. Seshiyer, *Modern Numerical Analysis*, CRC, (2009).
6. A. Gilat, V. Subramaniam, *Numerical Methods for Engineers and Scientists*, Wiley, (2014).

AE711 — EXPERIMENTAL AERODYNAMICS — (3 – 0 – 0) 3 Credits

Concept of similarity and design of experiments – Measurement uncertainty – Design of subsonic, transonic, supersonic, hypersonic, and high enthalpy test facilities – Transducers and their response characteristics – Measurement of pressure, temperature, velocity, forces, moments, and dynamic stability derivatives – Flow visualization techniques: Optical measurement techniques, refractive index based measurements, scattering based measurements – Data acquisition and signal conditioning – Signal and image processing.

References:

1. Tropea, C., Yarin, A. L., and Foss, J. F. (Eds.), *Springer Handbook of Experimental Fluid Mechanics*, Springer (2007).
2. Taylor, J. R., *Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*, 2nd ed., University Science Books (1997).
3. Barlow, J. B., Rae Jr, W. H., and Pope A., *Low-Speed Wind Tunnel Testing*, 3rd ed., Wiley (1999).
4. Pope, A. and Goin, K., *High-Speed Wind Tunnel Testing*, Krieger Pub. Co. (1972).
5. Settles, G., *Schlieren and Shadowgraph Techniques*, 3rd ed., Springer (2001).
6. Mayinger, F. and Feldmann, O. (Eds.), *Optical Measurements: Techniques and Applications*, 2nd ed., Springer (2001).
7. Doeblin, E. O., *Measurement Systems: Applications and Design*, 5th ed., McGraw-Hill (2003).

AE712 — AEROACOUSTICS — (3 – 0 – 0) 3 Credits

Basics of acoustics – General theory of aerodynamic sound – Flow and acoustic interactions – Feedback phenomenon – Supersonic jet noise – Sonic boom – Noise radiation from rotors and fans – Aeroacoustic measurements.

References:

1. Pierce, A. D., *Acoustics: An Introduction to Its Physical Principles and Applications*, Acoustical Society of America (1989).
2. Dowling, A. P. and Ffowcs Williams, J. E., *Sound and Sources of Sound*, Ellis Horwood (1983).
3. Goldstein, M. E., *Aeroacoustics*, McGraw-Hill (1976).
4. Blake, W. K., *Mechanics of Flow-Induced Sound and Vibration, Volume I and II*, Academic Press (1986).
5. Crighton, D. G., Dowling, A. P., Ffowcs Williams, J. E., Heckl, M. A., and Leppington, F. A., *Modern Methods in Analytical Acoustics: Lecture Notes*, Springer-Verlag (1992).

AE713 HYPERSONIC AEROTHERMODYNAMICS (3 – 0 – 0) 3 Credits

Introduction to Hypersonic Flows – Inviscid Hypersonic Flow: Newtonian flow, Mach number independence, Hypersonic similarity, Blast wave theory, Hypersonic small disturbance theory, Stagnation region flow – Viscous Hypersonic Flow: Similarity parameters, Self-similar solutions, Hypersonic turbulent boundary layer, Reference temperature method, Stagnation region flow field, Viscous interactions – Real Gas effects: Inviscid equilibrium and non-equilibrium flows, Viscous high temperature flows – Experimental facilities – Hypersonic design considerations.

References:

1. Anderson, J. D., *Hypersonic and High-Temperature Gas Dynamics*, 2nd ed., AIAA (2000).
2. Rasmussen, M., *Hypersonic Flow*, Wiley (1994).
3. Bertin, J. J., *Hypersonic Aerothermodynamics*, AIAA (1994).
4. Hirschel, E. H., *Basics of Aerothermodynamics*, Springer (2005).
5. Hirschel, E. H., *Selected Aerothermodynamic Design Problems of Hypersonic Vehicles*, Springer (2009).

AE714 TURBULENCE IN FLUID FLOWS (3 – 0 – 0) 3 Credits

Introduction to turbulence – Equations of fluid motion – Statistical description of turbulent flows – Mean-flow equations – Space and time scales of turbulent motion – Jets, wakes and boundary layers – Coherent structures – Spectral dynamics – Homogeneous and isotropic turbulence – Two-dimensional turbulence – Coherent structures – Vorticity dynamics – Intermittency – Modeling of turbulent flows.

