Indian Institute of Space Science and Technology

Thiruvananthapuram

M.Tech. Thermal and Propulsion
Curriculum and Syllabus

(Effective from 2019 Admission)

Department of Aerospace Engineering

Program Educational Objectives (PEO)

1. To lay firm foundations of of fundamental knowledge, analytical and experiment skills in thermal sciences and propulsion engineering.
2. To inculcate independent academic research activities and practical system designs with innovation.
3. To promote academic research based on the current technological need of industry and research establishments.
4. Graduates shall express ideas/ solutions with crisp and straightforward communication and work as a team for the upliftment of society.

Program Outcomes (PO)

1. To impart core competency in the field of thermal and aerospace propulsion engineering.
2. A capability to research independently to analyze and resolve real-life problems in thermal sciences and Aerospace propulsion engineering.
3. An ability to comprehend and critically evaluate research articles, compile the technological gap, and provide an alternative solution in thermal sciences and Aerospace propulsion engineering.
4. Potential to judge the need for a system-level or multidimensional approach in resolving Thermal sciences and Aerospace propulsion engineering challenges
5. A capability to perform experiments, numerical simulation, and theoretical analysis; and paraphrase the outcome through mutual comparison.
6. A capacity to analyze their own academic/ research outcomes with logical interpretation, and to present/ publish a well written article
7. A capability to innovate, design and optimize thermal or propulsion engineering equipment
8. An ability to progressively update academic and professional knowledge to cope with the future technological challenges
9. 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
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
AE802	Thermal and Propulsion Lab	0	0	3	1
	Total	18	0	3	19

SEMESTER III

CODE	TITLE	L	T	P	C
AE851	Seminar	0	0	0	1
AE852	Project Work – Phase I	0	0	0	15
	Total	0	0	0	16

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
AE731	Analytical Methods in Thermal and Fluid Science
AE732	Convective Heat Transfer
AE733	Cryogenic Engineering
AE734	Design and Modeling of Rocket Propulsion Systems
AE735	Turbomachines
AE736	Microscale and Nanoscale Heat Transfer
AE737	Hypersonic Air-Breathing Propulsion
AE738	Measurements in Fluid and Thermal Sciences
AE739	Spacecraft Thermal Control
AE740	Shockwave Dynamics
AE741	Two-Phase Flow and Heat Transfer - I
AE742	Optical and Laser Based Combustion Diagnostics
AE743	Instability and Transition of Fluid Flows
AE744	Two-Phase Flow and Heat Transfer - II
AE745	Radiation Heat Transfer

Following courses may also be taken as electives after due approval from course coordinator:

CODE	TITLE
AE704	Operations Research
AE714	Turbulence in Fluid Flows
AE720	Multidisciplinary Design Optimization

SEMESTER–WISE CREDITS

Semester	I	II	III	IV	Total
Credits	18	19	16	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.

AE603 ELEMENTS OF AEROSPACE ENGINEERING (3 – 0 – 0) 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*, 7$^{\text{th}}$ ed., McGraw-Hill (2011).
2. Anderson, D. F. and Eberhardt, S., *Understanding Flight*, 2$^{\text{nd}}$ ed., McGraw-Hill (2009).
3. Szebehely, V. G. and Mark, H., *Adventures in Celestial Mechanics*, 2$^{\text{nd}}$ ed., Wiley (1998).
4. Turner, M. J. L., *Rocket and Spacecraft Propulsion: Principles, Practice and New Developments*, 3$^{\text{rd}}$ ed., Springer (2009).

Course Outcomes (COs):

CO1: Develop a basic understanding about the classification of aircraft and its anatomy.

CO2: Equip with fundamental aerodynamic concepts related to aircraft.

CO3: Develop a basic knowledge about aircraft performance, aerospace materials and structures.
CO4: Exposure to various air breathing engines and its working principle for thrust generation in aircraft.
CO5: Equip with the basics of rocket propulsion and orbital mechanics.

AE621 FLUID DYNAMICS (3 – 0 – 0) 3 Credits

Eulerian and Lagrangian approach – fluid kinematics: material derivative, rotation, deformation – Reynolds transport theorem – physical conservation laws – integral and differential formulations – Navier–Stokes and energy equations – exact solution of Navier–Stokes equations: steady and unsteady flows – potential flows: basic flow patterns, superposition – waves in fluids – boundary layer theory: momentum integral approach, Blasius solution, Falkner–Skan solutions – turbulent flows: time-averaged equations – closure problem – turbulence modeling.

