MTech Aerospace Propulsion Technology
First Semester Syllabus Academic Year 2026-2027

MATHEMATICAL CONCEPTS FOR AEROSPACE ENGINEERING

Course Code	1MMAT101	Scheme	2026
Type of Course	MAT	Semester	I
Teaching Hours/Week (L:T:P)	3 : 0 : 0	CIE Marks	50
Total Hours of Pedagogy L /T/P/SL&TW:	90 (42: 0 : 0 : 48)	SEE Marks	50
Credits	03	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	03

Course Objectives

At the end of the course, the student will be able to:

CO1: Perform matrix operations to solve system of linear algebraic equations and uses the concept of Eigen values and Eigen vectors to solve system of ordinary differential equations by matrix method.

CO2: Find basis and dimension of a vector space. Also compute matrix transformations associated with linear maps, geometric transformations in a vector space and determine the kernel and range of linear transformations.

CO3: Predict the value of a dependent variable using the concept of interpolation for a given data.

CO4: Find the solution of an ordinary and partial differential equation numerically.

CO5: Construct an analytic function, apply bilinear transformation to map one complex plane to another complex plane and uses conformal mapping techniques to transform complex functions.

Module-1

Elementary transformations on a matrix, Echelon form & rank of a matrix, Consistency of system of linear equations. Gauss elimination & Gauss – Seidel method to solve system of linear equations. Applications to solve traffic flow problems and electric circuit problems. Eigenvalues and eigenvectors of a matrix, Rayleigh power method to determine the dominant eigenvalue of a matrix, diagonalization of square matrices. Solution of system of ODEs by matrix method.

Number of Hours: 09

Module-2

Vector Spaces, subspaces, Linear combination and span, linearly independent and dependent vectors, Basis and Dimension, Linear transformations, Matrix transformations, Rotation about the origin, Dilation, Contraction and Reflection, Kernel and Range. Four fundamental subspaces of a matrix.

Number of Hours: 09

Module-3

Forward and Backward differences, Interpolation, Newton-Gregory Forward and Backward Interpolation, Lagrange's interpolation and Newton's divided difference interpolation techniques. Derivatives using Newton-Gregory forward and backward interpolation formula. Newton-Cotes quadrature formula: Trapezoidal, Simpson's 1/3rd and Simpson's 3/8th rule.

Number of Hours: 08

Module-4

Taylor's series method, Euler's & modified Euler's method, fourth order Runge -Kutta method. Numerical solution of PDEs Heat Equation, Wave Equation, Laplace Equation.

Number of Hours: 08

Module-5

Functions of complex variable, Analytic function, Cauchy-Riemann Equations in Cartesian and polar coordinates, construction of analytic functions. Transformations: Conformal transformation, Discussion of the transformations $w = e^z$, $w = z^2$. Applications of Conformal Mapping- Electrostatic Potential, Potential in a Cylindrical Space, Two- Dimensional Fluid Flow, Stream Function, Bilinear transformations.

Number of Hours: 08

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Textbooks:

1. B. S. Grewal – Higher Engineering Mathematics – Khanna Publishers – 45th edition – 2024.
2. David C. Lay, Steven R. Lay and Judi J. Mc. Donald – Linear Algebra and its Applications Pearson – 5th edition – 2023.
3. James Ward Brown, Ruel V Churchill – Complex variables and Applications – McGraw Hill publishers - 9th edition-2021.

Reference books / Manuals:

1. Peter V. O'Neil – Advanced Engineering Mathematics – Cengage learning – 8 th edition – 2017.
2. Gareth Williams – Linear Algebra with Applications, Jones and Bartlett Press – 9 th edition – 2017.
3. Erwin Kreyszig –Advanced Engineering Mathematics – Wiley publication – 10th edition- 2015.
4. Gilbert Strang - Linear Algebra and its Applications, 5 th Edition (2016).

Assessment Structure (both CIE and SEE)

The assessment in each course is divided equally between Continuous Internal Evaluation (CIE) and the Semester End Examination (SEE), with each carrying 50% weightage.

- To qualify and become eligible to appear for SEE, in the **CIE**, a student must score at least **40% of 50 marks**, i.e., **20 marks**.
- To pass the **SEE**, a student must score at least **35% of 50 marks**, i.e., **18 marks**.

Notwithstanding the above, a student is considered to have **passed the course,** provided the combined total of **CIE and SEE** is at least **40 out of 100 marks**.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of **two Internal Assessment Tests (IA)** shall be conducted. Each test shall be conducted for a maximum of **25 marks.** The average of the two test marks shall be the marks secured by a student in IA.
In addition, **Continuous Comprehensive Assessment (CCA)** shall be conducted for a total of **25 marks**.

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Development of mathematical models foe engineering problems (eg. Beam bending, heat conduction etc.)	15
2.	Critically analyse and report mathematical formulations employed in Research Papers drawn from Aerospace domain	10

Continuous Internal Evaluation (CIE)

(i)The CIE marks shall be decided based on internal tests and other outcome-based activities. The continuous internal evaluation shall be carried out by the teacher handling the course.
(ii)Out of 50 marks earmarked for CIE, 25 marks shall be assigned for internal tests. The first test shall be conducted after completing two modules of the syllabus and the second one after completing the remaining three modules.
(iii) The remaining 25 marks shall be assigned for Continuous Course Assessment (CCA), conducted as per the rubrics listed in the assessment section of the respective syllabus.
(iv) A student shall obtain a minimum of 40% marks or 20 out of 50 marks allotted to CIE to become eligible to appear for the SEE.

Passing requirement in SEE

For a pass in the Semester End Examination (SEE), a student shall secure a minimum of 35 marks out of 100.
For the declaration of a pass grade, the sum of the Continuous Internal Evaluation (CIE) marks (out of 50) marks and the SEE marks scaled down to 50 shall be greater than or equal to 40 marks.
If the total (CIE + SEE) is less than 40 marks, the student shall be awarded the grade 'F' (Fail).

NUMERICAL TECHNIQUES FOR PROPULSION APPLICATIONS			
Course Code	1MAS102	Scheme	2026
Type of Course	PCC	Semester	I
Teaching Hours/Week (L:T:P)	3 : 0 : 0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42 : 0 : 0 : 48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3

Course outcomes (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Apply FEA principles to discretise domains, define appropriate boundary conditions for solving one-, two- and three-dimensional problems.
CO2: Analyse the structural behaviour of trusses, beams and plates using static and dynamic finite element analysis techniques
CO3: Analyse engineering problems involving nonlinear structural behaviour, optimization, heat transfer, and fluid flow using appropriate numerical models.
CO4: Use MATLAB programming skills to solve engineering equations, differential equations and perform data analysis.
CO5: Apply MATLAB/Simulink tools to model, simulate, and evaluate the dynamic response and control performance of aerospace systems such as propulsion systems.

Module-1

Introduction to Finite Element Method:
Basics of Finite Element Method (FEM): Fundamental concepts: Introduction to Elasticity discretization, and element types. **Boundary conditions:** Homogeneous and non-homogeneous for structural, heat transfer and fluid flow problems. Potential energy method, Rayleigh Ritz method, Convergence criteria, Discretisation process, Numerical Integration: One Dimensional Two- and Three-Dimensional, Static Structural Analysis: Performing and interpreting basic static structural analysis using Ansys Workbench

Number of Hours: 09

Module-2

Advanced Structural Analysis: Dynamic Analysis: Modal analysis, harmonic analysis, and transient dynamic analysis, stress analysis of trusses, beam and airframe structures, Finite Element Analysis of Thin Plate, Finite Element Analysis of Thick Plate.

Number of Hours: 08

Module-3

Optimization and Nonlinear Analysis: Optimization Techniques: Parameter optimization and response surface analysis. Nonlinear Analysis: Large deformation, material nonlinearity
Advanced Fluid Flow and Heat Transfer Analysis: Steady state heat transfer, Basic differential equation for fluid flow in pipes and fluid flow problems.

Number of Hours: 08

Module-4

Numerical Methods in MATLAB: Numerical Solutions of Equations: Root-finding methods, numerical integration, and differentiation. Solving ODEs and PDEs: Implementing numerical solutions for ordinary and partial differential equations. Data Analysis and Visualization: Techniques for data processing, curve fitting, and visualization in MATLAB.

Number of Hours: 09

Module-5

Dynamic Systems Simulation using MATLAB and Simulink: Introduction to Simulink: Building and simulating dynamic models in Simulink. Control Systems Design: Designing and analyzing control systems using Simulink. Case Studies: Simulation of aerospace systems such as flight dynamics and propulsion systems.

Number of Hours: 08

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. "Finite Element Procedures" by Klaus-Jürgen Bathe, Prentice Hall, ISBN: 978-0133014587.
2. "MATLAB for Engineers" by Holly Moore, Pearson, ISBN: 978-0134589645.
3. "The Finite Element Method: Its Basis and Fundamentals" by O.C. Zienkiewicz, R.L. Taylor, and J.Z. Zhu, Butterworth-Heinemann.

Reference books / Manuals:

1. "Introduction to MATLAB for Engineers" by William J. Palm III, McGraw-Hill Education.
2. "Engineering Analysis with ANSYS Workbench 18" by Saeed Moaveni, Pearson.
3. "The Finite Element Method In Engineering" by Singiresu S.Rao Sixth Edition., Elsevier, ISBN: 978-012811768-2

Web links and Video Lectures (e-Resources):

1. https://www.youtube.com/watch?v=h7dhDe-fZeg
2. https://www.youtube.com/watch?v=xoEhbJXCBEU&list=PLxeI6KO3PAQ_3xQzNdy5I9kIwdwKlNWNQ
3. https://youtu.be/-EYL9BPIZI4

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Flipped Classrooms
2. Project-Based Learning (PBL)

Assessment Structure:

The assessment in each course is divided equally between Continuous Internal Evaluation (CIE) and the Semester End Examination (SEE), with each carrying 50% weightage.

- To qualify and become eligible to appear for SEE, in the **CIE**, a student must score at least **40% of 50 marks**, i.e., **20 marks**.
- To pass the **SEE**, a student must score at least **35% of 50 marks**, i.e., **18 marks**.
- Notwithstanding the above, a student is considered to have **passed the course,** provided the combined total of **CIE and SEE** is at least **40 out of 100 marks**.

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of **two Internal Assessment Tests (IA)** shall be conducted, carrying a total of **25 marks.**

In addition, **Continuous Comprehensive Assessment (CCA)** shall be conducted for a total of **25 marks.**

It is recommended to include **a maximum of two learning activities** as part of the CCA to foster the **holistic development of students.** These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Case Study / Mini-project / Optimization Exercise / Research paper Review / Programming Challenge	25

Continuous Internal Evaluation (CIE)

(i)The CIE marks shall be decided based on internal tests and other outcome-based activities. The continuous internal evaluation shall be carried out by the teacher handling the course.

(ii)Out of 50 marks earmarked for CIE, 25 marks shall be assigned for internal tests. The first test shall be conducted after completing two modules of the syllabus and the second one after completing the remaining three modules.
(iii) The remaining 25 marks shall be assigned for Continuous Course Assessment (CCA), conducted as per the rubrics listed in the assessment section of the respective syllabus.
(iv) A student shall obtain a minimum of 40% marks or 20 out of 50 marks allotted to CIE to become eligible to appear for the SEE.

Passing requirement in SEE
For a pass in the Semester End Examination (SEE), a student shall secure a minimum of 35 marks out of 100.
For the declaration of a pass grade, the sum of the Continuous Internal Evaluation (CIE) marks (out of 50) marks and the SEE marks scaled down to 50 shall be greater than or equal to 40 marks.
If the total (CIE + SEE) is less than 40 marks, the student shall be awarded the grade 'F' (Fail).

INTRODUCTION TO SPACE TECHNOLOGY			
Course Code	1MAS103	Scheme	2026
Type of Course	PCC	Semester	I
Teaching Hours/Week (L:T:P)	3 : 0 : 0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42 : 0 : 0 : 48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

CO1: Apply the principles of rocket propulsion and trajectory analysis to estimate vehicle performance, determine staging requirements and feasibility of launch vehicles

CO2: Apply knowledge of re-entry dynamics to evaluate suitability of re-entry trajectories for different missions

CO3: Apply orbital mechanics principles for determining orbital parameters required for orbit transfer and manoeuvre strategies

CO4: Analyse the attitude dynamics and control mechanisms of spinning and non-spinning spacecraft for stability assessment

CO5: Apply space mission concepts for planning mission phases and ground support activities of different space missions

Module-1

Fundamentals of Rocket Propulsion: Space Mission-Types-Space Environment-Launch Vehicle Selection. Introduction to rocket propulsion-fundamentals of solid propellant rockets- Fundamentals of liquid propellant rockets-Rocket equation. Two-dimensional trajectories of rockets and missiles-multi-stage rockets-Vehicle Sizing-Two stage Multi-stage Rockets-Trade-off Ratios-Single Stage to Orbit-Sounding Rocket-Aerospace Plane-Gravity Turn Trajectories-Impact point calculation-injection conditions Flight dispersions.

Number of Hours: 10

Module-2

Atmospheric Reentry: Introduction-Steep Ballistic Reentry-Ballistic Orbital Reentry-Skip Reentry-"Double-Dip" Reentry - Aero-braking - Lifting Body Reentry.

