

Indian Institute of Space Science and Technology

Thiruvananthapuram



M.Tech. Aerodynamics and Flight Mechanics

Curriculum
(Effective from 2026 Admission)

Department of Aerospace Engineering

SEMESTER I

CODE	TITLE	L	T	P	C
AEXXX	Mathematical Methods in Aerospace Engg.	3	0	0	3
AEXXX	Compressible Flow	3	0	0	3
AEXXX	Aerodynamics	3	0	0	3
AEXXX	Flight Dynamics	3	0	0	3
AEXXX	Spaceflight Mechanics	3	0	0	3
AE8**	Scientific Computing Lab - 1	0	0	3	1
	Total	15	0	3	16

SEMESTER II

CODE	TITLE	L	T	P	C
E01	<i>Elective I</i>	3	0	0	3
E02	<i>Elective II</i>	3	0	0	3
E03	<i>Elective III</i>	3	0	0	3
E04	<i>Elective IV</i>	3	0	0	3
E05	<i>Elective V</i>	3	0	0	3
AE8**	Aerodynamics and Flight Mechanics Lab	0	0	3	1
AE8**	Scientific Computing Lab - 2	0	0	3	1
	Total	15	0	6	17

SEMESTER III

CODE	TITLE	L	T	P	C
AE8**	Seminar	0	0	0	1
AE8**	Project Work – Phase I	0	0	0	17
	Total	0	0	0	18

SEMESTER IV

CODE	TITLE	L	T	P	C
AE8**	Project Work – Phase II	0	0	0	17

LIST OF ELECTIVES

CODE	TITLE
AEXXX	Experimental Aerodynamics
AEXXX	Aeroacoustics
AEXXX	Hypersonic Aerothermodynamics
AEXXX	Turbulence in Fluid Flows
AEXXX	Computational Gas Dynamics
AEXXX	Navigation Guidance and Control
AEXXX	Optimal Control Theory
AEXXX	Space Mission Design
AEXXX	High Temperature Gas Dynamics
AEXXX	Multidisciplinary Design Optimization
AEXXX	Boundary Layer Theory
AEXXX	Introduction to Flow Instability
AEXXX	Applied Aerodynamics
AEXXX	Modern Aircraft Control Design
AEXXX	Modelling and Simulation of Aerospace Vehicles
AEXXX	Computational Plasma and Gas Dynamics
AEXXX	Unsteady Gas Dynamics

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

SEMESTER-WISE CREDITS

Semester	I	II	III	IV	Total
Credits	16	17	18	17	68

SEMESTER I

AEXXX MATHEMATICAL METHODS IN AEROSPACE ENGINEERING 3 - 0 - 0 - 3

Linear algebra: Vector Spaces and Matrices, Linear system of equations, Eigenvalues and eigenvectors, Orthogonality, Diagonalization and Similarity Transformations, Singular value decomposition – Vector Calculus: Fields, Gradient, Divergence, Curl and Integral theorems – Introduction to Complex Variables – Integral Transforms – Ordinary Differential Equations: Theory, analytical methods, system of equations and stability of fixed points – Partial Differential Equations: basics, classification, model equations and their solutions – Introduction to Calculus of Variations

References:

1. Strang, G., Introduction to Linear Algebra, Wellesley-Cambridge Press, Fourth Edition (2009).
2. Strang, G., Differential Equations and Linear Algebra, Wellesley-Cambridge Press (2014).
3. Kreyszig, E., Advanced Engineering Mathematics, John Wiley and Sons, 8th Revised Edition, 1999.
4. Boas, M. L., *Mathematical Methods in the Physical Sciences*, 3rd ed., Wiley (2005).
5. Gelfand, I. M. and Fomin, S. V., *Calculus of Variations*, Prentice Hall (1963).
6. Dasgupta, B., *Applied Mathematical Methods*, Pearson (2007).
7. Greenberg, M. D., *Advanced Engineering Mathematics*, 2nd ed., Pearson (1998).

AEXXX AERODYNAMICS 3 - 0 - 0 - 3

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 – 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 – 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).

