Department of Space Engineering and Rocketry
Birla Institute of Technology, Mesra, Ranchi - 835215 (India)

M. Tech. in Aerospace Engineering

Institute Vision

To become a Globally Recognized Academic Institution in consonance with the social, economic and ecological environment, striving continuously for excellence in education, research and technological service to the National needs.

Institute Mission

- To educate students at Undergraduate, Post Graduate Doctoral and Post-Doctoral levels to perform challenging engineering and managerial jobs in industry.
- To provide excellent research and development facilities to take up Ph.D. programmes and research projects.
- To develop effective teaching and learning skills and state of art research potential of the faculty.
- To build national capabilities in technology, education and research in emerging areas.
- To provide excellent technological services to satisfy the requirements of the industry and overall academic needs of society.

Department Vision

To effectively integrate teaching, research and innovation for significant contribution towards National Aerospace Programmes and related activities

Department Mission

- To impart quality education and advanced research training leading to postgraduate and doctoral degree
- To generate modern infrastructure and conducive research atmosphere for carrying out innovative sponsored research projects
- To nurture spirit of excellence and professional leadership in students and faculty members through exposure to leading academic/research organisations and external experts
- To create attractive opportunities for sustained interaction and collaboration with academia and industry

Program Educational Objectives (PEO) - (Aerospace Engineering)

PEO 1: To develop strong foundation in students to understand and analyse advance research problems in Space Engineering and Rocket Science.
PEO 2: Nurture professional graduates to develop ability in analysing real-life problems of Space Technology.
PEO 3: To foster attitude towards continuous learning for developmental activities in research, academia and industry.
PEO 4: To improve professional skills for teamwork with ethical awareness and practice in achieving goal.

Graduate Attributes (GAs)

GA1: Scholarship of Knowledge

Acquire in-depth knowledge of specific discipline or professional area, including wider and global perspective, with an ability to discriminate, evaluate, analyse and synthesise existing and new knowledge, and integration of the same for enhancement of knowledge.

GA2: Critical Thinking

Analyse complex engineering problems critically, apply independent judgement for synthesising information to make intellectual and/or creative advances for conducting research in a wider theoretical, practical and policy context.

GA3: Problem Solving

Think laterally and originally, conceptualise and solve engineering problems, evaluate a wide range of potential solutions for those problems and arrive at feasible, optimal solutions after considering public health and safety, cultural, societal and environmental factors in the core areas of expertise.

GA4: Research Skill

Extract information pertinent to unfamiliar problems through literature survey and experiments, apply appropriate research methodologies, techniques and tools, design, conduct experiments, analyse and interpret data, demonstrate higher order skill and view things in a broader perspective, contribute individually/in group(s) to the development of scientific/technological knowledge in one or more domains of engineering.

GA5: Usage of modern tools

Create, select, learn and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities with an understanding of the limitations.

GA6: Collaborative and Multidisciplinary work

Possess knowledge and understanding of group dynamics, recognise opportunities and contribute positively to collaborative-multidisciplinary scientific research, demonstrate a capacity for self-management and teamwork, decision-making based on open-mindedness, objectivity and rational analysis in order to achieve common goals and further the learning of themselves as well as others.

GA7: Project Management and Finance

Demonstrate knowledge and understanding of engineering and management principles and apply the same to one's own work, as a member and leader in a team, manage projects efficiently in respective disciplines and multidisciplinary environments after consideration of economical and financial factors.

GA8: Communication
Communicate with the engineering community, and with society at large, regarding complex engineering activities confidently and effectively, such as, being able to comprehend and write effective reports and design documentation by adhering to appropriate standards, make effective presentations, and give and receive clear instructions.

GA9: Life-long Learning
Recognise the need for, and have the preparation and ability to engage in life-long learning independently, with a high level of enthusiasm and commitment to improve knowledge and competence continuously.

GA10: Ethical Practices and Social Responsibility
Acquire professional and intellectual integrity, professional code of conduct, ethics of research and scholarship, consideration of the impact of research outcomes on professional practices and an understanding of responsibility to contribute to the community for sustainable development of society.

GA11: Independent and Reflective Learning
Observe and examine critically the outcomes of one's actions and make corrective measures subsequently, and learn from mistakes without depending on external feedback.

Program Outcomes (PO)

Common:
PO 1: An ability to independently carry out research and development work to solve practical problems in Aerospace Engineering.
PO 2: An ability to write and present substantial technical report and research article
PO 3: Students should be able to demonstrate a degree of mastery over and above the bachelor program in the areas of Aerospace Engineering.

Program Specific:
PO 4: Ability to design, perform and interpret data from experiments and correlate them with numerical and theoretical solutions
PO 5 : Students should be committed to professional ethics, responsibilities and norms of practices.
PO 6 : An ability to recognize the need for continuous learning throughout his professional career in the context of technological challenges and advancements

COURSE INFORMATION SHEET

Course code: SR 501
Course title: Elements of Rocket Propulsion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: I/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Describe various types of propulsion system with their merits of challenges.
2.	Classify various types of chemical rocket propulsion and their various parameters governing it.
3.	Identify the working concept of a nozzle with their applications in a propulsion system.
4.	Generate sufficient information about the thrust chamber and their associated parameters along with their significance in practical applications.
5.	Comprehend the basic requirements of the test facilities for rocket propulsion system.

Course Outcomes

At the end of the course, a student should be able to:

CO1	Analyze the propulsion system along with the advanced propulsion system.
CO2	Understand and examine various parameters used in a chemical rockets, especially in solid rocket motor and a liquid rocket engine.
CO3	Explain the fundamental concept of a nozzle along with their designing challenges.
CO4	Comprehend and illustrate the basics of thrust chamber in terms of their designing approach.
CO5	Relate the significance of test facilities and their associated parameters.

Syllabus

Module 1:
Introduction to Propulsion:
Jet Propulsion and Rocket Propulsion – Definition, Principle, Classification, Description and Application; Electrical, Nuclear and other Advanced Propulsion Systems. [8L]

Module 2:
Chemical Rockets:
Application and Classification of Solid Propellant Rocket Motors; Propellants and Characteristics; Ingredients and Processing; Propellant Burning Rate; Propellant Grains and Grain Configurations, Grain Design. Liquid Propellant and their Properties; Liquid Propellant Feed Systems; Injectors; Thrust Chamber Shapes and Characteristic Length, Design of liquid rocket; Hybrid Propellant Rocket

Motors; Gaseous Propellant Rocket Motors and Reaction Control Systems, Design of Hybrid Rocket. [8 L]

Module 3:
Nozzle Theory:
Ideal Rocket; Isentropic Flow through Nozzles; Exhaust Velocity; Choking; Nozzle Types; Nozzle Shape; Nozzle Area Expansion Ratio; Under-expansion and Overexpansion; Nozzle Configurations; Real Nozzles; Multiphase Flow. [8 L]

Module 4:
Thrust and Thrust Chambers:
Thrust Equation; Specific Impulse, Thrust Coefficient, Characteristic Velocity and other Performance Parameters; Thrust Chambers; Methods of Cooling of Thrust Chambers; Steady State and Transient Heat Transfer; Heat Transfer Distribution; Steady State Heat Transfer to Liquids in Cooling Jackets; Uncooled Thrust Chambers. [8L]

Module 5:
Rocket Testing:
Types of Tests; Test Facilities and Safeguards; Safety and Environmental Concerns; Monitoring and Control of Toxic Materials and Exhaust Gases; Instrumentation and Data Management; Reliability and Quality Control; Flight Testing. ` [8 L]

Text books:

1. Rocket Propulsion Elements, Sutton, G.P., Biblarz, O., 7thEd. John Wiley & Sons, Inc., New York, 2001. (**T1**)

Reference books:

1. Rocket Propulsion, Barrere, M., Jaumotte, A., Fraeijs de Veubeke, B.,Vandenkerckhove J., Elsevier Publishing Company, 1960.**(R1)**
2. Rocket and Spacecraft Propulsion: Principle, Practice and New Developments, Turner, M. J. L., Springer Verlag. 2000.**(R2)**
3. Understanding Chemical Rocket Propulsion, Mukunda, H.S., I K International Publishing House, 2017. **(R3)**
4. Rocket Propulsion, Ramamurthi, K., 2nd Edition, Trinity Press of Laxmi Publications Private Limited, India, 2016. **(R4)**

Gaps in the syllabus (to meet Industry/Profession requirements)
Detailed studies on the choice of neutral and other configurations in the grain design.

POs met through Gaps in the Syllabus: PO1, PO2, PO3, PO5, PO6

Topics beyond syllabus/Advanced topics/Design
Integral Ram Rocket
Types of Error in the Measurements

POs met through Topics beyond syllabus/Advanced topics/Design: PO4, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	1	1	3
CO2	1	1	2	1	-	3
CO3	1	1	1	1	1	3
CO4	3	2	2	1	-	2
CO5	1	1	2	1	2	2

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 502
Course title: Elements of Aerodynamics
Pre-requisite(s): Engineering Mathematics, Fluid dynamics
Co- requisite(s): Basic Physics
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: I/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the basics of fluid flow, its model and tool to solve the fluid flow problems.
2.	Describe and implement the elementary flows to combine and form realistic flows with assumptions.
3.	Apply the basics of low speed flow over two-dimensional aerofoils.
4.	Relate theory behind incompressible flow over three-dimensional bodies like wing.
5.	Implementation of viscous flows, boundary layers and their equations.

Course Outcomes

At the end of the course, a student should be able to:

CO1	Describe fundamental principles of the fluid flow
CO2	Solve Inviscid, incompressible and irrotational flows.
CO3	Theoretically solve and relate using numerical techniques for flow over 2D aerofoils.
CO4	Implementation of theories and numerical techniques in solving three-dimensional simple bodies like wings.
CO5	Use of viscous terms in the NS equations, different boundary layer thickness and boundary layer equation.

Syllabus

Module 1:
Some Fundamental Principles: Continuity and Momentum Equations; Application of Momentum Equation for the Estimation of Drag of a Two- dimensional Body; Energy Equation, Substantial Derivatives; Pathlines and Streamlines of a Flow; Angular Velocity, Vorticity and Strain; Circulation; Stream Function; Velocity Potential. [8L]

Module 2:
Fundamentals of Inviscid Flow: Incompressible Flow in a Low Speed Wind Tunnel; Flow Measuring Device – Pitot Tube; Laplace's Equation; Source Flow, Source- Sink Flows, Doublet Flow, Non- lifting Flow over a Circular Cylinder; Vortex Flow; Lifting Flow over a Cylinder; Kutta – Joukowski Theorem and the Generation of Lift; Numerical Source Panel Method; Kutta- Joukowski Transformation. [8 L]

Module 3:

Incompressible Flow over Aerofoils: Aerofoil Nomenclature and Aerofoil Characteristics; Vortex Sheet Method; Kutta's Conditions; Kelvin`s Circulation Theorem and Starting Vortex; Classical Thin Aerofoil Theory; Vortex Panel Method. [8 L]

Module 4:

Incompressible Flow over Finite Wings: Introduction; Downwash and Induced Drag; The Vortex Filament, Biot- Savart Law, Helmholtz`s Vortex Theorem; Prandtl's Classical Lifting Line Theory; [8 L]

Module 5:

Viscous Flows: Navier- Stokes Equation; Solutions of the Navier- Stokes Equations– Steady Parallel Flow, Couette Flow, Hagen – Poiseuille Flow, Laminar and Turbulent Flows; Boundary Layer and Boundary Layer Thickness; Displacement Thickness; Momentum Thickness and Energy Thickness; Estimation of Skin Friction Drag from Momentum Thickness over a Flat Plate; Derivation of Prandtl`s Boundary Layer Equation from Navier- Stokes Equation; Properties of Boundary Layer Equation. [8 L]

Text books:

1. Fundamentals of Aerodynamics – Anderson, J. D. (**T1**)
2. Aerodynamics for Engineering Students – Houghton, E. L. and Carpenter, P. W. (**T2**)

Reference books:

3. Boundary Layer Theory – Schlichting, H. **(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

1) Compressible flow basics
2) Introduction to numerical solutions of viscous flows

POs met through Gaps in the Syllabus

PO3, PO5, PO6

Topics beyond syllabus/Advanced topics/Design

1. Compressible boundary layers

POs met through Topics beyond syllabus/Advanced topics/Design

PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Programme Objectives and Course Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	1	2	2	-
CO2	3	-	2	1	1	-
CO3	2	3	-	3	3	2
CO4	3	2	3	1	2	3
CO5	1	3	3	1	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 503
Course title: Space Engineering and Space Dynamics
Pre-requisite(s): -
Co- requisite(s): -
Credits: L: 3 T: 0 P: 0 C: 3
Class schedule per week: 03
Class: M.Tech.
Semester/Level: I/05
Branch: Space Engineering and Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1	Introduce concepts of system design used for space exploration
2	Introduce mission design parameters from first principles of mechanics
3	Introduce fundamentals of orbital mechanics
4	Introduce sub-systems of a space vehicle
5	Introduce communication systems for space vehicles

Course Outcomes
At the end of the course, a student should be able to:

CO1	Perform mission design calculations using specialized software
CO2	Analyze the orbits of space vehicles using classical methods
CO3	Analyze dynamics of space vehicles
CO4	Identify design requirements for different phases of a space exploration program
CO5	Identify variations of design concepts implemented in recent space missions

Syllabus

Module 1:
Environment and Mission Design
Earth environment, launch environment, atmosphere, space and upper atmosphere; earth-bound orbits, lunar and deep space missions, advanced missions, launch vehicle selection, launching and deployment [8 L]

Module 2:
Trajectory of a Rocket
Mass ratio and propellant mass fraction; equation of motion of an ideal rocket; motion of a rocket in a gravitational field; simplified vertical trajectory; burn-out velocity and burn-out height; step-rockets; ideal mission velocity and losses; effect of launch angle; factors causing dispersion of rockets in flight; dispersion of finned rockets; stability of flight. [8 L]

Module 3:
Astrodynamics
Orbits and trajectories, Kepler's laws, orbital velocity and periods, eccentric elliptical orbits; effect of injection conditions, effect of earth's rotation, perturbation analysis; parking orbit, transfer trajectory, impulsive shot; rendezvous; recent interplanetary missions ` [8 L]

Module 4:
Atmospheric Entry, Attitude Determination and Control
Entry flight mechanics, entry heating, entry vehicle design, aero-assisted orbit transfer; concepts and terminology of attitude determination, rotational dynamics, rigid body dynamics, disturbance torques, passive attitude control, active control, attitude determination, system design considerations
[8L]

Module 5:
Configuration, Structural Design, and Communications
Design drivers and concepts, mass properties, structural loads; power sources, design drivers and practice, command subsystems, redundancy and autonomy, radio communications, tracking
[8L]

Textbooks:

1. M.D. Griffin and J.R. French, Space Vehicle Design. 2nd Edition, AIAA Education Series (2004). **(T1)**

Reference books:

1. J.W. Cornelisse, H.F.R. Schöyer, and K.F. Wakkar. Rocket Propulsion and Spacecraft Dynamics. 1st Edition, Pitman (1979). **(R1)**
2. E. Stuhlinger and G. Mesmer. Space Science and Engineering. 1st Edition, McGraw-Hill, New York (1965). **(R2)**
3. W.N. Hess. Space Science. 1st Edition, Blackie and Son (1965). **(R3)**

Gaps in the syllabus (to meet industry/profession requirements)

- Thermal control systems

POs met through Gaps in Syllabus

Gaps in Syllabus	POs
Thermal control systems	PO3

Topics beyond syllabus/advanced topics/design

- **Advanced topic:** Reliability analysis

POs met through topics beyond syllabus/advanced topics/design

Advanced Topic	POs
Reliability analysis	PO3

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery Methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Reading assignments
CD4	Group discussions

Mapping between Program Objectives and Course Outcomes

Mapping between Course Outcomes and Program Outcomes

CO	PO					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	1	3
CO2	1	-	1	-	1	1
CO3	1	-	2	-	1	1
CO4	2	-	2	-	1	2
CO5	3	-	3	2	1	3

Satisfying and < 34 %: 1; 34-66 %: 2; >66 %: 3

Mapping between Course Outcomes and Course Delivery (CD) Methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD3
CO2	CD1, CD2
CO3	CD1, CD2
CO4	CD1, CD2, CD3,CD4
CO5	CD1,CD2,CD3,CD4

COURSE INFORMATION SHEET

Course code: SR 514
Course title: Rocket and Missile Structure
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech
Semester / Level: I/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Identify various types of missiles and their applications based on their design configurations.
2.	Analyze different types of structural loading acting over the surfaces of rocket and missiles during its operation.
3.	Interpret the designing challenges associated in terms of material and structural weight selections of the rocket and missiles.
4.	Analyze the advantages and challenges linked with the use of composite material in the design of rocket and missiles in terms of its performance.

Course Outcomes
After the completion of this course, students will be able:

1.	To demonstrate working concept of missiles and its various configurations that is designed to meet the certain desired applications.
2.	To determine the various load acting over the missiles and explain the designing approach for practical system.
3.	To analyse the challenges associated in the selection of suitable material for the optimization of performance of the propulsion system.
4.	To examine challenges in using composite materials in the spacecraft applications based on its merits and demerits.
5.	To identify various aerodynamic forces acing over the missiles and its various approach utilized to optimize it.

Syllabus

Module 1:
Introduction to Missile Design: Types of missiles, Overview of Missile Design Process. Utility of System Integration. Configuration of sizing parameters, Conceptual design process. Detailed mission requirements. Sensitivity analysis. **[6L]**

Module 2:
Structural Analysis & Design approach: Major Section of Rocket and their Structure; Flight Loads; Forces and Moments acting on the Missile; Structural Analysis; Design Criteria; Principal Parameters Governing Rocket Engine Design; System Analysis and Design Layout; Stress Analysis; Selection of

Material; Design of Proof Motor and Flight Motor; Engine-to-vehicle Interface; Clustering of Rocket Engines; Reliability Concept. **[9L]**

Module 3:

Rocket and Missile design: Weight prediction and minimizing weight, Sizing of subsystems for flight performance requirements, Structure factor of safety, Structure concepts and manufacturing processes, Airframe materials, Structure loads prediction, Airframe and rocket motor case design, Aerodynamic heating prediction and insulation trades, Thermal Stress. **[8L]**

Module 4:

Composite Materials in Spacecraft Application: Composite Material and its Utilities, Classifications, Constituents of the Composite materials, Various types of matrix suitable for composite materials, Metal and Ceramic Matrix Composites, Advanced Composite Materials, Composite Materials and its application in Spacecraft Industries, Utilities in the design of Storage tank and Vessels. Composite Materials for Solid Propellant Missile Structure. **[9L]**

Module 5:

Aerodynamics in Missile Design: Optimizing missile aerodynamics. Shapes for low observables, Configuration layout options, Selecting flight control alternatives, Wing and tail sizing, Predicting normal force, drag, pitching moment, stability, flight control effectiveness, lift-to-drag ratio, and hinge moment. Skid-to-turn, bank-to-turn, rolling airframe, and divert manoeuvring alternatives. **[8L]**

Text books:

1. Missile Design and System Engineering, Fleeman, E.L., Schetz, J.A., AIAA Education Series. 2012.
2. Composite Materials, Agrawal, J.P., Defence Scientific Information and Documentation Centre, DRDO, Ministry of Defence, Delhi, 1990.

Reference books:

1. Introduction to Rocket Technology, Feodosiev, V.I., Siniarev, G.B., Academic Press, 2014.
2. Materials for missiles and spacecraft, Parker, E.R., McDonald, J.C., McGraw-Hill, New York, 1963.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	1	2
CO2	1	1	2	1	2	2
CO3	3	2	3	2	2	3
CO4	3	2	3	2	2	3
CO5	2	1	2	2	1	2

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 513
Course title: Applied Mathematics
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech
Semester / Level: I/05
Branch: SER
Name of Teacher:

Course Objectives

This course enables the students:

1.	To know the basic concepts of solving algebraic and transcendental equations, solution methods of linear systems.
2.	To learn the numerical techniques of interpolation in various intervals and lesat squares curve fitting procedures.
3.	To apply the numerical techniques for differentiation and integration.
4.	To know the various techniques and methods of solving ordinary differential equations.
5.	To apply the various techniques and methods of solving various types of partial differential equations.

