Indian Institute of Space Science and Technology

Thiruvananthapuram

M.Tech. Thermal and Propulsion

Curriculum & Syllabus (Effective from 2019 Admission)

Department of Aerospace Engineering

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
AE603	Elements of Aerospace Engineering	3	0	0	3
AE621	Fluid Dynamics	3	0	0	3
AE622	Aerospace Propulsion	3	0	0	3
AE623	Conduction and Radiation Heat Transfer	3	0	0	3
	Total	18	0	0	18

SEMESTER II

CODE	TITLE	L	T	P	C
AE624	Fundamentals of Combustion	3	0	0	3
AE625	Computational Fluid Dynamics	3	0	0	3
E01	*Elective I*	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
AE702	Thermal and Propulsion Lab	0	0	3	1
	Total	18	0	3	19

SEMESTER III

CODE	TITLE	L	T	P	C
AE751	Seminar	0	0	0	1
AE752	Project Work – Phase I	0	0	0	15
	Total	0	0	0	16

SEMESTER IV

CODE	TITLE	L	T	P	C
AE752	Project Work – Phase II	0	0	0	17

LIST OF ELECTIVES

CODE	TITLE
AE801	Linear Algebra and Perturbation Methods
AE831	Analytical Methods in Thermal and Fluid Science
AE832	Convective Heat Transfer
AE833	Cryogenic Engineering
AE834	Design and Modeling of Rocket Propulsion Systems
AE835	Turbomachines
AE836	Microscale and Nanoscale Heat Transfer
AE837	Hypersonic Air-Breathing Propulsion
AE838	Measurements in Fluid and Thermal Sciences
AE839	Spacecraft Thermal Control
AE840	Shockwave Dynamics
AE841	Two-Phase Flow and Heat Transfer
AE842	Optical & Laser Based Combustion Diagnostics
AE843	Physiological Fluid Mechanics
AE844	Instability and Transition of Fluid Flows

Courses from other streams may be taken as electives after due approval

SEMESTER–WISE CREDITS

Semester	I	II	III	IV	Total
Credits	18	19	16	17	70

SEMESTER I

AE601 MATHEMATICAL METHODS IN AEROSPACE ENGINEERING 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-Hugoniot 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*, Chapman & Hall (1995).
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 (2007).
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).

AE602 COMPRESSIBLE FLOW 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*, 2^{nd} ed., Prentice Hall (1993).
5. John, J. E. A. and Keith, T., *Gas Dynamics*, 3^{rd} ed., Prentice Hall (2006).
6. Rathakrishnan, E., *Gas Dynamics*, 2^{nd} ed., Prentice Hall (2009).

AE603 ELEMENTS OF AEROSPACE ENGINEERING 3 credits

History of aviation – types of flying machines – anatomy of an aircraft; fundamental aerodynamic variables – aerodynamic forces – lift generation – airfoils and wings – aerodynamic moments – concept of static stability – control surfaces; mechanism of thrust production – propellers – jet engines and their operation – elements of rocket propulsion; loads acting on an aircraft – load factor for simple maneuvers – Vn diagrams; aerospace materials; introduction to aerospace structures; basic orbital mechanics – satellite orbits; launch vehicles and reentry bodies.

References:

1. Anderson, J. D., *Introduction to Flight*, 7th ed., McGraw-Hill (2011).
2. Anderson, D. F. and Eberhardt, S., *Understanding Flight*, 2nd ed., McGraw-Hill (2009).
3. Szebehely, V. G. and Mark, H., *Adventures in Celestial Mechanics*, 2nd ed., Wiley (1998).
4. Turner, M. J. L., *Rocket and Spacecraft Propulsion: Principles, Practice and New Developments*, 3rd ed., Springer (2009).

