# 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 PhD programmes and research projects
- To develop effective teaching and learning skills and state of art research potential of the faculty
- To build national capabilities in technology, education and research in emerging areas
- To provide excellent technological services to satisfy the requirements of the industry and overall academic needs of society

### Department Vision

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

### Department Mission

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

### Program Educational Objectives (PEO)

**PEO 1:** To develop strong foundation in students to understand and analyse advance research problems in Space Engineering and Rocket Science

**PEO 2:** Nurture professional graduates to develop ability in analysing real life problems of Space Technology

**PEO 3:** To foster attitude towards continuous learning for developmental activities in research, academia and industry

**PEO 4:** To improve professional skills for teamwork with ethical awareness and practice in achieving goal

## Program Outcomes (PO)

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

**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 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:

| | |
|---|---|
| A. | To comprehend the knowledge about constituents of different types of solid propellant systems in processing of each category and determining key properties. |
| B. | To understand the fundamentals of solid propellant grain design |
| C. | To use grain design fundamentals in design of grains for static and flight rockets. |
| D. | To differentiate between various types of liquid propellants and to analyse the related aspects of ignition, combustion and performance evaluation. |
| E. | To 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**

**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]**

**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]**

**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]**

**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]**

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

**[10L]**

**Text books:**


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


**Reference books:**


1. Rocket Propulsion, Barrere, M., Jaumotte, A., Fraeijs de Veubeke, B., Vandenkerckhove, J., Elsevier Publishing Company, 1960

2. Internal Ballistics of Solid-Fuel Rockets: Military Rockets Using Dry-Processed Double-Base Propellant as Fuel, Wimpress, R.N., Sage, B.H.,ReInk Books, 2017.

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

**POs met through Gaps in the Syllabus**

**Topics beyond syllabus/Advanced topics/Design**

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

## COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

**Direct Assessment**

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

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

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

**Indirect Assessment –**

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

**Course Delivery methods**

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

## Mapping between Objectives and Outcomes

**Mapping of Course Outcomes onto Program Outcomes**

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

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

## MAPPING BETWEEN COURSE OUTCOMES AND COURSE DELIVERY METHOD

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

# COURSE INFORMATION SHEET

**Course code: SR 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:

| | |
|---|---|
| A. | To analyze the combustion mechanism involved in chemical propulsion. |
| B. | To interpret the significance of green propellant |
| C. | To analyze two-phase flow on the performance of solid rocket motor. |
| D. | To examine the effect of various parameters on the combustion and performance in a liquid rocket engine. |
| E. | To 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**

**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.

**[10L]**

**Green Propellants & Their Applications:** Introduction; Advantages of Green Propellants; Physico- chemical Properties; Performance, Design and Operational Requirements.

**[6L]**

**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]**

**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]**

**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**

| | |
|---|---|
| **A** | To introduce the governing equations of chemical kinetics, mass, momentum, and heat transfer |
| **B** | Introduce advanced mathematical modeling of laminar and turbulent flames |
| **C** | To employ methods of computational fluid dynamics for numerical solution of models developed for complex flow and combustion problems |
| **D** | Understand the best practices for reliable predictions from complex computational models of combustion problems |

**Course Outcomes**

| | |
|---|---|
| **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**

**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]**

**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]**

**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]**

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

**[6L]**

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

**[9L]**

**Textbooks:**

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

**Reference books:**

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

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

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

**POs met through Gaps in Syllabus**

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

**Topics beyond syllabus/advanced topics/design**

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

**POs met through topics beyond syllabus/advanced topics/design**

| Topic beyond Syllabus | POs |
|---|---|
| Large eddy simulation of reacting flows | PO6 |

## COURSE OUTCOME (CO) ATTAINMENT ASSESSMENT TOOLS & EVALUATION PROCEDURE

**Direct Assessment**

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

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

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

**Indirect Assessment –**

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

**Course Delivery methods**

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

**Mapping between Objectives and Outcomes**

| Course Outcome # | Program Outcomes |
|---|---|

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

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

**Mapping Between COs and Course Delivery (CD) methods**

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

**COURSE INFORMATION SHEET**

**Course code:** SR 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:

| | |
|---|---|
| A. | To identify various types of missiles and their applications based on their design configurations. |
| B. | To analyze different types of structural loading acting over the surfaces of rocket and missiles during its operation. |
| C. | To interpret the designing challenges associated in terms of material and structural weight selections of the rocket and missiles. |
| D. | To analyze the advantages and challenges linked with the use of composite material in the design of rocket and missiles in terms of its performance. |

**Course Outcomes**

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

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

**Syllabus**

**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]**

**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]**

**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]**

**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]**

**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:

| | |
|---|---|
| A. | To identify cryogenic substance and examine its characteristics in cryogenic environments. |
| B. | To analyze the storage and transfer vessel arrangements for the suitability of cryogenic propulsion system. |
| C. | To explain the working concept of the turbo-pump feed system designed for cryogenic fluids. |
| D. | To analyze the various challenges associated with cryogenic propulsion systems |
| E. | To 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**

**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]**

**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]**

**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]**

**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]**

**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**

| | |
|---|---|
| **A** | Impart training in the modern methods of data acquisition and analysis |
| **B** | Inculcate habits of critical analysis and assessment of reliability of results |
| **C** | To train students for independent handling of instruments and research tools |
| **D** | To evaluate methods for error analysis , validation and reporting of numerical solutions |
| **E** | To highlight the close interactions between experimental and numerical approaches in research |

**Course Outcomes**

| | |
|---|---|
| **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. Poinsot 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 |