References:

1. Tennekes, H. and Lumley, J. L., *A First Course in Turbulence*, The MIT Press (1972).
2. Frisch, U., *Turbulence*, Cambridge Univ. Press (1996).
3. Davidson, P. A., *Turbulence: An Introduction to Scientist and Engineers*, Oxford Univ. Press (2004).
4. Pope, S. B., *Turbulent Flows*, Cambridge Univ. Press (2000).
5. Mathieu, J. and Scott, J., *An Introduction to Turbulent Flow*, Cambridge Univ. Press (2000).
6. Lesieur, M., *Turbulence in Fluids*, 2nd ed., Springer (2008).
7. Monin, A. S. and Yaglom, A. M., *Statistical Fluid Mechanics*, Dover (2007).
8. McComb, W. D., *The Physics of Fluid Turbulence*, Oxford Univ. Press (1992).

AE715 COMPUTATIONAL METHODS FOR COMPRESSIBLE FLOWS (3 – 0 – 0) 3 Credits

Basic equations – Hierarchy of mathematical models – Mathematical nature of flow equations and boundary conditions – Finite difference and finite volume methods – Analysis of Schemes: Numerical errors, stability, numerical dissipation – Grid generation – Wave equation – Numerical Solution of Compressible Euler Equation: Discontinuities and entropy, mathematical properties of Euler equation – Reconstruction-evolution – Upwind methods – Boundary conditions – Numerical solution of compressible Navier-Stokes equations – Turbulence Modeling: RANS, LES, DNS – Higher-order methods – Uncertainty in CFD: Validation and verification.

References:

1. Hirsch, C., *Numerical Computation of Internal and External Flows*, Vol. I & II, Wiley (1998).
2. Laney, C. B., *Computational Gasdynamics*, Cambridge Univ. Press (1998).
3. LeVeque, R. J., *Numerical Methods for Conservation Laws*, 2nd ed., Birkhauser (2005).
4. Hoffmann, K. A. and Chiang, S. T., *Computational Fluid Dynamics for Engineers*, Vol. I, II & III, Engineering Education Systems (2000).
5. Toro, E. F., *Riemann Solvers and Numerical Methods for Fluid Dynamics: A Practical Introduction*, 3rd ed., Springer (2009).
6. Blazek, J., *Computational Fluid Dynamics: Principles and Applications*, 2nd ed., Elsevier (2006).
7. Roache, P. J., *Fundamentals of Verification and Validation*, Hermosa Publishers (2009).

Course Outcomes (COs):

CO1: Discretize a partial differential equation (PDE), and recognize the type of PDE.

CO2: Formulate finite-difference and finite-volume schemes of the necessary order (spatial and temporal discretization).

CO3: Choose the finite-difference/finite-volume method and the number of boundary conditions based on the type of PDE.

CO4: Understand the various discretization errors and their implications for the outcome.

CO5: Learn about iterative procedures and error damping using iterative strategies.

CO6: Develop conventional second-order finite-volume algorithms using limiters.

CO7: Use advanced CFD tools to evaluate complex fluid-flow systems.

AE716 NAVIGATION GUIDANCE AND CONTROL (3 – 0 – 0) 3 Credits

Principles of Inertial Navigation: Components, two-dimensional navigation – Coordinate systems – 3D strapdown navigation system – Strapdown system mechanizations – Attitude representation – Navigation equations expressed in component form – Effects of elliptic earth – Inertial Sensors: Gyroscope principles, single-axis rate gyroscope, accelerometers, rate integrating gyroscope – Elements of guidance system – Guidance phases – Guidance trajectories – Guidance sensors – Classification of Guidance and Navigation Systems: Basic navigation systems, combined navigation systems – Classification of guidance systems – Three-point tactical guidance laws – Two-point Tactical Guidance Laws: Strategic guidance laws, UAVs guidance laws – Control systems-classical linear time invariant control systems – Transfer function representations – Stability – Time domain characteristics – PID controller design for aerospace systems – Frequency domain characteristics – Root locus – Nyquist and Bode plots and their application to controller design for aerospace systems.