AE621 FLUID DYNAMICS 3 credits

Basic Concepts, definition and properties of Fluids, Fluid as continuum, Lagrangian and Eulerian, Fundamentals and description, Velocity and stress field, Fluid Kinematics.
Governing Equations: Reynolds transport theorem, Integral Formulation of Conservation Laws, of Fluid Motion, Differential forms of governing equations: mass, and momentum conservation equations, Navier-Stokes equations, The Vorticity Equation, Euler's equation, Bernoulli's Equation.
Incompressible Steady Flow between Parallel Plates, Steady Axisymmetric Flows, Steady Axisymmetric Viscous Flows and Torsional Flows, Steady Two-Dimensional Rectilinear Flows, The Hele-Shaw Flow, Non-Newtonian Flow through a Circular Tube.
Incompressible Impulsively Started Plate: Stokes' First Problem, Diffusion of a Vortex Transient Sheet, Decay of a Line Vortex, Start-up of Plane Couette Flow, Channel Flow Viscous Induced by Movement of Walls, Pipe Flow Induced by Movement of Wall, Starting Flows, Flow between Parallel Plates due to Pressure Gradient, Starting Flow in a Long Circular Tube due to Pressure Gradient, Flow Inside an Impulsively Rotated Cylinder, Flow due to Oscillating Plate (Stokes' Second Problem)
Laminar Boundary layer equations: Boundary layer thickness, Boundary layers on a flat plate, similarity solutions, Integral form of boundary layer equations, Approximate Methods
Turbulent Flow: Introduction, Fluctuations and time-averaging, General equations of turbulent flow, Turbulent boundary layer equation, Flat plate turbulent boundary layer, Turbulent pipe flow, Prandtl mixing hypothesis, Turbulence modelling, Free turbulent flows.
Concept of small-disturbance: stability, Linear Stability Theory, Kelvin-Helmholtz Instability, Stability of Nearly Parallel Viscous Flows

References:

1. Kundu, P. K., Cohen, I. M., and Dowling, D. R., *Fluid Mechanics*, 5th ed., Academic Press (2015).
2. Young, Donald F., et al., *A brief introduction to fluid mechanics*, 5th ed., John Wiley and Sons (2010).
3. Muralidhar, K. and Biswas, G., *Advanced Engineering Fluid Mechanics*, 2nd ed., Narosa (2005).
4. White, F. M.and Corfield, I., *Viscous Fluid Flow*, 3rd ed., Tata McGraw-Hill (2006).

5. P S Bernard., *Fluid dynamics*, Cambridge university Press (2015).
6. G Buresti, *Elements of fluid dynamics*, Imperial college press (2012).

AE622 AEROSPACE PROPULSION 3 credits

Introduction to air-breathing and rocket propulsion systems – classification of air-breathing engines – thrust and performance evaluation – cycle analysis of ramjet, turbojet, turbofan, turboprop – diffuser and nozzle component analysis – combustion chambers – rocket propulsion systems classification – performance parameters of rocket propulsion – nozzle flow theory – chemical rockets – liquid rocket engine cycles – liquid propellants – solid propellant rockets.

References:

1. Farokhi, S., *Aircraft Propulsion*, Wiley (2009).
2. Sutton, G. P. and Biblarz, O., *Rocket Propulsion Elements*, 7th ed., Wiley (2001).
3. Flack, R. D., *Fundamentals of Jet Propulsion with Applications*, Cambridge Univ. Press (2005).
4. Hill, P. and Peterson, C., *Mechanics and Thermodynamics of Propulsion*, 2nd ed., Pearson (1992).
5. Mattingly, J. D., *Elements of Propulsion: Gas Turbines and Rockets*, AIAA Edu. Series (2006).
6. Mukunda, H. S., *Understanding Combustion*, 2nd ed., Macmillan (2009).
7. Ramamurthi, K., *Rocket Propulsion*, Macmillan (2010).