Course Outcomes

After the completion of this course, students will be able to:

1.	know the basic concepts and techniques of solving algebraic and transcendental equations, solution of linear systems of equations.
2.	Understand the numerical techniques of interpolation in various intervals and least squares curve fitting procedures in real life situations.
3.	Apply the numerical techniques of differentiation and integration for engineering problems.
4.	Know the various numerical techniques and methods for solving first and second order ordinary differential equations.
5.	Apply the various numerical techniques and methods for solving partial differential equations with engineering applications.

Syllabus:

Module 1:
Solution of Equations and Eigenvalue Problem: Solution of Algebraic and Transcendental Equations - Bisection Method, Method of False Position, Iteration Method, Newton-Raphson Method, Secant Method, Muller's Method; Direct Methods for Solution of Linear Systems - Gauss Elimination, Gauss–Jordan Method, LU Decomposition Method; Iterative Methods for Solution of Linear Systems - Jacobi Method, Gauss-Seidel Method; Matrix Eigenvalue Problem. [8L]

Module 2:
Interpolation and Curve Fitting: Finite Differences, Newton's Formulae for Interpolation, Central Difference Interpolation Formulae, Interpolation with Unevenly Spaced Points - Lagrange's Interpolation Formula; Divided Differences and Their Properties; Cubic Splines, Least Squares Curve Fitting Procedures. [8L]

Module 3:
Numerical Differentiation and Integration: Numerical Differentiation, Numerical Integration - Trapezoidal Rule, Simpson's 1/3-Rule, Simpson's 3/8-Rule, Romberg Integration, Newton-Cotes Integration Formulae, Gaussian Integration, Numerical Double Integration. [8L]

Module 4:
Numerical Solution of Ordinary Differential Equations: Taylor's Series Method, Picard's Method, Euler's Method, Modified Euler's Method, Runge-Kutta Methods, Adams-Moulton and Milne's Predictor-Corrector Methods, Simultaneous and Higher-order Equations, Boundary-value Problems. [8L]

Module 5:
Numerical Solution of Partial Differential Equations: Classification of Second Order Equations, Finite Difference Approximations to Derivatives, Solution of Laplace's Equation, Solution of Poisson's Equation, Solution of One Dimensional Heat Equation, Solution of Wave Equation. [8L]

Text books:
1. S. S. Sastry, "Introductory Methods of Numerical Analysis", 5 th Edition, PHI Learning Pvt. Ltd, 2015. (**T1**)
2. S. D. Conte and Carl de Boor, "Elementary Numerical Analysis - An Algorithmic Approach", 3rd edition, McGraw-Hill, 1981. (**T2**)

Reference books:
1. B. S. Grewal, and J. S. Grewal, "Numerical Methods in Engineering and Science", Khanna Publishers, 10 th Edition, New Delhi, 2015. (**R1**)
2. K. E. Atkinson, "An Introduction to Numerical Analysis", 2nd edition, Wiley-India, 1989. (**R2**)

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	3
CO2	3	2	3	2	2	3
CO3	3	3	3	2	2	3
CO4	2	1	2	1	1	3
CO5	3	2	3	2	-	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD6
CO2	CD1,CD2,CD6
CO3	CD1,CD2,CD6
CO4	CD1,CD2,CD6
CO5	CD1,CD2,CD6

COURSE INFORMATION SHEET

Course code: SR 506
Course title: Rocket Propulsion Lab
Pre-requisite(s):NA
Co- requisite(s):NA
Credits: L: 0 T: 0 P: 4 C: 2
Class schedule per week: 4
Class: M.Tech.
Semester / Level: I/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the significance of the experiments to compliment theoretical information.
2.	Collect and interpret data obtained from various experiments.
3.	Examine the results individually or in a group and evaluate it to prepare the report.
4.	Have hands down experience of processing, assembly and use of instrumentation
5.	Recognize and follow various safety precautions required during the experimentations

Course Outcomes

At the end of the course, a student should be able to:

CO1	Carry out the solid propellant processing with different ingredients and evaluate burn rates.
CO2	Explain the significance of ignition delay and determine it using experimental techniques.
CO3	Differentiate the combustion mechanism of solid, liquid and gaseous mixture.
CO4	Compute data and analyse it for drawing conclusions as an individual or in a group.
CO5	Work on equipment used in the experiments along with knowing their significance and using them for allied applications.

List of the Experiments:

1. **Experiment No. 1**
   Name : Introduction to Rocket Propulsion Laboratory
   Objective :To introduce the rocket propulsion lab and know the operation/application of various equipment available.

2. **Experiment No. 2**
   Name : Preparation of Composite Solid Propellant
   Objective : To prepare composite solid propellants of different oxidizer/fuel ratio.

3. **<u>Experiment No. 3</u>**
   Name : Burn Rate of Composite Solid Propellants
   Objective : To determine the burn rates of composite solid propellant prepared with different oxidizer/fuel ratio.

4. **<u>Experiment No. 4</u>**
   Name : Ignition delay of Liquid Bipropellant Systems
   Objective : To determine the ignition delay of the conventional liquid bi-propellant system.

5. **<u>Experiment No. 5</u>**
   Name : Effect of Catalyst and Additives on Ignition Delay
   Objective : To determine the effect of additives and catalyst on the ignition delay of the liquid bi-propellant system.

6. **<u>Experiment No. 6</u>**
   Name : Preparation of Composite Solid Propellant with Burn Rate Modifiers
   Objective : To prepare composite solid propellants with additives at given oxidizer/fuel ratio.

7. **<u>Experiment No. 7</u>**
   Name : Effect of Additives on Burn Rate of Solid propellants
   Objective : To determine the effect of additives on the burn rate of composite solid propellant.

8. **<u>Experiment No. 8</u>**
   Name : Water Equivalent Measurement
   Objective : To determine the water equivalent of bomb calorimeter

9. **<u>Experiment No. 9</u>**
   Name : Bomb Calorimeter experiment
   Objective : To determine heat of combustion of a given solid sample by using a digital bomb calorimeter.

10. **<u>Experiment No. 10</u>**
    Name : Flame Propagation and Burning Velocity measurement
    Objective : To study the burning velocity of premixed flames at various air/fuel ratio using Hilton's Flame Stability Unit.

11. **<u>Experiment No. 11</u>**
    Name : Preparation of Igniters for Solid Rocket Motor
    Objective : To prepare the shellac based pyrotechnic igniters

12. **<u>Experiment No. 12</u>**
    Name : Ignition Delay Test of Igniter
    Objective : To determine the ignition delay of shellac igniter at various Voltage and Current level by using igniter testing apparatus.

Reference books:

1. G. P. Sutton and O. Biblarz, Rocket Propulsion Elements, 7thEd. John Wiley & Sons, Inc., New York, 2001.**(R1)**

2. H. S. Mukunda, Understanding Chemical Rocket Propulsion, I K International Publishing House, 2017. **(R2)**
3. K. Ramamurthy, Rocket Propulsion, 2nd Edition, Trinity Press of Laxmi Publications Private Limited, India, 2016. **(R3)**

Gaps in the syllabus (to meet Industry/Profession requirements): Focus is on Chemical Rocket Propulsion

POs met through Gaps in the Syllabus: PO4 will be improved with additional experiments

Topics beyond syllabus/Advanced topics/Design: Design of new experimental set ups to compliment other areas of theoretical exposure.

POs met through Topics beyond syllabus/Advanced topics/Design

Course Delivery methods

CD	**Course Delivery methods**
CD1	Lecture by use of boards/LCD Projectors
CD2	Assignments
CD3	Material Processing and Assembly of setup
CD4	Laboratory experiments/teaching aids
CD5	Self- learning such as use of NPTEL materials and internets

Mapping between Program Outcome and Course Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	**Program Outcomes**					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	1	3
CO2	3	2	2	1	1	3
CO3	1	1	3	1	2	2
CO4	3	2	1	3	3	2
CO5	2	1	3	1	1	3

If satisfying < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcome	**Course Delivery Method**
CO1	CD1, CD2,CD3, CD5
CO2	CD1, CD2, CD3, CD5
CO3	CD1, CD2, CD3,CD5
CO4	CD1, CD3, CD5
CO5	CD1, CD2, CD4, CD5

COURSE INFORMATION SHEET

Course code: SR 507
Course title: Aerodynamics Laboratory
Pre-requisite(s):Engineering Mathematics, Fluid dynamics
Co- requisite(s): Basic Physics
Credits: L:0 T:0 P:4 C: 2
Class schedule per week: 4
Class: M.Tech.
Semester / Level: I/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	The principles of wind tunnel and its operation.
2.	Measure velocities, pressure and drag from the subsonic wind tunnel.
3.	Basic skills of flow visualization at subsonic speed.
4.	Work in a group and evaluate the results to prepare the report.
5.	Practice ethical standards in measurements through experiments.

Course Outcomes
At the end of the course, a student should be able to:

CO1	Operate the wind tunnel and estimate basic parameters from the tunnel.
CO2	Organize and perform experiments for estimate of lift and drag coefficients over a body with adoption of suitable theories.
CO3	Do work pertaining to calibration and setup of electronic balance and pressure sensor.
CO4	Demonstrate experimental needs to obtain meaningful and quality results.
CO5	Examine the experimental results and write the report.

List of the Experiments:

1. **<u>Experiment No. 1</u>**
   Name: Introduction to Aerodynamics Laboratory
   Objective :Explanation of various existing wind tunnels in the lab. The details of operation principle and instrumentations.
2. **<u>Experiment No. 2</u>**
   Name : Introduction to Tuft flow and Oil flow visualisation over typical aerodynamic bodies.
   Objective : Hands on experience of oil flow technique and tuft flow technique to understand surface flow features over aerodynamic shapes.
3. **<u>Experiment No. 3</u>**
   Name: Calibration of Subsonic Wind Tunnel
   Objective: Velocity measurement and RPM distribution for running the tunnel at specific speeds. Velocity measurements at different locations of the tunnel to get the uniform velocity distribution.
4. **<u>Experiment No. 4</u>**
   Name : Determination of Lift Coefficient from measurement of pressures over

Infinite Cambered Aerofoil at 0° Angle of Attack at Subsonic Speed.
Objective: To obtain the pressure distribution over an infinite aerofoil and estimate the lift coefficient from the measured data using numerical integration.

5. **Experiment No. 5**
Name : Determination of Lift Curve Slope for an Infinite Cambered Aerofoil at Subsonic Speed.
Objective : To obtain the pressure distribution over an infinite aerofoil at various angles of attack and estimate the lift coefficient from the measured data using numerical integration and plot the lift coefficient Vs angles of attack.

6. **Experiment No. 6**
Name : Determination of Drag for a Cambered Aerofoil at Subsonic Speed using Drag Momentum Method.
Objective: Use of wake momentum method in estimating drag for an aerofoil.

7. **Experiment No. 7**
Name : Calibration of Strain Gauge Balance using Dead Weights.
Objective: To calibrate the 5-component strain gage balance to obtain the instrument constants

8. **Experiment No. 8**
Name : Estimation of Turbulent Intensity of the Subsonic Wind Tunnel using Constant Temperature Hot Wire Anemometer.
Objective: Use of hot wire anemometry to obtain fluctuating component of velocity in 1 dimension.

9. **Experiment No. 9**
Name : Calibration of typical pressure sensors.
Objective: To calibrate a typical pressure sensor using the manual pump and a digital pressure display.

10. **Experiment No. 10**
Name : Working of a Supersonic Wind Tunnel and Visualisation of shock wave over a typical aerodynamic body.
Objective: Operation of a supersonic wind tunnel at typical Mach number and display of a shock wave during the running of tunnel using schlieren technique

References :

1. HIGH SPEED WIND TUNNEL TESTING by Alan Pope and Kennith L. Goin**(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

3) Flow visualization through smoke or dye technique
4) Laser based visualization method

POs met through Gaps in the Syllabus

PO1, PO4, PO5

Topics beyond syllabus/Advanced topics/Design

1) Particle Image Velocimetry
2) Water tunnel experiments

POs met through Topics beyond syllabus/Advanced topics/Design

PO3, PO6

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Tutorials/Assignments
CD3	Laboratory experiments/teaching aids
CD4	Self- learning such as use of NPTEL materials and internets
CD5	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	-	2	2	2
CO2	3	-	2	2	1	-
CO3	2	-	3	2	-	2
CO4	1	3	2	-	1	-
CO5	3	2	3	3	-	-

Mapping between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1, CD3
CO2	CD1, CD3
CO3	CD1, CD2, CD3
CO4	CD1, CD3, CD4
CO5	CD3, CD5

Specialization: Aerodynamics

COURSE INFORMATION SHEET

Course code: SR 576
Course title: Compressible Flows
Pre-requisite(s): Engineering Mathematics, Fluid dynamics
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Simplify multidimensional complex compressible flow problems to 1D counterpart and understand and solve the basic flow features.
2.	Understand one-dimensional unsteady wave motion and its characteristics and usage in shock tubes
3.	Solve problems with oblique shock, expansion waves and the combination
4.	Relate starting of flow to diffuser with several example problems of supersonic intake, wind tunnel etc.
5.	Interpret problems associated with transonic flow theories.

Course Outcomes
After the completion of this course, students should able to:

CO1	Solve high speed 1D flow situations either with isolated isentropic condition, friction, heat transfer and shock wave or the combination of them.
CO2	Compare the differences between steady and unsteady wave motions.
CO3	Solve oblique shock, expansion waves, combination of shock and expansion.
CO4	Relate the start / unstart problems at supersonic speeds for flow in diffuser ducts and intakes.
CO5	To appraise the transonic flows and its associated problems / solutions

Syllabus
Module 1:
One-Dimensional Flow : 1- D Flow Equations; Quasi 1- D Flow; Area- Velocity Relation; Isentropic Flow through Variable Area Ducts; Diffusers; Speed of Sound and Mach Number; Normal Shock; Pressure, Temperature, Density and Entropy Relations across a Normal Shock; Shock Strength; Rarefaction Shock an Impossibility; Hugoniot Equation; 1- D Flow with Heat Addition; 1- D Flow with Friction; Reyleigh and Fanno Lines; [8]

Module 2:
Unsteady 1D Flow: Unsteady Wave Motion; Moving Normal Shock Wave; Reflected Shock Wave; Physical Picture of Wave Propagation; The acoustic equations; Propagation of acoustic wave, Pressure and particle velocity in a sound wave, Linerised shock tube, Propagation of finite wave; Centered expansion wave, Incident and Reflected Expansion Waves; The Shock Tube. [8]

Module 3:

Oblique Shock and Expansion Wave : Introduction and Source of Oblique Waves; Mach Wave; Mach Cone; Oblique Shock Relations for Pressure, Temperature and Mach Number; Supersonic Flow over Wedges and Cones; Weak Oblique Shock; Shock Polar; Pressure - Deflection Diagram; Reflection of Shock from a Solid Boundary; Intersection of Shocks of Opposite and Same Family; Detached Shock Wave; Physical Aspect of Conical Flow; Taylor and Maccoll Formulation; Numerical Procedure, Prandtl- Meyer Expansion Wave; Shock Expansion Theory; Laminar and Turbulent Flow Separation Caused by the Interaction of Shock Waves with the Boundary Layer. [9]

Module 4:

Supersonic Flow in Diffusers and Ducts : The Problem of Starting a Supersonic Flow in Diffusers; Supersonic Inlet – Internal, External and Mixed Compression, Total Pressure Recovery, Mass Flow Characteristics and Inlet Performance; Starting of Supersonic Inlets; Shock Wave Patterns in Ducts and Shock Train Behaviour. [7]

Module 5:

Similarity rules and Transonic Flows : 2D linearized flow, Prandtl-Glauert and Gothert rules, von Karman’s rule, Linearised axially symmetric and planar flow, Application; Physical and Theoretical Aspects of Transonic Flows; Definition of transonic range, Flow past wedge section, cone, smooth 2D shape, Example Solution of small Perturbation, full Velocity Potential Equations and Euler Equations. [8]

Text books:

1. Modern Compressible Flow – Anderson, John D.
2. Elements of Gas Dynamics – Liepmann, H. W. and Roshko, A.
3. Dynamics and Thermodynamics of Compressible Fluid Flow - Shapiro, A. H.

Reference books:

4. Gas Dynamics - Rathakrishnan, E.

Gaps in the syllabus (to meet Industry/Profession requirements)

5) High Speed high temperature flows
6) Solution strategies through numerical techniques for steady supersonic flows

POs met through Gaps in the Syllabus

PO4, PO6

Topics beyond syllabus/Advanced topics/Design

3) Hypersonic, non-equilibrium flows
4) Compressible turbulent boundary layers

POs met through Topics beyond syllabus/Advanced topics/Design

PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	3	2		2	2	-
2	3	-	2	1	-	2
3	3	3	3	2	1	2
4	1	3	2	-	1	3
5	1	2	-	1	-	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR577
Course title: Boundary Layer Theory
Pre-requisite(s): Fundamental of Aerodynamics
Co- requisite(s):
Credits: L: 03 T:0 P:0
Class schedule per week: 3
Class: M. TECH.
Semester / Level: 02/05
Branch : Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the basics of the fluid flow and the governing equations
2.	Apply fluid dynamic equation for solving simple fluid dynamic problem
3.	Analyze the interaction of fluid dynamics and heat transfer in a fluid flow
4.	Understand the behaviour of time dependent boundary layer.
5.	Design the boundary layer control techniques.

Course Outcomes
After the completion of this course, students should able to:

CO1	Distinguishing the different types of fluid flows and understand the governing equations.
CO2	Solving the mathematical equation for the simple fluid dynamic problem.
CO3	Able to solve the problems of the interaction of thermal and velocity boundary layers.
CO4	Recognizing the unsteady boundary layer.
CO5	Able to devise boundary layer control techniques depending upon the fluid problems.

Syllabus

Module 1:
Law of Viscosity : Types of Fluids; Dependence of Boundary Layer at Different Reynolds Number, Blassius Solution and Its Series; Asymptotic Solutions; Theory of Similarity; Separation of Boundary Layer; Similar Solutions; Reduction of the Navier- Stokes Equation to the Boundary Layer Equations. [8]

Module 2:
Solution of Boundary Layer Equations : Exact Solutions; Flow Past a Wedge; Flow Past a Cylinder; Flow in the Wake of Flat Plate at Zero Incidence; Momentum Integral and Energy Integral Equations; Approximate Solutions; Application of Momentum Equation to the Flat Plate; Karman- Pouhlsen Method; Approximate Methods for 2D Flows; Comparison of Exact and Approximate Methods for Flat Plate at Zero Incidence, Two- dimensional Stagnation Flow and Flow Past a Circular Cylinder. Axially symmetric boundary layers, Mangler Transformations. [9]

Module 3:
Thermal Boundary Layer : Derivation of Energy Equation; Theory of Similarity in Heat Transfer; Non Dimensional Numbers – Grashoff's, Prandtl, Reynolds and Eckert Numbers; Analogy between Heat Transfer and Momentum Transfer; Exact Solution of Temperature Distribution in Viscous Flows; Boundary Layer Simplification; Properties of Thermal Boundary Layer; Forced and Natural Flows;

Adiabatic Wall; Effect of Prandlt’s Number. Relation between Velocity and Temperature Fields – Adiabatic Wall and Heat Transfer; Recovery Factor. [9]

Module 4:

Unsteady Boundary Layer : Introduction to Unsteady Boundary Layers; Boundary Layer Equations, Methods of approximations, Boundary layer formation in accelerated motion, Transition and Origin of Turbulence; Turbulent boundary layer over a flat plate, Boundary layer in non zero pressure gradients. [8]

Module 5:

Boundary Layer Control : Introduction; Fundamental Equation with Suction/ Injection; Exact and Approximate Solutions with Suction and Injection; Solution of Pressure Gradient Cases; Prevention of Separation on Aerofoil; Control and Means to Increase Lift and to Reduce Drag; Some Experimental Results. [8]

Text books:

1. Boundary Layer Theory –H. Schlichting

2. Fundamental of Aerodynamics – John D. Anderson

Reference books:

1.. Viscous Fluid Flow – Frank M. White

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	-	-	3	-	-	2
2	2	-	3	3	1	1
3	2	1	3	2	-	1
4	-	-	3	1	-	2
5	3	2	3	3	2	2

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 578
Course title: Computational Fluid Dynamics
Pre-requisite(s): Fluid Mechanics, Numerical Analysis
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Know classification of partial differential equations, finite difference method, stability analysis.
2.	Learn the solution methods of finite difference equations of elliptic, parabolic and hyperbolic partial differential equations.
3.	Apply the methods to solve finite difference equations
4.	Understand the numerical techniques to solve incompressible Navier-Stokes equations.
5.	Know the finite volume method and apply it for inviscid problems.

