



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) - (ROCKET PROPULSION)

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 Rocket Propulsion

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 Rocket Propulsion.

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 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 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 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 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 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 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. Experiment No. 1

Name: Introduction to Aerodynamics Laboratory

Objective :Explanation of various existing wind tunnels in the lab. The details of operation principle and instrumentations.

2. Experiment No. 2

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. Experiment No. 3

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 Kenneth 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 #	Program Outcomes					
	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 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 applications.
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. Chiverini and Kenneth 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 of various performance parameters used in solid rocket motor in terms of its implication.
3.	Generate the sufficient information on the types of the nozzle and its utilization in practical applications.
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 used in solid rocket motor.
3.	To apply the basic knowledge of nozzle in the practical applications.
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. [9 L]

Module 2:

Performance of Solid Rocket Motor: Prediction and Measurements of Specific Impulse, Computation of Adiabatic Flame Temperature; Theoretical Performance Evaluation of Solid Rocket Propellants; Equilibrium and Frozen Flow; Methods of Calculating Equilibrium Composition; Experimental Determination of Rocket Performance. [9L]

Module 3:

Nozzle: Isentropic Flow through Nozzles, Nozzle Configuration; Convergent- Divergent Nozzles, Bell Nozzles, Annular Nozzles, Adapted Nozzles, Submerged Nozzles; Nozzle Flow and Design Optimization; Nozzle Construction; Throat Inserts. [7L]

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 Zaehring, 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 details of combustion process associated with double base and composite propellants and compare the condensed and gas phase theories related to them.
2.	Apply the concept of metal combustion in metallized composite solid propellants
3.	Identify the changes in energetics and combustion behaviour including erosive burning.
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	Comprehend principal concepts and predict the related theory for a typical case of solid propellant combustion.
CO2	Identify the effect of metal addition on the combustion processes and analyse its effect on energetics and combustion behaviour.
CO3	Illustrate the concept of erosive burning and interpret the instabilities associated with it and their remedial methods.
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:

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 2:

Combustion of Metals : Physical Considerations; **Glassman's Hypothesis**; Description and Classification of Various Burning Metals; Theories of Combustion of Metal Powders; Metal Combustion in Deflagrating Propellants; Effect of Aluminum on Propellant Burning Rate; Equilibrium Composition of Combustion Products of Metallized Propellants. [7L]

Module 3:

Erosive Burning : Introduction; Threshold Velocity; Laboratory Methods for Determination of the Erosion Function; Theories of Erosive Burning– **Lenoir and Robillard's Model**; **Razdan and Kuo's Model**, **King's Model** and Vandekerckhove Theory; Effect of Erosion on Geometry of Central Port; Effect of Cross- Flow Velocity, Effect of Propellant Characteristics and Combustion Chamber Pressure on Erosive Burning; Negative Erosion Phenomenon. [7L]

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. Fundamentals of Solid Propellant Combustion, Kuo, K. K., Summerfield, M., Progress in Astronautics & Aeronautics, Vol. 90, AIAA. 1984.
2. **Liquid Propellant Rockets**, Altman, D., Carter, J. M., Penner, S.S., Summerfield, M., Princeton University Press, 1960.
3. Heterogeneous Combustion, Wolfhard, H.G., Glassman, I., Green, L., Progress in Astronautics & Aeronautics, Vol. 15, AIAA. 1964.

Reference books:

1. **Solid Rocket Propulsion Technology**, Ed. Alain Davenas, Elsevier, 1992. (ISBN 978-0-08-040999-3)
2. Fundamental of Hybrid Rocket Combustion and Propulsion, Chiaverini, M.J., Kuo, K.K., Progress in Astronautics & Aeronautics, Vol. 218, AIAA. 2007.

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 Zaehring, 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 517

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. Experiment No. 1

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. Experiment No. 2

Name : Preparation of fuel grain

Objective : Processing of solid composite propellant grain with different perforations having compositions as PVC-DBP and AP.

3. Experiment No. 3

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. Experiment No. 1

Name : Introduction to liquid and hybrid lab

Objective : To introduce and give brief information about the equipments used in liquid and hybrid lab

2. Experiment No. 2

Name : Preparation of fuel grain

Objective : Processing of PVC-Plastisol based hybrid fuel grain with tubular perforation of two different compositions.