AE623 CONDUCTION AND RADIATION HEAT TRANSFER 3 credits

Heat conduction governing equation, extended surface heat transfer, multi-dimensional steady and unsteady conduction, conduction in semi-infinite domain, concept of superposition integral, applications, solidification and melting, inverse heat conduction. Laws of thermal radiation, radiation properties of surfaces, view factor for diffuse radiation, radiation exchange in black and diffuse gray enclosure, spectrally diffuse enclosure surfaces, specularly reflecting surfaces, Radiative transport equation in participating media, radiative properties of molecular gases, approximate solution methods for one dimensional media : Optically thick and optically thin approximations, gas radiation, combined conduction and radiation

References:

1. Incropera, F. P. and DeWitt, D. P., *Fundamentals of Heat and Mass Transfer*, 7th ed., John Wiley (2011).
2. Jiji, L.M, *Heat conduction* , 3rd ed., Springer (2009).
3. Hahn, D.W. and Özisik, M.N., *Heat conduction*, Wiley & Sons (2012).
4. Modest, M. F., *Radiation Heat Transfer*, 3rd ed., Academic Press (2013).
5. Howell, J.R., Menguc, M.P. and Siegel, R., *Thermal Radiation Heat Transfer*, 6th ed., CRC Press (2016).

SEMESTER II

AE624 FUNDAMENTALS OF COMBUSTION 3 credits

Classifications of combustion - thermo-chemistry – mass transfer – chemical kinetics - reaction mechanisms – combustion systems modeling with chemical kinetics – laminar premixed flames – turbulent premixed flames - detonation - laminar diffusion flames – turbulent diffusion flames - spray combustion – combustion instability – combustion diagnostics –solid combustion – emissions and its control

References:

1. Kuo, K. K., *Principles of Combustion*, 2nd ed., John Wiley (2005).
2. Glassman, I. and Yetter, R. A., *Combustion*, 4th ed., Elsevier (2008).
3. Warnatz, J., Maas, U., and Dibble, R. W., *Combustion* 4th ed., Springer (2006).
4. Lewis, B., and von Elbe. G, *Combustion, Flames and Explosions of Gases* Elsevier Inc (1987).
5. Williams, F.A., *Combustion Theory*, 2nd ed. (1984).
6. Turns, S. R., *An Introduction to Combustion*, 2nd ed., McGraw-Hill (2000).

7. Law C. K., *Combustion Physics*, Cambridge Univ. Press (2006).

AE625 COMPUTATIONAL FLUID DYNAMICS 3 credits

Mathematical models for fluid dynamics – classification of partial differential equations – discretization methods – finite difference formulation – numerical solution of elliptic equations – linear system of algebraic equations – numerical solution of parabolic equations – stability analysis – numerical solution of hyperbolic equations – finite volume method – time integration schemes – isentropic flow through CD nozzle – simulation of shockwave formation – incompressible Navier–Stokes equations and their solution algorithms – basics of grid generation.

References:

1. Hirsch, C., *Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics*, Vol. I, 2nd ed., Butterworth-Heinemann (2007).
2. Pletcher, R. H., Tannehill, J. C., and Anderson, D. A., *Computational Fluid Mechanics and Heat Transfer*, 3rd ed., Taylor & Francis (2011).
3. Hoffmann, K. A. and Chiang, S. T., *Computational Fluid Dynamics for Engineers*, 4th ed., Engineering Education Systems (2000).
4. Anderson, J. D., *Computational Fluid Dynamics: The Basics with Applications*, McGraw-Hill (1995).
5. Patankar, S. V., *Numerical Heat Transfer and Fluid Flow*, Hemisphere Pub. Corporation (1980).
6. Ferziger, J. H. and Perić, M., *Computational Methods for Fluid Dynamics*, 3rd ed., Springer (2002).
7. Roache, P. J., *Fundamentals of Computational Fluid Dynamics*, Hermosa Publishers (1998).
8. Fletcher, C. A. J., *Computational Techniques for Fluid Dynamics 1: Fundamental and General Techniques*, 2nd ed., Springer (1996).