References:

1. Zarchan, P., *Tactical and Strategic Missile Guidance*, 4th ed., AIAA (2002).
2. Siouris, G. M., *Missile Guidance and Control Systems*, AIAA (2004).
3. Titterton, D. H. and Weston, J. L., *Strapdown Inertial Navigation Technology*, AIAA (2004).

4. Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, 2nd ed., AIAA (2003).
5. Nise, N. S., *Control Systems Engineering*, Wiley India (2004).
6. Friedland, B., *Control System Design*, Dover (2005).

AE717 **OPTIMAL CONTROL THEORY** (3 – 0 – 0) 3 Credits

Problem formulation – Performance measures – Selection of performance measures – Dynamics programming – Optimal control law – Application to a routing problem – Recurrence relations – Computational procedures – Alternative approach through Hamiltonial-Jacobi-Bellman equation – Review of Calculus of Variations: Functionals involving several independent functions – Constrained minimization of functional – Optimal control: Variational approach – Necessary condition for optimal control – Pontryagin's minimum principle – Additional necessary conditions – Minimum time problems – Optimal control switches (bangbang control) – Numerical techniques for the solution of optimal control problem – Two point boundary value problem.

References:

1. Kirk, D. E., *Optimal Control Theory: An Introduction*, Dover (1998).
2. Bryson Jr., A. E. and Ho, Y.-C., *Applied Optimal Control: Optimization, Estimation, and Control*, Taylor & Francis (1975).
3. Subchan, S. and Zbikowski, R., *Computational Optimal Control: Tools and Practice*, Wiley (2009).
4. Naidu, D. S., *Optimal Control Systems*, CRC Press (2002).

AE718 **SPACE MISSION DESIGN** (3 – 0 – 0) 3 Credits

Launch vehicle ascent trajectory design – Reentry trajectory design – Low thrust trajectory design – Satellite constellation design – Rendezvous mission design – Ballistic lunar and interplanetary trajectory design – Basics of optimal control theory – Mission design elements for various missions – Space flight trajectory optimization – Direct and indirect optimization techniques – Restricted 3-body problem – Lagrangian points – Mission design to Lagrangian point.

References:

1. Osborne, G. F. and Ball, K. J., *Space Vehicle Dynamics*, Oxford Univ. Press (1967).
2. Hale, F. J., *Introduction to Space Flight*, Prentice Hall (1994).
3. Naidu, D. S., *Optimal Control Systems*, CRC Press (2002).
4. Chobotov, V., *Orbital Mechanics*, AIAA (2002).
5. Griffin, M. D. and French, J. R., *Space Vehicle Design*, 2nd ed., AIAA (2004).
6. Kirk, D. E., *Optimal Control Theory: An Introduction*, Dover (1998).

AE719 HIGH TEMPERATURE GAS DYNAMICS (3 – 0 – 0) 3 Credits

General features and applications of high temperature flows – Equilibrium Kinetic Theory: Maxwellian distribution, collision rates and mean free path – Chemical thermodynamics – Mixture of perfect gases, law of mass action – Statistical Mechanics: Enumeration of micro-states, energy distribution, contribution of internal structure – Equilibrium Flow: Ideal dissociating gas, equilibrium shock wave relations, nozzle flows – Vibrational and chemical rate processes – Flows with vibrational and chemical non-equilibrium.

References:

1. Vincenti, W. G. and Kruger, C. H., *Introduction to Physical Gas Dynamics*, Krieger Pub. Co. (1975).
2. Anderson, J. D., *Hypersonic and High-Temperature Gas Dynamics*, 2nd ed., AIAA (2006).
3. Clarke, J. F. and McChesney, M., *The Dynamics of Real Gases*, Butterworths (1964).
4. Brun, R., *Introduction to Reactive Gas Dynamics*, Oxford Univ. Press (2009).

Course Outcomes (COs):

CO1: Develop thermodynamic models for simple equilibrium and non equilibrium reacting gas mixtures.

CO2: Analyse 1D/Quasi 1D gas dynamic problems using equilibrium and simple thermo-chemical non-equilibrium air models.

CO3: Solve simple practically relevant high temperature equilibrium/non-equilibrium flows using appropriate scientific computing tools.

CO4: Devise methods for generating high enthalpy flows using ground test facilities for hypersonic flow simulation.