References:

1. White, F. M., *Viscous Fluid Flow*, 3rd ed., Tata McGraw-Hill (2011).
2. Panton, R. L., *Incompressible Flow*, 4th ed., John Wiley (2013).
3. Kundu, P. K., Cohen, I. M., and Dowling, D. R., *Fluid Mechanics*, 5th ed., Academic Press (2012).
4. Leal, L. G., *Advanced Transport Phenomena*, Cambridge Univ. Press (2007).
5. Muralidhar, K. and Biswas, G., *Advanced Engineering Fluid Mechanics*, 2nd ed., Narosa (2005).
6. Schlichting, H. and Gersten, K., *Boundary Layer Theory*, 8th ed., McGraw-Hill (2001).

Course Outcomes (COs):
CO1:
CO2:
CO3:
CO4:

AE622 AEROSPACE PROPULSION (3 – 0 – 0) 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*, 2^{nd} ed., Macmillan (2009).
7. Ramamurthi, K., *Rocket Propulsion*, Macmillan (2010).

Course Outcomes (COs):

CO1: Gain a comprehensive understanding of various air-breathing and rocket propulsion systems, including their principles, components, and classifications.

CO2: Analyze and evaluate the thrust and performance of different propulsion systems, including the ability to perform detailed cycle analysis for air-breathing engines.

CO3: Conduct component-level analysis of propulsion system elements such as diffusers, nozzles, and combustion chambers, and understand their roles in the overall performance.

CO4: Acquire detailed knowledge of rocket propulsion systems, including solid and liquid propellant rockets, and understand the underlying principles of nozzle flow and rocket engine cycles.

CO5: Apply the acquired knowledge of propulsion systems to solve practical engineering problems, including the design, analysis, and performance evaluation of both air-breathing and rocket propulsion systems.

AE623 **CONDUCTION AND RADIATION HEAT TRANSFER** (3 – 0 – 0) 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. Jiji, L.M, *Heat conduction*, 3^{rd} ed., Springer (2009).
2. Hahn, D.W. and Ozisik, M.N., *Heat conduction*, Wiley & Sons (2012).
3. Vedat S Arpaci, *Conduction Heat Transfer*, Longman Higher Education
4. Incropera, F. P. and DeWitt, D. P., *Fundamentals of Heat and Mass Transfer*, 7^{th} ed., John Wiley (2011).
5. Modest, M. F., *Radiation Heat Transfer*, 3^{rd} ed., Academic Press (2013).
6. Howell, J.R., Menguc, M.P. and Siegel, R., *Thermal Radiation Heat Transfer*, 6^{th} ed., CRC Press (2016).

Course Outcomes (COs):

CO1: To understand the importance of conduction and radiation in the practical applications.

CO2: To be able to derive the heat diffusion equations in all coordinate systems.

CO3: Should be in a position to find the temperature profile for 2D and 3D spatial problems with different types of boundary conditions using analytical solutions.

CO4: Capable of solving 1D transient problems analytically.

CO5: To know the importance of radiation properties, solid angles, and their estimation.

CO6: To calculate the radiation heat transfer in an enclosure quantitatively using network method for black and grey surfaces.

CO7: To achieve the essential knowhow to estimate the view factor in the presence of spectrally diffusion and reflecting surfaces.

CO8: To calculated the radiative heat transfer between two surfaces in the presence of participating medium.

SEMESTER II

AE624 FUNDAMENTALS OF COMBUSTION (3 – 0 – 0) 3 Credits

Introduction to combustion, thermochemistry – mass transfer – chemical kinetics, reaction mechanisms – modeling of reactors – laminar premixed flames – detonation – laminar diffusion flames – droplet combustion – introduction to turbulence – turbulent premixed flames – combustion instability – combustion diagnostics – solid combustion.

References:

1. Turns, S. R., *An Introduction to Combustion*, 2^{nd} ed., McGraw-Hill (2000).
2. Glassman, I. and Yetter, R. A., *Combustion*, 4^{th} ed., Elsevier (2008).
3. Kuo, K. K., *Principles of Combustion*, 2^{nd} ed., John Wiley (2005).
4. Warnatz, J., Maas, U., and Dibble, R. W., *Combustion* 4^{th} ed., Springer (2006).
5. Law C. K., *Combustion Physics*, Cambridge Univ. Press (2006).
6. Lefebvre A. H., *Gas Turbine Combustion*, Taylor & Francis (1999).

Course Outcomes (COs):

CO1: Understand fundamental combustion concepts related to thermochemistry, chemical thermodynamics and basic mass transfer.