Course Outcomes

After the completion of this course, students will be able to:

1.	know the basics of CFD, classification of partial differential equations, initial and different boundary conditions.
2.	Understand finite difference methods Taylor series expansion and polynomial expansion, discrete perturbation and Von Neumann stability analysis, artificial viscosity.
3.	Apply the solution methods of finite difference equations to solve elliptic, parabolic and hyperbolic problems.
4.	Understand the different forms of incompressible Navier-Stoke equations and techniques to solve it numerically.
5.	Develop the proceddure to solve the Euler equations by finite volume method.

Syllabus

Module 1:
Introduction: Computational Fluid Dynamics; Classification of Partial Differential Equations; Linear and Non- linear Partial Differential Equations – Model Equation, Elliptic Equation, Parabolic Equation and Hyperbolic Equation; System of 1st order Partial Differential Equations; System of 2nd order Partial Difference Equations; Initial Conditions; Boundary Conditions. [8L]

Module 2:
Finite Difference Formulations: Introduction; Taylor Series Expansion; Finite Difference by Polynomial; Finite Difference Equations; Higher Order Derivatives; Multidimensional Finite

Difference Formulas; Applications; Finite Difference Approximation of Mixed Partial Derivatives; Stability Analysis; Discrete Perturbation Stability Analysis; Von Neumann Stability Analysis; Multidimensional Problem; Error Analysis; Artificial Viscosity. [8L]

Module 3:

Solution Methods of Finite Difference Equations: Elliptic Equations – Finite Difference Formulations, Jacobi Iteration Method, Point Gauss Seidel Iteration Method, Line Gauss Seidel Iteration Method, Point Successive Over Relaxation Method, Line Successive Over Relaxation Method, Alternating Direction Implicit Method, Applications; Parabolic Equations – Finite Difference Formulations, Explicit Schemes, Implicit Schemes, Alternating Direction Implicit Schemes, Parabolic Equations in Two-space Dimensions, Approximate Factorization, Fractional Step Methods; Hyperbolic Equations – Explicit and Implicit Schemes, Splitting Methods, Multistep Methods, Application to Linear and Non-linear Problems, Flux Corrected Transport, Classification of Numerical Scheme, TVD Formulations; Application – Heat conduction, Couette Flow and Wave Motion. [10L]

Module 4:

Incompressible Navier- Stokes Equations: Introduction; Primitive Variable and Vorticity Stream Function Formulations; Poisson Equations for Pressure (Primitive Variable and Vorticity Stream Function Formulation); Numerical Algorithm (Primitive Variable); Artificial Compressibility; Solution on a Regular Grid; Crank Nicolson Implicit Method; Boundary Conditions (Body Surface, Far Field, Symmetry, Inflow, Outflow); Staggered Grid; Marker and Cell Method; Implementation of Boundary Conditions; DuFort Frankel Scheme; Use of the Poisson Equation for Pressure; Unsteady Incompressible Navier- Stokes Equation. [10L]

Module 5:

Euler Equations and Finite Volume Method: Explicit Formulations – Steger and Warming Flux Vector Splitting, Van Leer Flux Vector Splitting, Runge Kutta Formulation, Implicit Formulations – Steger and Warming Flux Vector Splitting; Boundary Conditions; Global Time Step and Local Time Step; Application – Diverging Nozzle Configuration, Shock Tube or Reimann Problem, Supersonic Channel Flow; Approximation of Surface Integrals; Cell centered and Nodal Point Scheme; Interpolation and Differentiation Practices; Implementation of Boundary Conditions. [8L]

Text books:

1. Hoffmann, K.A. and Chiang, S.T., Computational Fluid Dynamics (Vol. I & II), Engineering Education System, 2000. (**T1**)

Reference books:

1. Hirsch, C., Numerical Computation of Internal and External Flows (Vol. I & II), John Wiley and Sons, 1994. (**R1**)

2. Anderson, John D., Computational Fluid Dynamics, McGraw-Hill, 1995. (**R2**)

Gaps in the syllabus (to meet Industry/Profession requirements) : Unsteady flow simulation

POs met through Gaps in the Syllabus : PO1, PO3

Topics beyond syllabus/Advanced topics/Design : Simulation of turbulent flows

POs met through Topics beyond syllabus/Advanced topics/Design : PO1, PO2, PO3, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	2
CO2	2	2	2	1	1	2
CO3	2	2	3	2	1	2
CO4	3	2	2	2	2	3
CO5	3	3	2	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD2,CD6
CO3	CD1, CD2, CD6
CO4	CD1, CD2,CD6
CO5	CD1,CD2,CD6

COURSE INFORMATION SHEET

Course code: SR 579
Course title: Experimental Aerodynamics
Pre-requisite(s): Engineering Mathematics, Fluid dynamics
Co- requisite(s): Basic Physics
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the basics of Wind Tunnel and its components with specific orientation to its operation.
2.	Describe and implement the different wind tunnel measurement techniques adopted recently and in the past.
3.	Understand the basics of advanced flow diagnostic systems with knowledge towards its components and devices.
4.	Understand unsteady features of a flow and its associated measurement techniques.
5.	Be able to understand, use and operate advanced data acquisition system and its components.

Course Outcomes
After the completion of this course, students will be:

CO1	Describe wind tunnels and their components.
CO2	Organise in performing experiments using wind tunnel measurement techniques which are in practice.
CO3	Demonstrate the advanced measurement techniques for wind tunnel tests.
CO4	Implement the unsteady flow measurements with possible recognition to its stochastic behaviour and analysis.
CO5	Perform experiments with advanced data acquisition system with good level of confidence and minimal error.

Syllabus

Module 1:
Wind Tunnel: Necessity of Wind Tunnels; Basic Principle; Types of Wind Tunnels; Components of Subsonic Tunnel, Supersonic Tunnel, Hypersonic Tunnel and Shock Tunnel; Special Purpose Wind Tunnel; Design Consideration of Subsonic Tunnel and Supersonic Tunnel; Calibration Methods of Different Wind Tunnels; [8 L]

Module 2:

Flow Visualisation: Different Types of Flow Visualization Techniques for Subsonic, Supersonic and Hypersonic Tunnels; Basics of Schlieren, Shadowgraph and Interferometers; Laser Based Flow Visualization Technique. [6 L]

Module 3:

Pressure, Velocity, Force and Moment Measurement: Pitot Static Probe; Laser Doppler Velocimeter; Mechanical System for Pressure Measurement; Water and Mercury Manometers; Principle of Pressure Transducer; Different Types of Pressure Transducers; Mechanical Pressure Scanner, Electronic Pressure Scanner; Pressure Sensitive Paint; Calibration of Pressure Measuring Units, Definition of Forces and Moments on Aerospace Vehicles; Basic Principle of Mechanical Balance and Strain Gage Balance; Interaction between Different Components of Forces and Moments; Major Components for Force and Moment Measuring Systems. [12L]

Module 4:

Unsteady Measurement: Introduction to Unsteady data; Introduction to Turbulent measurements; Basic Principle of Hot Wire Anemometer; Constant Current and Constant Temperature Anemometer, Measurement of Unsteady Velocities Using Hot Wire Anemometers; Measurement of Turbulent Stresses; Single and Multiple Hot Wire Probes; Basic Principles of Unsteady Pressure Transducers; Calibration of Steady and Unsteady Pressure Transducers. [10L]

Module 5:

Data Acquisition System: Analog and Digital Signals; Mean and Fluctuating Signals; ADC Cards; Amplifiers; Signal Conditioners; P C Based Data Acquisition System; Data Acquisition Software; Error Analysis. [8 L]

Text books:

1. High Speed Wind Tunnel Testing, Roe, W. H. and Pope, A., Wiley, 1965. **(T1)**
2. Low Speed Wind Tunnel Testing, Pope, A. and Goin, L., Wiley, 1966. **(T2)**

Reference books:

3. Random Data: Analysis and Measurement Procedures, Bendat, J. S. and Piersol. A.G., Wiley, 2010. **(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

Emphasis on data analysis

More elaboration on the data acquisition system and its component

POs met through Gaps in the Syllabus: PO1, PO5, PO6

Topics beyond syllabus/Advanced topics/Design

Elaborate studies on PIV instrumentation and data interpretation

Compressible boundary layer measurement techniques

POs met through Topics beyond syllabus/Advanced topics/Design: PO4, PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Tutorials/Assignments
CD3	Self- learning such as use of NPTEL materials and internets

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1		2	2	1	1	
CO2	3		3	3	2	3
CO3	2	1	2			2
CO4	1	2	2	1	3	3
CO5	3		3	3	3	2

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1
CO2	CD1
CO3	CD1, CD2
CO4	CD1, CD2, CD3
CO5	CD1,CD2,CD3

COURSE INFORMATION SHEET

Course code: SR 508
Course title: Aerodynamic Stability and Control
Pre-requisite(s): Fundamentals of Aerodynamics
Co- requisite(s):
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech.
Semester / Level:II/05
Branch: Space Engg. & Rocketry (Aerodynamics)
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the basics of flight dynamics and classifications.
2.	Understand and apply the concept of static stability on the aerospace vehicles.
3.	Recognize the behaviour of aerospace vehicle in a flow with respect to time.
4.	Comprehend the basics of the control systems related to the flight control
5.	The understand the reliability and failure concepts pertaining to the aerospace vehicles

Course Outcomes
At the end of the course, a student should be able to:

CO1.	Describe the forces and moments over an aerospace vehicle.
CO2.	Analyzing the static stability on an aerospace vehicle.
CO3.	Examining the behaviour of disturbed flight w.r.t. time.
CO4.	Realizing and applying the concept of control system to aerospace vehicles.
CO5.	Apply the concept of reliability engineering to aerospace vehicles.

Syllabus

Module 1:
Introduction : Missile Aerodynamics Versus Airplane Aerodynamics; Classification of missiles, Axes and angles, Aerodynamic characteristics of rectangular and triangular lifting surfaces on the basis of supersonic wing theory, Types of missile design and control, Aerodynamic characteristics of airframe components. [8L]

Module 2:
Static Stability : Introduction to Six Degrees of Freedom; Forces and Moments for Two Degrees of Freedom; Derivation of Static Margin; Load factor, Static longitudinal stability, Maneuvering flight, Directional stability, Lateral stability. [8L]

Module 3:

Dynamic Stability : Necessity and Approximate Analysis; Damping; Time- to- half Response Characteristics, Oscillatory and Non- Oscillatory Motion; Effect of Various Control Surfaces. [8 L]

Module 4:

Controls : Different Types of Disturbances, Time- to- Half; Time- to- Double; Active and Passive Controls; Open Loop and Closed Loop Controls; Feed back, Types of Feed back, Time Domain Analysis, Frequency Domain Analysis, Nyquist criterion, Response, Attitude control of aircraft, Staging of Missile and rockets, it's advantages and disadvantages. [8 L]

Module 5:

Performance : Introduction to Reliability; Theories of Reliability, Estimation of reliability and it's importance, Accuracy; Safety of Aircraft, Missiles, Rockets, Description and necessity of Launcher & launch complex, Safety aspects for different launchers and Associated Problems. [8 L]

Text books:

1. Aerodynamics for Engineering Students – Houghton, E. L. and Carruthers, N. B. (**T1**)
2. Airplane Performance, Stability & Control – Perkins, C. D. and Hege, R. E.(**T2**)
3. Missile Aerodynamics – Chin, S. S. (**T3**)
4. Automatic Control system – B. C. Kuo (**T4**)
5. Reliability Engineering - Alessandro Birolini(**T5**)

Reference books:

1. Fundamentals of Aerodynamics – Anderson, J. D. **(R1**)

Gaps in the syllabus (to meet Industry/Profession requirements)

1. Design of aerospace vehicles
2. Failure analysis

POs met through Gaps in the Syllabus

PO1, PO4

Topics beyond syllabus/Advanced topics/Design

1. Design of control system in stability of aerospace vehicles

POs met through Topics beyond syllabus/Advanced topics/Design

PO1, PO3

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO 6
1	-	-	3	1	-	2
2	2	-	3	2	-	2
3	1	1	3	2	1	1
4	1	1	3	2	1	2
5	3	1	3	2	3	2

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 509
Course title: Aeroacoustics
Pre-requisite(s): Engineering Mathematics
Co- requisite(s): Basic Physics
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M.Tech.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the basics concepts of acoustics, sound, wave, moving source, etc.
2.	Describe and implement the acoustic analogies with boundary conditions.
3.	Applythe acoustic estimation theories using instruments.
4.	Examine and differentiate the capacities of different acoustic instrumentation.
5.	Appraise the various characteristics of supersonic jet noise.

Course Outcomes
After the completion of this course, students will be to:

CO1	Describe fundamental principles of the acoustics
CO2	Solution of acoustic theories with and without boundaries.
CO3	Differentiate the different methods for acoustic testing.
CO4	Organise acoustic methods through proper instrumentation.
CO5	Evaluate the characteristics of supersonic jet noise.

Syllabus

Module 1:
Fundamental Principles: Introduction to basic concepts in acoustics, Quantification of sound, Wave like solutions of acoustic equations, Superposition of elementary flows, Sound radiation by pulsating sphere, Oscillating piston in a baffle, Scattering by a solid sphere, Somerfeld Radiation condition in exterior acoustics, Source distribution in unbounded regions, Radiation field, Energy relations, moving sound source. [8L]

Module 2:
Aerodynamic Sound: Introduction, Kovasznay's modal decomposition, sound sources – monopole, dipole and quadrupole, Lighthill's acoustic analogy, Solution to Lighthill's theory when no solid boundaries are present, Application to turbulent flows, Physics of Jet noise. [8L]

Module 3:

Effect of Solid Boundaries: Introduction, Derivation of fundamental equation, Ffowcs Williams – Hawkings equation, Calculation of Aerodynamic forces, Application of Ffowcs Williams – Hawkings equation, Flows with sound field determined by Green's Function equations tailored to the geometry. [8L]

Module 4:

Acoustic Testing and Instrumentation: Aeroacoustic wind tunnels, Wind tunnel acoustic corrections, Sound measurement, Sound pressure level and sound power level, Decibels, A-weighting, Octave bands, Sound level meter, Measurement of turbulent pressure fluctuations, Velocity measurement, Limitations of measured data, Uncertainty, Fourier transforms, Time spectra and correlations. [8L]

Module 5:

Jet Noise: Characteristics of Supersonic Jet Noise, Turbulent mixing noise, Broadband shock-associated noise, Screech tones, Shock Cell structure of Supersonic Jets, Phased point-source array model, Acoustically excited Jets, Jet noise reduction techniques. [8L]

Text books:

1. Aeroacoustics – M.E. Goldstein.**(T1)**
2. Aeroacoustic Measurements - T.J. Mueller (Ed.). **(T2)**
3. Fundamentals of Acoustics - L.E. Kinsler, A.R. Frey, A.B. Coppens and J. V. Sanders. **(T3)**
4. Theoretical Acoustics – P. M. Morse and K. U. Ingard**(T4)**
5. Sound and Sources of Sound – Ann P. Dowling and John E. Ffowcs Williams**(T5)**

Reference books:

1. Fundamentals of Engineering Numerical Analysis – ParvizMoin **(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Course Outcome and Program Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	-	2	1	2	1
CO2	3	1	-	2	3	2
CO3	2	-	-	3	3	3
CO4	3	-	1	2	-	-
CO5	3	3	-	2	2	1

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 515
Course title: Fundamental of Turbulence
Pre-requisite(s): Fundamental of Aerodynamics
Co- requisite(s):
Credits: 3 L:03 T: P:
Class schedule per week: 03
Class: M. TECH.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the origin of turbulence in fluids.
2.	Recognize the turbulence transport equations.
3.	Examine the effect of parametric variation in turbulence.
4.	Understand the flow with and without wall boundaries.
5.	Analyze turbulence using statistics.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Illustrating the growth of turbulence in a fluid flow.
CO2	Able to describe transport equations related to fluid flow.
CO3	Explaining the variation in turbulence due to various factors.
CO4	Able to demonstrate the turbulence in free shear and wall bounded flows.
CO5	Applying the statistical approach for turbulence realization in a fluid flow.

Syllabus

Module 1:
Turbulence : Introduction, Nature of Turbulence, Methods of Analysis- Dimensional, Asymptotic and local invariance, Origin, Diffusivity with length and time scale, Eddy Diffusivity. [7]

Module 2:
Turbulent Transport : Reynolds equation, decomposition, mean flow, Reynolds Stress, Introduction to kinetic theory of gases, Estimates of Reynolds stresses, Reynolds stress and vortex stretching, Mixing length model, heat transfer. [7]

Module 3:
Dynamics of turbulence: Kinetic energy of the mean flow, Effect of viscosity, Production and dissipation, Taylor microscale, Spectral energy, Wind tunnel turbulence, Pure Shear Flows, Vorticity dynamics, vector and tensor, Reynolds Stress and vorticity equations, Two dimensional mean flows, Multiple length scales. [9]

Module 4:
Free Shear and wall bounded Flows: Two dimensional flows, plane flows, Cross stream momentum equation, wakes, mixing, Multiple scales- sublayer, velocity defect law, Channel flows, Logarithmic friction law, Effect of pressure gradient. [8]

Module 5:
Statistical description, Turbulent Transport, Spectral Dynamics: Probability density, Effect of spikes and discontinuities, Correlations, Transport in stationary, homogenous turbulence, Diffusion equation, Uniform shear flow, Grid turbulence, one and three dimensional spectra, Three dimensional spectrum, Isotropic relations, effect of production and dissipation. [9]

Text books:

1. **A first course in Turbulence – Tennekes and Lumley**
2. **Turbulent Flow – Steven B. Pope**

Reference books:

1. **Turbulence – J. O. Hinze**
2. **Basics of Engineering Turbulence – S. David, K. Ting**

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes into Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	-	-	3	1	-	-
2	2	-	3	2	-	1
3	3	1	3	3	2	2
4	3	2	3	3	2	2
5	3	2	3	3	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 580
Course title: Elements of Hypersonic Flight
Pre-requisite(s): Compressible Flow
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Know fundamental of hypersonic flow and its importance.
2.	Learn hypersonic shock, expansion-wave relations.
3.	Analyze the hypersonic inviscid flowfields using approximate and exact methods.
4.	Comprehend basic aspects boundary layer and aerodynamic heating in viscous hypersonic flow.
5.	Apply computational fluid dynamics in hypersonic viscous flow.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Learn the basics of hypersonic flow, high temperature and low density flows.
CO2	Understand the hypersonic shock and expansion-wave theory, Newtonian and modified Newtonian laws.
CO3	Analyze the inviscid flowfields in hypersonic flow using approximate and exact methods.
CO4	Learn the hypersonic boundary layer theory and hypersonic aerodynamic heating.
CO5	Apply the computational fluid dynamics for Navier- Stokes solutions in hypersonic flows.