Number of Hours: 08

Module-3

Fundamentals of Orbit Mechanics, Orbit Maneuvers: Two-body motion-Circular, elliptic, hyperbolic, and parabolic orbits-Basic Orbital Elements-Ground trace In-Plane Orbit changes-Hohmann Transfer-Bielliptical Transfer-Plane Changes - Combined Maneuvers - Propulsion for Maneuvers

Number of Hours: 08

Module-4

Satellite Attitude Dynamics: Torque free Axi-symmetric rigid body-Attitude Control for Spining Spacecraft - Attitude Control for Nonspinning Spacecraft - The Yo-Yo Mechanism - Gravity - Gradient Satellite-Dual Spin Spacecraft- Attitude Determination.

Number of Hours: 08

Module-5

Space Mission Operations: Supporting Ground Systems Architecture and Team interfaces - Mission phases and Core operations - Team Responsibilities - Mission Diversity - Standard Operations Practices.

Number of Hours: 08

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. "Spaceflight Dynamics", W.E. Wiesel, McGraw Hill, 1997.

2. ”Rocket Propulsion and Space flight dynamics", Cornelisse, Schoyer HFR and Wakker KF, Pitman, 1984.

Reference books / Manuals:

1. "Fundamentals of Space Systems", Vincet L. Pisacane, Oxford University Press, 2005.
2. "Understanding Space: An Introduction to Astronautics", J.Sellers, McGraw Hill, 2000.
3. "Introduction to Space Flight", Francis J Hale, Prentice-Hall, 1994.
4. "Spacecraft Mission Design", Charies D. Brown, AIAA education Series, 1998.
5. "Elements of Space Technology for aerospace Engineers", Meyer Rudolph X, Academic Press, 1999.

Web links and Video Lectures (e-Resources):

1. https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine/tutorial/media/III.4.2.1_Rockets_and_Launch_Vehicles.pdf
2. https://www.youtube.com/watch?v=N6dzEELLoeg.
3. https://www.youtube.com/watch?v=nJ_f1h49jfM&list=PLOIRBaljOV8hBJS4m6brpmUrncqkyXBjB
4. https://www.youtube.com/watch?v=Q_P3S7t5lS4&list=PLbRMhDVUMngfOt5ATLzSIlqia0-IZbDI0
5. https://www.youtube.com/watch?v=N8nRpf79Uy4

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Problem (Mission)-based learning to allow students to work individually or in teams as mission analysts
2. Discuss cases involving space mission failure analysis
3. Encourage students to develop computational models of spacecraft trajectories and attitude dynamics

Assessment Structure:

The assessment in each course is divided equally between Continuous Internal Evaluation (CIE) and the Semester End Examination (SEE), with each carrying 50% weightage.

- To qualify and become eligible to appear for SEE, in the **CIE**, a student must score at least **40% of 50 marks**, i.e., **20 marks**.
- To pass the **SEE**, a student must score at least **35% of 50 marks**, i.e., **18 marks**.
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Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of **two Internal Assessment Tests(IA)** shall be conducted, carrying a total of **25 marks**.

In addition, **Continuous Comprehensive Assessment (CCA)** shall be conducted for a total of **25 marks**.

It is recommended to include **a maximum of two learning activities** as part of the CCA to foster the **holistic development of students**. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Simulation Exercises / Research Paper Reviews / Case Studies on Space Mission Operations / Mini-Design Projects / Functional Model Development	25

Continuous Internal Evaluation (CIE)

(i)The CIE marks shall be decided based on internal tests and other outcome-based activities. The continuous internal evaluation shall be carried out by the teacher handling the course.

(ii)Out of 50 marks earmarked for CIE, 25 marks shall be assigned for internal tests. The first test shall be conducted after completing two modules of the syllabus and the second one after completing the remaining three modules.
(iii) The remaining 25 marks shall be assigned for Continuous Course Assessment (CCA), conducted as per the rubrics listed in the assessment section of the respective syllabus.
(iv) A student shall obtain a minimum of 40% marks or 20 out of 50 marks allotted to CIE to become eligible to appear for the SEE.

Passing requirement in SEE

For a pass in the Semester End Examination (SEE), a student shall secure a minimum of 35 marks out of 100.
For the declaration of a pass grade, the sum of the Continuous Internal Evaluation (CIE) marks (out of 50) marks and the SEE marks scaled down to 50 shall be greater than or equal to 40 marks.
If the total (CIE + SEE) is less than 40 marks, the student shall be awarded the grade ‘F’ (Fail).

MECHANICS AND THERMODYNAMICS OF PROPULSION			
Course Code	1MAS104A	Scheme	2026
Type of course	IPCC	Semester	I
Teaching Hours/Week (L:T:P)	3: 0 : 2	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	120 (42 : 00 : 28 : 50)	SEE Marks	50
Credits	04	Total Marks	100
Type of Examination (IPCC):	Theory- CIE +SEE, and Lab- CIE only.	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

CO1: Explain the operating principles of air-breathing and rocket propulsion systems along with the governing thermodynamic and fluid flow principles.

CO2: Analyse compressible flow phenomena, combustion processes, boundary layer behaviour, and heat transfer in propulsion applications.

CO3: Evaluate the performance of aircraft propulsion systems including turbojet, turbofan, ramjet, and gas turbine engine components.

CO4: Analyse the design and performance characteristics of compressors, turbines, combustors, and nozzles used in propulsion systems.

CO5: Apply propulsion principles to analyse rocket engines, propellants, combustion chambers, turbomachinery, and advanced electrical propulsion systems.

Module-1

Fundamentals of Jet Propulsion and Fluid Flow : Introduction to Jet Propulsion, Historical development, Classification of propulsion systems, Newton's laws applied to propulsion, Fluid momentum and reaction force, Propellers, Rockets, Turbojets, Turbofans and Ramjets, Fundamental equations of fluid flow, Conservation of mass, momentum and energy, Thermodynamics of gases, Equation of state, Equilibrium combustion thermodynamics, Chemical reactions, Stoichiometric combustion, Combustion products and thermodynamic properties.

Number of Hours: 08

Module-2

Compressible Flow and Boundary Layer Theory: One-dimensional flow of a perfect gas, Governing equations, Isentropic flow relations, Non-isentropic flow, Constant-area flow with heat transfer (Rayleigh flow), Constant-area flow with friction (Fanno flow), Normal shock waves, Boundary layer theory, Boundary layer equations, Laminar boundary layer, Turbulent boundary layer, Boundary layer heat transfer, Engineering applications in propulsion systems.

Number of Hours: 08

Module-3

Air-Breathing Propulsion Systems: Thermodynamics of aircraft jet engines, Engine performance parameters, Thrust equation, Specific thrust, Specific fuel consumption, Thermal, propulsive and overall efficiencies, Ramjet engine, Turbojet engine, Turbofan engine, Turboprop and Turboshaft engines, Engine performance characteristics, Engine-aircraft matching, Aerothermodynamics of inlets, Subsonic and supersonic inlets, Gas turbine combustors, Afterburners, Ramjet combustors, Supersonic combustion, Exhaust nozzles.

Number of Hours: 09

Module-4

Gas Turbine Components: Axial compressors, Angular momentum principle, Work and compression, Single-stage and multistage compressor performance, Compressor characteristics, Compressor efficiency, Degree of reaction, Radial equilibrium, Axial compressor design, Transonic fan stage, Axial turbines, Turbine stage, Stage efficiency, Rotor blade and disc stresses, Blade cooling techniques, Turbine performance, Turbine-compressor matching, Turbine stage design, Centrifugal compressors, Stage dynamics, Inducer, Impeller, Diffuser, Performance characteristics, Stage design.

Number of Hours: 08

Module-5

Rocket Propulsion Systems: Rocket vehicle performance, Static performance, Vehicle acceleration, Chemical rockets, Electrical rocket propulsion, Space missions, Chemical rocket thrust chambers, Rocket nozzles, Rocket heat transfer, Liquid-propellant rocket performance, Liquid and solid propellants, Equilibrium and non-equilibrium expansion, Liquid and solid propellant combustion chambers, Combustion instabilities, Turbomachinery for liquid-propellant rockets, Centrifugal pumps, Inducers, Axial pumps, Rocket turbines, Electrostatic propulsion, Ion thrusters, Arc jets, Pulsed jets

Number of Hours: 09

PRACTICAL COMPONENTS OF IPCC

List of experiments

1. Numerical Investigation of Normal Shock Wave in a Supersonic Nozzle (Work Bench FLUENT)
2. CFD Analysis and Performance Prediction of an Axial Turbine Stage (Modelling through BLADE GEN, Meshing through TURBO-GRID, and Analysis through CFX)
3. Preliminary Design and Performance Analysis of an Axial Compressor Stage using ANSYS Vista CCD
4. Preliminary Design of a Centrifugal Compressor using ANSYS Vista CCD
5. CFD Analysis of Rotor–Stator Interaction in an Axial Turbomachine (Modelling through BLADE GEN, Meshing through TURBO-GRID, and Analysis through CFX)
6. One-Way FSI Analysis of an Axial Turbine Blade Under Aerodynamic Loading (Modelling through BLADE GEN, Meshing through TURBO-GRID, and Analysis through CFX Link to Static Structure for Structural Analysis)
7. One-Way FSI Analysis of a Gas Turbine Rotor Blade Using ANSYS CFX and Mechanical (Modelling through BLADE GEN, Meshing through TURBO-GRID, and Analysis through CFX Link to Static Structure for Structural Analysis)
8. CFD Analysis of a Multistage Axial Compressor (Modelling through BLADE GEN, Meshing through TURBO-GRID, and Analysis through CFX)
9. CFD Analysis of Shock–Boundary Layer Interaction in a Rocket Nozzle (FLUENT)
10. CFD Analysis of Regenerative Cooling in a Liquid Rocket Combustion Chamber, Conjugate heat transfer, wall temperature, heat flux (FLUENT)

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. Philip G. Hill and Carl R. Peterson, Mechanics and Thermodynamics of Propulsion, 2nd Edition, Pearson Education Inc., 1992.

<u>Reference books / Manuals:</u>

1. Bruce R. Munson, Donald F. Young, Fundamentals of Fluid Mechanics, 9th Edition, John Wiley & Sons, 2024.
2. Richard E. Sonntag, Claus Borgnakke and Gordon J. Van Wylen, Fundamentals of Thermodynamics, 9th Edition, John Wiley & Sons, 2018.
3. Yunus A. Çengel and Michael A. Boles, Thermodynamics: An Engineering Approach, 10th Edition, McGraw-Hill Education, 2023.

Web links and Video Lectures (e-Resources):

1. https://onlinecourses.nptel.ac.in/e-learning/preview/noc26_me192
2. https://onlinecourses.nptel.ac.in/e-learning/preview/noc21_ae10
3. https://onlinecourses.nptel.ac.in/e-learning/preview/noc26_me183

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

(i)Theory component

The CIE marks of 25 shall be earmarked for two tests.

The first test shall be conducted after completing two modules of the syllabus and the second one after completing the rest three modules.

Each test shall be conducted for 25 marks. The average of the two tests scaled down to 25 marks shall constitute the test marks for a maximum of 25 marks.

(ii) Laboratory component

Out of 25 marks, 15 marks shall be assigned for assessment of regular laboratory classwork as per the rubrics listed in Table - ICs/IPCCs1.

The remaining 10 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table – ICs/IPCCs 1.

To qualify and become eligible to appear for the SEE of the IC/IPCC, a student shall secure at least 13 marks out of 25 in the CIE theory component, and at least 12 marks in the CIE Practical component.

Table – ICs/IPCCs 1 Distribution of marks corresponding to laboratory component

Component	Description	Marks
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	5 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	10 marks
	Subtotal	**15**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	5 marks
	Subtotal	**10**
	Total	**25**

MATERIALS AND MANUFACTURING FOR HIGH TEMPERATURE APPLICATIONS			
Course Code	1MAS104B	Scheme	2026
Type of course	IPCC	Semester	I
Teaching Hours/Week (L:T:P)	3: 0 : 2	CIE Marks	50
Total Hours of Pedagogy L: T:P:SL:TW	120 (42 : 00 : 28 : 50)	SEE Marks	50
Credits	04	Total Marks	100
Type of Examination (IPCC):	Theory- CIE +SEE, and Lab- CIE only.	Exam Hours	03

Course outcome (Course Skill Set)
This course will enable students to
CO1: Analyse the degradation mechanisms of materials in extreme thermal environments and evaluate the suitability of the materials for the applications.
CO2: Evaluate and select high-temperature non-ferrous alloys, composites and engineering materials for specific aerospace applications.
CO3: Assess the advanced manufacturing techniques required to process difficult-to-machine, high-temperature materials for realizing aerospace components.
CO4: Analyse the processing methods, toughening mechanisms, and high-temperature performance of carbon-carbon and ceramic matrix composites for aerospace and hypersonic applications.
CO5: Apply the concepts of thermal and environmental barrier coatings to select appropriate coating / deposition techniques for improving the performance of high-temperature aerospace components.

Module-1

High-Temperature Degradation Mechanisms: Operating environments in gas turbines, rockets, and hypersonic vehicles.

Mechanics of elevated-temperature failure: Creep and stress rupture (Nabarro-Herring and Coble creep mechanisms).

Thermal fatigue, thermomechanical fatigue (TMF), and hot corrosion. Oxidation kinetics and the formation of protective oxide scales.