CO2: Acquire knowledge on chemical kinetics and reaction mechanisms for approaching combustion problems.

CO3: To derive and understand the governing equations for modelling reacting flows.

CO4: To acquire knowledge on the important aspects of premixed and nonpremixed flames.

CO5: To acquire basic knowledge on spray combustion and sold fuel combustion.

CO6: To know about combustion related emissions and its control.

AE625 COMPUTATIONAL FLUID DYNAMICS (3 – 0 – 0) 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, 2^{nd} ed., Butterworth-Heinemann (2007).
2. Pletcher, R. H., Tannehill, J. C., and Anderson, D. A., *Computational Fluid Mechanics and Heat Transfer*, 3^{rd} ed., Taylor & Francis (2011).
3. Hoffmann, K. A. and Chiang, S. T., *Computational Fluid Dynamics for Engineers*, 4^{th} 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).

Course Outcomes (COs):

CO1: To develop an understanding for major theories, approaches and methodologies used in CFD.

CO2: To understand the central difference, upwind, hybrid, power law, QUICK and other higher order schemes to convection-diffusion problems.

CO3: To understand the stability problems of the convection schemes, to understand the solution algorithms for pressure-velocity coupling.

CO4: To understand and use the finite volume method for one, two and three-dimensional steady state diffusion problems.

CO5: To apply the TDMA method for the solution of one, two and three-dimensional problems.

CO6: To gain experience in the application of CFD analysis to real life engineering designs.

CO7: Set up the most appropriate CFD model (in terms of boundary conditions, material properties, solution control parameters, solution monitor, etc.) for the problem in hand.

CO8: Explain how to conduct both Steady state and Transient (time dependent) fluid flow simulations.

CO9: Explain how to solve for both Incompressible and Compressible fluid flow applications.

CO10: Describe how and extract the required results and plots from the wealth of information available at the solution stage.

E01 **ELECTIVE I** (3 – 0 – 0) 3 Credits

- Refer list of electives

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

AE802 **THERMAL AND PROPULSION LAB** (0 – 0 – 3) 1 Credit

1. Flame speed measurement
2. Void fraction measurement
3. Cryogenic flow regimes identification
4. Experiments on film cooling
5. Flow over blade cascades
6. Nozzle flow characterization

Course Outcomes (COs):

CO1: The students will be able to perform propulsion experiments in a safe manner.

CO2: The students will learn about the working principle of some of the traditional and advanced propulsion systems used.

CO3: The students will learn to perform measurements in standard, laboratory-based propulsion devices/systems.

CO4: The student will learn to perform optical diagnostic techniques in combustion or propulsion environments.

CO5: The student will learn to document experimental test conditions and data measured professionally.

CO6: The students will learn to prepare scientific reports of the findings and present them in oral forms.

CO7: The student will learn to work efficiently in teams and perform propulsion experiments in a safe manner.

SEMESTER III

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

AE852 **PROJECT WORK — PHASE I** (0 – 0 – 0) 15 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*, 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).

AE731 **ANALYTICAL METHODS IN THERMAL AND FLUID SCIENCE** (3 – 0 – 0) 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, 7th ed., Academic Press (2012).

AE732 CONVECTIVE HEAT TRANSFER (3 – 0 – 0) 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.

References:

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

AE733 CRYOGENIC ENGINEERING (3 – 0 – 0) 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*, 2nd ed., Oxford Univ. Press (1985).
2. Weisend, J. G., *The Handbook of Cryogenic Engineering*, Taylor & Francis (1998).

AE734 DESIGN AND MODELING OF ROCKET PROPULSION SYSTEM (3 – 0 – 0) 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).

AE735 TURBOMACHINES (3 – 0 – 0) 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. Dixon, S. L. and Hall C. A., *Fluid Mechanics and Thermodynamics of Turbomachinery*, 7th ed., Butterworth-Heinemann (2014).
2. Seppo A Korpella., *Principles of Turbomachinery*, Wiley Publications (2011)
3. Hill, P. G. and Peterson, C. R., *Mechanics and Thermodynamics of Propulsion*, 2**nd** ed., Addison-Wesley (1992).
4. Erian A. Baskharone, *Principles of Turbomachinery in Air-Breathing Engines*, Cambridge University Press, (2006)
5. Edward M. Greitzer, Choon Sooi Tan, Martin B. Graf., *Internal Flow Concepts and Applications*, Cambridge (2010)
6. Cumpsty, N. A., *Compressor Aerodynamics*, 2nd ed., Krieger Pub. Co. (2004).
7. Johnsen, I. A. and Bullock, R. O. (Eds.), *Aerodynamic Design of Axial-Flow Compressors*, NASA SP-36 (1965).
8. El-Wakil, M. M., *Powerplant Technology*, McGraw-Hill (1985).
9. Glassman, A. J. (Ed.), *Turbine Design and Application*, NASA SP-290 (1972).
10. Lakshminarayana, B., *Fluid Dynamics and Heat Transfer of Turbomachinery*, Wiley (1995).