AE720 MULTIDISCIPLINARY DESIGN OPTIMIZATION (3 – 0 – 0) 3 Credits

Multidisciplinary Design Optimization (MDO): Need and importance – Coupled systems – Analyser vs. evaluator – Single vs. bi-level optimisation – Nested vs. simultaneous analysis/design – MDO architectures – Concurrent subspace, collaborative optimisation and BLISS – Sensitivity analysis – AD (forward and reverse mode) – Complex variable and hyperdual numbers – Gradient and Hessian – Uncertainty quantification – Moment methods – PDF and CDF – Uncertainty propagation – Monte Carlo methods – Surrogate modelling – Design of experiments – Robust, reliability based and multi-point optimisation formulations.

References:

1. Keane, A. J. and Nair, P. B., *Computational Approaches for Aerospace Design: The Pursuit of Excellence*, Wiley (2005).
2. Khuri, A. I. and Cornell, J. A., *Response Surfaces: Design and Analyses*, 2nd ed., Marcel Dekker (1996).
3. Montgomery, D. C., *Design and Analysis of Experiments*, 8th ed., John Wiley (2012).
4. Griewank, A. and Walther, A., *Evaluating Derivatives: Principles and Techniques of Algorithmic Differentiation*, 2nd ed., SIAM (2008).

5. Forrester, A., Sobester, A., and Keane, A., *Engineering Design via Surrogate Modelling: A Practical Guide*, Wiley (2008).

Course Outcomes (COs):

CO1: Convert complex design requirements to an optimisation problem statement.
CO2: Apply and analyse gradient and non-gradient optimisation algorithms for problem solution.
CO3: Create surrogate models to replace expensive analysis modules.
CO4: Solve optimisation problems under uncertainty.
CO5: Solve multi-objective optimisation problems.

AE721 **BOUNDARY LAYER THEORY** (3 – 0 – 0) 3 Credits

Governing equations for viscous fluid flow – Heat conduction and compressibility – Exact solutions – Laminar boundary layer approximations – Similar and nonsimilar boundary layers – Momentum integral methods – Separation of boundary layer – Compressible boundary layer equations – Recovery factor – Reynolds analogy – Similar solutions – Stability of boundary layer flows: Transition prediction and bypass transition – Turbulent Flows: Phenomenological theories – Reynolds stress – Turbulent boundary layer – Momentum integral methods – Turbulent free shear layer – Flow separation.

References:

1. Schlichting, H. and Gersten, K., *Boundary Layer Theory*, 8^{th} ed., McGraw-Hill (2001).
2. Batchelor, G. K., *Introduction to Fluid Dynamics*, 2^{nd} ed., Cambridge Univ. Press (2000).
3. White, F. M., *Viscous Fluid Flow*, 3^{rd} ed., McGraw-Hill (2006).
4. Pope, S. B., *Turbulent Flows*, Cambridge Univ. Press (2000).
5. Panton, R. L., *Incompressible Flow*, 4th ed., Wiley (2013).
6. Kundu, P. K., Cohen, I. M., and Dowling, D. R., *Fluid Mechanics*, 6th ed., Academic Press (2015).

Course Outcomes (COs):

CO1: Apply relevant approximations in governing equations suitable for a particular problem to understand the flow physics.
CO2: Apply concepts from the boundary layer theory to compute and /or understand the drag and heat transfer in laminar flows.
CO3: Apply concepts from the statistical description of turbulence to understand the flow characteristics.
CO4: Able to compute numerical solutions for boundary layer equations.
CO5: Analyse the results from analytical and numerical solutions and disseminate the findings in the form of reports.

AE722 **INTRODUCTION TO FLOW INSTABILITY** (3 – 0 – 0) 3 Credits

Introduction to stability – Review of dynamical systems concepts – Instabilities of fluids at rest – Stability of open shear flows: Inviscid and viscous theory, spatio-temporal stability analysis (absolute and convective instabilities) – Parabolized stability equation – Transient growth – Introduction to global instabilities.

References:

1. Charru, F., *Hydrodynamic Instabilities*, Cambridge Univ. Press (2011).
2. Drazin, P. G., *Introduction to Hydrodynamic Stability*, Cambridge Univ. Press (2002).
3. Drazin, P. G. and Reid, W. H., *Hydrodynamic Stability*, 2nd ed., CUP (2004).
4. Criminale, W. O., Jackson, T. L., and Joslin, R. D., *Theory and Computation of Hydrodynamic Stability*, Cambridge Univ. Press (2003).
5. Schmid, P. J. and Henningson, D. S., *Stability and Transition in Shear Flows*, Springer (2001).
6. Sengupta, T. K., *The Instabilities of Flows and Transition to Turbulence*, CRC Press (2012).