Syllabus

Module 1:
Introduction: Hypersonic Flow and Its Importance; Shock Layer; Entropy Layer; Viscous Interaction; High Temperature Flows; Low Density Flows; Hypersonic Flight Paths: Velocity-Altitude Map. [7 L]

Module2:
Hypersonic Shock- Expansion Theory: Shock Relation; Hypersonic Shock Relations in Terms of the Hypersonic Similarity Parameter; Expansion-Wave Relation; Newtonian Flow; Modified Newtonian Law; Centrifugal Force Corrections to Newtonian Theory; Tangent- Wedge/ Tangent- Cone Methods; Shock- Expansion Method. [10 L]

Module 3:

Hypersonic Inviscid Flowfields (Approximate and Exact Methods): Introduction; The Governing Equations; Mach Number Independence; The Hypersonic Small- Disturbance Equations; Hypersonic Similarity; Hypersonic Small- Disturbance Theory; The Hypersonic Equivalence Principle and Blast Wave Theory; Thin Shock- Layer Theory; Method of Characteristics; The Hypersonic Blunt- Body Problem; Correlations for Hypersonic Shock- Wave Shapes; Modern Computational Hypersonics. [10 L]

Module 4:

Viscous Hypersonic Flow: Governing Equations for Viscous Flow; The Navier- Stokes Equations; Similarity Parameters and Boundary Conditions; The Boundary Layer Equations for Hypersonic Flow; Hypersonic Boundary Layer Theory: Self- Similar Solutions, Flat Plate Case, Stagnation Point Case; Hypersonic Transition; Hypersonic Turbulent Boundary Layer; Hypersonic Aerodynamic Heating; Entropy Layer Effects on Aerodynamic Heating. [10 L]

Module 5:

Computational Fluid Dynamic Solutions of Hypersonic Viscous Flows: Introduction; Viscous Shock- Layer Technique; Parabolized Navier- Stokes Solutions; Full Navier- Stokes Solutions. [7 L]

Text books:

1. Hypersonic and High Temperature Gas Dynamics – Anderson, John D., McGraw Hill, 1989. **(T1)**

Reference books:

1. Selected Aerothermodynamic Design Problems of Hypersonic Flight Vehicles, E. Hirschel, C. Weiland., Springer-Verlag Berlin and AIAA, 2009. **(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

Thermodynamics of Chemically Reacting Gases

POs met through Gaps in the Syllabus: PO1, PO3, PO6

Topics beyond syllabus/Advanced topics/Design

Statistical Thermodynamics

POs met through Topics beyond syllabus/Advanced topics/Design: PO1, PO3, PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Tutorials/Assignments
CD3	Seminars
CD4	Self- learning such as use of NPTEL materials and internets
CD5	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	1	2
CO2	2	2	2	1	1	2
CO3	3	2	2	2	1	3
CO4	3	2	3	2	1	3
CO5	3	2	2	2	1	3

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1
CO2	CD1, CD2,CD3
CO3	CD1, CD2,CD3
CO4	CD1, CD2,CD3,CD4
CO5	CD1, CD2, CD3,CD4,CD5

COURSE INFORMATION SHEET

Course code: SR 516
Course title: Aerodynamics of Internal Flows
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the kinematics and dynamics of vorticity and circulation
2.	Describe the variety of boundary layer equations for different surfaces of diffusers
3.	Classify unsteady, inviscid, compressible flows inside a channel.
4.	Relate starting of flow, effect of friction, heat on the compressible channel flow
5.	Implement flow process in ramjet and scramjet system.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Describe fundamental principles of rotational flows in terms of vorticity / circulation
CO2	Interpret boundary layers and shear layers over different categories of surfaces
CO3	Classify unsteady channel flows.
CO4	Relate different influences inside a compressible channel flow
CO5	Distinguish characters of flow process in a ramjet and scramjet system with heat considerations.

Syllabus

Module 1:
Vorticity and Circulation: Vorticity kinematics and dynamics; Vorticity changes in incompressible and compressible inviscid flows; Circulation behavior in an incompressible and compressible inviscid flow; Rotational flows in terms of vorticity and circulation; Crocco's theorem. [8]

Module 2:
Boundary layers and free shear layers: Boundary layer equations for plane and curved surfaces; Laminar, transitional and Turbulent boundary layers; Viscous-Inviscid interactions in a diffuser; Free turbulent flows; Turbulent entrainment; Jets and wakes in pressure gradients. [8]

Module 3:
Unsteady flow: Reduced frequency; Examples of unsteady flows; Shear layer instability; System instabilities; Unsteady disturbances in compressible inviscid flow; Oscillating boundary; Oscillating channel; Unsteady boundary layers. [8]

Module 4:

Compressible internal flow: Introduction; Effect of friction, heat addition on compressible channel flow; Starting of supersonic diffusers; Characteristics of supersonic flow in passages and channels; Compound channel flows: Flow angle, Mach number, and pressure changes in isentropic supersonic flow; shock boundary layer interaction in internal flows. [9]

Module 5:

Flow with Heat addition: Heat addition and vorticity generation; H-K diagram; Flow process in ramjet and scramjet systems; An approximate substitution principle, Flow with heat addition and mixing, Two-stream mixing (constant area, low Mach number, uniform inlet stagnation pressure), Two-stream mixing (non-uniform inlet stagnation pressures), Effects of inlet Mach number level; Applications of the approximate principle (Lobed nozzles, Jets, Ejectors, etc.). [9]

Text books:

1. Internal Flow – Greitzer, E. M., Tan, C. S., and Graf, M. B.
2. Aspects of Internal Flow - Ackeret, J., : in *Fluid Mechanics of Internal Flow,* Sovran, G. (ed.), Elsevier Publishing Company, Amsterdam.
3. Internal Flows - Johnston, J. P., 1978, : in *Turbulence*, Bradshaw, P. (ed.), Springer Verlag, Berlin, 109–172.

Reference books:

4. Boundary Layers in Internal Flow - Performance Prediction - Johnston, J. P., 1986,:, in *Advanced Topics in Turbomachinery Technology*, Japikse, D. (ed.), Concepts ETI Press, Wilder, VT.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	2	-	2		3	3
2	2	-	3	2	2	
3	2	3	-	3	-	2
4	3	2	3	-	-	3
5	3	2	3	2	-	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 517
Course title: Basics of Measurement
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II / 5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the fundamentals of measurement
2.	Describe the quality of measured and measuring system
3.	Use the different tools for quality and accurate measurement.
4.	Select the different sensors for variety of measurements.
5.	Test acoustical parameters using theoretical as well as instrumental considerations.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Discuss fundamental principles of measurement and its system
CO2	Describe the different tools and features for analog measurements
CO3	Demonstrate the need for amplifiers, signal conditioning, filters, etc.
CO4	Select sensors required for pressure, flow, temperature, etc.
CO5	Organise and perform acoustical measurement.

Syllabus

Module 1:
Fundamentals of measurement: Methods of measurement; Measuring system; Types of input quantities; Standards; Calibration; Error analysis; Uncertainty (estimation, propagation and analysis); sources of error; Chi-squared distribution; Method of least squares; Different types of Sensors and Transducers. [8L]

Module 2:
Analog Measurand and Response of measuring system: Simple harmonic relation; Cyclic frequency; Complex relations; Frequency spectrum; Fourier Analysis; Amplitudes of waveform; Amplitude/Frequency/Phase response; Delay, rise time, and slew rate; Response of experimental system elements; Mechanical and electrical elements; Calibration for System response. [8L]

Module 3:
Signal Conditioning and Processing: Signal conditioning; Operational amplifiers; Protection; Filtering theory; Active filters; Electronic counters; Analog meters; Multimeter; Cathod ray oscilloscope; Oscillograph; Plotters; Spectrum analyzer. [7L]

Module 4:

Measurement of Pressure, Flow and Temperature: Static and Dynamic pressure; Pressure measuring system and transducers; Dynamic characteristics of pressure measuring system; Calibration method; Obstruction meter; Flow meters; Pressure probes; Thermal anemometer; Calibration of flow measuring devices; Pressure thermometer; Thermo resistive elements; Thermocouple; Errors; Measurement of temperature in fluid flow; Measurement of heat flux. [9L]

Module 5:

Acoustical measurement: Characteristics of sound; Sound pressure; Sound pressure level; Power; Intensity; Power level; Combination of sound pressure level; Attenuation with distance; Microphones; Sound level meter; Frequency spectrum analyser; DFT; Equivalent sound meter; Sound exposure level; Sound intensity measurement. [8]

Text books:

1. Mechanical Measurements – Bechwith, T. G., Marangoni, R. D., and LienhardV, J. H.. 5th Edition, Pearson Education Asia, ISBN 81-7808-055-9.
2. Mechatronics – Bolton, W., 2nd Edition, Pearson Education, ISBN 81-7808-339-6.
3. Instrumentation, Experiments and Measurements in Fluids- E. Rathakrishnan

Reference books:

4. Handbook of Experimental Fluid Mechanics – Tropia, Yarin and Foss

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	2	-	-	1	2	3
2	2	-	1	2	2	2
3	3	1	2	2	2	2
4	2	-	2	1	-	2
5	3	2	3	3	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 518
Course title: Turbulence Modeling in CFD
Pre-requisite(s): Fluid Mechanics, Numerical Analysis, Computational Fluid Dynamics
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Know basics of turbulence and numerical techniques to solve the governing equations.
2.	Understand the averating techniques and RANS equations.
3.	Learn the algebraic models and their application in different flows.
4.	Understand the one and two equation turbulence models and numerical implementation.
5.	Know the Large Eddy Simulation and Direct Numerical Simulation and their advantages and disadvantages.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Know the fundamental concepts of turbulence and numerical techniques to solve pdes in fluid flows.
CO2	Understand different averaging techniques and RANS equations.
CO3	Apply the algebraic turbulence models to solve problems like wall bounded and separated flows.
CO4	Learn and implement the one and two equation turbulence models and compare the different models.
CO5	Understand the Large Eddy Simulation, Detached Eddy Simulation, Direct Numerical Simulations and their limitations.

Syllabus

Module 1:
Introduction to Turbulence and CFD: Fundamental Concepts of Turbulence, Transition from Laminar to Turbulent Flows, Descriptors of Turbulent Flows, Characteristics of Simple Turbulent Flows, Numerical Techniques to Solve Governing Equations in Fluid Flows, Inviscid Flux Schemes, Boundary Conditions. [10L]

Module 2:
Basic Equations of Turbulence: Reynolds Averaging, Favre (Mass) Averaging, The Navier-Stokes Equations, Reynolds-Averaged Navier-Stokes (RANS) Equations, Favre- and Reynolds-Averaged Navier-Stokes Equations, Eddy Viscosity Hypothesis, Numerical Implementation of Euler / Navier-Stokes Equations. [10L]

Module 3:

Algebraic Models: Molecular Transport of Momentum, The Mixing-Length Hypothesis, Application to Free Shear Flows, Cebeci-Smith Model, Baldwin-Lomax Model, Application to Wall-Bounded Flows, Separated Flows, The ½ Equation Model. [8L]

Module 4:

One and Two Equations Models: Baldwin-Barth One-Equation Turbulence Model, Spalart-Allmaras One-Equation Turbulence Model, K- ε Two-Equation Tubulence Model, RNG K- ε Model, k-ω Two-Equation Turbulence Model, SST k-ω Model, Comparison of Various Turbulence Models, Numerical Implementation. [8L]

Module 5:

Large Eddy Simulation and Direct Numerical Simulation: Large Eddy Simulation (LES), Spatial Filtering, Filtered Governing Equations, Eddy Viscosity Models, Smagorinsky SGS Model, Dynamic SGS Models, Detached Eddy Simulation (DES), Direct Numerical Simulation (DNS), Advantages and Limitations of LES, DES and DNS. [8L]

Text books:

1. Wilcox, D. C., Turbulence Modeling for CFD, DCW Industries, 1994. (**T1**)
2. Versteeg, H. K., and Malalasekera, W., An Introduction to Computational Fluid Dynamics, Pearson Education Limited, 2007. (**T2**)

Reference books:

1. Blazek, J., Computational Fluid Dynamics: Principles and Applications, Elsevier, 2001. (**R1**)
2. Hoffmann, K. A. and Chiang, S. T., Computational Fluid Dynamics (Vol. III), Engineering Education System, 2000. (**R2**)

Gaps in the syllabus (to meet Industry/Profession requirements) : Developing a RANS code

POs met through Gaps in the Syllabus : PO1, PO2, PO3, PO4, PO5, PO6

Topics beyond syllabus/Advanced topics/Design : Developing a LES code
POs met through Topics beyond syllabus/Advanced topics/Design : PO1, PO2, PO3, PO4, PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	1
CO2	2	1	3	1	1	2
CO3	2	2	2	2	1	3
CO4	3	2	3	2	2	3
CO5	3	2	3	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD2,CD6
CO3	CD1, CD2, CD6
CO4	CD1, CD2,CD6
CO5	CD1,CD2,CD6

COURSE INFORMATION SHEET

Course code: SR 582
Course title: Low Speed Aerodynamics Laboratory
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 2 L: T:0 P:4
Class schedule per week: 4 Lectures
Class: M. Tech.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	The basics of instrument calibration, handling of electronic instruments.
2.	Measure different forces and moments of the wind tunnel model
3.	Basic skills of flow visualization.
4.	Measure the steady and unsteady quantities on a wind tunnel model.
5.	Work in a group and evaluate the results to prepare the report.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Operate the instruments and perform the calibration independently.
CO2	Organize and perform any experiment with data acquisition system and adopt suitable precautions.
CO3	Demonstrate experimental needs to obtain meaningful and quality results.
CO4	Analyse the experimental results and write the report.
CO5	Do experimental work in the field of low speed flows in a group as well as individually.

List of the Experiments:

S. No.	Experiment	Class Hours
1	Force and Moment measurements on Delta Wing at Subsonic Speed and at different Angles of Attack.	6
2	Oil and Tuft flow visualisation over Slender Body and Delta Wing at High Angles of Attack.	6
3	Calibration of Pressure Sensors mounted in the Scanner Box for Subsonic applications.	3
4	Pressure measurements over a Delta Wing using Sensors and DAQ System.	3
5	Unsteady Pressure measurement on the Leeward side of a Delta Wing at Subsonic Speed and at different Angles of Attack.	3

6	Preparation of Hot-Wire probes for experiments with Hot-Wire Anemometer.	3
7	Boundary Layer measurement on a Flat Plate using Hot-Wire Anemometer at different Subsonic Speeds.	3
8	Measurement of Boundary Layer along the length of the Flat Plate.	3

Gaps in the syllabus (to meet Industry/Profession requirements):

Turbulence experiments

Good quality flow visualisation

POs met through Gaps in the Syllabus: PO4, PO5

Topics beyond syllabus/Advanced topics/Design:

1. Particle Image Velocimetry
2. Schlieren technique

POs met through Topics beyond syllabus/Advanced topics/Design: PO6

Mapping between CO and PO

COURSE OUTCOME	**Program Outcome**					
	PO1	PO2	PO3	PO4	PO5	PO6
1	3	1	1	1	2	2
2	3	2	1	1	3	1
3	1	3	2	2	3	2
4	2	3	3	1	1	2
5	1	3	1	1	3	1

COURSE INFORMATION SHEET

Course code: SR 583
Course title: High Speed Aerodynamics Laboratory
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L: T:0 P:3
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives: This course enables the students to:

1.	The basics of instrument calibration, handling of electronic instruments.
2.	Measure different components form the wind tunnel model.
3.	Plan an experiment with all steps, precaution and limitations.
4.	Basic skills of flow visualization.
5.	Work in a group and evaluate the results to prepare the report.

Course Outcomes
After the completion of this course, students will be able:

CO1	Operate and communicate with any instruments and calibrate them.
CO2	Organize and perform any experiment with high speed data acquisition system and adopt suitable precautions.
CO3	Demonstrate experimental needs to obtain meaningful and quality results.
CO4	Examine the experimental results and write the report.
CO5	Do experimental work in the field of compressible fluid dynamics in a group as well as individual.

List of the Experiments:

1. **<u>Experiment No. 1</u>**
   Name: Wind Tunnel Calibration
   Object : Calibration of Supersonic Wind Tunnel using the following techniques
   a) Area ratio
   b) Static Pressure Distribution
   c) Pitot Probe Measurement

2. **<u>Experiment No. 2</u>**
   Name : Study noise measurements using unsteady pressure pickups
   Object : To study the noise measurement of the tunnel and obtain the RMS pressure and overall sound pressure level.

3. **<u>Experiment No. 3</u>**
   Name: Study pressure measurements using static pressure transducers and manometer
   Object: To study pressure distribution around cylindrical protrusion placed in a

supersonic flow with M=2.0

4. **Experiment No. 4**
   Name: Flow Visualisation Techniques at supersonic speed
   Object: To study flow visualization over a typical cylindrical protrusion and other isolated models using
   a) Oil Flow Visualisation
   b) Schlieren optical method
   c) Shadowgraph technique

5. **Experiment No. 5**
   Name: Cavity Pressure Fluctuation
   Object : To study the pressure fluctuations inside a generic cavity at Supersonic speed

6. **Experiment No. 6**
   Name: Free Jet Studies
   Object: To obtain the flow patterns at the exit of a free jet and influence of pressure ratio on the flow.

7. **Experiment No. 7**
   Name: Drag Measurement using single component strain gage balance
   Object: To measure drag over a blunt nose body and establish a drag reduction with adoption of spike ahead of the blunt body

References :

1. HIGH SPEED WIND TUNNEL TESTING by Alan Pope and Kennith L. Goin
2. SCHLIEREN AND SHADOWGRAPH TECHNIQUES by G.S.Settles

Gaps in the syllabus (to meet Industry/Profession requirements)

7) Boundary layer measurement technique
8) Force and moment measurements at different angles of attack

POs met through Gaps in the Syllabus

PO1, PO4, PO5

Topics beyond syllabus/Advanced topics/Design

5) Particle Image Velocimetry
6) Background Oriented Schlieren technique

POs met through Topics beyond syllabus/Advanced topics/Design

PO3, PO6

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids

Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets
Simulation

Mapping of Course Outcomes into Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	2	1		2	2	2
2	2	-	2	2	1	-
3	2	-	2	2		2
4	1	2	2		1	-
5	2	2	2	2	-	-

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

Specialization
Rocket Propulsion

COURSE INFORMATION SHEET

Course code: SR 550
Course title: Liquid & Hybrid Rocket Propulsion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Explain the working theory of liquid rocket engine, cryogenic engine and hybrid rocket propulsion system.
2.	Identify the fundamental concept of the feed systems of the liquid rocket propulsion system in terms of designing in a practical application.
3.	Identify the concept of thrust chamber and other combustion devices of liquid rocket engine in the design approach.
4.	Generate sufficient information on the precautions and designing challenges of a cryogenic propulsion system.
5.	Create a basic platform for designing a hybrid rocket propulsion system.

Course Outcomes
After the completion of this course, students will be able:

1.	To get the knowledge on the various basic terms and performance parameters used in a liquid rocket engine.
2.	To analyze and investigate various types of feed system used in a liquid rocket engine and later utilize it in the designing process.
3.	To comprehend the concept of thrust chamber and other combustion devices of liquid rocket engine in the design approach.
4.	To describe the basic information related to the designing challenges of the cryogenic propulsion system.
5.	To explain the limitations and designing challenges of the hybrid rocket motor.

Syllabus

Module 1:
Liquid Propellants and LPR Engine
Basic Elements of an LPR Engine; Performance Parameters of selected existing Liquid Rocket Engines. [6L]

Module 2:
Feed Systems
Types of feed system in liquid rocket engine, Purpose; Types of Pressure Feed Systems; Methods of Tank- pressure Control; Types of Pressurization Systems; Desirable Characteristics of Pressurants; Tank Pressurant requirements and its Determination; Pressurized Gas Systems, Elements of Pump

Feed Systems; Centrifugal Pumps and Axial Flow Pumps; Turbines; Design Layout of Turbo-pump Assemblies; Control Valves and their selection; Transient Pressures due to Valve Closure and Valve Opening; Design of the Wall Thickness of Propellant Line; Frictional Losses in Propellant Feed Lines, Overall design of feed systems both pressure fed and turbo pump fed systems. **[10L]**

Module 3:

Thrust Chambers and Auxiliary Combustion Devices: Basic Thrust Chamber Elements; Combustion Chamber Design and Characteristic Length; Combustion Process; Performance Parameters; Engine Design and Control; Configuration Layout; Materials and Selection; Types of Injectors; Injector Design and Performance; Ignition Devices; Heat Transfer; Regenerative Cooling; design of regenerative cooled engines, Uncooled Chambers; Combustion Instability; Nozzle Flow; Nozzle Design; Thrust Vector Control. Design of liquid rockets with sub system design. **[9L]**

Module 4:

Cryogenic Propulsion: Cryogenic Loading Problems; Temperature and Pressure Effects on Loading; Tank Collapse; Phenomenon of Thermal Stratification; Effect of Thermal Stratification on Rocket Engine Performance; Prediction and Methods of Elimination of Thermal Stratification. **[7L]**

Module 5:

Hybrid Rocket Propulsion: Introduction; Classification; System Arrangement and Components; Typical Fuels and Oxidizers; Advantages and Disadvantages; Application Areas; Performance and Limitations; Performance Parameters of selected existing Hybrid Rocket Engines; System Integration; Manufacturing Methods for Low- and High- Thrust Engines. Design of hybrid rockets with sub system design including grain design. [8L]

Text books:

1. Design of Liquid Propellant Rocket Engine – Huzel, D. K. & Huang, D. H., NASA SP-125
2. Fundamental of Hybrid Rocket Combustion and Propulsion, Martin J. Chiaverini and Kennith K. Kuo, Progress in Aeronautics & Astronautics, Vol. 218, AIAA.
3. Safety in the Handling of Cryogenic Fluids, Frederick J. Edeskuty and Walter F. Stewart. The International Cryogenic Monograph Series, Springer Science + Business Media New York.