3. Experiment No. 3

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 performance 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 Kenneth 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

COURSE INFORMATION SHEET

Course code: SR 601

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: III/06

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., Zaehring, A.J., John Wiley New York, 1967.

Reference books:

1. Rocket Propulsion, Barrere, M., Jaumotte, A., Fraeijs de Veubeke, B., Vandekerckhove, J., Elsevier Publishing Company, 1960
2. Internal Ballistics of Solid-Fuel Rockets: Military Rockets Using Dry-Processed Double-Base Propellant as Fuel, Wimpres, 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 602

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: III/06

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 603

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: III/06

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. Poinso 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 604
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: III/06
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 acting 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 605
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: III/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 606

Course title: Energetics and Combustion Laboratory

Pre-requisite(s): NA

Co-requisite(s): NA

Credits: L: 0 T: 0 P: 4

Class schedule per week: 04

Class: M. Tech

Semester/Level: III/06

Program: SER

Name of Teacher:

Course Objectives: This course enables the students to:

1.	Impart training in the modern methods of data acquisition and analysis
2.	Inculcate habits of critical analysis and assessment of reliability of results
3.	To train students for independent handling of instruments and research tools
4.	To evaluate methods for error analysis , validation and reporting of numerical solutions
5.	To highlight the close interactions between experimental and numerical approaches in research

Course Outcomes

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

CO1	Be able to use image processing methods
CO2	Demonstrate capability to perform automatic data acquisition
CO3	Be able to perform error analysis of experimental results
CO4	Demonstrate capability to undertake error analysis, validation, and reporting of numerical simulations
CO5	Be able to make complimentary use of experimental and numerical tools

Syllabus

(Number in bracket gives assigned laboratory sessions from maximum of 13 sessions)

Experiment No. 1 [1]

Title: Calibration and error analysis of instruments

Objective: To calibrate a dynamic pressure sensor, perform error analysis, and prepare a calibration report

Experiment No. 2 [1]

Title: Measurement of motor performance characteristics

Objective: To measure pressure rise and estimation of ignition delay, c^* efficiency, specific impulse, density impulse, and compare with equilibrium calculations (liquid/solid/hybrid propellants)

Experiment No. 3 [2]

Title: Development of basic virtual instruments

Objective: To develop basic virtual instruments using LabVIEW for acquisition of output signals, signal conditioning, display of calibrated output of sensor, and data storage

Experiment No. 4 [2]

Title: Development of virtual instrument for a static firing test set up

Objective: To design and develop a specific virtual instrument using LabVIEW for static firing test of a given rocket motor

Experiment No. 5 [2]

Title: Characterization of combustion instability

Objective: To characterize combustion instability in solid/hybrid rocket motors and perform time-series analysis

Experiment No. 6 [2]

Title: Characterization of spray properties

Objective: To measure spray properties by photographic techniques and image processing using injectors for liquid rocket engines

Experiment No. 7 [3]

Title: Numerical analysis of a diffusion flame

Objective: To mathematically model a turbulent diffusion flame, obtain numerical solution of the model using CFD techniques employed in ANSYS-Fluent, and perform rigorous error analysis

Reference books:

1. D. P. Mishra. Experimental Combustion: An Introduction. 1st Edition. CRC Press, USA (2017).
2. E. Rathakrishnan. Instrumentation, Measurements, and Experiments in Fluids. 2nd Edition. CRC Press, USA (2016).
3. V. Yang and W.E. Anderson. Liquid Rocket Engine Combustion Instability. Progress in Astronautics and Aeronautics Vol. 169, AIAA (1995).
4. T. Poinso and D. Veynante. Theoretical and Numerical Combustion. 2nd Edition. R. T. Edwards Inc., USA (2005).

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

- Characterization of flame properties

POs met through Gaps in Syllabus

Gaps in Syllabus	POs
Characterization of flame properties	PO3

Topics beyond syllabus/advanced topics/design

- **Topic beyond syllabus:** LASER diagnostics in combustion

POs met through topics beyond syllabus/advanced topics/design

Topics beyond Syllabus	POs
LASER diagnostics in combustion	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 Objectives and Outcomes

Mapping of Course Outcomes onto Program Outcomes

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