11. El-Sayed, A. F., *Aircraft Propulsion and Gas Turbine Engines*, CRC Press (2008).
12. Saed Farokhi, *Aircraft Propulsion*, 2^{nd} edition, Wiley (2014).

Course Outcomes (COs):

CO1: To be thorough with thermodynamic performance of diffusers, compressors, turbines, nozzles along with Euler turbine equation.

CO2: To study the performance of axial compressors with velocity triangle and dimensional analysis.

CO3: To design and analyse axial compressors based on Degree of reaction, Stability margin, Cascade analysis, and by following different vortex theories.

CO4: To know the importance of radial compressors.

CO5: To construct velocity triangles of radial compressor at different reactions.

CO6: To understand the performance of radial compressor based on non-dimensional analysis and stability.

CO7: To be familiar with velocity triangles of axial/ radial turbines as well as their difference from the compressors.

CO8: To know the different types of turbines based on reaction and their design.

AE736 MICROSCALE AND NANOSCALE HEAT TRANSFER (3 – 0 – 0) 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, T., Arunava M., Frank M. G., *Microscale Energy Transport*, Taylor & Francis (1998).
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. Agrawal, A., Kushwaha, H. M., & Jadhav, R. S., *Microscale Flow and Heat Transfer: Mathematical Modelling and Flow Physics*, Springer (2019).

AE737 HYPERSONIC AIR-BREATHING PROPULSION (3 – 0 – 0) 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).

AE738 HYPERSONIC AIR-BREATHING PROPULSION (3 – 0 – 0) 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*, 7th ed., Tata McGraw-Hill (2006).
2. Doebelin, E. O., *Measurement Systems: Application and Design*, 4th ed., McGraw-Hill (1998).
3. Venkateshan, S. P., *Mechanical Measurements*, Ane Books, India (2008).
4. Meschede, D., *Optics, Light and Lasers*, 2nd ed., Wiley-VCH (2007).

AE739 SPACECRAFT THERMAL CONTROL (3 – 0 – 0) 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).

AE740 **SHOCKWAVE DYNAMICS** (3 – 0 – 0) 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).

AE741 **TWO-PHASE FLOW AND HEAT TRANSFER – I** (3 – 0 – 0) 3 Credits

Review of field equations in single phase flows and heat transfer – introduction to two-phase flows – basic averaging concepts – formulation and treatment of one-dimensional homogeneous flow model – separated flow model – drift flux model – predictive methodologies for flow pattern transition in adiabatic and diabatic flows – Liquid-Vapour Phase Change Phenomenon: pool boiling – wetting phenomenon – nucleation and bubble growth – bubble dynamics – convective boiling – heat transfer in partially and fully developed sub-cooled boiling – heat transfer in saturated boiling – Condensation – condensation in the presence of non-condensable gases – Choked two-phase flows.

References:

1. J. G., Collier and J. R., Thome, *Convective Boiling and Condensation*, Oxford University Press, (1996).
2. Van, P. Carey, *Liquid-Vapour Phase-Change Phenomenon-An Introduction to The Thermophysics of Vapourisation and Condensation Process in Heat Transfer Equipment*, Taylor & Francis, (1992).

3. G. B. Wallis, *One-Dimensional Two-Phase Flow*, Mc Graw Hill, (1969).
4. Ghiaasiaan, S. M., *Two-phase Flow Boiling and Condensation in Conventional and Miniature systems*, Cambridge, (2014)

Course Outcomes (COs):

CO1: The student would be able to do a 1D model of typical real life application.
CO2: Be able to solve typical two-phase flow problems using mixture models.
CO3: Be able to size typical two-phase flow systems for given requirements.

AE742 OPTICAL AND LASER BASED COMBUSTION DIAGNOSTICS (3 – 0 – 0) 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).

Course Outcomes (COs):

CO1: The student should be able to decide on the kind of optical or laser based diagnostic methodology that needs to be implemented for the investigation of the combustion system of interest.