Reference books:

1. Rocket Propellant and Pressurization Systems – Ring, E.
2. Heterogeneous Combustion – Wolfhard,H. G., Progress in Aeronautics & Astronautics, Vol. 15, AIAA.
3. Liquid Rocket and Propellants – Bollinger, L. E., Progress in Aeronautics & Astronautics, Vol. AIAA.
4. Cryogenic Systems – Barron, R.
5. Thermodynamic Properties of Cryogenic Fluids, Richard T Jacobsen, Steven G Penoncello and Eric W. Lemmon, The International Cryogenic Monograph Series, Springer Science + Business Media New York.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	3
CO2	3	2	3	2	2	3
CO3	3	3	3	2	2	3
CO4	2	1	2	1	1	3
CO5	3	2	3	2	-	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3
CO2	CD1, CD2,CD3,CD4
CO3	CD1, CD2,CD3
CO4	CD1, CD2
CO5	CD1, CD2

COURSE INFORMATION SHEET

Course code: SR 551
Course title: Solid Rocket Propulsion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Demonstrate the information and implications of the types of grain suitable for a particular solid rocket motor.
2.	Examine the importance on the types of the nozzle and performance parameters utilization in practical applications.
3.	Apply the concept of metal combustion and identify the changes in energetics and combustion behaviour due to erosive burning.
4.	Apply the basic knowledge of an igniters in the designing process of a solid rocket motor.
5.	Examine the various types of instabilities occurring in solid rocket motor along with their remedies.

Course Outcomes

After the completion of this course, students will be able:

1.	To interpret different types of propellant grain and its significance in the designing of solid rocket motor.
2.	To analyze the various performance parameters and application of different types of nozzle used in solid rocket motor.
3.	Identify and analyze the effect of metal addition on the combustion energetics and interpret the instabilities associated with erosive burning, their remedial methods.
4.	To describe the concept of ignition system in designing the igniters for a solid rocket motor.
5.	To predict the various types of instabilities occurring in solid rocket motor along with their remedies.

Syllabus
Module 1:
Solid Rocket Motor: Introduction to Solid Rocket, Classification, Types of Grain and its importance, Propellant Characteristics, Star Configuration; Design Criteria; Segmented Grains; Burning Surface Area Evaluation; Dual Thrust Grains. Structural Analysis of Propellant Grain, Types of Mechanical Load, Structure Failure of Grains. **[9L]**

Module 2:

Nozzle and Performance prediction methods: Nozzle Configuration; Annular Nozzles, Adopted Nozzles, Submerged Nozzles; Nozzle Construction; Prediction and Measurements of Specific Impulse, Computation of Adiabatic Flame Temperature; Theoretical Performance Evaluation of Solid Rocket Propellants; Equilibrium and Frozen Flow; Experimental Determination of Rocket Performance. **[8L]**

Module 3:

Metals and Erosive Burning: Description and Classification of Various Burning Metals; Theories of Combustion of Metal Powders; Effect of Aluminum on Propellant Burning Rate; Erosive burning; Laboratory Methods for Determination of the Erosion Function; Theories of Erosive Burning, Effect of Erosion on various parameters, Negative Erosion Phenomenon.

[8L]

Module 4:

Associated Systems : Ignition and Ignition Delay; Selection Criteria of Igniter Composition, Quantity and Location; Design of Igniters; Sample Calculation; Igniters for Solid Rocket Motor; Igniter Hardware; Igniter Pellets; Pyrogen Igniters; Extinction of Solid Rocket Motors; Restart of Solid Rocket Motors; Inhibition and Inhibitors; Insulation and Liners; Thrust Vector Control; Mechanism and Methods of TVC; Testing and Integration with Vehicle. **[9L]**

Module 5:

Combustion Instability: Types of Instability – Bulk Mode, Transverse Mode and Axial Mode Instabilities; Causes of Instability in Solid Rocket Motors; Analysis of Instability in Solid Rocket Motors; Remedial Methods. **[6L]**

Text books:

1. Solid Rocket Propulsion – Barrere, M., et. Al
2. Rocket Propulsion Elements – Sutton, G. P. and Biblarz, O., 7th Ed.

Reference books:

1. Solid Rocket Technology – Shorr, M. and Zaehringer, A. J.
2. Understanding Aerospace Chemical Propulsion, H S Mukunda
3. Rocket Propulsion, K Ramamurthi.
4. Introduction to Rocket Technology, V. I. Feodosiev and G. B. Siniarev
5. Materials for Missiles and Spacecraft, E. R. Parker

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	2	1	3
CO2	3	2	3	2	2	3
CO3	1	1	2	1	1	3
CO4	3	1	3	1	1	2
CO5	3	1	3	1	1	2

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

COURSE INFORMATION SHEET

Course code: SR 552
Course title: Rocket Combustion Processes
Pre-requisite(s): NA
Co- requisite(s):NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the concept of enthalpy, adiabatic flame temperature, chemical kinetics and their application to combustion related problems.
2.	Comprehend the various types of flames, along with detonation waves observed in rocket motors.
3.	Understand details of combustion process associated with double base and composite propellants and compare the condensed and gas phase theories related to them.
4.	Understand combustion of liquid propellants in rocket motor with emphasis on atomization and related combustion models.
5.	Comprehend combustion model of hybrid propellants in view of existing theories of hybrid combustion and related operating parameters in a hybrid rocket motor.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Apply the basic concept of thermochemistry and chemical kinetics to combustion related problems.
CO2	Distinguish between premixed, diffusion flames, deflagration and detonation process and their use in combustion devices and rockets.
CO3	Comprehend principal concepts and predict the related theory for a typical case of solid propellant combustion.
CO4	Summarize the effect of atomization and droplet size distribution in the combustion of liquid propellant and evaluate the effect of different parameters in the combustion process.
CO5	Comprehend the theories of hybrid combustion and evaluate the effect of related operating parameters in a hybrid rocket motor.

Syllabus

Module 1:
Basics to Rocket Combustion: Stoichiometry, Adiabatic Flame Temperature and its Application in Rocket combustion; Enthalpy of Formation; Enthalpy of Combustion; Rate and Order of Different Reactions; Arrhenius Equation; Chain Reaction, Explosion Limits; Combustion Products in Equilibrium, Ionization in Rocket Exhaust.

[8 L]

Module 2:

Flames and Detonation: Concept of Flame; Properties of Premixed Flames; Properties of Diffusion Flames; Burning Velocity; Flame Stabilization; Flame Quenching; Detonation Wave and their Characteristics; Deflagration to Detonation Transition; Chapman- Jouguet States and their Properties; Computation of Detonation Velocity.

[8 L]

Module 3:

Solid Propellant Combustion : Combustion of Double Base Propellants; Combustion Mechanisms in Condensed Phase and Gas Phase; Theories of Combustion of D. B. Propellants – Boys & Corner Theory, Two- temperature Postulate of composite propellant; **Guirao-Williams Model for Combustion of Ammonium Perchlorate**; Combustion Mechanism of Composite Propellants; Theories of Combustion – Outline of Thermal Theory, GDF Model and Multiple Flame (BDP) Combustion Model. **[11L]**

Module 4:

Liquid Propellant Combustion: Physico- Chemical Description of Combustion in a Liquid Propellant Rocket Motor; Atomization and Droplet Size Distribution in Injection Sprays; Spherico- symmetric Model of Fuel Burning in Oxidizing Atmosphere; Correlation for Non-spherical Model; Effect of Drag on Combustion; Effect of Pressure on Combustion; Droplet Burning Rate Measurement; Combustion Models for Monopropellants. **[7L]**

Module 5:

Hybrid Propellant Combustion : Introduction; Combustion Model for a Hybrid Fuel Burning in an Oxidizer Stream; Theories of Hybrid Combustion – Laminar Boundary Layer Theories, Turbulent Boundary Layer Theories, Theories Based on Chemical Kinetics; Effect of Pressure and Mass Flow Rate on Hybrid Combustion; Transient Behaviour of Hybrid Regression Rate; Temperature Profile inside the Regressing Solid Fuel; Combustion of Metallized Hybrid Fuel; Effect of Radiation, Burning Time, Length and Port Size on Fuel Regression Rate. **[8L]**

Text books:

1. S. R. Turn, An Introduction to Combustion - Concepts and Applications, 3rd Edition, McGraw-Hill, India, 2012.(T1)
2. Fundamentals of Solid Propellant Combustion, Kuo, K. K., Summerfield, M., Progress in Astronautics & Aeronautics, Vol. 90, AIAA. 1984.
3. Liquid Propellant Rockets, Altman, D., Carter, J. M., Penner, S.S., Summerfield, M., Princeton University Press, 1960.

Reference books:

1. B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 3rd Edition, Academic Press, Orlando, 1987. (R1)
2. A. G. Gaydon and H. D. Wolfhard, Flames: Their Structure, Radiation and Temperature, 3rd Edition, Springer NY, USA, 1970. (R2)
3. Solid Rocket Propulaion Technology, Ed. Alain Davenas, Elsevier, 1992. (ISBN 978-0-08-040999-3 (R3)
4. Fundamental of Hybrid Rocket Combustion and Propulsion, Chiaverini, M.J., Kuo, K.K., Progress in Astronautics & Aeronautics, Vol. 218, AIAA. 2007. (R4)

5. Heterogeneous Combustion, Wolfhard, H.G., Glassman, I., Green, L., Progress in Astronautics & Aeronautics, Vol. 15, AIAA. 1964.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	2	1		3
CO2	2	1	2	1		3
CO3	3	2	3	2	3	3
CO4	2	1	3	2		1
CO5	3	3	3	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

COURSE INFORMATION SHEET

Course code: SR 553
Course title: Ignition and Extinction in Chemical Rocket
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M.Tech.
Semester / Level: II/05
Branch: Space Engineering & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Identify and interpret the factors affecting the ignition energy release and its mechanism for any given ignition source.
2.	Examine the suitability of ignitions for any chemical rocket based on its merits and demerits.
3.	Judge the type of igniters to be designed for any chemical rocket propulsion system.
4.	Generate the sufficient information about the flame spreading and its mechanism in solid rocket motor.
5.	Assess the knowledge of solid propellant extinction in the designing process of a solid rocket motor.

Course Outcomes

After the completion of this course, students will be able to:

1.	Interpret different types of igniters and its applications in the propulsion system.
2.	Analyze the ignition mechanism and its sequence mainly for solid rocket applications.
3.	Design an igniter for the given chemical rocket propulsion system for the given thrust range.
4.	Describe the concept of flame spreading and ignition transient in a solid rocket motor.
5.	Predict the various mechanism of extinction utilized in the solid rocket motor along with their advantages and disadvantages.

Syllabus

Module 1:
Ignition & Factors affecting Ignition Energy: Introduction; Process of Self- ignition; Induction Period; Limits of Self-ignition; Forced ignition; Basic Idea of Ignition by Spark; Pilot Flames; Hot Gases and Shock Waves; Effect of Composition, Type of Electrode, Spark Duration, Pressure, Temperature, Diluents, Effect of Mixture Velocity and Turbulence on Ignition Energy. [8L]

Module 2:
Ignition Mechanism: Sequence of Ignition; Theories of Ignition – Thermal Ignition Theory, Gas-Phase Theory and Heterogeneous Theory; Pre- ignition Reactions; Effect of Catalyst on Ignition Process; Shock Tube and Ignition Experiments. [7L]

Module 3:
Igniters for Chemical Rocket : Igniters for Solid Rocket Motors – Role and Requirements; Classification of Igniters based on Mounting Locations and Energy Release Systems; Construction and Initiation Systems; Hardware Components; Design of Pyrotechnic and Pyrogen Igniters; Testing and Evaluation; Igniters for Liquid Propellant Engines, Hypergolic Ignition and Ignition Delay; Catalyst Induced Ignition; Igniters for Cryogenic Engines – Spark Torch, Pyrotechnic, Pyrogen and Plasma Igniters; Igniters for Hybrid Motors and Air Breathing Engines; Laser Induced Ignition and its Applications. [11L]

Module 4:
Flame Spreading and Ignition Transient: Physical Processes during Ignition Transient; Ignition Transient Models and Experiments; Flame Spreading over Solid Propellants, Fuels, Defects and Cracks. [6L]

Module 5:
Extinction: Controlled Termination of Thrust – Approaches; Energy Balance at Burning Surface; Dynamic Extinction by Fast Depressurization, Fast Deradiation and other Quenching Techniques, like Injection of Flame Inhibitors, Heat Sink, etc.; Theories and Experiments of Extinction. [8L]

Text books:
1. Fuels & Combustion – Sharma, S.P. & Mohan, C., Tata- McGraw Hill, 1984 **(T1)**
2. Fundamental Aspects of Solid Propellant Rockets, Williams, F.A., Barrère, M., Huang, N.C., The Advisory Group for Aerospace Research and Development of N.A.T.O. [by] Technivision Services, 1969.**(T2)**

Reference books:
1. Advanced Chemical Rocket Propulsion Elements – Timnat, Y.M., Academic Press, 1987.**(R1)**
2. Fundamentals of Solid Propellant Combustion – Kuo, K.K., Summerfield, M., Progress in Astronautics & Aeronautics, Vol. 90, AIAA. 1984.**(R2)**
3. Solid Rocket Technology – Shorr, M. and Zaehringer, A. J.**(R3)**
4. Understanding Aerospace Chemical Propulsion, H S Mukunda**(R4)**
5. Rocket Propulsion, K Ramamurthi.**(R5)**

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Course Outcome and Program Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	1	3
CO2	2	2	3	2	1	3
CO3	3	3	3	2	2	3
CO4	2	2	3	1	2	3
CO5	1	1	2	2	1	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD2, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD2, CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 554
Course title: Advanced Propulsion Systems
Pre-requisite(s): Elements of Rocket Propulsion
Co- requisite(s): Nil
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3
Class: ME
Semester / Level: II/05
Branch: Propulsion
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the concept of various types of advanced propulsion system
2.	Apply the concept of the different combustion systems used in scramjet, ramjet propulsion and hypersonic propulsion
3.	Analyse the characteristics of nuclear propulsion and the hazards associated with it
4.	Interpret the various electric propulsion system and the ways power generation in space
5.	Interpret the various micro-propulsion systems developed and emerging technologies involved

Course Outcomes
After the completion of this course, students will be:

CO1	To understand the concept of various types of advanced chemical propulsion system and its application to real systems.
CO2	To demonstrate the utilization of combustion systems in scramjet, ramjet propulsion and hypersonic propulsion.
CO3	To infer the concept of nuclear rockets and evaluate the performance, operation parameters and handling hazard involved
CO4	To differentiate between electro-thermal and pure electric thrusters and interpret the concept for power generation in space.
CO5	To appraise the various micro-propulsion systems developed and emerging technologies involved.

Syllabus

Module1:
Advanced Chemical Propulsion System: High Performance Chemical Propulsion Systems, Tripropellants; Metalized Propellants; Free Radical Propulsion; Flight Hybrid Rocket Propulsion Systems. [8L]

Module2:
Scramjet and Hypersonic Propulsion: Scramjet and Ram Rocket Propulsion System; Scramjet Inlets; Scramjet Performance, Introduction to Hypersonic Propulsion; Developments in High Speed Vehicle Propulsion System; Aerodynamic Shape of a Hypersonic Vehicle with an Air

Breathing Engine; Engine Cycle; Diffusion Flame Combustion and Supersonic Combustion; Supersonic Flow Combustors; Dual-mode Combustion System. [10L]

Module3:

Nuclear Propulsion System : Types of Nuclear Propulsion Systems; Heat Transfer in Nuclear Rockets; Gaseous Core Nuclear Rockets; Pure Nuclear Propulsion System; Operation, Performance and Application Areas; Nuclear Hazards; Nuclear Power Generation in Space. [7L]

Module 4:

Electric Propulsion System : Overview of Application Areas; Ideal Flight Performance; Electro-thermal Thrusters – Resistojets and Arcjets. Pure Electric Thrusters – Electrostatic, Electro Magnetic and Hall- effect Thrusters; Optimum Flight Performance; Electric Power Generation in Space. [7L]

Module 5:

Micropropulsion System : Recent Micro Spacecraft Developments; Micro-propulsion Options; Primary Set of Micropropulsion Requirements; Chemical Propulsion Options; Review of Electric Propulsion Technologies for Micro and Nano- satellites; Emerging Technologies: MEMS and MEMS- Hybrid Propulsion System. [8L]

Text books:

1. Developments in High Speed- Vehicle Propulsion System, Murthy, S.N.B, Curran, E.T., Progress in Astronautics & Aeronautics, Vol.165, AIAA, 1996.
2. Scramjet Propulsion, Curran, E.T., Murthy, S.N.B., Progress in Astronautics & Aeronautics, Vol. 189, AIAA,2001.
3. Micropropulsion for Small Spacecraft, Paul, Z., Progress in Astronautics &Aeronautics, Vol. 187, AIAA,2000.

Reference books:

1. Rocket Propulsion Elements, Sutton, G.P., Biblarz, O., 7th Ed. John Wiley & Sons, Inc., New York, 2001.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	1	2	2
CO2	3	2	3	3	1	2
CO3	3	3	3	3	2	3
CO4	3	2	3	3	1	3
CO5	3	3	3	3	2	3

Mapping Between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

COURSE INFORMATION SHEET

Course code: SR 555
Course title: Heat Transfer in Space Applications
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M.Tech.
Semester / Level: II/05
Branch: Space Engineering & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Identify various heat transfer mechanism and its utilities in the spacecraft applications.
2.	Select and examine the suitability of material at higher temperature of the spacecraft.
3.	Assess various equation for the analysis of heat transfer problem in the spacecraft.
4.	Analyze the thermal environmental effect on the spacecraft structure during launch and ascent phases.
5.	Interpret the heat transfer process and its controlling mechanisms of the various devices used in spacecraft.

Course Outcomes
After the completion of this course, students will be able to:

CO1	Distinguish different modes of heat transfer and utilize effectively in space application.
CO2	Apply the knowledge of the heat transfer mechanism in the design of spacecraft thermal system.
CO3	Analyze the heat transfer equation for the spacecraft applications.
CO4	Examine the influence of thermal environment on the spacecraft during its various phases of launch.
CO5	Interpret the working principles of various high temperature resistive devices and hardware of the spacecraft.

Syllabus

Module 1:
Introduction to heat transfer: Heat Transfer Mechanisms, Conduction, Convection and Radiation, Basic equations governing these Heat Transfer, Simultaneous Heat Transfer Mechanism. [8L]

Module 2:
Spacecraft Thermal Design: Fundamental of Thermal Radiation, Spacecraft Surface Material, Thermal Blanket, Diurnal and Annual Variations of Solar Heating, Need of Spacecraft Thermal Control – Temperature Specification – Energy Balance in a Spacecraft, Factors that influence Energy Balance in a spacecraft – Principles of Spacecraft Thermal Control. [10L]

Module 3:
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. [10L]

Module 4:
Spacecraft Thermal Environments: Launch and Ascent – Earth Bound Orbits – Interplanetary Mission and Re-entry Mission. [5L]

Module 5:
Devices and Hardware for Spacecraft TCS: 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. Application of principles for the Development of Spacecraft TCS. [8L]

Text books:

1. Fundamentals of Heat and Mass Transfer, Incropera, F.P., DeWitt, D.P., 7th ed., John Wiley, 2011**(T1)**.
2. Spacecraft Thermal Control Handbook, Volume I: Fundamental Technologies, Gilmore, D.G., 2nd ed., The Aerospace Press, AIAA, 2002**(T2)**.

