Department of Space Engineering and Rocketry

Birla Institute of Technology, Mesra, Ranchi - 835215 (India)

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)

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.

Program Outcomes (PO)

PO 1 : An ability to independently carry out research and development work to solve practical problems in Aerodynamics

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 Aerodynamics.

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

Module II:
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 III:
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 IV:
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. [8 L]

Module V:
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 Delivery methods

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

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	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, CD5
CO2	CD1, CD3, CD5
CO3	CD1, CD5
CO4	CD1, CD2, CD4, CD5
CO5	CD1,CD4, CD5

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 I:

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. [8 L]

Module II:

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 III:

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 IV:

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 V:

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 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 I:
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 II:
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 III:
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 IV:
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 [8 L]

Module V:
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
[8 L]

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 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 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 (Rocket Propulsion)
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 I:

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 II:

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 III:

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.

[8 L]

Module IV:

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 V:

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.

[8 L]

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 and Mass 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 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 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: I/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 I:

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.

[8 L]

Module II:

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 III:

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

Module IV:

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. [8 L]

Module V:

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.

[8 L]

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

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

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

5. **Experiment No. 5**
   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. **Experiment No. 6**
   Name : Preparation of Composite Solid Propellant with Burn Rate Modifiers
   Objective : To prepare composite solid propellants with additives at given oxidizer/fuel ratio.

7. **Experiment No. 7**
   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. **Experiment No. 8**
   Name : Water Equivalent Measurement
   Objective : To determine the water equivalent of bomb calorimeter

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

10. **Experiment No. 10**
    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. **Experiment No. 11**
    Name : Preparation of Igniters for Solid Rocket Motor
    Objective : To prepare the shellac based pyrotechnic igniters

12. **Experiment No. 12**
    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. **Experiment No. 4**

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

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: I/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 I:

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. [8 L]

Module II:

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. [8 L]

Module III:

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 IV:

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 V:

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 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

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: I /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.	Apply the 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 I:

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. [8 L]

Module II:

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. [8 L]

Module III:

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. [8 L]

Module IV:

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. [8 L]

Module V:

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. [8 L]

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 – Parviz Moin **(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 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