E01 *ELECTIVE I* 3 credits

E02 *ELECTIVE II* 3 credits

E03 *ELECTIVE III* 3 credits

E04 *ELECTIVE IV* 3 credits

AE702 THERMAL AND PROPULSION LAB 1 credit

1. Flame speed measurement
2. Performance Analysis on TURBOJET engine
3. Performance Analysis on RAMJET engine
4. Performance Analysis on Axial fan
5. Flow regime mapping in a supersonic flow using non-intrusive techniques
6. Nozzle flow characterization

SEMESTER III

AE751 SEMINAR 1 credit

AE752 PROJECT WORK — PHASE I 15 credits

SEMESTER IV

AE752 PROJECT WORK — PHASE II 17 credits

ELECTIVES

AE801 LINEAR ALGEBRA AND PERTURBATION METHODS 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*, 4th ed., Cambridge Univ. Press (2011).
2. Strang, G., *Linear Algebra and its Applications*, 4th ed., Cengage Learning (2007).
3. Lang S., *Linear Algebra*, 2nd ed., Springer (2004).
4. Golub, G. H. and Van Loan, C. F., *Matrix Computations*, 4th 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).

AE831 ANALYTICAL METHODS IN THERMAL AND FLUID SCIENCE 3 credits

Special Functions, Bessel equation and related functions, Laplace transform methods: Inverse Laplace transform, Complex numbers, Bromwich Integral, bilateral laplace transforms, solution to ordinary and partial differential equation, Green function and boundary value problems, Fourier transform methods, Mellin transforms. Eigen Value problems and Eigen function expansions: Sturm-Liouville problems. Integral equations, Perturbation methods.

References:

1. Herron, I. and Foster, M., *Partial differential equations in fluid dynamics*, Cambridge Univ. Press (2008).
2. Telionis, D.P. and Telionis, D.P. *Unsteady viscous flows (Vol. 9)*, Springer-Verlag (1981).
3. Duffy, D.G., *Advanced Engineering Mathematics with MATLAB*, 4th ed., CRC Press (2016).
4. Greenberg, M, *Advanced Engineering Mathematics*, 2nd ed., Pearson Education (2015).

5. Myers, G. E., *Analytical Methods in Conduction Heat Transfer*, Genium Pub Corp (1987).
6. Bernhard Weigand, *Analytical methods for heat transfer and fluid flow problems*, Springer (2004).
7. Arfken, G.B. and Weber, H.J., *Mathematical Methods for Physicists*, 7^{th} ed., Academic Press (2012).

AE832 CONVECTIVE HEAT TRANSFER 3 credits

Introduction-– fundamental conservation equations; Navier-Stokes equations and energy equation– dimensionless parameters and order of magnitude analysis –boundary layer flows, boundary layer separation– External laminar flow solutions, free shear flows: Similarity solution and Integral solution approaches- Internal laminar flows, typical solutions-Fundamentals of incompressible turbulent mean flows –Introduction to turbulence models- free convection flows : similarity solution, free convection in enclosure: Rayleigh Bernard Convection, Mixed convection.

Textbooks:

1. Bejan, A., *Convection Heat Transfer*, Wiley, 3^{rd} ed., Wiley (2004).
2. Burmeister, L. C., *Convective Heat Transfer*, 2^{nd} ed., Wiley (1993).
3. Jiji, L. M., *Heat convection*, 2^{nd} ed., Springer, (2009).
4. Mostafa Ghiaasian, S, *Convective heat and mass transfer*, Cambridge Univ Press (2014).

AE833 CRYOGENIC ENGINEERING 3 credits

Cryogenic Engineering: Historical background and applications – gas liquefaction systems – gas separation and gas purification systems – cryogenic refrigeration systems – storage and handling of cryogens – cryogenic insulations – liquefied natural – gas-properties of materials of low temperatures – material of construction and techniques of fabrication – instrumentation – ultra-low temperature techniques – application.

References:

1. Barron, R. F., *Cryogenic Systems*, 2^{nd} ed., Oxford Univ. Press (1985).
2. Weisend, J. G., *The Handbook of Cryogenic Engineering*, Taylor & Francis (1998).

AE834 DESIGN AND MODELING OF ROCKET PROPULSION SYSTEM 3 credits

Elements of rocket propulsion – nozzle design, characteristic parameters, heterogeneous flow analysis – aerothermochemistry of combustion, dissociation, equilibrium composition, adiabatic temperature, and combustion product equilibrium flow nozzle expansion – elements of solid propellant system – internal ballistics and design of solid propellant – grain design and optimization – elements of liquid propulsion system – design and selection of injectors, combustion chambers, nozzle, cooling system, feed systems and tanks – combustion instability, low and high frequency instability and scaling – overall and optimized rocket performance – ideal velocity gain, gravitational losses, optimal mass ratio for multistage rockets, trajectory analysis, vertical flight of staged rocket, thrust programming along the path.