Reference books:

1. Elements of Space Technology, Meyer, R.X., Academic Press, 1999 **(R1)**.
2. Numerical Methods for Engineers, Chapra, S.C., Canale, R.P., 7th ed., McGraw-Hill 2014**(R2)**.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Course Outcome and Program Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	2	3
CO2	3	2	3	2	3	3
CO3	2	2	3	2	2	3
CO4	1	1	2	1	1	2
CO5	2	1	2	1	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

COURSE INFORMATION SHEET

Course code: SR 519
Course title: Propellant Technology
Pre-requisite(s): NA
Co- requisite(s):NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Comprehend the knowledge about constituents of different types of solid propellant systems in processing of each category and determining key properties.
2.	Understand the fundamentals of solid propellant grain design
3.	Use grain design fundamentals in design of grains for static and flight rockets.
4.	Differentiate between various types of liquid propellants and to analyse the related aspects of ignition, combustion and performance evaluation.
5.	Analyze the concept of propellant loading in liquid rocket tanks, and their effective utilization including specific technical issues related to cryogenic propellants.

Course Outcomes

After the completion of this course, students will be able to:

1.	Demonstrate the processing of different types of solid propellants and effect of processing on the vital properties of solid propellants.
2.	To comprehend the fundamentals of solid propellant grain design.
3.	Design solid propellant grain for static and flight rocket motors.
4.	Evaluate the ignition delay and combustion parameters of a liquid rocket engine for different combustion chamber configurations.
5.	Evaluate the technical problems associated with propellant loading and other design issues associated with a liquid rockets engine.

Syllabus

Module 1:
Solid Propellant: Classification – Double Base, Composite, Composite Modified Double Base, Fuel-rich and Metallized Propellants; Ingredients; Composition and Processing; Mechanical and Ballistic Properties; Ageing Characteristics. [8L]

Module 2:
Grain Design Fundamentals: Classification of Solid Propellant Grains; End Burning, Radial Burning and Non- cylindrical Burning Grains; Fundamental Characteristics; Various Configurations; Internal Burning Star Configuration; Segmented Grains; Grain Clustering; Burning Surface

Area Evaluation; Design Criteria; Dual Thrust Grains; Free- standing and Case- bonded Grains; Inhibitors and Insulators. **[8L]**

Module 3:

Grain Design: Design Parameters; Performance Parameters; End Burning and Radial Burning Grain Design as applicable to Static Motors and Flight Rockets; Sample Calculations; Stress Analysis in Solid Propellant Grains. **[6L]**

Module 4:

Liquid Propellant: Classification – Mono-; Bi- and Tri- Propellants; Non Hypergolic and Hypergolic Systems; Gel Propellant Systems; Essential Characteristics of Liquid Propellants; Physical Properties; Ignition Characteristics; Ignition Delay; Ignition and Combustion Properties; Performance of Selected Bipropellant Systems; Factors affecting the Performance. **[8L]**

Module 5:

Propellant Loading: Cryogenic Propellants, Performance Considerations; Loading Concepts; Outage – Prediction and Control; Calibrated and Propellant Utilization Systems; Tank Ullage; Propellant Slosh; Estimation of Sloshing Mass; Frequency and Stiffness of an Equivalent System; Cavitation Drop- out and Vortexing; Design of Tank Outlet. **[10L]**

Text books:

1. Fundamental Aspects of Solid Propellant Rockets, Williams, F.A., Barrère, M., Huang, N.C., The Advisory Group for Aerospace Research and Development of N.A.T.O. [by] Technivision Services, 1969.
2. Solid Rocket Technology – Shorr, M.,Zaehringer, A.J., John Wiley New York, 1967.

Reference books:

1. Rocket Propulsion, Barrere, M., Jaumotte, A., Fraeijs de Veubeke, B., Vandenkerckhove, J., Elsevier Publishing Company, 1960
2. Internal Ballistics of Solid-Fuel Rockets: Military Rockets Using Dry-Processed Double-Base Propellant as Fuel, Wimpress, R.N., Sage, B.H.,ReInk Books, 2017.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	2	1	1	2
CO2	2		3	1	1	3
CO3	3	2	3	2	3	3
CO4	3	1	3	1	1	1
CO5	3		3	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD2,CD6
CO3	CD1, CD2, CD6
CO4	CD1, CD2,CD6
CO5	CD1,CD2,CD6

COURSE INFORMATION SHEET

Course code: SR 520
Course title: Special Topics in Chemical Propulsion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Analyze the combustion mechanism involved in chemical propulsion.
2.	Interpret the significance of green propellant
3.	Analyze two-phase flow on the performance of solid rocket motor.
4.	Examine the effect of various parameters on the combustion and performance in a liquid rocket engine.
5.	Demonstrate the significance of the studying about rocket plume and its real applications.

Course Outcomes
After the completion of this course, students will be able:

CO1	To analyze the importance of combustion modeling in solid rocket propulsion system.
CO2	To assess the significance of green propellant and its effective utilization in practical applications.
CO3	To interpret the influence of two-phase flow in the performance of solid rocket motor.
CO4	To demonstrate the effect of various parameters on the performance of a liquid rocket engine.
CO5	To examine the rocket plume and identify their control methods to qualify the propulsion system for a real time applications.

Syllabus

Module 1:
Combustion Modeling: Introduction; Theoretical Formulation – Solid Phase Region; Subsurface Multiphase Region and Gas Phase Region; Boundary Conditions; Numerical Methods; Effect of Chemical Additives on Burn Rate of Solid Propellants; Modeling of Liquid Propellant Combustion Phenomena – Basic Idea of Droplet and Spray Combustion Modeling. [10 L]

Module 2:
Green Propellants & Their Applications: Introduction; Advantages of Green Propellants; Physico-chemical Properties; Performance, Design and Operational Requirements. [6L]

Module 3:
Two- Phase Flow in Solid Rocket Motors: Introduction; Aluminium Oxide Formation; Interactions between Droplet and Gas Flow fields; Slag Accumulation; Two- phase Flow fields; Effect of Droplet Coalescence; Effect of Vortices. [7L]

Module 4:
Jet Atomization & Spray Characterization: Introduction; General Characteristics of Impinging Liquid Jets; Theoretical Models of Impinging Jet Atomization; Effect of Flow Conditions; Droplet Size Distribution; Orifice L/ D Ratio and Impingement Length Effects; Primary Atomization Mechanisms. Introduction to Spray; Confined and Unconfined Sprays; Experimental Methods for Spray Characterization; Effect of Gas Velocity; Orifice Diameter; Flow Rate; Chamber Pressure on Spray Characteristics; Composite Mean Droplet Sizes. [10L]

Module 5:
Rocket Plume: Introduction; Chemical Origin of Smoke; Homogeneous and Heterogeneous Nucleation of Smoke; Plume Visibility; Ionization in Rocket Exhaust Plume; Smoke Measurements; Methods for Reducing Smoke. [7L]

Text books:

1. Solid Propellant Chemistry, Combustion and Motor Interior Ballistics – Yang, V., Brill, T.B. and Ren, W., Progress in Astronautics & Aeronautics, Vol. 185, AIAA, 2000.
2. Advanced Propulsion Systems and Technologies, Today to 2020, Bruno, C., Accettura, A.G., Progress in Astronautics & Aeronautics, Vol. 223, AIAA, 2009.

Reference books:

1. Liquid Rocket Engine Combustion Instability – Yang, V., Anderson, W., Progress in Astronautics & Aeronautics, Vol. 169, AIAA, 1995.
2. Fundamentals of Solid Propellant Combustion – Kuo, K.K., Summerfield, M., Progress in Astronautics & Aeronautics, Vol. 90, AIAA, 1984.
3. Rocket Propulsion Elements, Sutton, G.P., Biblarz, O., 7th Ed. John Wiley & Sons, Inc., New York, 2001.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design
POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	2	2	3
CO2	2	1	2	1	2	3
CO3	2	1	2	1	2	2
CO4	3	2	3	2	2	3
CO5	3	2	3	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 521
Course title: Computational Combustion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L: 3 T: 0 P: 0
Class schedule per week: 03
Class: M.Tech
Semester/Level: II/05
Program: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Introduce the governing equations of chemical kinetics, mass, momentum, and heat transfer
2.	Introduce advanced mathematical modeling of laminar and turbulent flames
3.	Employ methods of computational fluid dynamics for numerical solution of models developed for complex flow and combustion problems
4.	Understand the best practices for reliable predictions from complex computational models of combustion problems

Course Outcomes
After the completion of this course, students will be able:

CO1	Demonstrate capability to analyze governing equations and coupling among them
CO2	Be able to solve ignition problems
CO3	Be able to solve laminar flame propagation problems using multistep kinetics
CO4	Be able to apply the concepts used in the modeling of turbulent flames for selecting appropriate models during calculations
CO5	Be able to comprehensively analyze complex combustion problems using specialized software

Syllabus

Module 1:
Governing Equations for Reacting Flows and Solution Methods: Governing equations for mass, energy, momentum, and species transport; constitutive relations; chemical kinetics models; boundary and initial conditions; solution methods and algorithms; solution strategies for reacting flows. **[6L]**

Module 2:
Laminar Reacting Flows: solution of ignition and flame propagation problems; premixed combustion, non-premixed combustion, partially premixed combustion; wall-stabilized laminar flames; laminar flame dynamics. **[7L]**

Module 3:
Turbulent Reacting Flows: description of turbulence, scales of turbulence, turbulence models; turbulence-flame interactions; premixed combustion; progress variable, turbulent flame speed,

EBU/ED and BML models; nonpremixed combustion; mixture fraction, PDF methods; partially premixed combustion; explicit accounting of chemical kinetics in turbulence. **[12L]**

Module 4:

Liquid-Gas Reacting Flows: Simplified models of droplet combustion; detailed multiphase flow models; atomizer modeling; ignition and stabilization of spray flame**.** **[6L]**

Module 5:

Advanced Topics: Solid propellant combustion; compressible flow equations; low Mach number approximation; supersonic combustion; convergence and error analysis. **[9L]**

Textbooks:

1. T. Poinsot and D. Veynante. Theoretical and Numerical Combustion. 2nd Edition. R. T. Edwards Inc., USA (2005).

Reference books:

1. J. Warnatz, U. Mass, and R. W. Dibble. Combustion: Physical and Chemical Fundamentals, Modeling and Simulation, Experiments, Pollutant Formation. 3rd Edition. Springer-Verlag, Germany (2001).
2. R. Fox. Computational Models for Turbulent Reacting Flows. Cambridge University Press, UK (2003).
3. E. S. Oran and J. P. Boris. Numerical Simulation of Reactive Flow. 2nd Edition. Cambridge University Press, UK (2001).

Gaps in the syllabus (to meet industry/profession requirements)

- Computational modeling of solid propellant combustion
- Different approaches in computations of nonpremixed flames

POs met through Gaps in Syllabus

Gaps in Syllabus	POs
Computational modeling of solid propellant combustion	PO1
Different approaches in computations of nonpremixed flames	PO1, PO6

Topics beyond syllabus/advanced topics/design

- **Topic beyond syllabus:** Large eddy simulation of reacting flows

POs met through topics beyond syllabus/advanced topics/design

Topic beyond Syllabus	POs
Large eddy simulation of reacting flows	PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	-	2	-	-	1
CO2	1	-	3	3	-	1
CO3	3	-	3	3	-	2
CO4	3	-	2	2	-	2
CO5	3	3	3	3	2	3

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 522
Course title: Cryogenic Propulsion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech
Semester / Level: II/06
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Identify cryogenic substance and examine its characteristics in cryogenic environments.
2..	Analyze the storage and transfer vessel arrangements for the suitability of cryogenic propulsion system.
3.	Explain the working concept of the turbo-pump feed system designed for cryogenic fluids.
4.	Analyze the various challenges associated with cryogenic propulsion systems
5.	Design cryogenic propulsion system for the given operating conditions

Course Outcomes
After the completion of this course, students will be able:

1.	To demonstrate the characteristics of the cryogenic fluid and the challenges acquired in achieving it.
2.	To design and demonstrate the storage vessels used for the practical application of cryogenic propulsion system.
3.	To analyse the turbo-pump feed system utilized for injecting cryogenic fluid and various challenges associated with it.
4.	To examine cryogenic propulsion system and their various challenges associated during practical operating conditions.
5.	To interpret the various testing process to be conducted prior to the actual launch of the cryogenic propulsion system.

Syllabus

Module 1:
Introduction to Cryogenics: Cryogenic fluid, Materials at low temperature mainly for cryogenic propulsion, Thermo physical and fluid dynamic properties of liquid and gas hydrogen and oxygen, Liquefaction systems of hydrogen and oxygen gases, Joule Thomson effect and inversion curve; Adiabatic and isenthalpic expansion with their comparison. Cryogenic heat exchangers. **[8L]**

Module 2:
Storage and Loading of Cryogenic Liquids: Design considerations of storage vessel; Dewar vessels; Storage of cryogenic fluids in space; Transfer systems and Lines for cryogenic liquids; Cryogenic valves in transfer lines; Two phase flow in Transfer system; Cool-down of storage and transfer

systems, Measurement of strain, pressure, flow, liquid level and Temperature in cryogenic environment. **[8L]**

Module 3:

Turbo-Pump Feed System: GG cycle, Expander cycle and SSC and their performance comparison. Various types of turbine and pumps and their arrangements in turbo-pump feed system. Prevention of pump cavitation-NPSH, Starting of the turbo-pump system at time t=0. Bearing and Sealants. Design of injectors-various types and injection pattern, fluid flow circuits of various rockets such as SSME, SPACEX, Ariane etc. **[8L]**

Module 4:

Cryogenic Propulsion System: Cryogenic propellants, fuels and oxidizers – properties, performance comparison, evaporation system for cryogenic propellants, Geysering Phenomenon and its prevention, Zero –'g' problem, Effects and prevention of Thermal Stratification; Methods of Elimination of Thermal Stratification. On-board storage of cryogenic propellants and insulation, LOX-Methane propulsion system, Semi-cryo system using LOX and Kerosene and tri-propellant system using kerosene+LOX+LH2. **[8L]**

Module 5:

Cryogenic Engine Testing: Test Configuration and Test Readiness, Hot Run, Hot run Preparation, Start up Transient, Control and Regulation, Monitoring of Engine parameters, Shut-down and Transient, Engine Performance Map, Principles of Erection of Test facilities, Fuel and Oxidizer supply, Measurement, Control and Command System, Detection system. **[8L]**

Text books:

1. Cryogenic Process Engineering, Timmerhaus, K.D, Flynn, T.M, Plenum Press, USA, 2009.
2. Operation of a Cryogenic Rocket Engine, Wolfgaug K., Springer-Verlag Berlin Heidelberg 2011.

Reference books:

1. Rocket Propellant and Pressurization Systems, Ring, E, Prentice Hall Inc, N.J., 1964.
2. Cryogenic Engineering, Flynn, T.M, Dekker, M., Plenum Press, USA, 2009.
3. Design of Liquid Propellant Rocket Engine, Huzel, D.K., Huang, D.H., NASA SP-125, Scientific and Technical Information Division, NASA, Washington, 1971.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	1	1	2	3
CO2	3	2	2	2	3	3
CO3	3	2	3	3	2	3
CO4	2	2	2	2	2	3
CO5	1	1	1	1	2	2

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 523
Course title: Combustion Instability in Rocket Engines
Pre-requisite(s): SR550, SR551, SR552
Co- requisite(s):
Credits: L: 3 T: 0 P: 0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: II/05
Branch: Space Engineering and Rocketry (Rocket Propulsion)
Name of Teacher:
Course Objectives

A.	To introduce concepts useful for understanding combustion instability
B.	To introduce measurement methods for combustion instability
C.	To introduce methods for analysis of combustion instability using linear theory
D.	To introduce methods for mitigation and stabilization of combustion instability
E.	To introduce the effects of instability in the design of rocket motors

Course Outcomes

At the end of the course, a student should be able to:

1.	Identify the type of combustion instability in different types of rocket motors
2.	Analyze experimental data on combustion instability
3.	Identify measures to be taken for stabilizing unstable combustion
4.	Carry out linear instability analysis
5.	Design rocket motors with consideration to the effects of instabilities

Syllabus

Module I: Introduction to Combustion Instability
Steady and unsteady combustion; origins of combustion instability; types of combustion instability; effects of combustion instability; factors affecting combustion instability.
[4 L]

Module II: Instabilities in Solid Rocket Propulsion
Introduction; general features; bulk, transverse, and axial mode instabilities; aerodynamic instabilities; processes contributing to stability; measurement methods for stability testing; particulate damping; effect of propellant characteristics; control of combustion instability.
[9 L]

Module III: Instabilities in Liquid Rocket Propulsion
Overview; classification of instabilities; initiation of instabilities; dynamic stability; dynamics of processes in liquid rocket engines; wave propagation; effects of design factors on excitation and damping; effects of atomization and droplet combustion; experimental evaluation of instability; control of combustion instability. [10 L]

Module IV: Analysis of Combustion Instability
Introduction; thermal lags in solid phase; linear analysis of instability in solid rocket motors; analysis of low, intermediate, and high-frequency instability in liquid rocket engines using time lag models. [8 L]

Module V: Instabilities in Hybrid Rocket Propulsion
Introduction; subsystems of hybrid rocket motors; transient events in hybrid rocket propulsion; hybrid rocket instabilities; feed system coupled instabilities; chuffing; low-frequency instabilities; comparison among solid, liquid, and hybrid low-frequency instabilities; experimental evaluation of instability; driving mechanisms for instabilities; control of combustion instability; analysis of instability in hybrid rocket motors. [9 L]

Textbooks:

- M. Barrere, A. Jaumotte, B.F. DeVeubeke and J. Vandenkerchove, Rocket Propulsion, Elsevier (Latest Edition) **(T1)**
- M.S. Natanzon and F.E.C. Culick, Combustion Instability, Progress in Astronautics and Aeronautics, 2008, ISBN: 978-1-56347-928-1, eISBN: 978-1-60086-691-3 **(T2)**

Reference books:

- E.W. Price. Experimental observations of combustion instability (Chapter 13); J.S. T'ien. Theoretical analysis of combustion instability (Chapter 14). In K. Kuo and M. Summerfield (Eds.). Fundamentals of Solid-Propellant Combustion. Progress in Astronautics and Aeronautics Vol. 90, AIAA, New York, 1984. **(R1)**
- V. Yang and W. Anderson (Eds.). Liquid Rocket Engine Combustion Instability. Progress in Astronautics and Aeronautics Vol. 169, AIAA, Washington DC, 1995. **(R2)**
- A. Karabeyoglu. Combustion instability and transient behavior in hybrid rocket motors (Chapter 9). In M.J. Chiaverini and K.K. Kuo (Eds.) Fundamentals of Hybrid Rocket Combustion and Propulsion. Progress in Astronautics and Aeronautics Vol. 218, AIAA, Reston, Virginia, 2007. **(R3)**

Gaps in the syllabus (to meet Industry/Profession requirements): stability rating

POs met through gaps in the syllabus: PO1

Topics beyond syllabus/advanced topics/design: nonlinear analysis of instability

POs met through topics beyond syllabus/advanced topics/design: PO1, PO4

Course Delivery methods
Lecture by use of boards/projectors
Assignments
Laboratory experiments/teaching aids (available for hybrid combustion)
Simulation (demonstration of active control methods)
Self-learning such as use of NPTEL, internet (Limited number of lectures delivered by Prof. K. Ramamurthi and Prof. S.R. Chakravarthy are available.)