AEXXX

FLIGHT DYNAMICS

3 - 0 - 0 - 3

Equations of Motion: Rigid body dynamics, Coordinate transformation, Euler angle & quaternion formulation, 6-DoF equations of motion in Body and Wind Reference Frames – Trim Analysis for Forces: Derivation of Trim Conditions for Level Flight, Glide, Climb and Coordinated Turn – Trim Analysis for Moments: Longitudinal Static Stability, Neutral Point (Stick-Fixed and Stick-Free), Lateral-Directional Static Stability – Perturbation and Linearization: Small perturbations theory, Linearised equations of motion for longitudinal & lateral dynamics, Aerodynamic and Control derivatives – Aircraft Dynamic modes: Short and Long Period modes for Longitudinal Dynamics, Roll, Spiral and Dutch Roll modes for Lateral-Directional Dynamics, Effect of trim variations on dynamic modes.

References:

1. Nelson, R. C., *Flight Stability and Automatic Control*, 2nd ed., Tata McGraw-Hill (1997).
2. Phillips, W. F., *Mechanics of Flight*, 2nd ed., John Wiley (2010).
3. Perkins, C. D. and Hage, R. E., *Airplane Performance Stability and Control*, John Wiley (1949).
4. McCormick, B. W., *Aerodynamics, Aeronautics, and Flight Dynamics*, 2nd ed., Wiley (1994).
5. Etkin, B. and Reid, L. D., *Dynamics of Flight: Stability and Control*, 3rd ed., Wiley (1996).
6. Cook, M., *Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control*, 3rd ed., Elsevier (2012).
7. Stevens, B. L. and Lewis, F. L., *Aircraft Control and Simulation*, 2nd ed., Wiley (2003).
8. Stengel, R. F., *Flight Dynamics*, Princeton Univ. Press (2004).
9. Pamadi, B. N., *Performance, Stability, Dynamics, and Control of Airplanes*, 2nd ed., AIAA Edu. Series (2004).

AEXXX

SPACEFLIGHT MECHANICS

3 - 0 - 0 - 3

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).

AEXXX

COMPRESSIBLE FLOW

3 - 0 - 0 - 3

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).

AE8***

SCIENTIFIC COMPUTING LAB - 1

0 - 0 - 3 - 1

Introduction to computer programming – Introduction to git – Interpolation – Numerical Techniques for ODEs: Initial and Boundary Value problems – Optimization Techniques.

SEMESTER II

E01	<i>ELECTIVE I</i>	3 credits
------------	--------------------------	------------------

E02	<i>ELECTIVE II</i>	3 credits
------------	---------------------------	------------------

E02	<i>ELECTIVE II</i>	3 credits
------------	---------------------------	------------------

E03	<i>ELECTIVE III</i>	3 credits
------------	----------------------------	------------------

E04	<i>ELECTIVE IV</i>	3 credits
------------	---------------------------	------------------

E05	<i>ELECTIVE V</i>	3 credits
------------	--------------------------	------------------

AE8**	AERODYNAMICS AND FLIGHT MECHANICS LAB	0 - 0 - 3 - 1
--------------	--	----------------------

Aerodynamics: Measurement of Aerodynamic Forces and Moments – Measurements of Pressure and Velocity – Flow Visualisation Techniques – Shock tubes.

Flight Mechanics: Study of Pull Up - Pull Down Maneuver – Introduction to Flight Simulator – Estimation of Neutral Point – Estimation of Drag Polar – Measurement of Moment of Inertia of an UAV.

AE8***	SCIENTIFIC COMPUTING LAB - 2	0 - 0 - 3 - 1
---------------	-------------------------------------	----------------------

Introduction to data analysis techniques – Introduction to parallel computing using MPI, OpenMP, – Introduction to Machine Learning.

SEMESTER III

AE8**	SEMINAR	1 credit
--------------	----------------	-----------------

AE8**	PROJECT WORK — PHASE I	14 credits
--------------	-------------------------------	-------------------

SEMESTER IV

AE8**	PROJECT WORK — PHASE II	17 credits
--------------	--------------------------------	-------------------

ELECTIVES

AEXXX

EXPERIMENTAL AERODYNAMICS

3 - 0 - 0 - 3

Concept of similarity and design of experiments – Measurement uncertainty – Design of sub-sonic, 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. Doebelin, E. O., *Measurement Systems: Applications and Design*, 5th ed., McGraw-Hill (2003).

AEXXX

AEROACOUSTICS

3 - 0 - 0 - 3

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 – Aeroacoustic suppression techniques – Introduction to CAA.

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).

AEXXX

HYPERSONIC AEROTHERMODYNAMICS

3 - 0 - 0 - 3

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).

AEXXX

TURBULENCE IN FLUID FLOWS

3 - 0 - 0 - 3

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).