References:

1. Barrere, M., Jaumotte, A., de Veubeke, B. F., and Vandenkerckhove, J., *Rocket Propulsion*, Elsevier (1960).
2. Sutton, G. P. and Biblarz, O., *Rocket Propulsion Elements*, 7th ed., Wiley (2001).
3. Ramamurthi, K., *Rocket Propulsion*, Macmillan (2010).
4. Hill, P. and Peterson, C., *Mechanics and Thermodynamics of Propulsion*, 2nd ed., Pearson (1992).

AE835 TURBOMACHINES 3 credits

Introduction to Turbomachines. Dimensional Analyses and Performance Laws.

Axial Flow Compressors and Fans: Introduction – aero-thermodynamics of flow through an axial flow compressor stage – losses in axial flow compressor stage – losses and blade performance estimation, radial equilibrium equation – design of compressor blades – 2-D blade section design, axial compressor characteristics – multi-staging of compressor characteristics – high Mach number compressor stages – stall and surge phenomenon – low speed ducted fans.

Axial Flow Turbines: Introduction – turbine stage – turbine blade 2-D (cascade) analysis work done – degree of reaction – losses and efficiency – flow passage – subsonic, transonic and supersonic turbines – multi-staging of turbine – exit flow conditions – turbine cooling – turbine blade design – turbine profiles, airfoil data and profile construction.

Centrifugal Compressors: Introduction – elements of centrifugal compressor/fan – inlet duct impeller – slip factor – concept of rothalpy – modified work done – incidence and lag angles – diffuser – centrifugal compressor characteristics – surging, chocking, rotating stall.

Radial Turbine: Introduction – thermodynamics and aerodynamics of radial turbines – radial turbine characteristics – losses and efficiency.

References:

1. Cumpsty, N. A., *Compressor Aerodynamics*, 2nd ed., Krieger Pub. Co. (2004).
2. Johnsen, I. A. and Bullock, R. O. (Eds.), *Aerodynamic Design of Axial-Flow Compressors*, NASA SP-36 (1965).
3. El-Wakil, M. M., *Powerplant Technology*, McGraw-Hill (1985).
4. Glassman, A. J. (Ed.), *Turbine Design and Application*, NASA SP-290 (1972).
5. Lakshminarayana, B., *Fluid Dynamics and Heat Transfer of Turbomachinery*, Wiley (1995).
6. El-Sayed, A. F., *Aircraft Propulsion and Gas Turbine Engines*, CRC Press (2008).
7. Dixon, S. L. and Hall C. A., *Fluid Mechanics and Thermodynamics of Turbomachinery*, 7th ed., Butterworth-Heinemann (2014).

AE836 MICROSCALE AND NANOSCALE TRANSPORT PHENOMENA 3 credits

Introduction to microscale and nanoscale transport- basic phenomenon of conductive transport in nanoscale- basic aspects of quantum mechanics- basics of kinetic theory and statistical mechanics – thermodynamic relations– Boltzmann transport equation –microscale heat conduction– basics of electron and phonon transport – thermal conductivity models – Equilibrium breakdown and characterisation of flow regimes in micro and nano scale – continuum approach – heat transfer in Poiseuille microflows – single phase convection in micro channels–rarefied gas flows– Slip models– Burnett and Grad equations –boiling and condensation in mini and micro channels – introduction to microscale and nanoscale radiative transport- heat transfer enhancement using nanoparticles

References:

1. Chang-Lin Tien,, Arunava Majumdar, Frank M Gerner., *Microscale Energy Transport*.
2. Zhang, Z. M., *Nano/Microscale Heat Transfer*, McGraw-Hill (2007).
3. Van P. Carey, *Statistical thermodynamics and microscale physics*, Cambridge Press.
4. Panigrahi, P. K., *Transport Phenomena in Microfluidic Systems*, Wiley (2015).
5. Gang Chen, *Nanoscale Energy Transport and Conversion*, Oxford.
6. Amit Agrawal, Hari Mohan Kushawaha, Ravi Sudam Jadhav., *Microscale Flow and Heat Transfer- Mathematical Modeling and flow physics*.