Course Outcome (CO) Attainment Assessment tools & Evaluation procedure

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10 %)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment	H	H	M	M	H
Semester End Examination	L	M	M	H	H

Indirect Assessment:

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome	Program Outcomes					
	1	2	3	4	5	6
1	M	L	H	M	L	L
2	M	H	H	H	L	L
3	H	H	H	M	M	M
4	M	H	H	H	M	M
5	H	L	H	H	M	M

Mapping Between COs and Course Delivery (CD) methods			
CD	**Course Delivery methods**	**Course Outcome**	**Course Delivery Method**
CD1	Lecture by use of boards/LCD projectors/OHP projectors	CO1, CO5	CD1
CD2	Assignments	CO4, CO5	CD1, CD2, CD4

CD3	Laboratory experiments/teaching aids	CO2	CD3
CD4	Simulation	CO2, CO3	CD4
CD5	Self-learning such as use of NPTEL, internet	CO1, CO3	CD5

COURSE INFORMATION SHEET

Course code: SR 505
Course title: Flame Propagation & Stability
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L: 3 T: 0 P: 0 C: 3
Class schedule per week: 3
Class: M.Tech.
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the structure of laminar flames and the theories associated with flame propagation.
2.	Perceive the structure of turbulent flames and comprehend theories associated with flame propagation.
3.	Relate the concepts of flame noise and flame oscillation and the instabilities associated with it.
4.	Interpret the concept of flame spreading and the mechanism involved.
5.	Realize concept of stabilisation of flames and the methods involved therein.

Course Outcomes
At the end of the course, a student should be able to:

CO1	Comprehend the structure of laminar flame and apply related theories of flame propagation for various types of laminar flames.
CO2	Apply the knowledge of structure of turbulent flames in predicting the factors affecting burning velocity.
CO3	Distinguish between flame noise and oscillation and mitigate their effect in combustion devices and rockets.
CO4	Analyse the concept of flame spreading and its mechanism on propellant grain surface and cracks.
CO5	Evaluate the methods of stabilisation of flames and their application in burners.

Syllabus

Module 1:
Laminar Flame Propagation: Structure of Laminar Flame; Temperature Profile; Concentration Profile; Adiabatic Plane Combustion Wave; General Description of Heat Sink and Flow Effects; Laminar Flame Propagation in Tubes; Theories of Laminar Flame Propagation - Thermal Theories, Semenov Equation, Diffusion Theories, Comprehensive Theories; Limits of Flammability. [8L]

Module 2:
Turbulent Flame Propagation: Description of Turbulent Flames; Concept of Turbulent Flow; Turbulent Burning Velocity; Factors affecting Turbulent Burning Velocity; Structure of a Turbulent Flame; Turbulent Flame Theories. [8 L]

Module 3:
Flame Noise and Flame Oscillations: Jet Noise; Singing Flames; Combustion Chamber Oscillations; Flame Flicker and other Instabilities; Sensitive Flames. [8 L]

Module 4:
Ignition Transient and Flame Spreading: Ignition and Thrust Transient in Solid Rocket Motors; Flame Spreading over Solid Propellants and Fuels; Flame Spreading Mechanism; Theories and Experiments; Flame Spreading into Solid Propellant Cracks and Flaws; Theories and Experiments of Flame Spreading in Propellant Cracks. [8L]

Module 5:
Flame Stability: Flame stabilization; Characteristic Stability Diagram; Mechanism of Flame Stabilization; Flame Stretch Theory; Flames Supported by Inserting a Solid Object in a Gas Stream; Flame Stabilization by Eddies; Quenching Distance; Penetration Distance and Dual Space.
[8L]

Text Books:

1. S. R. Turn, An Introduction to Combustion-Concepts and Applications, 3rd Edition, Tata McGraw-Hill, India, 2012. (**T1)**
2. K. K. Kuo, Principles of Combustion, John Wiley and Sons, New York, 1986. (**T2**)

Reference Books:

1. B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 3rd Edition, Academic Press, Orlando, 1987. **(R1)**
2. A. G. Gaydon and H. D. Wolfhard, Flames: Their Structure, Radiation and Temperature, 3rd Edition, Springer USA, 1970.**(R2)**

Gaps in the syllabus (to meet Industry/Profession requirements): Hand down practical training on turbulent flame propagation

POs met through Gaps in the Syllabus: PO5 will be met through virtual lab/presentation/assignment.

Topics beyond syllabus/Advanced topics/Design: Flame propagation in mines/closed spaces and design of burners

POs met through Topics beyond syllabus/Advanced topics/Design: PO6
Course Delivery methods

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD Projector
CD2	Assignments
CD3	Seminars
CD4	Laboratory experiments/teaching aids
CD5	Self- learning such as use of NPTEL materials and internets/open sources

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	1	1	2
CO2	2	2	3	1	1	2
CO3	3	3	3	3	1	3
CO4	3	2	3	2	1	3
CO5	3	3	3	3	2	3

If satisfying < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD5
CO2	CD1, CD3, CD4, CD5
CO3	CD1, CD5
CO4	CD1, CD2, CD4, CD5
CO5	CD1,CD4, CD5

COURSE INFORMATION SHEET

Course code: SR 556
Course title: Solid Rocket Propulsion lab
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 2 L:0 T:0 P:3
Class schedule per week: 4
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives: This course enables the students to:

1.	Understand the significance of the experiment with respect to theoretical information.
2.	Collect and interpret data obtained from experiments.
3.	Examine the results in a group of team and evaluate it to utilize in preparing the report.
4.	Explain the working and designing procedure of the solid rocket motor.
5.	Follow and utilize all the safety features required during the experimentations

Course Outcomes
After the completion of this course, students will be able:

CO1	To analyze the types of error observed during the experiments.
CO2	To explain the significance of the processing of the propellants in correlation with practical applications.
CO3	To comprehend and illustrate various methods of improving the burn rate in a solid rocket motor
CO4	To operate the solid rocket experimental setup and generate results for the meaning analysis as an individual and as in a group.
CO5	To identify the equipments used in the experiment along with their significance of using them.

List of the Experiments:

1. **<u>Experiment No. 1</u>**
   Name : Introduction to solid rocket and its processing lab
   Objective : To introduce and give brief information about the equipments used in solid rocket propulsion lab.

2. **<u>Experiment No. 2</u>**
   Name : Preparation of fuel grain
   Objective : Processing of solid composite propellant grain with different perforations having compositions as PVC-DBP and AP.
3. **<u>Experiment No. 3</u>**
   Name : Rheological study
   Objective : To study the rheological properties of the freshly prepared solid propellant mix.

4. **Experiment No. 4**
   Name : Heat of Combustion
   Objective : To determine the heat of combustion of solid propellant sample at least at two different inert gas pressures.

5. **Experiment No. 5**
   Name : Study of mechanical properties
   Objective : To evaluate the mechanical properties of composite solid propellant.

6. **Experiment No. 6**
   Name SEM Analysis
   Objective : To study the surface morphology of solid propellant with the help of Scanning Electron Microscope.

7. **Experiment No. 7**
   Name : Experiments on STA
   Objective : Thermal decomposition study of solid propellant with the help of Simultaneous Thermal Analyzer.

   Experiment No. 8
   Name : Burn rate measurement at higher pressure
   Objective : To measure the burn rate of solid propellant strands at various pressures by using Crawford Bomb set-up.

   Experiment No. 9
   Name : Burn rate measurement at sub-atmospheric pressure
   Objective : To measure the burn rate of solid propellant strands at sub-atmospheric pressures.

8. **Experiment No. 10**
   Name : Preparation of igniter
   Objective : To prepare pyrotechnic igniters and determine its ignition delay.

9. **Experiment No. 11**
   Name : Solid Rocket Static Firing
   Objective : To perform static solid rocket firing and determine its performance parameters such as thrust and Specific impulse.

Reference books:

1. Rocket Propulsion Elements – Sutton, G. P. and Biblarz, O., 7th Ed.
2. Understanding Aerospace Chemical Propulsion, H S Mukunda.
3. Rocket Propulsion, K Ramamurthi.

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Program Outcome and Course Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	**Program Outcomes**					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	3	2	1	2
CO2	3	2	1	1	2	3
CO3	2	1	2	2	1	3
CO4	2	2	3	1	1	2
CO5	2	1	3	1	1	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

COURSE INFORMATION SHEET

Course code: SR 557
Course title: Liquid and Hybrid Propulsion Lab
Pre-requisite(s): NA
Co- requisite(s):NA
Credits: 2 L:0 T:0 P:3
Class schedule per week: 4
Class: M.Tech
Semester / Level: II/05
Branch: SER
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the significance of the experiment with respect to theoretical information.
2.	Collect and interpret data obtained from experiments.
3.	Examine the results in a group of team and evaluate it to utilize in preparing the report.
4.	Explain the working and designing procedure of the liquid and hybrid rocket motor.
5.	Follow and utilize all the safety features required during the experimentations

Course Outcomes

After the completion of this course, students will be able:

CO1	To analyze the types of error observed during the experiments.
CO2	To explain the various methods of improving the burn rate in a hybrid rocket motor
CO3	To operate the experimental setup and collect data as an individual and as in a group.
CO4	To demonstrate the output of the results for the meaningful analysis.
CO5	To identify the equipments used in the experiment with their significance of using them.

List of the Experiments:

1. **<u>Experiment No. 1</u>**
   Name : Introduction to liquid and hybrid lab
   Objective : To introduce and give brief information about the equipments used in liquid and hybrid lab
2. **<u>Experiment No. 2</u>**
   Name : Preparation of fuel grain
   Objective : Processing of PVC-Plastisol based hybrid fuel grain with tubular perforation of two different compositions.
3. **<u>Experiment No. 3</u>**
   Name : Effect of solid loading on regression rate
   Objective : To study the effect of solid loading on the regression rate of PVC based fuel in a hybrid rocket motor.

4. **Experiment No. 4**
   Name : Pressure Effect on Regression Rate
   Objective : To Study the effect of chamber pressure on regression rate in a hybrid rocket motor.

5. **Experiment No. 5**
   Name : Processing of paraffin based fuel
   Objective : To measure regression rate of paraffin based fuel and compare with the PVC based fuel in a hybrid rocket.

6. **Experiment No. 6**
   Name : Effect of injectors
   Objective : To study the effect of varying oxidizer injectors on the regression rate of hybrid fuel.

7. **Experiment No. 7**
   Name : Performance Evaluation through CEA Software
   Objective : To Evaluate the theoretical performace parameters of the given fuel and oxidizer combinations at various O/F ratios.

8. **Experiment No. 8**
   Name : Effect of protrusion on efficiencies
   Objective : To study the effect of protrusion on the efficiencies of hybrid rocket motor.

9. **Experiment No. 9**
   Name : Synthesis of energetic fuel
   Objective : Synthesis of the Aniline-Furfuryldehyde condensate as hybrid fuel.

10. **Experiment No. 10**
    Name : Ignition delay test
    Objective : To conduct hypergolic ignition delay test for the Aniline-Furfuryldehyde hybrid fuel with red fuming nitric acid.

11. **Experiment No. 11**
    Name : Effect of burn duration on regression rate
    Objective : To study the effect of burn duration on the regression rate using PVC-DBP as a hybrid fuel.

12. **Experiment No. 12**
    Name : Liquid rocket firing
    Objective : To conduct experiment on a liquid rocket firing set-up to understand the operation of liquid rocket engine.

Reference books:

1. Design of Liquid Propellant Rocket Engine – Huzel, D. K. & Huang, D. H., NASA SP-125.
2. Fundamental of Hybrid Rocket Combustion and Propulsion, Martin J. Chiaverini and Kennith K. Kuo, Progress in Aeronautics & Astronautics, Vol. 218, AIAA.
3. Rocket Propulsion Elements – Sutton, G. P. and Biblarz, O., 7th Ed.
4. Understanding Aerospace Chemical Propulsion, H S Mukunda

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus

Topics beyond syllabus/Advanced topics/Design

POs met through Topics beyond syllabus/Advanced topics/Design

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Program Outcome and Course Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	**Program Outcomes**					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	3	2	1	2
CO2	3	2	1	2	1	3
CO3	3	2	2	2	3	2
CO4	2	2	3	1	1	2
CO5	2	1	3	1	1	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

Mapping between COs and Course Delivery (CD) methods

Course Outcomes	Course Delivery Method
CO1	CD1,CD2, CD6
CO2	CD1, CD2, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD6
CO5	CD1,CD2, CD6

OPEN ELECTIVE

COURSE INFORMATION SHEET

Course code: SR 512
Course title: Acoustics
Mode of Course: Open Elective
Pre-requisite(s): Engineering Mathematics
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: I/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

1.	Associate vibration basics with concept of wave traversing
2.	Relate free, forced and damped vibration in membranes.
3.	Understand the acoustic equations and its applications
4.	Illustrate the transmission of waves in pipes
5.	Interpret various factors of sound generation and measurement

Course Outcomes

After the completion of this course, students should able to:

CO1	Substantiate theory of string vibrations
CO2	Categorise the vibration of planar membranes
CO3	Appraise the characteristics of linear wave acoustic equations
CO4	Evaluate the acoustics of pipes flows and resonating devices.
CO5	To appraise the generated sound and methods to measure it.

Syllabus

SR 512: ACOUSTICS

Module I: Introduction:

Concept of complex variable, Fundamental of vibration: simple oscillator, damped oscillation, forced oscillation, transient response, power, resonance and frequency; Vibrating string: 1-D wave equation, forced vibration of infinite and finite strings; Vibration of bars: longitudinal and transverse vibrations, forced vibration of bars; Concepts of String Instruments.

Module II: Two-dimensional wave equations:

Vibration of plane surface, Free vibrations, Symmetric vibrations, Damped free vibration, Forced vibration of a membrane, Vibration of thin plates, Concepts of percussion instruments.

Module III: Acoustic Wave equation:

Euler's equation, Linear wave equation, Harmonic plane wave, Acoustic intensities, Spherical waves, Reflection and transmission, Radiation and reception of acoustic waves.

Module IV: Pipes, Resonators and Filters:

Resonance in pipe, Radiation from open ended pipes, Acoustic impedance, Helmholtz resonator, reflection and transmission of waves in a pipe, Acoustic filters.

Module V: Noise, Signal, Hearing and Speech

Measurement of sound, Microphones, Spectrum and band level, Tones, Signals in noise, detection threshold, Ear, Loudness, Pitch and frequency, Voice, Monopole, Dipole and Quadrupole sound sources, Environmental acoustics, Control techniques.

Text Book:

1) Fundamentals of Acoustics, L.E. Kinsler, A.R. Frey, A.B.Coppens and J.V.Sanders, John Wiley & Sons, Inc.

Reference Books:

1) Theoretical Acoustics, P.M.Morse and K.U.Ingard, McGraw-Hill Book Company.
2) Principles of Musical Acoustics, William M. Hartmann, Springer.
3) Master Handbook of Acoustics, 6th Edition, F. Alton Everest and Ken Pohlmann, McGraw-Hill Education
4) Acoustics of Ducts and Mufflers, 2^{nd} Edition, M. L. Munjal, Wiley

Gaps in the syllabus (to meet Industry/Profession requirements)

9) Non Linear acoustics

POs met through Gaps in the Syllabus

PO6

Topics beyond syllabus/Advanced topics/Design

7) Aeroacoustics
8) Acoustics of moving sources

POs met through Topics beyond syllabus/Advanced topics/Design

PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods
Lecture by use of boards/LCD projectors/OHP projectors
Tutorials/Assignments
Seminars
Mini projects/Projects
Laboratory experiments/teaching aids
Industrial/guest lectures
Industrial visits/in-plant training
Self- learning such as use of NPTEL materials and internets

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
1	2	2		2	1	-
2	1	-	2	1	-	2
3	2	2	2	2	1	2
4	1	2	2	-	1	3
5	1	2	-	1	-	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

<u>MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD</u>

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD6,CD7
CO3	CD1, CD2, CD3,CD6,CD7
CO4	CD1, CD3,CD6,CD7
CO5	CD1,CD2,CD3,CD4,CD5,CD7

COURSE INFORMATION SHEET

Course code: SR 578
Course title: Computational Fluid Dynamics
Pre-requisite(s): Fluid Mechanics, Numerical Analysis
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Know classification of partial differential equations, finite difference method, stability analysis.
2.	Learn the solution methods of finite difference equations of elliptic, parabolic and hyperbolic partial differential equations.
3.	Apply the methods to solve finite difference equations
4.	Understand the numerical techniques to solve incompressible Navier-Stokes equations.
5.	Know the finite volume method and apply it for inviscid problems.

Course Outcomes

After the completion of this course, students will be able to:

1.	know the basics of CFD, classification of partial differential equations, initial and different boundary conditions.
2.	Understand finite difference methods Taylor series expansion and polynomial expansion, discrete perturbation and Von Neumann stability analysis, artificial viscosity.
3.	Apply the solution methods of finite difference equations to solve elliptic, parabolic and hyperbolic problems.
4.	Understand the different forms of incompressible Navier-Stoke equations and techniques to solve it numerically.
5.	Develop the proceddure to solve the Euler equations by finite volume method.

Syllabus

Module 1:
Introduction: Computational Fluid Dynamics; Classification of Partial Differential Equations; Linear and Non- linear Partial Differential Equations – Model Equation, Elliptic Equation, Parabolic Equation and Hyperbolic Equation; System of 1st order Partial Differential Equations; System of 2nd order Partial Difference Equations; Initial Conditions; Boundary Conditions. [8L]

Module 2:

Finite Difference Formulations: Introduction; Taylor Series Expansion; Finite Difference by Polynomial; Finite Difference Equations; Higher Order Derivatives; Multidimensional Finite Difference Formulas; Applications; Finite Difference Approximation of Mixed Partial Derivatives; Stability Analysis; Discrete Perturbation Stability Analysis; Von Neumann Stability Analysis; Multidimensional Problem; Error Analysis; Artificial Viscosity. [8L]

Module 3:
Solution Methods of Finite Difference Equations: Elliptic Equations – Finite Difference Formulations, Jacobi Iteration Method, Point Gauss Seidel Iteration Method, Line Gauss Seidel Iteration Method, Point Successive Over Relaxation Method, Line Successive Over Relaxation Method, Alternating Direction Implicit Method, Applications; Parabolic Equations – Finite Difference Formulations, Explicit Schemes, Implicit Schemes, Alternating Direction Implicit Schemes, Parabolic Equations in Two-space Dimensions, Approximate Factorization, Fractional Step Methods; Hyperbolic Equations – Explicit and Implicit Schemes, Splitting Methods, Multistep Methods, Application to Linear and Non-linear Problems, Flux Corrected Transport, Classification of Numerical Scheme, TVD Formulations; Application – Heat conduction, Couette Flow and Wave Motion. [10L]

Module 4:
Incompressible Navier- Stokes Equations: Introduction; Primitive Variable and Vorticity Stream Function Formulations; Poisson Equations for Pressure (Primitive Variable and Vorticity Stream Function Formulation); Numerical Algorithm (Primitive Variable); Artificial Compressibility; Solution on a Regular Grid; Crank Nicolson Implicit Method; Boundary Conditions (Body Surface, Far Field, Symmetry, Inflow, Outflow); Staggered Grid; Marker and Cell Method; Implementation of Boundary Conditions; DuFort Frankel Scheme; Use of the Poisson Equation for Pressure; Unsteady Incompressible Navier- Stokes Equation. [10L]

Module 5:
Euler Equations and Finite Volume Method: Explicit Formulations – Steger and Warming Flux Vector Splitting, Van Leer Flux Vector Splitting, Runge Kutta Formulation, Implicit Formulations – Steger and Warming Flux Vector Splitting; Boundary Conditions; Global Time Step and Local Time Step; Application – Diverging Nozzle Configuration, Shock Tube or Reimann Problem, Supersonic Channel Flow; Approximation of Surface Integrals; Cell centered and Nodal Point Scheme; Interpolation and Differentiation Practices; Implementation of Boundary Conditions. [8L]

Text books:
1. Hoffmann, K.A. and Chiang, S.T., Computational Fluid Dynamics (Vol. I & II), Engineering Education System, 2000. (**T1**)

Reference books:
1. Hirsch, C., Numerical Computation of Internal and External Flows (Vol. I & II), John Wiley and Sons, 1994. (**R1**)
2. Anderson, John D., Computational Fluid Dynamics, McGraw-Hill, 1995. (**R2**)

Gaps in the syllabus (to meet Industry/Profession requirements) : Unsteady flow simulation

POs met through Gaps in the Syllabus : PO1, PO3

Topics beyond syllabus/Advanced topics/Design : Simulation of turbulent flows

POs met through Topics beyond syllabus/Advanced topics/Design : PO1, PO2, PO3, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	2
CO2	2	2	2	1	1	2
CO3	2	2	3	2	1	2
CO4	3	2	2	2	2	3
CO5	3	3	2	2	2	3

If satisfying and < 34% = 1, 34-66% = 2, > 66% = 3

MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

Course Outcomes	Course Delivery Method
CO1	CD1,CD6
CO2	CD1, CD2,CD6
CO3	CD1, CD2, CD6

CO4	CD1, CD2,CD6
CO5	CD1,CD2,CD6

COURSE INFORMATION SHEET

Course code: SR 579
Course title: Experimental Aerodynamics
Pre-requisite(s): Engineering Mathematics, Fluid dynamics
Co- requisite(s): Basic Physics
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech
Semester / Level: II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the basics of Wind Tunnel and its components with specific orientation to its operation.
2.	Describe and implement the different wind tunnel measurement techniques adopted recently and in the past.
3.	Understand the basics of advanced flow diagnostic systems with knowledge towards its components and devices.
4.	Understand unsteady features of a flow and its associated measurement techniques.
5.	Be able to understand, use and operate advanced data acquisition system and its components.