Number of Hours: 09

Module-2

Non-ferrous materials in aircraft construction:

Aluminium and its alloys: Types and identification. Properties -Castings-Heat treatment processes - Surface treatments.

Magnesium and its alloys: Cast and Wrought alloys-Aircraft application, features specification, fabrication problems, Special treatments.

Titanium and its alloys: Applications, machining, forming, welding and heat treatment, Copper Alloys.

Wood and fabric in aircraft construction and specifications- Glues Use of glass, plastics & rubber in aircraft, Transparent materials for aircraft canopies, Introduction to glass & carbon composite.

Number of Hours: 09

Module-3

Advanced Manufacturing of High-Temperature Metals:

Limitations of conventional machining for superalloys.

Advanced casting techniques: Vacuum Induction Melting (VIM), Directional Solidification (DS), and Single-Crystal (SX) casting for turbine blades. Powder metallurgy for turbine disks (Hot Isostatic Pressing - HIP). Additive Manufacturing (Selective Laser Melting, Electron Beam Melting) of aerospace superalloys.

Number of Hours: 08

Module-4

Ceramic Matrix Composites (CMCs) and Carbon-Carbon: Shift from metals to structural ceramics. Carbon-Carbon (C/C) composites: Processing, properties, and applications in rocket nozzles and hypersonic leading edges. Ceramic Matrix Composites (SiC/SiC, C/SiC): Toughening mechanisms, chemical vapor infiltration (CVI), and polymer infiltration and pyrolysis (PIP).

Number of Hours: 08

Module-5

Thermal & Environmental Barrier Coatings (TBCs & EBCs): The necessity of coatings to operate engines above the melting point of the base metal. Architecture of Thermal Barrier Coatings: Bond coats, Thermally Grown Oxide (TGO), and ceramic topcoats (Yttria-Stabilized Zirconia). Application methods: Air Plasma Spray (APS) and Electron Beam Physical Vapor Deposition (EB-PVD). Introduction to Environmental Barrier Coatings (EBCs) for CMCs.

Number of Hours: 08

PRACTICAL COMPONENTS OF IPCC

PART – A: FIXED SET OF EXPERIMENTS

1. Evaluate the temperature distribution and transient thermal response of a jet engine turbine blade and a rocket nozzle under high-temperature operating conditions using FEM simulation.
2. Perform a coupled thermal-structural analysis on a Nickel-based super alloy component to identify stress concentrations, thermal expansion deformations, and simulated creep failure zones over time.
3. Perform solutionising and artificial aging heat treatments on aluminium/titanium alloys using a standard furnace. Evaluate the hardness changes using a Vickers tester and observe grain boundaries under an optical microscope.
4. Investigate the nonlinear thermal expansion and stress distribution of a Ceramic Matrix Composite (CMC) or Carbon-Carbon panel subjected to severe thermal gradients (mimicking hypersonic leading-edge conditions).
5. Analyse the effect of heat treatment on the microstructural changes of Aluminium / titanium alloys.
6. Model coated and uncoated turbine blade materials using finite element software to evaluate the effect of thermal barrier coatings on temperature distribution, thermal stresses, and coating effectiveness under cyclic thermal loading.
7. Select a material for a specified aerospace application (e.g., aircraft wing skin, turbine blade, rocket nozzle, or hypersonic leading edge). Compare at least three candidate materials based on mechanical, thermal, corrosion, weight, manufacturability, and cost considerations using material selection charts or software.
8. Develop a numerical model of a turbine blade, combustor liner, or rocket nozzle to investigate the influence of material type, geometry, or cooling conditions on thermal stresses, and structural integrity
9. Design a "Functionally Graded" bond coat. Use ANSYS to simulate two metal-to-ceramic transition ratios, identify an interface gradient profile that effectively minimizes peak thermal stress concentrations and shear energy at the bond line.
10. Compare the mechanical and microstructural characteristics of aerospace components manufactured using conventional casting, powder metallurgy (HIP), and additive manufacturing (SLM/EBM) through simulation and/or metallographic analysis.

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1 *Introduction to Aerospace Materials*, Adrian P. Mouritz, Woodhead Publishing / AIAA, 1st Edition, 2012.

2 *The Superalloys: Fundamentals and Applications*, Roger C. Reed, Cambridge University Press, 1st Edition, 2006.

3 *Ceramic Matrix Composites: Materials, Modeling and Applications*, Narottam P. Bansal and Jacques Lamon, Wiley, 1st Edition, 2015.

4 *Introduction to the High Temperature Oxidation of Metals*, Neil Birks, Gerald H. Meier, and Frederick S. Pettit, Cambridge University Press, 2nd Edition, 2006

Reference books / Manuals:

1 *Engineering Analysis with ANSYS Workbench*, Saeed Moaveni, Pearson, 3rd Edition, 2015.

2 *Mechanical Behavior of Materials*, Marc André Meyers and Krishan Kumar Chawla, Cambridge University Press, 2nd Edition, 2009.
3 *Physical Metallurgy Principles*, Robert E. Reed-Hill and Reza Abbaschian, Cengage Learning, 4th Edition, 2009.
4 *Failure Analysis of Engineering Materials*, Charles R. Brooks and Ashok Choudhury, McGraw-Hill, 1st Edition, 2002

Web links and Video Lectures (e-Resources):

1 "Advanced Materials and Processes", Prof. Jayanta Das, IIT Kharagpur [Online NPTEL Core Portal]. Available at: https://nptel.ac.in/courses/113105081
2 "Theory and Practice of Non-Destructive Testing", Prof. Ranjit Bauri, IIT Madras [Online NPTEL Core Portal]. Available at: https://nptel.ac.in/courses/113106070
3 "Technology of Surface Coating", Prof. A.K. Chattopadhyay, IIT Kharagpur [Online NPTEL Engineering Portal]. Available at: https://nptel.ac.in/courses/112105053
4 "Mechanics Of Fiber Reinforced Polymer Composite Structures", Prof. Debabrata Chakraborty, IIT Guwahati [Online NPTEL Aerospace Portal]. Available at: https://nptel.ac.in/courses/112103308

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

(i)Theory component

The CIE marks of 25 shall be earmarked for two tests.

The first test shall be conducted after completing two modules of the syllabus and the second one after completing the rest three modules.

Each test shall be conducted for 25 marks. The average of the two tests scaled down to 25 marks shall constitute the test marks for a maximum of 25 marks.

(ii) Laboratory component

Out of 25 marks, 15 marks shall be assigned for assessment of regular laboratory classwork as per the rubrics listed in Table - ICs/IPCCs1.

The remaining 10 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table – ICs/IPCCs 1.

To qualify and become eligible to appear for the SEE of the IC/IPCC, a student shall secure at least 13 marks out of 25 in the CIE theory component, and at least 12 marks in the CIE Practical component.

Table – ICs/IPCCs 1 Distribution of marks corresponding to laboratory component

Component	Description	Marks
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	5 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	10 marks
	Subtotal	**15**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks

Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	5 marks
	Subtotal	**10**
	Total	**25**

HEAT AND MASS TRANSFER IN PROPULSION SYSTEMS			
Course Code	1MAS104C	Scheme	2026
Type of course	IPCC	Semester	I
Teaching Hours/Week (L: T:P)	3: 0 : 2	CIE Marks	50
Total Hours of Pedagogy L: T:P:SL:TW	120 (42 : 00 : 28 : 50)	SEE Marks	50
Credits	04	Total Marks	100
Type of Examination (IPCC):	Theory- CIE +SEE, and Lab- CIE only.	Exam Hours	3

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Apply fundamentals of heat transfer in aero engines.
CO2: Distinguish turbine film cooling, jet impingement cooling.
CO3: Apply cooling and their techniques (such as Rib turbulated cooling, pin fin cooling and temperature measurement techniques)
CO4: Analyse pin fin cooling and engine temperature monitoring techniques for aerospace applications.
CO5: Apply mass transfer principles and advanced cooling techniques in thermal systems.

Module-1

Fundamentals: Conduction, Convection, Radiation, Concept of boundary layers - velocity / thermal. Need for turbine blade cooling, turbine cooling technology, turbine heat transfer and cooling issues.

Turbine-Stage Heat Transfer: Introduction, Real engine turbine stage, simulated turbine stage, time-resolved heat-transfer measurement on a rotor blade. Cascade blade heat transfer. Airfoil end wall heat transfer. Turbine rotor blade tip heat transfer. Leading edge region heat transfer. Flat surface heat transfer.

Number of Hours: 09

Module-2

Turbine Film Cooling: Fundamentals of film cooling. Film cooling on rotating turbine blades. Film cooling on cascade vane simulations, Film cooling on cascade blade simulations, Film cooling on airfoil end walls. Turbine blade tip film cooling. Leading edge region film cooling. Flat surface film cooling. Film cooling effectiveness. Discharge coefficient of turbine cooling holes. Film cooling effect on aerodynamic losses.

Jet Impingement Cooling: Heat transfer enhancement by a single jet, Impingement heat transfer in the mid chord region by jet array, Impingement cooling of leading edge.

Number of Hours:09

Module-3

Rib Turbulated Cooling: Effect of rib layouts and flow parameters on ribbed channel heat transfer, heat transfer coefficient and friction factor correlation, high performance ribs, effect of surface heating conditions, nonrectangular cross section channels, effect of high blockage ratio ribs, effect of rib profile effect of number of ribbed walls, effect of a 180^0 sharp turn, detailed heat transfer coefficient measurements in ribbed channel, effect of film cooling hole on ribbed channel heat transfer.

Number of Hours:08

Module-4

Pin Fin Cooling: Flow and heat transfer analysis with single pin, pin array and correlation, effect of pin shape on heat transfer, effect of non-uniform array and flow convergence, effect of skewed pin array, partial pin arrangements, effect of turning flow, pin fin cooling with ejection, effect of missing pin on heat transfer coefficient.
Temperature Measurement Techniques: Infrared thermography, Thermocouples, Heat flux gauges, Liquid crystal thermography, Temperature sensitive paints. Engine Temperature and Health Monitoring- Thermal barrier coatings, Engine temperature monitoring, Engine safety and health monitoring.

Number of Hours: 08

Module-5

Mass Transfer: Basic Concepts – Modes of mass transfer, Concentrations, Velocities and Fluxes, Diffusion Mass Transfer – Fick's Law of Diffusion; General mass diffusion equation in Stationary Media, Steady state diffusion through a plain membrane, Mass transfer coefficient, Convective mass transfer, Convective Mass Transfer Correlations. Numerical.

Advanced cooling techniques: Impingement on ribbed walls, impingement on pinned and dimpled walls, combined effect of ribbed wall with grooves,

Number of Hours:08

PRACTICAL COMPONENTS OF IPCC

List of experiments

1. Cascade testing of a model of turbine blade row and study of wake survey.
2. Estimation of propeller performance.
3. Forced Convective heat transfer on a flat surface
4. Measurement of Burning Velocity of a Premixed Flame
5. Determination of heat of combustion of aviation fuels
6. Measurement of static overall pressure rise & rotor static pressure rise & fan overall efficiency through axial flow fan unit.
7. Effect of inlet flow distortion on measurement of static overall pressure rise & rotor static pressure rise & fan overall efficiency through axial flow fan unit.
8. Study of Jet Engine characteristics (thrust, static and total pressures, temperatures, exhaust velocity & fuel consumption).
9. Free and wall jet experimental studies.
10. Measurement of Nozzle flow setup.

Textbooks:

1. Je Chin Han, Sandip Dutta & Srinath V Ekkad, "Gas Turbine Heat Transfer and Cooling", Taylor and Francis New York publication,2nd edition, 2000
2. JP Holman, "Heat Transfer", McGraw Hill Education publisher, 10th edition,2009
3. P.K. Nag, "Heat and Mass Transfer", Tata Mc Graw Hill publisher, 3rd Edition, 2011

Reference books / Manuals:

1. Anthony Giampaolo, "Gas Turbine Handbook", Fairmont Press,1997
2. E Rathakrishnan, "Elements of Heat Transfer", Taylor and Francis, CRC Press, 2012.
3. R.K.Rajput," Heat and Mass Transfer", S. Chand, 5t^{h} edition, 2014.

Web links and Video Lectures (e-Resources):

1. nptel.ac.in/courses/112108149
2. nptel.ac.in/courses/112101097
3. nptel.ac.in/courses/112/106/112106222/

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

(i)Theory component

The CIE marks of 25 shall be earmarked for two tests.

The first test shall be conducted after completing two modules of the syllabus and the second one after completing the rest three modules.

Each test shall be conducted for 25 marks. The average of the two tests scaled down to 25 marks shall constitute the test marks for a maximum of 25 marks.

(ii) Laboratory component

Out of 25 marks, 15 marks shall be assigned for assessment of regular laboratory classwork as per the rubrics listed in Table - ICs/IPCCs1.

The remaining 10 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table – ICs/IPCCs 1.

To qualify and become eligible to appear for the SEE of the IC/IPCC, a student shall secure at least 13 marks out of 25 in the CIE theory component, and at least 12 marks in the CIE Practical component.