Conservation Laws: Hierarchy of mathematical models - Mathematical nature of flow equations and boundary conditions - Concepts of characteristics - Riemann problem for linear equations - Finite difference and finite volume methods – Analysis of Schemes: Numerical errors, stability, numerical dissipation - Numerical Solution of Compressible Euler Equation: Discontinuities and entropy, mathematical properties of Euler equation - Reconstruction-evolution - Upwind methods - Godunov scheme - High resolution schemes: TVD and limiting - Approximate Riemann solvers - Temporal discretisation - Higher-order methods - Introduction to LES - 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. Jameson, A., *Computational Aerodynamics*, Cambridge Univ. Press (2022).
7. Anderson D.A., Tannehill J.C. and Pletcher R.H. *Computational Fluid Mechanics and Heat Transfer*, Cambridge University Press (2012).

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).

AEXXX

OPTIMAL CONTROL THEORY

3 - 0 - 0 - 3

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 Hamiltonian-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).

AEXXX

SPACE MISSION DESIGN

3 - 0 - 0 - 3

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).

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).

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).

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.

References:

1. Schlichting, H. and Gersten, K., *Boundary Layer Theory*, 8th ed., McGraw-Hill (2001).
2. Batchelor, G. K., *Introduction to Fluid Dynamics*, 2nd ed., Cambridge Univ. Press (2000).
3. White, F. M., *Viscous Fluid Flow*, 3rd 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).

Introduction to stability – Review of dynamical systems concepts – Linear stability equation – 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 – Non-modal stability: transient growth, optimal disturbance and optimal response – 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).

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).

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).

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).

Foundations of Gas Dynamics: Equations of gas dynamics, Shock waves and contact discontinuities, The Riemann Problem – Numerical Methods for Conservation Laws: finite volume methods, high-resolution methods – Introduction to Plasma Physics: basics of plasma physics, mathematical models in plasma physics – Numerical Methods for Problems in Plasma Physics: numerical schemes for MHD equations, particle in cell methods – Applications in Aerospace Engineering: Hypersonic flows, flow control by plasma actuators, electric propulsion – Other Applications: introduction to nuclear fusion.

References:

1. Toro EF, *Riemann Solvers and Numerical Methods for Fluid Dynamics*, Springer Berlin, Heidelberg, 2009.
2. LeVeque RJ, *Numerical Methods for Conservation Laws, Lectures in Mathematics*, ETH Zürich, 1992
3. Choudhuri AR., *The Physics of Fluids and Plasmas: An Introduction for Astrophysicists*, Cambridge University Press, 1998.

4. Goedbloed JPH, Poedts S., *Principles of Magnetohydrodynamics: With Applications to Laboratory and Astrophysical Plasmas*, Cambridge University Press; 2004.
5. Jardin S, *Computational Methods in Plasma Physics*, CRC Press, 2010.
6. Birdsall, C.K., Langdon, A.B., & Langdon, A.B., *Plasma Physics via Computer Simulation*, CRC Press, 1991.
7. Hirschel E H, *Basics of Aerothermodynamics*, Springer Cham, 2015
8. Anderson JD, *Hypersonic and High-Temperature Gas Dynamics*, AIAA, 2019.
9. Dan M. Goebel, Ira Katz, *Fundamentals of Electric Propulsion: Ion and Hall Thrusters*, John Wiley & Sons, Inc., 2008.

AEXXX

UNSTEADY GAS DYNAMICS

3 - 0 - 0 - 3

Fundamentals of unsteady gas dynamics, shock waves, expansion waves, detonation waves and related discontinuities, reflections and interaction of waves, shock tube problem, Non-ideal gas effects, viscosity effects.

References:

1. Thompson, P. A., *Compressible Fluid Dynamics*, McGraw Hill, 1971.
 2. Hayes, W. D., *Gas Dynamic Discontinuities*, Princeton University Press, 1960.
 3. Glass, I. I. and Sislian, J. P., *Nonstationary Flows and Shock Waves*, Oxford Univ. Press (1994).
 4. Ben-Dor, G., *Shock Wave Reflection Phenomena*, Springer (2007).
 5. George, R., *Nonsteady Duct Flow: Wave-diagram Analysis*, Dover Publications (1969).
 6. Courant, R and Friedrichs, K.O, *Supersonic Flow and Shock Waves*, Springer, (1948).
 7. Whitham, G. B., *Linear and Nonlinear Waves*, Wiley, (1999).
-