CO2: The student will be having awareness in deciding the different components and specification of the laser diagnostic system required.

CO3: The student will be able to better understand and appreciate peer reviewed literature/reports where optical and laser diagnostic methods are used for investigations.

CO4: The student should be able to write scientific reports with good analysis of the experimental data and discuss on the limitations of the methods used.

AE743 INSTABILITY AND TRANSITION OF FLUID FLOWS (3 – 0 – 0) 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 – OrrSommerfeld 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 Volume II: Elements of thermal hydraulic design*, Taylor & Francis (1990).
7. Strogatz, S.H., *Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering*, CRC Press (2018).

AE744 **TWO-PHASE FLOW AND HEAT TRANSFER – II** (3 – 0 – 0) 3 Credits

Generalised flow field equation in two-phase flows – Eulerian averaging –modelling perspectives – one dimensional two-fluid model – modelling annular flow, slug flow and bubbly flow – fluid dispersions – flows with particles of one phase in turbulent field of another phase gas-particle flows in rocket nozzle, Compressible two-phase flows – 1d transient two-phase flow. Cavitation, Simple modelling of cavitating flows.

Interfacial waves – dynamic behaviour of interface – linear stability analysis – Kelvin-Helmholtz instability, Rayleigh-Taylor Instability – application to typical cases – linear stability analysis in 1D two phase flows and some typical situations – Introduction to waves in fluids-analytical solution of sloshing in tank – introduction to level set and volume of fluid methods. Introduction to Interface tracking problem solving using diffuse interface methods.

Introduction to liquefaction of gases-cryogenic two-phase flows – chilldown modelling. Liquid Vapour phase change behaviour under reduced gravity conditions.

References:

1. M.Ishii and T.Hibiki, *Thermo-Fluid Dynamics of Two-Phase Flows*, Springer, 2006.
2. Ghiaasiaan, S. M., *Two-phase Flow Boiling and Condensation in Conventional and Miniature systems*, Cambridge, (2014)
3. Todreas, N.E., Kazimi, M.S. and Massoud, M., *Nuclear Systems Volume II: Elements of Thermal Hydraulic Design*, CRC Press, (2021).

4. Faghri, A. and Zhang, Y., *Fundamentals of Multiphase Heat Transfer and Flow*, Springer, 2020.
5. Franc, J.P. and Michel, J.M., *Fundamentals of cavitation*, Kluwer Academic Press (2004).
6. Filina, N. N. and JG Weisend, I. I., *Cryogenic Two-Phase Flow: Applications to Large Scale Systems*, Cambridge University Press, (1996).

Course Outcomes (COs):

CO1: Be able to handle engineering solutions to two-phase problems in different situations.
CO2: Be able to size typical two-phase flow systems for given requirements.

AE745 RADIATION HEAT TRANSFER (3 – 0 – 0) 3 Credits

Overview of thermal radiation, radiation properties of surfaces, view factor for diffuse radiation,radiation exchange in black and diffuse gray enclosure, spectrally diffuse enclosure surfaces, secularly reflecting surfaces, Monte Carlo ray tracing, Windows, Coatings, Introduction to satellite thermal control.

Radiative transport equation in participating media, approximate solution methods for one dimensional media: Optically thick and optically thin approximations. Formal solution and one dimensional transfer. Moment methods: diffusion and spherical harmonics. Gas Radiation:Introduction to gas radiation, Plane parallel model, Diffusion approximation, radiative equilibrium,Optically thick limit, radiation spectroscopy, Isothermal gas emissivity, band models, total emissivity method, Isothermal gas enclosures.

Radiative transfer in absorbing, emitting, and scattering media. The discrete ordinates method: spatial and angular discretization, false scattering and ray effects, the finite volume method. Handling interaction with other modes, heat radiation at micro/nanoscales.

References:

1. Modest, M. F., and Mazumder, S., *Radiative Heat Transfer*, 4^{th} ed., Academic Press (2021).
2. Brewster, M. Q., *Thermal Radiative Transfer and Properties*, John Wiley & Sons (1992).
3. Howell, J.R., Mengüç, M. P., Daun, K. and Siegel, R., *Thermal Radiation Heat Transfer*, CRC press (2020).
4. Mahan, J.R., *Radiation Heat Transfer: A Statistical Approach*, John Wiley & Sons, (2002).
5. J., Meseguer, I. Pérez-Grande, and A. Sanz-Andrés, *pacecraft Thermal Control*, Woodhead Publishing, (2012).