AE837 HYPERSONIC AIR-BREATHING PROPULSION 3 credits

Hypersonic air-breathing propulsion – overview of hypersonic propulsion research – challenges in system design – system performance and analysis – hypersonic intakes – supersonic combustors – expansion systems – engine cooling – liquid air-cycle engines – space plane applications – experimental and testing facilities – CFD applications and simulation exercises.

References:

1. Heiser, W. H. and Pratt, D. T., *Hypersonic Air-breathing Propulsion*, The American Institute of Aeronautics and Astronautics Education Series (1994).
2. Curran, E. T. and Murthy, S. N. B. (Eds.), *Scramjet Propulsion*, The American Institute of Aeronautics and Astronautics Education Series (2001).
3. Segal, C., The Scramjet *Engine Processes and Characteristics*, Cambridge Univ. Press (2011).

AE838 MEASUREMENTS IN FLUID AND THERMAL SCIENCES 3 credits

Introduction configuration of an experimental set-up-error-calibration – uncertainty analysis, error propagation formula, analysis of scatter, design of experiments based on uncertainty – review of probes and transducers – integral measurements of volume, velocity and temperature – introduction to wind tunnels, open and closed circuit tunnels – optical instrumentation, lasers and coherent optics, refractive index variation in transparent media, interferometry, schlieren and shadowgraph methods, analysis of interferograms, Rayleigh scattering technique – transient response and instruments – zeroth, first and second order systems – treatment of spatially distributed variables – compensation and recovery of original signals from measured data – computerized data acquisition.

References:

1. Holman, J. P., *Experimental Methods for Engineers*, 7^{th} ed., Tata McGraw-Hill (2006).
2. Doebelin, E. O., *Measurement Systems: Application & Design*, 4^{th} ed., McGraw-Hill (1998).
3. Venkateshan, S. P., *Mechanical Measurements*, Ane Books, India (2008).
4. Meschede, D., *Optics, Light and Lasers*, 2^{nd} ed., Wiley-VCH (2007).

AE839 SPACECRAFT THERMAL CONTROL 3 credits

Introduction Spacecraft Thermal Control: need of spacecraft thermal control – temperature specification – energy balance in a spacecraft – modes of heat transfer – factors that influence energy balance in a spacecraft – principles of spacecraft thermal control.

Spacecraft Thermal Analysis: formulation of energy – momentum and continuity equations for problems in spacecraft heat transfer – development of discretized equation – treatment of radiative heat exchange (for non-participative media based on radiosity and Gebhart method) – incorporation of environmental heat flux in energy equation – numerical solution methods – input parameters required for analysis.

Spacecraft Thermal Environments: launch and ascent – earth bound orbits – interplanetary mission and reentry mission.

Devices and Hardware for Spacecraft TCS (Principles & Operation): passive thermal control - mechanical joints – heat sinks and doublers – phase change materials – thermal louvers and switches – heat pipes – thermal coating materials – thermal insulation – ablative heat transfer – active thermal control techniques: electrical heaters, HPR fluid systems, space borne cooling systems.

Design and Analysis of Spacecraft: application of principles described above for development of spacecraft TCS.

References:

1. Gilmore, D. G. (Ed.), *Spacecraft Thermal Control Handbook, Volume I: Fundamental Technologies*, 2^{nd} ed., The Aerospace Press, AIAA (2002).
2. Lyle, R., Stabekis, P. and Stroud, R, *Spacecraft thermal control*, NASA SP 8105 (1973).
3. Fortescue, P., Swinerd, G. and Stark, J. eds, *Spacecraft systems engineering*,7^{th} ed., John Wiley (2011).
4. Mayer, R. X., *Elements of Space Technology*, Academic Press (1999).