AE723 APPLIED AERODYNAMICS (3 – 0 – 0) 3 Credits

Panel methods – Unsteady potential flows – Compressible flow over wings – Axisymmetric flows and slender body theories – Boundary layer analysis – Viscous-inviscid coupling – Flight vehicle aerodynamics – Rotor aerodynamics – Low Reynolds number aerodynamics – Flapping wings – Two- and three-dimensional flow separation.

References:

1. Drela, M., *Flight Vehicle Aerodynamics*, MIT Press (2014).
2. Rom, J., *High Angle of Attack Aerodynamics*, Springer (1992).
3. Shyy, W., Aono, H., Kang, C.-K., and Liu, H., *An Introduction to Flapping Wing Aerodynamics*, Cambridge Univ. Press (2013).
4. Chattot, J. J. and Hafez, M. M., *Theoretical and Applied Aerodynamics*, Springer (2015).
5. Bisplinghoff, R. L., Ashley, H., and Halfman, R. L., *Aeroelasticity*, Dover (1996).
6. Telionis, D. P., *Unsteady Viscous Flows*, Springer (2012).

AE724 MODERN AIRCRAFT CONTROL DESIGN (3 – 0 – 0) 3 Credits

Fundamentals of matrix algebra and vector spaces – Solution of simultaneous equations for square, under-determined, and over-determined systems – Concepts of basis vector transformations – Similarity and adjoint transformations – Eigenvalues and eigenvectors – Jordan form – Characteristic equation – Analytic functions of square matrices and Cayley-Hamilton theorem – Concepts of state, state-space, state-vector – Methods for obtaining the system mathematical model in the state-space form – State-space Form for Aerospace Systems: Aircraft dynamics, missile dynamics, inertial navigation system – Solution of homogeneous state equations – Concept of fundamental matrix and state transition matrix – Methods for evaluating state transition matrix – Solution of nonhomogeneous equations – Phase variable and Jordan canonical forms – Controllability and observability of the systems, pole placement design with full state feedback – Introduction to optimal control.

References:

1. Friedland, B., *Control System Design: An Introduction to State-Space Methods*, McGraw-Hill (1987).
2. Dazzo, J. J. and Houpis, C. H., *Linear Control System Analysis and Design: Conventional and Modern*, McGraw-Hill (1995).
3. Etkin, B., *Dynamics of Atmospheric Flight*, Dover (2005).

AE725 MODELING AND SIMULATION OF AEROSPACE VEHICLES (3 – 0 – 0) 3 Credits

Introduction: Simulation classification – Objectives, concepts, and types of models – Modeling: 6-DOF models for aerospace vehicle with prescribed control surface inputs – Control Systems: Mechanical (structural), Hydraulic systems and their modeling – Block diagram representation of systems – Dynamics of aerospace vehicles – Pilot station inputs – Cues for the Pilot: Visual, biological, and stick force – Virtual Simulation: Fly-by-wire system simulation – Uncertainty Modeling & Simulation: Characterization of uncertainty in model parameters and inputs, use of simulation to propagate the uncertainty to system response, Monte Carlo simulation – Simulation of stiff systems – Differential algebraic equations – Applications: Modeling and simulation methodologies for a complex engineering system simulation, aerospace system simulation – Model Building Techniques: Parameter identification, system identification – Least square estimation, maximum likelihood estimation, Kalman filters, neural networks.

References:

1. Ogata, K., *System Dynamics*, 4th ed., Pearson Education (2004).
2. Doebelin, E. O., *System Dynamics: Modeling, Analysis, Simulation, Designs*, Marcel Dekker (1998).
3. Ljung, L., *System Identification: Theory for the User*, Prentice Hall (1987).
4. Jategaonkar, R., V., *Flight Vehicle System Identification: A Time Domain Methodology*, AIAA Progress in Aeronautics and Astronautics, Vol. 216 (2006).
5. Klein, V. and Morelli, E, A., *Aircraft System Identification: Theory and Practice*, AIAA Education Series (2006).