Course Outcomes
After the completion of this course, students will be:

CO1	Describe wind tunnels and their components.
CO2	Organise in performing experiments using wind tunnel measurement techniques which are in practice.
CO3	Demonstrate the advanced measurement techniques for wind tunnel tests.
CO4	Implement the unsteady flow measurements with possible recognition to its stochastic behaviour and analysis.
CO5	Perform experiments with advanced data acquisition system with good level of confidence and minimal error.

Syllabus

Module 1:
Wind Tunnel: Necessity of Wind Tunnels; Basic Principle; Types of Wind Tunnels; Components of Subsonic Tunnel, Supersonic Tunnel, Hypersonic Tunnel and Shock Tunnel; Special Purpose Wind Tunnel; Design Consideration of Subsonic Tunnel and Supersonic Tunnel; Calibration Methods of Different Wind Tunnels; [8 L]

Module 2:

Flow Visualisation: Different Types of Flow Visualization Techniques for Subsonic, Supersonic and Hypersonic Tunnels; Basics of Schlieren, Shadowgraph and Interferometers; Laser Based Flow Visualization Technique. [6 L]

Module 3:

Pressure, Velocity, Force and Moment Measurement: Pitot Static Probe; Laser Doppler Velocimeter; Mechanical System for Pressure Measurement; Water and Mercury Manometers; Principle of Pressure Transducer; Different Types of Pressure Transducers; Mechanical Pressure Scanner, Electronic Pressure Scanner; Pressure Sensitive Paint; Calibration of Pressure Measuring Units, Definition of Forces and Moments on Aerospace Vehicles; Basic Principle of Mechanical Balance and Strain Gage Balance; Interaction between Different Components of Forces and Moments; Major Components for Force and Moment Measuring Systems. [12L]

Module 4:

Unsteady Measurement: Introduction to Unsteady data; Introduction to Turbulent measurements; Basic Principle of Hot Wire Anemometer; Constant Current and Constant Temperature Anemometer, Measurement of Unsteady Velocities Using Hot Wire Anemometers; Measurement of Turbulent Stresses; Single and Multiple Hot Wire Probes; Basic Principles of Unsteady Pressure Transducers; Calibration of Steady and Unsteady Pressure Transducers. [10L]

Module 5:

Data Acquisition System: Analog and Digital Signals; Mean and Fluctuating Signals; ADC Cards; Amplifiers; Signal Conditioners; P C Based Data Acquisition System; Data Acquisition Software; Error Analysis. [8 L]

Text books:

1. High Speed Wind Tunnel Testing, Roe, W. H. and Pope, A., Wiley, 1965. **(T1)**
2. Low Speed Wind Tunnel Testing, Pope, A. and Goin, L., Wiley, 1966. **(T2)**

Reference books:

3. Random Data: Analysis and Measurement Procedures, Bendat, J. S. and Piersol. A.G., Wiley, 2010. **(R1)**

Gaps in the syllabus (to meet Industry/Profession requirements)

Emphasis on data analysis

More elaboration on the data acquisition system and its component

POs met through Gaps in the Syllabus: PO1, PO5, PO6

Topics beyond syllabus/Advanced topics/Design

Elaborate studies on PIV instrumentation and data interpretation

Compressible boundary layer measurement techniques

POs met through Topics beyond syllabus/Advanced topics/Design: PO4, PO5, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Tutorials/Assignments
CD3	Self- learning such as use of NPTEL materials and internets

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1		2	2	1	1	
CO2	3		3	3	2	3
CO3	2	1	2			2
CO4	1	2	2	1	3	3
CO5	3		3	3	3	2

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1
CO2	CD1
CO3	CD1, CD2
CO4	CD1, CD2, CD3
CO5	CD1,CD2,CD3

COURSE INFORMATION SHEET

Course code: SR 504
Course title: Fundamentals of Combustion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L: 3 T: 0 P: 0 C: 3
Class schedule per week: 3
Class: M.Tech.
Semester / Level: I/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives : This course enables the students to:

1.	Understand the concept of thermochemistry, enthalpy, adiabatic flame temperature, combustion products and their application to combustion related problems
2.	Apply the concept of chemical rates of reaction, collision theory and Arrhenius equation for analysing the different types of reactions.
3.	Compare the properties and characteristics of different type of flames and apply the same to combustion phenomenon in rocket motors and its exhaust.
4.	Comprehend subsonic and supersonic combustion phenomenon, their transition and properties related to Detonation
5.	Interpret the various combustion processes that takes place in a solid rocket motor, liquid rocket engine and the hybrid rocket motor.

Course Outcomes
At the end of the course, a student should be able to:

CO1	Apply the basic concept of thermochemistry to combustion related problems.
CO2	Demonstrate the utilization of the concept of chemical kinetics in combustion reactions.
CO3	Distinguish between premixed and diffusion flames including their properties, and their use in combustion devices and rockets.
CO4	Differentiate between deflagration and detonation process and interpret the concept for computation and analysis of the transition phenomenon.
CO5	Evaluate the combustion processes taking place in different types of chemical rockets.

Syllabus

Module 1:
Thermochemistry: Stoichiometry; Absolute Enthalpy and Enthalpy of Formation; Enthalpy of Combustion and Heating Value; Laws of Thermochemistry; Pressure and Temperature Effect on Enthalpy of Formation; Adiabatic Flame Temperature; Chemical and Equilibrium Products of Combustion; Some Applications; Sample Calculations. [8 L]

Module 2:

Combustion Kinetics: Rate and Order of Reaction; First, Second and Third Order Reaction, Reversible Reactions; Arrhenius Equation; Molecular Kinetics: Molecularity and Order, Theories of Collision; Chain Reaction, Explosion Limits Equilibrium constants and their Relationship; Dissociation and Reassociation; Combustion Products in Equilibrium; Gibbs phase rule. [8 L]

Module 3:

Flames: Concept of Flame; Definition, Classification and Properties of Premixed Flames; Properties of Diffusion Flames; Measurement of Burning Velocity; Flame Stabilization; Quenching; Flame Temperature Measurement Techniques; Ionization in Rocket Exhaust. [8L]

Module 4:

Detonation: Detonation Wave and their Characteristics; Deflagration to Detonation Transition; Derivation of Rankine- Hugoniot equation; Chapman- Jouguet States and their Properties; Computation of Detonation Velocity. [8 L]

Module 5:

Combustion in Rocket Motors: Solid Propellant Combustion- Composite and Double Base Propellants, Combustion in a Liquid Propellant Rocket Motor; Combustion in a Hybrid Rocket Motor, Various Process of Ignition and Extinction in Chemical Rockets. [8L]

Text Books:

1. S. R. Turn, An Introduction to Combustion - Concepts and Applications, 3rd Edition, McGraw-Hill, India, 2012.**(T1)**
2. K. K. Kuo, Principles of Combustion, John Wiley and Sons, New York, 1986. **(T2)**

Reference Books:

1. B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 3rd Edition, Academic Press, Orlando, 1987. **(R1)**
2. A. G. Gaydon and H. D. Wolfhard, Flames: Their Structure, Radiation and Temperature, 3rd Edition, Springer NY, USA, 1970. **(R2)**

Gaps in the syllabus (to meet Industry/Profession requirements): Experimental exposure to detonation process involves safety issues and is deliberately left out.

POs met through Gaps in the Syllabus: PO 5 will be met through assignment and seminar/ presentation.

Topics beyond syllabus/Advanced topics/Design: Heat andMass Transfer and Turbulent Flames are not covered in this syllabus.
POs met through Topics beyond syllabus/Advanced topics/Design: Information shared through relevant research papers and invited expert lectures/industrial visit.

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD Projector
CD2	Assignments
CD3	Seminars
CD4	Laboratory experiments/teaching aids
CD5	Self- learning such as use of NPTEL materials and internets/ Exposure to outside world

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	1	1	2
CO2	3	-	3	1	1	2
CO3	3	3	3	3	1	3
CO4	3	-	3	2	1	3
CO5	3	3	3	3	3	3

If satisfying ,< 34% = 1, 34-66% = 2, > 66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD5
CO2	CD1, CD3, CD5
CO3	CD1, CD5
CO4	CD1, CD2, CD4, CD5
CO5	CD1,CD4, CD5

COURSE INFORMATION SHEET

Course code: SR 510
Course title: Fundamentals of Aerospace Engineering
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M.Tech.
Semester / Level: I/II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

1.	Understand the basics of fluid dynamics and aircraft aerodynamics
2.	Understand the concept of high speed aerodynamics
3.	Describe various types of airbreating propulsion system with their merits and challenges.
4.	Classify various types of chemical rocket propulsion and their various parameters governing it.
5.	Describe the fundamentals of orbital mechanics and motion in space

Course Outcomes

At the end of the course, a student should be able to:

CO1	Implementation of basic concept of fluid dynamics and aircraft aerodynamics for analysing the operational parameters of hydraulic problems and aircraft performance
CO2	Implementation of basis of high speed aerodynamics for simple problem solving
CO3	Analyze the propulsion system along with performance parameters for solving the designing challenges.
CO4	Understand and examine various parameters used in a chemical rockets, especially in solid rocket motor and a liquid rocket engine.
CO5	Analyze space dynamics and its effects on motions in space

Module I:
Fluid dynamics and basics of aerodynamics:
Fluid Dynamics: Continuity equation, Basic laws of fluid dynamics – conservation of mass, conservation of linear momentum, conservation of energy, Ideal fluid flow, Application of Bernoulli's equation, Real fluid flow, Viscosity, Determination of losses, Reynolds experiment, Laminar and turbulent flow, Boundary layer, Velocity profile, Flow past a body, Flow Separation, Generation of Lift, Drag & Moment, Nondimensional coefficients, Airfoils & Wings.

[8L]

Module II:

Aerodynamics of high speed flights:

Flow regimes, compressible flow, Speed of sound, Normal shock, oblique shock, expansion fans, governing equation for quasi one dimensional flow, Nozzle, Supersonic Wind tunnels.

[8L]

Module III:

Air-breathing Propulsion:

Principles of propulsion, Various air-breathing propulsion systems: Piston Engine-propeller, Turbojet, Turbo-prop, Turbofan, Turboshaft, Pulsejet, Ramjet and Scramjets, Thrust and other performance parameters, Efficiencies, Cycle analysis. [8L]

Module IV:

Non-air breathing Propulsion:

Introduction, Classifications of rockets, Description and Application; Various propulsive devices used for aerospace applications, Chemical, Electrical, Nuclear and other Advanced Propulsion Systems. Basic requirements, Thrust Equation; Specific Impulse, Thrust Coefficient, Characteristic Velocity and other Performance Parameters. [8 L]

Module V:

Motion in Space: Requirement for orbits

Motion of bodies in Space, Equation of Motion of an Ideal Rocket, Motion of a Rocket in a Gravitational Field, Simplified Vertical Trajectory, Burn- out Velocity and Burn- out Height; Orbits and Trajectories; Conic Sections; Kepler's Laws of Satellite Motion; Orbital Velocity of Satellites; Orbital Periods; Eccentric Elliptical Orbits; Geosynchronous and geostationary orbits, Energy and velocity requirements to reach a particular orbit, Escape velocity, Free falling bodies.

[8 L]

Text books:

2. Fundamentals of Aerodynamics – Anderson, J. D., Tata McGraw-Hill Education, New Delhi, 2007. **(T1)**
3. Understanding Chemical Rocket Propulsion, Mukunda, H.S., I K International Publishing House, 2017. **(T2)**
4. Rocket Propulsion Elements, Sutton, G.P., Biblarz, O., 7th Ed. John Wiley & Sons, Inc., New York, 2001. (**T3**)
5. Source book on the Space Science, Glasstone, S, 1st Edition D. Van Nostrand Co., 1965. (**T4**)

Reference books:

5. Rocket Propulsion, Ramamurthi, K., 2nd Edition, Trinity Press of Laxmi Publications Private Limited, India, 2016. **(R1)**
6. Mechanics and Thermodynamics of Propulsion, Hill P. and Peterson C., 2nd Edition, Pearson Publisher. 1991. **(R3)**
7. Introduction to Flight, Anderson, J. D., 5th Edition, Tata McGraw-Hill Education, New Delhi, 2007. (**R4**)
8. Rocket and Spacecraft Propulsion: Principle, Practice and New Developments, Turner, M. J. L., Springer Verlag. 2000.**(R2)**

Gaps in the syllabus (to meet Industry/Profession requirements)

POs met through Gaps in the Syllabus: PO3, PO6

Topics beyond syllabus/Advanced topics/Design
Types of Error in the Measurements

POs met through Topics beyond syllabus/Advanced topics/Design: PO4, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD1	Lecture by use of boards/LCD projectors/OHP projectors
CD2	Assignments/Seminars
CD3	Laboratory experiments/teaching aids
CD4	Industrial/guest lectures
CD5	Industrial visits/in-plant training
CD6	Self- learning such as use of NPTEL materials and internets
CD7	Simulation

Course Outcome (CO) Attainment Assessment tools & Evaluation procedure

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	1	1	3
CO2	1	1	2	1	-	3
CO3	1	1	2	2	1	3
CO4	3	2	3	1	-	2
CO5	1	-	2	-	1	1

If satisfying ,< 34% = 1, 34-66% = 2, >66% = 3

Mapping Between COs and Course Delivery (CD) methods

Course Outcome	Course Delivery Method
CO1	CD1,CD2,CD3, CD6
CO2	CD1, CD3, CD6
CO3	CD1, CD6
CO4	CD1, CD2, CD3, CD6
CO5	CD1,CD3, CD6

COURSE INFORMATION SHEET

Course code: SR 511
Course title: Fundamentals of Fuels and Combustion
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: L: 3 T: 0 P: 0 C: 3
Class schedule per week: 3
Class: M.Tech.
Semester / Level: I or II/05
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

1.	Introduction to the various classification of fuel energy sources
2.	Identify the manufacture methods of various types of derived fuels and their applicability in the fuel industry
3.	Understand the concept of thermochemistry, enthalpy, adiabatic flame temperature, ignition, combustion products and their application to combustion related problems
4.	Apply the concept of chemical rates of reaction, collision theory and Arrhenius equation for analysing the different types of reactions.
5.	Compare the properties and characteristics of different type of flames and apply the same to combustion phenomenon in rocket motors and its exhaust.

Course Outcomes

At the end of the course, a student should be able to:

CO1	Classification of various fuel energy sources and their ways of utilization
CO2	Analyse the various types of derived fuels with methods of manufacture and their utilization
CO3	Apply the basic concept of thermochemistry, adiabatic flame temperature and ignition to combustion related problems
CO4	Demonstrate the utilization of the concept of chemical kinetics in combustion reactions.
CO5	Distinguish between premixed, diffusion flames an laminar and turbulent flames and their use in combustion devices.

Module I:
Fuels and their classification: Different fuel energy sources, Classification of fuels sources -Non-renewable and Renewable fuels, primary fuels and secondary fuels and solid, liquid and gaseous fuels.
[8L]

Module II:
Manufactured fuels and derived fuels: Manufactured liquid and gaseous fuels. Derived fuels from coal- coal gasification, liquefaction and carbonization of coal, refuse derived fuels, bio-fuels, biomass, algae, bio-diesel, alcohol fuels [8L]

Module III:
Thermochemistry: Stoichiometry; Absolute Enthalpy and Enthalpy of Formation, Enthalpy of Combustion, Pressure and Temperature Effect on Enthalpy of Formation, Adiabatic Flame Temperature, Chemical and Equilibrium Products of Combustion, Some Applications, Ignition-Self Ignition and Forced Ignition, Factors affecting Ignition Energy. [8L]

Module IV:
Combustion Kinetics: Rate and order of Reaction; First, Second and Third Order Reaction, Reversible Reactions, Arrhenius Equation, Molecular Kinetics: Molecularity and Order, Theories of Collision, Chain Reaction, Explosion Limits Equilibrium constants and their Relationship, Combustion Products in Equilibrium, Gibbs phase rule. [8L]

Module V:
Flames and Combustion: Concept of Flame; Definition, Classification and Properties of Premixed Flames; Properties of Diffusion Flames; Measurement of Burning Velocity, Flame Stabilization; Quenching; Flame Temperature Measurement Techniques Structure of Laminar Flame, Laminar Flame Propagation in Tubes, Description of Turbulent Flames, Concept of Turbulent Flow; Turbulent Burning Velocity, Solid fuel combustion and Liquid droplet combustion.
[8L]

Text Books:

3. S. Sarkar, Fuels and Combustion, Orient Longman, 2nd edition, 1990. **(T1)**
4. Fuels & Combustion – Sharma, S.P. & Mohan, C., Tata- McGraw Hill, 1984. **(T2)**
5. S. R. Turn, An Introduction to Combustion - Concepts and Applications, 3rd Edition, McGraw-Hill, India, 2012. **(T3)**

Reference Books:

3. J.G. Speight, The Chemistry and Technology of Coal, CRC Press. 2013. **(R1)**
4. J.G. Speight, The Chemistry and Technology of Petroleum, 4th Edition, CRC Press. 2006 **(R2)**
5. K. K. Kuo, Principles of Combustion, John Wiley and Sons, New York, 1986. **(R3)**

Gaps in the syllabus (to meet Industry/Profession requirements):
Petroleum fuels and their distillation process not included

POs met through Gaps in the Syllabus: PO5 will be met through assignment and seminar/ presentation.

Topics beyond syllabus/Advanced topics/Design: Detonation not covered in this syllabus.

POs met through Topics beyond syllabus/Advanced topics/Design: PO4, PO6

COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

Direct Assessment

Assessment Tool	% Contribution during CO Assessment
Continuous Internal Assessment	50
Semester End Examination	50

Continuous Internal Assessment	% Distribution
3 Quizzes	30 % (3 × 10%)
Assignment (s)	10
Seminar before a committee	10

Assessment Components	CO1	CO2	CO3	CO4	CO5
Continuous Internal Assessment					
Semester End Examination					

Indirect Assessment –

1. Student Feedback on Faculty
2. Student Feedback on Course Outcome

Course Delivery methods

CD	Course Delivery methods
CD1	Lecture by use of boards/LCD Projector
CD2	Assignments
CD3	Seminars
CD4	Laboratory experiments/teaching aids
CD5	Self- learning such as use of NPTEL materials and internets/ Exposure to outside world

Mapping between Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

Course Outcome #	Program Outcomes					
	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	-	1	2
CO2	3	-	3	-	3	2
CO3	3	-	3	-	1	3
CO4	3	-	2	-	1	3
CO5	3	-	3	-	3	3

If satisfying ,< 34% = 1, 34-66% = 2, > 66% = 3

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