AE840 SHOCKWAVE DYNAMICS 3 credits

Hugoniot relation – normal shocks – unsteady 1-D flows – finite amplitude waves – characteristics – Riemann invariants – unsteady shock waves – shock tubes – shock tunnels – weak and strong shocks – shock interactions – reflections – shock-boundary layer interaction – shock polar – diffraction – shock focussing – contact discontinuities – Richtmyer–Meshkov instability – spherical blast waves – internal, near-field and external ballistics – various shock structures.

References:

1. Glass, I. I. and Sislian, J. P., *Nonstationary Flows and Shock Waves*, Oxford Univ. Press (1994).
2. Ben-Dor, G., *Shock Wave Reflection Phenomena*, Springer (2007).
3. George, R., *Nonsteady Duct Flow: Wave-diagram Analysis*, Dover Publications (1969).
4. Courant, R. and Friedrichs, K. O., *Supersonic Flow and Shock Waves*, Springer (1976).

AE841 TWO-PHASE FLOW AND HEAT TRANSFER 3 credits

Review of field equations in single phase flows – introduction to two-phase flows – basic averaging concepts- formulation and treatment of one-dimensional homogeneous flow model – separated flow model – drift flux model – simplified treatment of bubbly, slug, and annular flows –predictive methodologies for flow pattern transition in adiabatic and diabatic flows –Liquid-Vapour Phase Change Phenomenon: pool boiling – wetting phenomenon – bubble dynamics – nucleation concepts – convective boiling – heat transfer in partially and fully developed sub-cooled boiling – heat transfer in saturated boiling. Introduction to cryogenic two-phase flows-simple modelling of chilldown. Simple treatment of transient flow situations-Modelling instabilities using perturbation theory- Kelvin-Helmholtz stability, Rayleigh-Benard convection, Rayleigh-Taylor instability. Introduction to waves in fluids-analytical solution of sloshing in tank-introduction to levelset method

References:

1. Collier, J. G. and Thome, J. R., *Convective Boiling and Condensation*, 3rd ed., Oxford Univ. Press (2002).
2. Carey, V. P., *Liquid-Vapour Phase-Change Phenomenon: An Introduction to the Thermophysics of Vaporization and Condensation Process in Heat Transfer Equipment*, 2nd ed., Taylor & Francis (2007).
3. Wallis, G. B., *One-Dimensional Two-Phase Flow*, McGraw-Hill (1969).
4. Mostafa Ghiaasiaan, S., *Two-phase flow boiling and condensation in Conventional and Miniature systems*, Cambridge (2014).
5. Todreas, N.E. and Kazimi, M.S., *BoilingNuclear systems II: Elements of thermal hydraulic design (Vol. 2)*, Taylor & Francis (1990).
6. Kundu, P., Cohen, I., Dowling, D, *AdvancedFluid mechanics*, 6th ed., Academic Press (2015).

AE842 OPTICAL & LASER BASED COMBUSTION DIAGNOSTICS 3 credits

Role of Optical Diagnostic Techniques in Combustion Studies - Planar Imaging Systems (Lasers, Camera, Optics, Signal and Noise) - Optical Diagnostics (Shadowgraphy, Schlieren, Luminosity, Chemiluminescence) - Scattering Processes (Elastic, Inelastic) - Laser Diagnostics (Background Physics, Absorption, LIF, Rayleigh, Raman, CARS, LII, PIV, LDV, PDPA) - High speed Diagnostics - Simultaneous Diagnostics - Safety Procedures

References:

1. Alan C. Eckbreth, *Laser Diagnostics For Combustion Temperature and Species*, 3rd ed., CRC Press, 1996.
2. Ronald K. Hanson, *Spectroscopy and Optical Diagnostics for Gases*, Spearrin & Goldenstein; Springer, 2016.
3. Atkins., *Physical Chemistry*, Oxford University Press.
4. Franz Mayinger & Oliver Feldmann (Eds.), *Measurements:Techniques and Applications*, Springer, 2013.