Table – ICs/IPCCs 1 Distribution of marks corresponding to laboratory component		
Component	**Description**	**Marks**
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	5 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	10 marks
	Subtotal	**15**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	5 marks
	Subtotal	**10**
	Total	**25**

AIRCRAFT ENGINE PERFORMANCE AND MATCHING			
Course Code	1MAS104D	Scheme	2026
Type of course	IPCC	Semester	I
Teaching Hours/Week (L: T:P)	3: 0 : 2	CIE Marks	50
Total Hours of Pedagogy L: T:P:SL:TW	120 (42: 00: 28 :50)	SEE Marks	50
Credits	04	Total Marks	100
Type of Examination (IPCC):	Theory- CIE +SEE, and Lab- CIE only.	Exam Hours	3

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

CO1: Apply the principles of thermodynamic cycles to evaluate the performance of gas turbines

CO2: Assess the performance characteristics of gas turbine components and integrate them to predict the overall performance

CO3: Understand and analyse the off-design and transient performance of aero engines under varying operating conditions

CO4: Apply the principles of aircraft performance to determine steady-level flight characteristics

CO5: Analyse aircraft performance during different stages of flight under different flight regimes.

Module-1

Introduction to Aero Engine Performance Analysis: Fundamentals of Aero Engine Performance: Overview of thermodynamic cycles, efficiency, and performance metrics. Gas Turbine Engines: Analysis of various gas turbine cycles (Brayton cycle, turbojet, turbofan, etc.). Performance Parameters: Specific thrust, specific fuel consumption (SFC), thermal efficiency, and propulsive efficiency.

Number of Hours:08

Module-2

Component-Level Performance Analysis: Compressor and Turbine Performance: Characteristics, efficiency, and matching of components. Combustion Chamber Analysis: Heat addition, pressure loss, and efficiency Engine Performance Modelling: Integration of component performance to predict overall engine performance.

Number of Hours: 08

Module-3

Advanced Topics in Aero Engine Performance: Off-Design Performance: Analysis of engine performance at different operating conditions (altitude, speed, etc.). Transient Performance: Engine behaviour during start-up, acceleration, and deceleration. Case Studies: Performance analysis of modern aero engines, including afterburning turbojets and high-bypass turbofans

Number of Hours: 09

Module-4

Aircraft Performance: Fundamentals and Steady-Level Flight: Basics of Aircraft Performance: Forces acting on an aircraft, equations of motion, and energy methods. Steady-Level Flight: Lift-to-drag ratio, minimum drag, and maximum range and endurance. Power Required and Available: Thrust, power curves, and flight envelope.

Number of Hours: 09

Module-5

Aircraft Performance: Manoeuvring and High-Speed Flight: Climb Performance: Rate of climb, ceiling, and climb optimization. Take-off and Landing Performance: Factors affecting take-off and landing distances, performance under different conditions. High-Speed Flight: Performance analysis in transonic, supersonic, and hypersonic regimes.

Number of Hours: 08

PRACTICAL COMPONENTS OF IPCC

List of experiments

1. Determine specific thrust, thrust-specific fuel consumption (TSFC), thermal efficiency, and propulsive efficiency at different flight Mach numbers using a simplified cycle analysis.
2. Plot compressor pressure ratio versus efficiency and analyse the effect of operating conditions on compressor performance.
3. Calculate the turbine work required to drive the compressor at different pressure ratios and turbine inlet temperatures to study component matching.
4. Analyse the effect of nozzle pressure ratio on exit velocity, thrust, and nozzle efficiency for convergent and convergent-divergent nozzles.
5. Investigate the influence of compressor pressure ratio on specific thrust, TSFC, and overall engine efficiency.
6. Evaluate the impact of turbine inlet temperature on engine thrust, fuel consumption, and thermal efficiency.
7. Match compressor and turbine operating points using simplified characteristic maps to identify stable operating conditions.
8. Compare the performance of turbojet and turbofan engines in terms of thrust, TSFC, and propulsive efficiency under identical flight conditions.
9. Determine the variation of thrust, TSFC, and engine efficiency with altitude using standard atmospheric conditions.
10. Evaluate engine performance during take-off, climb, cruise, and descent to understand the influence of operating conditions on engine matching and performance.

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. "Mechanics and Thermodynamics of Propulsion" by Philip G. Hill and Carl R. Peterson, Pearson, ISBN: 9780201146592.
2. "Aircraft Performance & Design" by John D. Anderson Jr., McGraw-Hill Education, ISBN: 978-0070019715.

Reference books / Manuals:

1. "Jet Propulsion: A Simple Guide to the Aerodynamics and Thermodynamic Design and Performance of Jet Engines" by Nicholas Cumpsty, Cambridge University Press.
2. "Gas Turbine Theory" by H.I.H. Saravanamuttoo, G.F.C. Rogers, and H. Cohen, Pearson.
3. "Flight Performance of Fixed and Rotary Wing Aircraft" by Antonio Filippone, Butterworth-Heinemann.

Web links and Video Lectures (e-Resources):

1. https://archive.nptel.ac.in/courses/101/104/101104061/
2. https://www.digimat.in/nptel/courses/video/101101002/L01.html

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

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Continuous Internal Evaluation:

(i)Theory component

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	Subtotal	**15**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	5 marks
	Subtotal	**10**
	Total	**25**

MISSILES AND LAUNCH VEHICLES			
Course Code	1MAS105A	Scheme	2026
Type of Course	PEC-I	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42:00:00:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3 Hrs

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Classify missile and launch vehicle systems based on their mission requirements, propulsion systems, and staging concepts
CO2: Examine the aerodynamic characteristics, stability, flight mechanics, and trajectory behaviour of ballistic and cruise missiles
CO3: Differentiate missile guidance, navigation, and control techniques to assess their suitability for various interception and mission scenarios.
CO4: Determine launch vehicle design parameters and other aspects for specified mission requirements
CO5: Evaluate advanced missile and launch vehicle technologies for modern aerospace applications.

Module-1

Introduction: Space launch vehicles and military missiles, function, classification, role and applications, mission requirements, mission profiles, thrust profiles, propulsion systems, payloads, staging concepts, control and guidance requirements, performance measures, design philosophy, construction and operation, similarities and differences between missiles and launch vehicles. Overview of Indian and international missile and launch vehicle programs. Case studies of PSLV, GSLV, LVM3, Falcon 9, Ariane 6, Agni series, Prithvi, BrahMos and Akash missile systems.

Number of Hours:08

Module-2

Missile Aerodynamics and Flight Mechanics: Aerodynamic forces and moments, aerodynamic coefficients, center of gravity and center of pressure, static and dynamic stability, missile configurations and aerodynamic layouts, slender body theory, fin and canard aerodynamics, transonic, supersonic and hypersonic aerodynamics, aerodynamic heating, shock waves, drag estimation, maneuvering flight, atmospheric disturbances, missile performance analysis, trajectory calculations, ballistic and cruise missile flight mechanics, 3-DOF and 6-DOF equations of motion, aerodynamic design considerations for high-speed missiles.

Number of Hours:08

Module-3

Missile Guidance, Navigation and Control: Fundamentals of guidance, navigation and control (GNC), missile guidance methods—command guidance, beam-rider guidance, inertial guidance, homing guidance and satellite-aided guidance. Navigation systems, inertial measurement units (IMU), GPS/INS integration, target tracking and interception. Missile control systems, longitudinal and lateral-directional dynamics, autopilot design, control surface actuation systems, thrust vector control (TVC), reaction jet control, proportional navigation, terminal guidance, modern control methods, stability augmentation systems, guidance and control system integration, simulation of missile engagement scenarios.

Number of Hours:08

Module-4

Launch Vehicle Design Concepts and Space Flight Dynamics: Launch vehicle mission analysis, payload-orbit requirements, orbital mechanics fundamentals, velocity requirements and rocket equation, mass fraction and structural efficiency, launch vehicle sizing and configuration selection, stage optimization, serial and parallel staging, booster design, ascent trajectory design, gravity turn maneuver, aerodynamic loads during ascent, Max-Q considerations, launch vehicle guidance and control, attitude control systems, reaction control systems, stage separation dynamics, payload deployment mechanisms, launch operations and mission planning.

Number of Hours:09

Module-5

Advanced Missile and Launch Vehicle Systems: Multidisciplinary design optimization (MDO), propulsion-airframe integration, structural design of missiles and launch vehicles, composite materials and lightweight structures, thermal protection systems, re-entry vehicle aerodynamics and heating, hypersonic missile systems, cruise missile technologies, reusable launch vehicles, space transportation systems, reliability and safety analysis, fault-tolerant systems, flight termination systems, system integration and testing, current trends in missile and launch vehicle technology, emerging concepts in autonomous guidance, reusable boosters and next-generation space access systems.

Number of Hours:09

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. Fleeman, E.L., Tactical Missile Design, AIAA Education Series.
2. Sutton, G.P. and Biblarz, O., Rocket Propulsion Elements, Wiley.
3. Siouris, G.M., Missile Guidance and Control Systems, Springer.
4. Cornelisse, J.W., Schöyer, H.F.R. and Wakker, K.F., Rocket Propulsion and Spaceflight Dynamics.
5. Zipfel, P.H., Modeling and Simulation of Aerospace Vehicle Dynamics.
6. Anderson, J.D., Modern Compressible Flow.
7. Humble, R.W., Larson, W.J. and Wertz, J.R., Space Propulsion Analysis and Design.

<u>Reference books / Manuals:</u>

1. Fortescue, P., Swinerd, G. and Stark, J., Spacecraft Systems Engineering.
2. Wiesel, W.E., Spaceflight Dynamics.
3. Etkin, B. and Reid, L.D., Dynamics of Flight: Stability and Control.
4. Blakelock, J.H., Automatic Control of Aircraft and Missiles.
5. Hill, P. and Peterson, C., Mechanics and Thermodynamics of Propulsion.

Web links and Video Lectures (e-Resources):

1. https://www.isro.gov.in/
2. https://science.nasa.gov/
3. https://ocw.mit.edu/courses/16-512-rocket-propulsion-fall-2005/
4. https://nptel.ac.in/courses/101106082

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Flipped Classroom
2. Problem-Based Learning (PBL)
3. Case-Based Teaching
4. Simulation and Virtual Labs

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester

Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)

Sl. No.	Term Work (TW) Activity	Number of Hours / Semester
1.	Micro Projects / Seminars / Industry Visits	24

SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1.	MOOCs / Tutorials / Online Courses etc.	24

TURBOMACHINERY FUNDAMENTALS FOR PROPULSION			
Course Code	1MAS105B	Scheme	2026
Type of Course	PEC-I	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy L /T/P/SL&TW:	90 (42:0:0:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3 Hrs

Course Objectives

At the end of the course, the student will be able to:

CO1: Understand the fundamental principles of turbomachinery, including fluid–rotor interactions, Euler's equation, velocity triangles, and performance parameters governing energy transfer in propulsion systems.

CO2: Analyse the flow processes, performance characteristics, and operational limitations of centrifugal compressors used in gas turbine engines.

CO3: Evaluate the aerodynamic behaviour and performance of axial flow compressors through cascade analysis, stage loading, degree of reaction, and off-design operating conditions.

CO4: Examine combustion processes and axial flow turbine operation, including work extraction mechanisms, turbine cooling techniques, and loss analysis in propulsion systems.

CO5: Assess the performance of radial inflow turbines and apply engine matching principles for the integrated operation of gas turbine engine components under varying flight conditions.

Module-1

Principles of Turbomachinery

Energy Transfer: Principles of fluid-rotor interaction. **Euler's Equation**: The fundamental equation relating change in angular momentum to work and power in a turbomachine. **Velocity Triangles:** Vector analysis of blade angles, fluid angles, and absolute/relative velocities at rotor inlet and outlet. **Key Metrics:** Degree of Reaction, slip factors, and dimensionless parameters (flow coefficient, head coefficient, and Reynolds number).

Number of Hours: 08

Module-2

Centrifugal Compressors

Components: Flow processes through the impeller, diffuser, and collector. **Performance Metrics:** Pressure ratio, isentropic efficiency, slip factor, and choking limitations. **Phenomena:** Inducer losses, pre-whirl, and surge/stall margins.

Number of Hours: 08

Module-3

Axial Flow Compressors

Cascade Aerodynamics: Lift and drag coefficients, cascade nomenclature, and flow deflection. **Stage Analysis:** 2D and 3D flow analysis, degree of reaction, and stage loading. **Off-Design Performance:** Blade stalling, surging, choking, and performance map characteristics.

Number of Hours: 08

Module-4

Combustion and Axial Flow Turbines

Combustion Fundamentals: Introduction to the combustor environment, total pressure loss, and combustion efficiency. **Turbine Stages:** Work extraction, impulse and reaction blading, and the vortex theory. **Cooling Techniques:** Blade cooling methods (film cooling, transpiration) used to withstand high turbine inlet temperatures. **Losses:** Profile losses, tip clearance losses, and secondary flow losses.

Number of Hours:10

Module-5

Radial Turbines and Engine Matching

Radial Inflow Turbines: Velocity triangles and isentropic efficiency for small gas turbines.

Engine Matching: Techniques for integrating components (compressor, combustor, turbine) to ensure stable and efficient operation at varying throttle settings. **Off-Design Operation:** Behaviour of gas turbines at varying altitudes and flight Mach numbers

Number of Hours: 08

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Textbooks:

1. Saeed Farokhi, *Aircraft Propulsion*, John Wiley & Sons, 3rd Edition, 2021;
2. H. I. H. Saravanamuttoo, G. F. C. Rogers, D. H. Cohen and P. V. Straznicky, *Gas Turbine Theory*, Pearson Education, 7th Edition, 2017;
3. S. L. Dixon and C. A. Hall, *Fluid Mechanics and Thermodynamics of Turbomachinery*, Butterworth-Heinemann (Elsevier), 8th Edition, 2022.