AE843 PHYSIOLOGICAL FLUID MECHANICS 3 credits

Introduction to Physiological Fluid Mechanics; Review of Concepts in Fluid Mechanics, Kinematics, Hydrostatics, Conservation relations, Viscous Flow, Unsteady Flow; Clinical Fluid Dynamic Measurements; Analysis of Total Peripheral Flow; Circulatory Bio-fluid Mechanics, Blood Rheology, Blood Composition and Structure, Flow Properties of Blood, Blood Vessel Structure; Models of Biofluid Flow, Models of Blood Flow, Applications of Poiseuilli's Law for the study of Blood Flow; Introduction to Non-Newtonian Fluids, Power Law Model, Herschel-Bulkley Model, Casson Model, Non-Newtonian Flow in Elastic Tubes; Introduction to Heart Mechanics, Cardiac Geometry, Materials, and Electric System, Mechanical Cycle Events & Vent. Function Curve, Operation of Heart Valves, Blood Flow in Arteries, Shear Stress on Vessel Wall, Blood Vessel Bifurcation, Bifurcation Patterns, Uniform Shear Hypothesis

References:

1. J. N. Mazumdar, *Biofluid Mechanics*, World Scientific, 2004.
2. Y.C. Fung, *Biodynamics: Circulation*, Springer-Verlag NY, 1997.
3. AC.Ross Ethier and Craigg A. Simmons, *Introductory Biomechanics*, Cambridge texts in Biomedical Engineering, 2007.
4. C. Kleinstreuer, *Biofluid Dynamics: Principles and Applications*, CRC Press, 2006.
5. M. Zamir, *The Physics of pulsatile flow*, Springer-Verlag NY, 2000.
6. L. Waite, *Applied Biofluid Mechanics*, McGraw Hill, 2007.
7. L. Waite, *Biofluid Mechanics in Cardiovascular Systems*, McGraw-Hill , 2006.

AE844 INSTABILITY AND TRANSITION OF FLUID FLOWS 3 credits

Static and dynamic instability, causes and mechanism of instability normal mode analysis, global stability, role of viscosity- dynamical systems, equilibrium points, linearization, concept of limit cycles and other fixed points of a non-linear dynamical system, asymptotic stability and Lyapunov stability, steady and dynamic bifurcations, bifurcations in 1-D and 2-D non-linear dynamical systems, attractor bifurcations for nonlinear evolutions. Concept of linear stability analysis, Linearization of disturbance equations, three-dimensionality, squire transformation, Kelvin-Helmholtz stability, laminar mixing layer, Gaster transformation, centrifugal stability- Orr-Sommerfeld equations Evolution of flows with increasing Reynolds number, route to chaos and turbulence, instability of flow past a flat plate at zero incidence, jet and shear layer instability. The Boussinesq equations, free-free boundaries, rigid-rigid boundaries, free rigid boundaries. Benard problem, Couette-Benard flow, Rayleigh-Benard convection, Rayleigh-Taylor instability, Marangoni instability Basic aspects of two-phase flows, simple transient flow modelling in two-phase, concept of density wave oscillation, simple model for ledinegg instability, perturbation theory to model density wave oscillation in two-phase flow Temporal chaos in dissipative systems, strange attractors, fractional dimensions, quasiperiodicity, subharmonic cascade, intermittency.

References:

1. Drazin, P.G. and Reid, W.H., *Hydrodynamic stability*, Cambridge university press (2004).
2. Drazin, P.G., *Introduction to hydrodynamic stability*, Cambridge university press (2002).
3. White, F.M. and Corfield, I., *Viscous fluid flow*, 3rd ed., McGraw-Hill, (2006).
4. Kundu, P., Cohen, I., Dowling, D., *Fluid mechanics*, 6th ed., Academic Press, New York, NY, (2015).
5. Todreas, N.E. and Kazimi, M.S., *Nuclear Systems Volume I: Thermal Hydraulic Fundamentals*, CRC press. (2011).
6. Todreas, N.E. and Kazimi, M.S., *Nuclear systems II: Elements of thermal hydraulic design (Vol. 2)*, Taylor & Francis (1990).
7. Strogatz, S.H., *Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering*, CRC Press (2018).