Reference books / Manuals:

1. Nicholas Cumpsty, *Jet Propulsion: A Simple Guide to the Aerodynamic and Thermodynamic Design and Performance of Jet Engines*, Cambridge University Press, 3rd Edition, 2015;
2. Ronald H. Aungier, *Axial Flow Compressors: A Strategy for Aerodynamic Design and Analysis*, ASME Press, 1st Edition, 2003;
3. M. Yahya, *Turbine Aerodynamics: Axial-Flow and Radial-Flow Turbine Design and Analysis*, Tata McGraw-Hill Education (Reprint of Wiley Eastern Edition), Reprint Edition, 2011.

Web links and Video Lectures (e-Resources):

1. https://nptel.ac.in/courses/112104305
2. https://www.youtube.com/watch?v=1n_8muLD3Yo&t=3s
3. https://ocw.mit.edu/courses/16-540-internal-flows-in-turbomachines-spring-2006/download/

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Use of digital twin concepts – employ MATLAB/Simulink or other tools to develop digital models of turbomachinery equipment
2. Use of Inquiry-based learning to explain the influence of various factors behind performance trends
3. Use of case- studies to understand the influence of turbomachinery design on the overall engine performance

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester

Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)

Sl. No.	Term Work (TW) Activity	Number of Hours / Semester
1	Micro Projects / Seminars / Industry Visits	24

SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	MOOCs / Tutorials / Online Courses etc.	24

REACTING FLOWS AND COMBUSTION MODELLING

Course Code	1MAS105C	Scheme	2026
Type of Course	PEC-I	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42:0:0:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

CO1: Derive and interpret conservation equations for chemically reacting, multi-species flows.

CO2: Model laminar premixed and non-premixed flames: compute flame speed, thickness, flamelet structure, and extinction limits.

CO3: Apply RANS, LES, and DNS modelling strategies to turbulent premixed combustion.

CO4: Apply RANS, LES, and DNS modelling strategies to turbulent non-premixed combustion including PDF and CMC approaches.

CO5: Evaluate advanced combustion phenomena: two-phase spray flows, flame-wall interaction, thermoacoustic instabilities, and supersonic combustion.

Module-1

Introduction & Governing Equations: Motivation and scope; Conservation equations for reacting flows: continuity, momentum, energy, species transport; Chemical source terms; Equation of state for mixtures; Transport properties: viscosity, thermal conductivity, diffusion coefficients; Simplified 1-D flow models; Stiff ODE systems in chemistry.

Number of Hours: 08

Module-2

Laminar Premixed & Non-Premixed Flames: Premixed flames: Conservation equations for 1-D laminar flames; Numerical methods for steady and unsteady 1-D flames; Activation energy asymptotics; Calculation of laminar flame speed and flame thickness; Flame stretch and curvature effects; Flame stability and quenching. Non-premixed flames: Mixture fraction formulation; Flame structure for irreversible, infinitely fast chemistry (Burke-Schumann limit); Finite-rate chemistry effects; Flamelet concept; Extinction and re-ignition.

Number of Hours: 09

Module-3

Turbulent Premixed Combustion Modelling: Phenomenological description of turbulent premixed flames; Turbulent flame regimes (Borghi diagram); RANS modelling: Eddy-Break-Up (EBU) model, BML model, G-equation (Level-Set) approach; LES modelling: Thickened Flame Model (TFM), Coherent Flamelet Model; DNS modelling: fundamentals, database generation; Flame surface density approaches.

Number of Hours: 08

Module-4

Turbulent Non-Premixed Combustion Modelling: Phenomenological description of turbulent non-premixed flames; Turbulent non-premixed combustion regimes; RANS modelling: conserved scalar approach, presumed PDF methods (beta-PDF), flamelet libraries; LES modelling: dynamic flamelet approach, Conditional Moment Closure (CMC); DNS modelling; Partially premixed combustion models; NOx and soot formation models.

Number of Hours: 09

Module-5

Advanced Modelling Topics: Combustion in two-phase flows: spray combustion, droplet evaporation models, Lagrangian particle tracking; Boundary conditions for reacting flow solvers; Flame-wall interaction: thermal and chemical effects; Flame-acoustics interaction: combustion instability, thermoacoustic oscillations; Overview of chemical kinetics reduction methods; Introduction to supersonic combustion (scramjet).

Number of Hours: 08

Suggested Learning Resources: (Text Book/ Reference Book/ Manuals):

Text books:

1. T. Poinsot & D. Veynante, Theoretical and Numerical Combustion, 3rd Edition, RT Edwards (2005).
2. N. Peters, Turbulent Combustion, Cambridge University Press (2000).
3. I. Glassman & R. A. Yetter, Combustion, 4th Edition, Academic Press (2008).

Reference books / Manuals:

1. F. A. Williams, Combustion Theory, 2nd Edition, Benjamin/Cummings (1985).
2. C. K. Law, Combustion Physics, Cambridge University Press (2006).
3. R. Turns, An Introduction to Combustion, 3rd Edition, McGraw-Hill (2012).
4. J. Warnatz, U. Maas & R. W. Dibble, Combustion, 4th Edition, Springer (2006).
5. H. K. Versteeg & W. Malalasekera, An Introduction to Computational Fluid Dynamics, 2nd Edition, Pearson (2007).

Web links and Video Lectures (e-Resources):

1. IITK AE658A — Numerical Modeling of Chemically Reacting Flows: https://www.iitk.ac.in/ae658a
2. IITK M.Tech Course Template (Propulsion / ATTS): https://www.iitk.ac.in/aero/data/MTech-course-template-12-03-21.pdf
3. Princeton MAE — Graduate Combustion Courses: https://gradschool.princeton.edu
4. NMSU ME — Graduate Combustion Syllabus: https://catalogs.nmsu.edu/nmsu/engineering/mechanical-aerospace-engineering/
5. CHEMKIN-Pro / OpenFOAM — Industry-standard reacting flow solvers (practicals).

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Use CFD tools to visualize complex combustion phenomena
2. Encourage students to connect mathematical models with real combustion performance
3. Assign research papers and encourage students to summarize them
4. AI-assisted combustion modelling workshop to improve modelling and data analysis skills

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester

Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)

Sl. No.	Term Work (TW) Activity	Number of Hours / Semester
1	Micro Projects / Seminars / Industry Visits	24

SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	MOOCs / Tutorials / Online Courses etc.	24

GAS DYNAMICS			
Course Code	1MAS105D	Scheme	2026
Type of Course	PEC-I	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy L /T/P/SL&TW:	90 (42:00:00:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course Objectives

At the end of the course, the student will be able to:
CO1: Understand the fundamental concepts of compressible flow, thermodynamics, and aerodynamic forces.
CO2: Explain the conservation equations and one-dimensional compressible flow phenomena, including sound waves and normal shocks.
CO3: Analyse oblique shocks, expansion waves, and supersonic flow over aerodynamic bodies.
CO4: Understand quasi-one-dimensional flows, nozzle flows, Rayleigh flow, and Fanno flow.
CO5: Understand unsteady wave motion, shock tubes, and the fundamentals of hypersonic flow

Module-1

Introduction to Compressible Flows: Definition of compressible flow. Flow regimes: Speed and Mach number, Viscous and inviscid flow. Brief review of thermodynamics: Ideal gas, Internal energy and enthalpy, Laws of thermodynamics, Entropy, its calculations and isentropic relations. Aerodynamic forces on a body.

Number of Hours:08

Module-2

Integral Forms of Conservation Equations for Inviscid Flows: Brief review of philosophy and approach. Conservation of mass. Conservation of momentum. Conservation of energy.

Sound and Normal Shock Waves: Introduction to frictionless adiabatic 1-d flows. Speed of sound and Mach number. Stagnation condition. Implication of Mach number revisited. Normal shock relations. Hugoniot equation.

Number of Hours:08

Module-3

Oblique Shock and Expansion Waves: Introduction to oblique shock waves. Oblique shock derivation: The $\theta - \beta - M$ relation, Supersonic flow over wedges and cones. Detached shock wave. Shock reflection from a solid surface. Shock-shock interactions: Interaction of shocks of opposite families, Interaction of shocks of the same family, Mach reflection. Prandtl Meyer expansion waves. Reflection of oblique shock and expansion wave from a free surface. Shock-expansion theory

Number of Hours:10

Module-4

Quasi-One-Dimensional Flow: Introduction to quasi 1-d flow. Area-velocity relation. Convergent-divergent nozzles. Diffusers. Wave reflections from a free boundary.
One-Dimensional Flow with Heat Addition -Rayleigh flow.
One-Dimensional Adiabatic Flow with Friction -Fanno flow.

Number of Hours:08

Module-5

One-Dimensional Unsteady Wave Motion: Introduction to unsteady wave motion in 1-d. Moving and reflected normal shocks. Moving and reflected expansion waves. Shock tube.

Hypersonic Flow: Characteristics of hypersonic flows – high-temperature effects. Newtonian theory. Mach number independence

Number of Hours:08

Textbooks:

1. Anderson, Jr., J. D., Modern Compressible Flow: with Historical Perspective, 4th ed., McGraw Hill, 2021
2. Oosthuizen, P. H. and Carscallen, W. W., Introduction to Compressible Fluid Flow, 2nd edition, CRC Press, 2015

Reference books / Manuals:

1. Rathakrishnan, E., Gas Dynamics, 6th ed., PHI Learning, 2017
2. Yahya, S. M., Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion, 6th edition, New Age International Publishers, 2018
3. Zucker, R. D. and Biblarz, O., Fundamentals of Gas Dynamics, 3rd ed., John Wiley and Sons, 2002.
4. Liepmann, H. W. and Roshko, A., Elements of Gasdynamics, Dover, 2002.

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Use Simulation techniques for visualizing shock waves and explain the effect of different parameters
2. Engage students by discussing case studies from the aerospace industry
3. Use AI tools to explain concepts

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester		
Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)		
Sl. No.	**Term Work (TW) Activity**	**Number of Hours / Semester**
1	Micro Projects / Seminars / Industry Visits	24
SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.		
Sl. No.	**Self-Learning (SL) Activity**	**Number of Hours / Semester**
1	MOOCs / Tutorials / Online Courses etc.	24

ADVANCED AERODYNAMICS FOR AIR-BREATHING ENGINES			
Course Code	1MAS106A	Scheme	2026
Type of Course	PEC-II	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy L /T/P/SL&TW:	90 (42:0:0:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course Objectives

At the end of the course, the student will be able to:

CO1: Develop a comprehensive understanding of compressible flow phenomena and intake aerodynamics.

CO2: Analyse the aerodynamic behaviour and performance characteristics of compressors, combustors, turbines, and exhaust nozzles.

CO3: Apply aerodynamic principles to high-speed propulsion systems.

CO4: Utilize computational and experimental techniques for propulsion system analysis and design.

CO5: Evaluate emerging and sustainable propulsion technologies.

Module-1

Fundamentals of Compressible Flow: Review of thermodynamics and fluid mechanics, Speed of sound and Mach number, Isentropic flow relations, Normal and oblique shock waves, Expansion waves, Area-Mach number relationships. Engine Air Intakes: Subsonic and supersonic inlet design, Diffuser aerodynamics, Boundary layer effects, Shock-boundary layer interaction, Inlet pressure recovery, Distortion and engine operability.

Number of Hours: 08

Module-2

Compressor Aerodynamics: Axial and centrifugal compressors, Velocity triangles, Blade cascade theory, Secondary flows, Stall and surge phenomena, Compressor performance maps. Combustor Aerodynamics: Flow stabilization mechanisms, Swirl generation, Mixing processes, Fuel-air atomization, Pressure loss characteristics, Combustion efficiency considerations.

Number of Hours: 08

Module-3

Turbine Aerodynamics: Axial turbine flow analysis, Blade loading and losses, Cooling flow, aerodynamics, Secondary flow structures, Tip leakage effects, Turbine efficiency optimization. Exhaust Nozzle Aerodynamics: Convergent and convergent-divergent nozzles, choked flow, thrust generation, shock structures in nozzles, Thrust vectoring concepts.

Number of Hours: 08

Module-4

High-Speed Propulsion Aerodynamics: Ramjet operation, Scramjet flow physics, Hypersonic inlet design, Shock interactions, Thermal effects and real-gas phenomena. Computational and Experimental Methods: CFD techniques for propulsion systems, Turbulence modelling, Wind tunnel testing, Flow visualization techniques, Particle Image Velocimetry (PIV).

Number of Hours: 08

Module-5

Hybrid-Electric and Distributed Propulsion: Propulsor-airframe interaction, Electric fan aerodynamic optimization, Distributed propulsion flow characteristics. Hydrogen-Powered

Sustainable Aviation Technologies: Ultra-high bypass ratio engines, Open rotor aerodynamics, Sustainable aviation fuel integration, Artificial Intelligence in Engine

Aerodynamics: Machine learning for blade optimization, Predictive maintenance models, Reduced-order aerodynamic modeling.

Digital Twin Technology: Real-time engine performance prediction, Health monitoring and diagnostics, Lifecycle aerodynamic optimization. Advanced Turbomachinery Design: Additive-manufactured blade geometries, Bio-inspired blade concepts, Active flow control technologies.

Number of Hours:10

Textbooks:

1. Ahmed F. El-Sayed, "Aircraft Propulsion and Gas Turbine Engines", CRC Press Publication, 2nd Edition 2017.
2. John David Anderson, "Modern Compressible Flow: With Historical Perspective", McGraw-Hill Science Engineering Publication, 2002.
3. Nicholas A. Cumpsty, "Jet Propulsion", Cambridge University Press Publication, 1997.

Reference books / Manuals:

1. Saeed Farokhi, "Aircraft Propulsion", John Wiley & Sons Inc Publication, 2nd Edition, 2014.
2. Jack D. Mattingly, William H. Heiser, David T. Pratt, Keith M. Boyer Brenda A. Haven, "Aircraft Engine Design", American Institute of Aeronautics & Astronautics Publication, 2019.
3. HIH Saravanamuttoo, GFC Rogers, H Cohen, PV Straznicky, AC Nix," Gas Turbine Theory", Pearson, 7th Edition, 2017

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. **Virtual Wind Tunnel Simulations:** Visualize aerodynamic phenomena using CFD-based interactive simulations.
2. **Project-Based Aircraft Design:** Develop and optimize aircraft or UAV components through team design projects.
3. **Augmented Reality Visualization:** Explore airflow patterns, pressure distribution, and vortices using AR models.
4. **Hands-On Experimental Learning:** Investigate aerodynamic principles through low-cost wind tunnel and flow visualization experiments.
5. **Flipped Classroom with AI:** Combine pre-class digital learning with AI-assisted in-class problem solving and design activities.

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	**Name of the Learning activity**	**Maximum Marks**
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester		
Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)		
Sl. No.	**Term Work (TW) Activity**	**Number of Hours / Semester**
1	Micro Projects / Seminars / Industry Visits	24
SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.		
Sl. No.	**Self-Learning (SL) Activity**	**Number of Hours / Semester**
1	MOOCs / Tutorials / Online Courses etc.	24

GAS TURBINE MAINTENANCE AND OVERHAUL			
Course Code	1MAS106B	Scheme	2026
Type of Course	PEC-II	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42:0:0:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course Objectives

At the end of the course, the student will be able to:
CO1: Explain the construction and working principles of gas turbine engines.
CO2: Analyse gas turbine thermodynamic cycles and engine performance.
CO3: Evaluate combustion processes and emission characteristics.
CO4: Conduct gas turbine performance testing using appropriate instrumentation.
CO5: Apply advanced diagnostic and computational techniques for gas turbine performance evaluation.

Module-1

Fundamentals of Gas Turbine Engines: Introduction to aircraft propulsion, classification of gas turbine engines, historical development, Brayton cycle, ideal and actual cycles, engine stations, inlet and diffuser, compressor types, compressor characteristics, surge and stall, combustion chamber types, turbine construction, exhaust nozzle, engine accessories.

Number of Hours: 09

Module-2

Gas Turbine Performance Analysis: Specific thrust, thrust equation, TSFC, thermal efficiency, propulsive efficiency, overall efficiency, altitude effects, Mach number effects, engine matching, off-design performance, compressor and turbine matching, performance maps.

Number of Hours: 08

Module-3

Combustion and Emissions: Combustion fundamentals, fuel properties, combustion efficiency, flame stabilization, combustor design, pollutant formation (NOx, CO, UHC, smoke), emission regulations, sustainable aviation fuels (SAF), hydrogen fuel, combustion instability.

Number of Hours: 08

Module-4

Gas Turbine Testing and Instrumentation: Performance testing procedures, instrumentation, pressure measurement, temperature measurement, airflow measurement, fuel flow measurement, thrust measurement, vibration monitoring, data acquisition systems, calibration techniques, uncertainty analysis, engine health monitoring.

Number of Hours: 09

Module-5

Advanced Gas Turbine Technologies: FADEC systems, digital engine control, engine diagnostics, condition monitoring, predictive maintenance, computational performance modelling, AI and machine learning applications in gas turbines, hybrid-electric propulsion, future propulsion systems.

Number of Hours: 08

Textbooks:

1. Jack D. Mattingly, Elements of Gas Turbine Propulsion, McGraw-Hill.
2. Jack D. Mattingly, William H. Heiser and David T. Pratt, Aircraft Engine Design, AIAA Education Series.
3. H.I.H. Saravanamuttoo, G.F.C. Rogers, H. Cohen and P.V. Straznicky, Gas Turbine Theory, Pearson Education.

Reference books / Manuals:

1. Gordon C. Oates, Aircraft Propulsion Systems Technology and Design, AIAA.
2. Meherwan P. Boyce, Gas Turbine Engineering Handbook, Elsevier.
3. Rolls-Royce, The Jet Engine, Rolls-Royce Plc.

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Use VR platforms to demonstrate engine inspection and overhaul operations
2. Employ case studies to explain failures
3. Provide practical sessions in laboratories
4. Use AI-assisted tools to discuss predictive maintenance projects

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester		
Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)		
Sl. No.	**Term Work (TW) Activity**	**Number of Hours / Semester**
1	Micro Projects / Seminars / Industry Visits	24
SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.		
Sl. No.	**Self-Learning (SL) Activity**	**Number of Hours / Semester**
1	MOOCs / Tutorials / Online Courses etc.	24

HYPERSONIC AERODYNAMICS			
Course Code	1MAS106C	Scheme	2026
Type of Course	PEC-II	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy L /T/P/SL&TW:	90 (42:00:00:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course Objectives

At the end of the course, the student will be able to:

CO1: Understand the fundamental principles and characteristics of hypersonic flows.

CO2: Learn the aerodynamic theories used for analysing hypersonic vehicles.

CO3: Study shock waves, shock-layer structures, and viscous interaction effects in hypersonic flow.

CO4: Understand boundary-layer behaviour, rarefied gas dynamics, and high-speed flow phenomena.

CO5: Familiarize with hypersonic testing facilities, scaling laws, and experimental techniques.

Module-1

General Considerations. Characteristics General features of hypersonic flow field. Assumptions underlying inviscid hypersonic theory. Normal shock waves, oblique & curved shocks. Mach number independence principles. General strip theory.

Small Disturbance Theory. Introduction to basic equations. Hypersonic Similitude, United supersonic-hypersonic similitude. Slender – body strip theory.

Number of Hours:08

Module-2

Small Disturbance Theory. Slightly blunted slender bodies, large incidence & correlation of Similitude. Unsteady flow theory. Non equilibrium effects.

Newtonian Theory. Two-dimensional axis symmetric bodies, simple shapes & free layers. Optimum shapes, shock layer structure.

Number of Hours:08

Module-3

Newtonian Theory. Shock layer structure with cross flow. Conical flow, bodies of revolution at small incidences.

Theory of Thin Shock Layers. Basic concepts, successive approximation schemes. Constant stream tube-area approximation. Two-dimensional axis symmetric blunt faced bodies.

Number of Hours:08

Module-4

Viscous Flows. Hypersonic Viscous effects, Boundary Layer equations. Similar laminar boundary layer solutions. Local similarity concept. Viscous interactions - flow models and interaction parameters. Weak pressure interaction. Strong pressure interaction. General features of rarified gas flows.

Number of Hours:09

Module-5

Hypersonic Testing. Hypersonic Scaling, high enthalpy & high speed, types of hypersonic facilities. Shock tunnels & expansion tubes. Features of Hypersonic wind tunnel design. Instrumentation to hypersonic vehicle testing. Test model similarity laws.

Number of Hours:09

Textbooks:

1. Wallace D. Hayes, Ronald F. Probstein, "Hypersonic Inviscid Flows", Dover Publications,2004.
2. Wallace Hayes, "Hypersonic Flow Theory", Academic Press Inc, 1959.

Reference books / Manuals:

1. John D Anderson Jr, "Hypersonic and High Temperature Gas Dynamics", AIAA,2000.
2. Frank K.Lu and Dart E. Marran, "Advanced Hypersonic Test Facilities", AIAA,2002.
3. Cherynl C. G. "Introduction to Hypersonic Flow", Academic Press, 1961.

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

1. Discuss case studies pertaining to design and development of hypersonic air vehicles
2. Employ virtual wind tunnel and flow visualization techniques to discuss various topics
3. Review of literature and paper presentations
4. AI-assisted design optimization activities

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

Term Work (TW) and Self Learning (SL) components in Number of Hours per semester		
Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)		
Sl. No.	**Term Work (TW) Activity**	**Number of Hours / Semester**
1	Micro Projects / Seminars / Industry Visits	24
SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.		
Sl. No.	**Self-Learning (SL) Activity**	**Number of Hours / Semester**
1	MOOCs / Tutorials / Online Courses etc.	24

AI AND ML IN AEROSPACE ENGINEERING			
Course Code	1MAS106D	Scheme	2026
Type of Course	PEC-II	Semester	I
Teaching Hours/Week (L:T:P)	3:0:0	CIE Marks	50
Total Hours of Pedagogy per semester L /T/P/SL&TW:	90 (42:0:0:48)	SEE Marks	50
Credits	3	Total Marks	100
Examination type (SEE)	Theory	Exam Hours	3Hrs

Course Objectives

At the end of the course, the student will be able to:

CO1: Explain the fundamentals of AI, ML, and their aerospace applications.

CO2: Apply AI and ML techniques to aerospace engineering problems.

CO3: Analyse aerospace data using machine learning models.

CO4: Evaluate the performance of AI and ML models for aerospace applications.

CO5: Develop AI-based solutions for aerospace engineering applications.

Module-1

Introduction to Data Science and AI & ML, Data Science, AI & ML, Essential Concepts in AI and ML Representation and Visualisation, Basics of statistics - Mean, Median, Variance, and Standard Deviation; outlier detection and data cleaning, Data Understanding

Number of Hours: 08

Module-2

Machine Learning: Linear Methods, Linear Regression, Multiple Linear Regression, Non-Linear Regression, Clustering, Forecasting models, Perceptron and Neural Network, Decision Trees Fundamentals, splitting criteria and decision boundaries; overfitting and pruning; ensemble models- Random Forest and Boosting methods

Number of Hours: 08

Module-3

Probabilistic Models, Dynamic programming and Reinforcement Programming, Evolutionary Algorithms, Time Series Models, Deep Learning, Emerging Trends in ML, Unsupervised Learning

Number of Hours: 09

Module-4

Foundations for AI, AI Basics, AI Classification, Supervised Learning, Feature Engineering Regression, Model Selection, Model Performance, Ranking, Artificial Neural Network (ANN) fundamentals; network architecture and decision boundaries; loss functions and activation functions; learning rate and stochastic gradient descent; regularization in ANN

Number of Hours: 08

Module-5

Introduction to ML with R and using Python, Python and R for Artificial Intelligence, Machine Learning, and Data Science, AI/ML in aerospace industry, Fundamentals of Generative and Agentic AI: LLMs, Prompt Engineering Concepts.

Number of Hours: 09

Textbooks:

1. Machine Learning and Artificial Intelligence, Ameet V Joshi, Springer, 2019.
2. Artificial Intelligence and Machine Learning fundamentals, Zsolt Nagy, Packt Publishing, 2019.

Reference books / Manuals:

1. Artificial Intelligence and Machine Learning, Vinod Chandra SS, PHI Learning, 2014
2. Basics of Artificial Intelligence and Machine Learning, Dheeraj Mehrotra, Notion Press 2019

Teaching-Learning Process (Innovative Delivery Methods):

The following are sample strategies that educators may adopt to enhance the effectiveness of the teaching-learning process and facilitate the achievement of course outcomes.

5. Discuss case studies pertaining to design and development of hypersonic air vehicles
6. Employ virtual wind tunnel and flow visualization techniques to discuss various topics
7. Review of literature and paper presentations
8. AI-assisted design optimization activities

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for passing.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject/course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation:

Continuous Comprehensive Assessments (CCA)+ Internal Assessment Test (IA) = Continuous Internal Evaluation CIE [25+25=50 marks]

A minimum of two Internal Assessment Tests(IA) shall be conducted, carrying a total of 25 marks.

In addition, Continuous Comprehensive Assessment (CCA) shall be conducted for a total of 25 marks.

It is recommended to include a maximum of two learning activities as part of the CCA to foster the holistic development of students. These activities shall be:

Sl. No.	Name of the Learning activity	Maximum Marks
1.	Course Project / Case Study Presentation / Research Paper Review / Assignment (at RBL3, RBL4, or RBL5 levels)	25

<table>
<tr><th colspan="3">Term Work (TW) and Self Learning (SL) components in
Number of Hours per semester</th></tr>
<tr><td colspan="3">Term work (includes assignments, seminars, micro projects, industrial visits, any other student activities etc.)</td></tr>
<tr><td>Sl. No.</td><td>Term Work (TW) Activity</td><td>Number of Hours / Semester</td></tr>
<tr><td>1</td><td>Micro Projects / Seminars</td><td>24</td></tr>
<tr><td colspan="3">SL: Self Learning, MOOCs, spoken tutorials, online educational resources etc.</td></tr>
<tr><td>Sl. No.</td><td>Self-Learning (SL) Activity</td><td>Number of Hours / Semester</td></tr>
<tr><td>1</td><td>Tutorials / Online Courses etc.</td><td>24</td></tr>
</table>

AIRCRAFT PROPULSION LAB			
Course Code	1MASL107A	Scheme	2026
Type of course	PCCL	Semester	I
Teaching Hours/Week (L:T:P)	0 : 0 : 2	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	30 (0 : 0 : 28 : 2)	SEE Marks	50
Credits	1	Total Marks	100
Type of Examination	Practical	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Conduct experiments to evaluate aerodynamic, thermal, and turbomachinery performance.
CO2: Investigate combustion, fuel injection, and flame characteristics using standard laboratory techniques.
CO3: Interpret experimental results to assess the performance of propulsion and combustion systems.

Note:

1. The laboratory syllabus consists of PART-A and PART-B. While PART-A has 6-8 conventional experiments, PART-B has 6 typical open-ended experiments. The maximum marks for the laboratory course are 100.
2. Both PART-A and PART-B are considered for CIE and SEE.
3. Students have answer 1(one) question from PART-A and 1(one) question from PART-B.
   a. The questions set for SEE shall be from among the experiments under PART-A. It is evaluated for **80 marks** out of the maximum 100 marks.
   b. The open-ended question set for SEE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for **20 marks.**

For Continuous Internal Evaluation (CIE) during the semester, classwork shall typically include open-ended questions from **Part-B**, along with other similar questions designed to enhance the students' skills.

PART – A
List of experiments

1. Cascade testing of a model of turbine blade row and study of wake survey.
2. Estimation of propeller performance.
3. Forced Convective heat transfer on a flat surface.
4. Measurement of Burning Velocity of a Premixed Flame.
5. Determination of heat of combustion of aviation fuels.
6. Fuel injection characteristics (spray cone geometry; spray speed, etc. for various types of injectors)

PART – B
OPEN ENDED EXPERIMENTS

Open-ended experiments are a type of laboratory activity where the outcome is not predetermined and students are given the freedom to explore, design, and conduct the experiment based on the problem statements as per the concepts defined by the course coordinator. It encourages creativity, critical thinking, and inquiry-based learning.

1. Investigate the influence of operating parameters on the pressure rise and efficiency characteristics of an axial flow fan, and recommend operating conditions for improved performance
2. Effect of inlet flow distortion on measurement of static overall pressure rise & rotor static pressure rise & fan overall efficiency through axial flow fan unit.
3. Investigation of relationship between flame speed and air-fuel ratio for a slow burning gaseous fuel.
4. Construction of flame stability diagram through flame lift up and flame fall back.
5. Measurement of static overall pressure rise & rotor static pressure rise & fan overall efficiency through counter rotating axial flow fan unit.

6. Effect of inlet flow distortion on measurement of static overall pressure rise & rotor static pressure rise & fan overall efficiency through contra rotating axial flow fan unit

Textbooks:

1. Lab Manual

Reference Books:

1. S. M. Yahya, Turbines, Compressors and Fans, 5th Edition, McGraw Hill Education.
2. P. K. Nag, Engineering Thermodynamics, 7th Edition, McGraw Hill Education.

Web links and Video Lectures (e-Resources):

2. NPTEL Courses : https://nptel.ac.in/courses
3. MIT OpenCourseWare: https://ocw.mit.edu
4. NASA Beginner's Guide to Propulsion: NASA Beginner's Guide to Propulsion

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	Online Tutorials / Subject Videos etc.	2 (minimum)

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation (CIE):

For the Professional Core Course Laboratory, the maximum marks prescribed are 100. Out of these, 50 marks are allotted for Continuous Internal Evaluation (CIE) and 100 marks for the Semester End Examination (SEE). The SEE marks obtained out of 100 shall be proportionately scaled down to 50 marks. The final result shall be declared based on the aggregate of the CIE marks (50) and the scaled-down SEE marks (50), totalling 100 marks."

Out of 50 marks, 40 marks shall be assigned for assessment of regular laboratory PART -A classwork, and 10 marks for Part – B. (Table 1)

Out of 40 marks, 25 marks shall be based on the regular classwork and allotment of marks shall be as per rubrics listed in Table 1.

The remaining 15 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table 1.

The open-ended question set for CIE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for 10 marks. The allotment of marks shall be as per rubrics listed in Table 2

<table>
<tr><th colspan="3">Table – 1 Distribution of marks corresponding to laboratory component</th></tr>
<tr><th>Component</th><th>Description</th><th>Marks</th></tr>
<tr><th colspan="3">Allotment of marks for regular classwork</th></tr>
<tr><td>Ability in Conducting Experiments</td><td>Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.</td><td>10 marks</td></tr>
<tr><td>Laboratory Record / Journal</td><td>Regular and neat maintenance of lab record, accuracy of results, and timely submission.</td><td>15 marks</td></tr>
<tr><td colspan="2">Subtotal</td><td>25</td></tr>
<tr><th colspan="3">Allotment of marks for CIE practical test</th></tr>
<tr><td>Laboratory Test / Experiment Performance</td><td>Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.</td><td>5 marks</td></tr>
<tr><td>Viva-Voce</td><td>Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.</td><td>10marks</td></tr>
<tr><td colspan="2">Subtotal</td><td>15</td></tr>
<tr><td colspan="2">Total</td><td>40</td></tr>
</table>

<table>
<tr><th colspan="5">Table 2 Distribution of marks corresponding to PART -B of the laboratory component</th></tr>
<tr><th colspan="5">Evaluation Rubrics for continuous internal evaluation CIE). Maximum marks:10</th></tr>
<tr><th rowspan="3">Criteria and Guiding factors</th><th colspan="4">Students' Level and Rubrics</th></tr>
<tr><th colspan="4">Excellent: E, Good: G, Fair: F
Needs Improvements: NI</th></tr>
<tr><th>E</th><th>G</th><th>F</th><th>NI</th></tr>
<tr><td>(1) Problem Understanding
Criteria: Is the problem understood correctly and framed appropriately?
(i)Clarity in interpreting the given problem.
(ii)Identification of relevant concepts and constraints.
(iii) Ability to rephrase or model the problem logically.</td><td>2.0</td><td>1.5</td><td>1.0</td><td>0.5</td></tr>
<tr><td>(2) Conceptual Knowledge
Criteria: Are the chosen methods or concepts valid for this type of problem?
(i)Application of appropriate theories, principles, or laws.
(ii)Integration of multiple concepts where necessary.
(iii)Accuracy in stating relevant equations or models.</td><td>2.0</td><td>1.5</td><td>1.0</td><td>0.5</td></tr>
<tr><td>(3) Approach and Strategy
Criteria: Is the approach well thought out and methodical?
(i)Logical structure and progression.
(ii)Use of diagrams, sketches, or flowcharts if applicable.
(iii)Identification of assumptions and boundary conditions.</td><td>2.0</td><td>1.5</td><td>1.0</td><td>0.5</td></tr>
<tr><td>(4) Execution and Accuracy
Criteria: Are the calculations correct? Is the final solution reasonable?
(i) Correct application of formulas/methods.
(ii)Accuracy of calculations or simulations (if any).
(iii)Unit consistency and result verification.</td><td>2.0</td><td>1.5</td><td>1.0</td><td>0.5</td></tr>
</table>

(5) Innovation or Depth **Criteria**: Has the student shown original thinking or alternative methods? (i)Novel or efficient solutions. (ii)Consideration of alternate approaches. (iii)Interdisciplinary integration or practical extensions.	1	0.75	0.5	0.25
(6) Presentation and Clarity **Criteria**: Is the answer easy to follow and professionally written? (i)Organization and neatness. (ii)Clarity of explanation, labelling, and steps. (iii) Use of proper technical terminology.	1	0.75	0.5	0.25
Total	10	7.5	5.0	2.5

Note:
(i)The marks shown for *Excellent, Good, Fair, Needs Improvement* are indicative. The evaluator may also assign intermediate scores depending on the quality of work.
(ii)If the total score results in a fraction, it should be rounded off to the next higher integer.
(iii)The listed criteria are guidelines; evaluators may also consider other authentic dimensions (e.g., depth of insight, critical thinking, and practical awareness, recognition of limitations, or justified compromises.
(iv)To award the full10 marks in the excellent category, the student must demonstrate reasonably good performance across all six criteria; otherwise, proportionally lower marks may be given.

GAS TURBINE PERFORMANCE AND TESTING LAB			
Course Code	1MASL107B	Scheme	2026
Type of course	PCCL	Semester	I
Teaching Hours/Week (L:T:P)	0 : 0 : 2	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	30 (0: 0: 28 : 2)	SEE Marks	50
Credits	1	Total Marks	100
Type of Examination	Practical	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Operate a micro gas turbine engine and acquire experimental data using modern instrumentation.
CO2: Analyse the performance of gas turbine components and evaluate overall engine performance using experimental measurements.
CO3: Design and conduct experimental investigations to diagnose engine performance and recommend improvements using engineering principles and computational tools.

Note:

1. The laboratory syllabus consists of PART-A and PART-B. While PART-A has 6-8 conventional experiments, PART-B has 6 typical open-ended experiments. The maximum marks for the laboratory course are 100.
2. Both PART-A and PART-B are considered for CIE and SEE.
3. Students have answer 1(one) question from PART-A and 1(one) question from PART-B.
    a. The questions set for SEE shall be from among the experiments under PART-A. It is evaluated for **80 marks** out of the maximum 100 marks.
    b. The open-ended question set for SEE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for **20 marks.**
4. For Continuous Internal Evaluation (CIE) during the semester, classwork shall typically include open-ended questions from **Part-B**, along with other similar questions designed to enhance the students' skills.

PART – A
List of experiments

1. Familiarization of Micro Gas Turbine Engine, Instrumentation and Data Acquisition System
2. Experimental Investigation of Transient Engine Characteristics
3. Measurement of Pressure and Temperature variation at different sections of the micro gas turbine engine
4. Experimental Performance Analysis of the Compressor
5. Experimental Analysis of Combustor and Turbine Performance
6. Experimental Investigation of Exhaust Nozzle Performance

PART – B
OPEN ENDED EXPERIMENTS

Open-ended experiments are a type of laboratory activity where the outcome is not predetermined and students are given the freedom to explore, design, and conduct the experiment based on the problem statements as per the concepts defined by the course coordinator. It encourages creativity, critical thinking, and inquiry-based learning.

1. Performance Optimization of a Micro Turbojet Engine under Different Operating Conditions
2. Experimental Investigation of Factors Affecting Gas Turbine Thermal Efficiency
3. Fault Diagnosis and Engine Health Monitoring
4. Data-Driven Performance Prediction of a Micro Turbojet Engine
5. Experimental Design and Validation of a Gas Turbine Performance Test
6. Mini Research Project on Advanced Gas Turbine Performance

Textbooks:

1. Gas Turbine Theory, H. I. H. Saravanamuttoo, G. F. C. Rogers, H. Cohen and P. V. Straznicky, Pearson Education.
2. Aircraft Propulsion, Saeed Farokhi, John Wiley & Sons.
3. Mechanics and Thermodynamics of Propulsion, Philip G. Hill and Carl R. Peterson, Pearson Education.

Reference books / Manuals:

1. Lab Manual
2. Gas Turbine Engineering Handbook, Meherwan P. Boyce, Elsevier.
3. Aircraft Engine Design, Jack D. Mattingly, AIAA Education Series.
4. Jet Propulsion, Nicholas Cumpsty, Cambridge University Press.

Web links and Video Lectures (e-Resources):

1. NASA Glenn Research Center – Beginner's Guide to Propulsion
2. MIT OpenCourseWare – Gas Turbine and Jet Propulsion
3. NPTEL Courses on Aircraft Propulsion and Gas Turbine Engineering
4. Dewesoft Academy – Data Acquisition Systems

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	Online Tutorials / Subject Videos etc.	2 (minimum)

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation (CIE):

For the Professional Core Course Laboratory, the maximum marks prescribed are 100. Out of these, 50 marks are allotted for Continuous Internal Evaluation (CIE) and 100 marks for the Semester End Examination (SEE). The SEE marks obtained out of 100 shall be proportionately scaled down to 50 marks. The final result shall be declared based on the aggregate of the CIE marks (50) and the scaled-down SEE marks (50), totalling 100 marks."

Out of 50 marks, 40 marks shall be assigned for assessment of regular laboratory PART -A classwork, and 10 marks for Part – B. (Table 1)

Out of 40 marks, 25 marks shall be based on the regular classwork and allotment of marks shall be as per rubrics listed in Table 1.

The remaining 15 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table 1.

The open-ended question set for CIE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for 10 marks. The allotment of marks shall be as per rubrics listed in Table 2

Table – 1 Distribution of marks corresponding to laboratory component		
Component	**Description**	**Marks**
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	10 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	15 marks
	Subtotal	**25**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	10marks
	Subtotal	**15**
	Total	**40**

Table 2 Distribution of marks corresponding to PART -B of the laboratory component				
Evaluation Rubrics for continuous internal evaluation CIE). Maximum marks:10				
Criteria and Guiding factors	**Students' Level and Rubrics**			
	Excellent: E, Good: G, Fair: F Needs Improvements: NI			
	E	**G**	**F**	**NI**
(1) Problem Understanding **Criteria:** Is the problem understood correctly and framed appropriately? (i)Clarity in interpreting the given problem. (ii)Identification of relevant concepts and constraints. (iii) Ability to rephrase or model the problem logically.	2.0	1.5	1.0	0.5
(2) Conceptual Knowledge **Criteria**: Are the chosen methods or concepts valid for this type of problem? (i)Application of appropriate theories, principles, or laws. (ii)Integration of multiple concepts where necessary. (iii)Accuracy in stating relevant equations or models.	2.0	1.5	1.0	0.5
(3) Approach and Strategy **Criteria**: Is the approach well thought out and methodical? (i)Logical structure and progression. (ii)Use of diagrams, sketches, or flowcharts if applicable. (iii)Identification of assumptions and boundary conditions.	2.0	1.5	1.0	0.5
(4) Execution and Accuracy **Criteria**: Are the calculations correct? Is the final solution reasonable? (i) Correct application of formulas/methods. (ii)Accuracy of calculations or simulations (if any).	2.0	1.5	1.0	0.5

(iii)Unit consistency and result verification.				
(5) Innovation or Depth **Criteria**: Has the student shown original thinking or alternative methods? (i)Novel or efficient solutions. (ii)Consideration of alternate approaches. (iii)Interdisciplinary integration or practical extensions.	1	0.75	0.5	0.25
(6) Presentation and Clarity **Criteria**: Is the answer easy to follow and professionally written? (i)Organization and neatness. (ii)Clarity of explanation, labelling, and steps. (iii) Use of proper technical terminology.	1	0.75	0.5	0.25
Total	10	7.5	5.0	2.5

Note:
(i)The marks shown for *Excellent, Good, Fair, Needs Improvement* are indicative. The evaluator may also assign intermediate scores depending on the quality of work.
(ii)If the total score results in a fraction, it should be rounded off to the next higher integer.
(iii)The listed criteria are guidelines; evaluators may also consider other authentic dimensions (e.g., depth of insight, critical thinking, and practical awareness, recognition of limitations, or justified compromises.
(iv)To award the full10 marks in the excellent category, the student must demonstrate reasonably good performance across all six criteria; otherwise, proportionally lower marks may be given.

MATERIALS AND THERMAL TESTING LAB FOR ENGINES			
Course Code	1MASL107C	Scheme	2026
Type of course	PCCL	Semester	I
Teaching Hours/Week (L:T:P)	0 : 0 : 2	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	30 (0 : 0: 28 : 2)	SEE Marks	50
Credits	1	Total Marks	100
Type of Examination	Practical	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:

CO1: Analyse and evaluate high-temperature environmental degradation mechanisms, such as oxidation kinetics, thermal shock, and microstructural aging, using advanced experimental metallurgy and non-destructive testing (NDT) techniques.

CO2: Quantify and characterize the thermal insulation effectiveness, heat flux limits, and localized failure modes of advanced aerospace materials and thermal barrier coatings (TBCs) under live flame impingement conditions.

CO3: Formulate and validate coupled thermo-mechanical and transient finite element models to predict operational hot-spots, thermal stresses, and manufacturing-induced residual stresses in complex engine propulsion components.

Note:

1. The laboratory syllabus consists of PART-A and PART-B. While PART-A has 6-8 conventional experiments, PART-B has 6 typical open-ended experiments. The maximum marks for the laboratory course are 100.
2. Both PART-A and PART-B are considered for CIE and SEE.
3. Students have answer 1(one) question from PART-A and 1(one) question from PART-B.
   a. The questions set for SEE shall be from among the experiments under PART-A. It is evaluated for **80 marks** out of the maximum 100 marks.
   b. The open-ended question set for SEE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for **20 marks.**
4. For Continuous Internal Evaluation (CIE) during the semester, classwork shall typically include open-ended questions from **Part-B**, along with other similar questions designed to enhance the students' skills.

PART – A

List of experiments

1. Flame Impingement & Thermal Barrier Evaluation: Quantify the thermal insulation effectiveness of ceramic coatings by exposing them to a standard Propulsion Lab burner flame and monitoring the rear-face temperature.
2. High-Temperature Oxidation Kinetics: To subject superalloy specimens to sustained exposure in a muffle furnace at temperatures ranging from 800°C to 1100°C for extended durations. Analyse mass change over time to determine the oxidation rate constant and characterize oxide scale formation.
3. Microstructural Evolution under Thermal Aging: To subject specimens to simulated "in-service" thermal aging (extended exposure at high temperatures) and evaluate the degradation of mechanical properties using Vickers hardness testing/optical microscopy to observe precipitate coarsening
4. Thermal Shock & NDT Failure Analysis: To perform rapid quench cycling on metallic and ceramic specimens. Utilize Dye Penetrant or Ultrasonic NDT facilities to map the propagation of thermal fatigue cracks.

5. Steady-State Thermal Analysis of Turbine Components: To numerically simulate the convective and conductive heat transfer across a turbine blade model to identify potential "hot spots" that would exceed the material's metallurgical limit.
6. Residual Stress Simulation in Additive Manufacturing: To numerically simulate the layer-by-layer transient thermal gradients and associated residual stresses during the Additive Manufacturing (SLM) to predict warpage or cracking.

PART – B
OPEN ENDED EXPERIMENTS

Open-ended experiments are a type of laboratory activity where the outcome is not predetermined and students are given the freedom to explore, design, and conduct the experiment based on the problem statements as per the concepts defined by the course coordinator. It encourages creativity, critical thinking, and inquiry-based learning.

1. Optimization of Thermal Barrier Coating (TBC) Architecture: To mitigate the risk of spallation in turbine blades, students will design a multi-layer TBC system. Given a fixed operating temperature and heat flux, they must define the optimal ratio of bond-coat thickness to top-coat thickness using numerical simulations to minimize thermal expansion mismatch stresses. They will validate their design by using the Propulsion Lab burner setup to expose a sample to a high-temperature jet, measuring the back-face temperature reduction to correlate simulation results with physical performance.
2. Forensic Failure Analysis of Thermally Aged Components: Students will be provided with a set of "failed" super alloy specimens that have been subjected to undisclosed thermal cycling and stress. Utilizing optical microscopy, Vickers hardness testing, and NDT (Dye Penetrant), they must determine the root cause of failure—specifically distinguishing between grain boundary coarsening (precipitate aging) and oxidation-induced surface cracking. Students are required to define their own forensic protocol to map the failure progression and recommend an improved heat-treatment cycle to prevent recurrence.
3. Effectiveness of Film Cooling Geometries in Combustor Liners: To address the overheating of combustor liners, students will investigate the efficacy of different cooling-hole configurations. Using the Propulsion Lab's flame/burner setup, they must design a test rig to evaluate various hole geometries (e.g., simple circular vs. shaped holes) on a test plate. They are responsible for determining the measurement method for cooling effectiveness (e.g., infrared thermography or strategic thermocouple placement) and identifying the optimal hole-to-pitch ratio that maximizes cooling with minimal bleed-air consumption.
4. Predicting Creep-Rupture Life via Accelerated Testing: Students will conduct an accelerated creep-testing simulation using a muffle furnace and a tensile-load frame. They must design a testing matrix using the Larson-Miller Parameter (LMP) to correlate short-term, high-temperature test data with long-term engine component life. The goal is for the students to determine the "Design Life" of a specific alloy and create a life-prediction model that estimates the safe operating hours for a turbine component under varying throttle profiles.
5. Process-Structure-Property Optimization in Additive Manufacturing: Students will use numerical simulation to model the transient thermal gradients present during the Laser Powder Bed Fusion

process of a high-temperature engine nozzle. They must vary process parameters such as laser power, scan speed, and cooling rates in their simulation to identify the combination that produces the lowest residual stress and the most uniform microstructure. They will then fabricate (or simulate the fabrication of) a sample and propose a post-processing heat treatment to "heal" any predicted manufacturing-induced defects.

6. Comparative Material Selection for Hypersonic Leading Edges: Given the extreme aerodynamic heating profiles of a hypersonic flight mission, students must perform a comparative material trade-off study between Carbon-Carbon (C/C) composites and SiC/SiC Ceramic Matrix Composites. Using available data and simulation, they must define the "point of failure" for each material under simulated hypersonic heat-flux conditions and recommend a material solution based on the specific mission duration and weight constraints. They will present their trade-off matrix as the final deliverable.

Textbooks:

1. Birks, N., Meier, G.H. and Pettit, F.S. (2006) Introduction to the high temperature oxidation of metals. 2nd edn. Cambridge: Cambridge University Press.
2. Moaveni, S. (2015) Engineering analysis with ANSYS Workbench. 3rd edn. Harlow: Pearson Education.
3. Mukherji, D. (2013) High temperature materials for gas turbine applications. New Delhi: Indian Books and Periodicals Publishers.

<u>Reference books / Manuals:</u>

1. Baldev, R., Jayakumar, T. and Thavasimuthu, M. (2013) Practical non-destructive testing. 3rd edn. New Delhi: Narosa Publishing House.
2. Jung, Y.G. (ed.) (2018) Science and technology of thermal barrier coatings. Basel: MDPI Books.
3. Saravanamuttoo, H.I.H., Rogers, G.F.C., Cohen, H. and Straznicky, P.V. (2009) Gas turbine theory. 6th edn. Harlow: Pearson Education.

Web links and Video Lectures (e-Resources):

1. Dwivedi, D.K. (2018) Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations, NPTEL (IIT Roorkee) [Online]. Available at: https://nptel.ac.in/courses/112107248
2. NPTEL (2019) Advanced Materials and Processes [Online]. Available at: https://nptel.ac.in/courses/113105081
3. NPTEL (2023) Fundamentals of Composite and Cellular Materials [Online]. Available at: https://nptel.ac.in/courses/113105109
4. MIT OpenCourseWare (2021) Unified Engineering: Materials and Structures, Massachusetts Institute of Technology [Online]. Available at: https://ocw.mit.edu/courses/16-001-unified-engineering-materials-and-structures-fall-2021/

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	Online Tutorials / Subject Videos etc.	2 (minimum)

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.
Continuous Internal Evaluation (CIE): For the Professional Core Course Laboratory, the maximum marks prescribed are 100. Out of these, 50 marks are allotted for Continuous Internal Evaluation (CIE) and 100 marks for the Semester End Examination (SEE). The SEE marks obtained out of 100 shall be proportionately scaled down to 50 marks. The final result shall be declared based on the aggregate of the CIE marks (50) and the scaled-down SEE marks (50), totalling 100 marks." Out of 50 marks, 40 marks shall be assigned for assessment of regular laboratory PART -A classwork, and 10 marks for Part – B. (Table 1) Out of 40 marks, 25 marks shall be based on the regular classwork and allotment of marks shall be as per rubrics listed in Table 1. The remaining 15 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table 1. The open-ended question set for CIE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for 10 marks. The allotment of marks shall be as per rubrics listed in Table 2

Table – 1 Distribution of marks corresponding to laboratory component		
Component	**Description**	**Marks**
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	10 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	15 marks
	Subtotal	**25**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	10marks
	Subtotal	**15**
	Total	**40**

Table 2 Distribution of marks corresponding to PART -B of the laboratory component				
Evaluation Rubrics for continuous internal evaluation CIE). Maximum marks:10				
Criteria and Guiding factors	**Students' Level and Rubrics**			
	Excellent: E, Good: G, Fair: F Needs Improvements: NI			
	E	**G**	**F**	**NI**

(1) Problem Understanding **Criteria:** Is the problem understood correctly and framed appropriately? (i)Clarity in interpreting the given problem. (ii)Identification of relevant concepts and constraints. (iii) Ability to rephrase or model the problem logically.	2.0	1.5	1.0	0.5
(2) Conceptual Knowledge **Criteria**: Are the chosen methods or concepts valid for this type of problem? (i)Application of appropriate theories, principles, or laws. (ii)Integration of multiple concepts where necessary. (iii)Accuracy in stating relevant equations or models.	2.0	1.5	1.0	0.5
(3) Approach and Strategy **Criteria**: Is the approach well thought out and methodical? (i)Logical structure and progression. (ii)Use of diagrams, sketches, or flowcharts if applicable. (iii)Identification of assumptions and boundary conditions.	2.0	1.5	1.0	0.5
(4) Execution and Accuracy **Criteria**: Are the calculations correct? Is the final solution reasonable? (i) Correct application of formulas/methods. (ii)Accuracy of calculations or simulations (if any). (iii)Unit consistency and result verification.	2.0	1.5	1.0	0.5
(5) Innovation or Depth **Criteria**: Has the student shown original thinking or alternative methods? (i)Novel or efficient solutions. (ii)Consideration of alternate approaches. (iii)Interdisciplinary integration or practical extensions.	1	0.75	0.5	0.25
(6) Presentation and Clarity **Criteria**: Is the answer easy to follow and professionally written? (i)Organization and neatness. (ii)Clarity of explanation, labelling, and steps. (iii) Use of proper technical terminology.	1	0.75	0.5	0.25
Total	10	7.5	5.0	2.5

Note:
(i)The marks shown for *Excellent, Good, Fair, Needs Improvement* are indicative. The evaluator may also assign intermediate scores depending on the quality of work.
(ii)If the total score results in a fraction, it should be rounded off to the next higher integer.
(iii)The listed criteria are guidelines; evaluators may also consider other authentic dimensions (e.g., depth of insight, critical thinking, and practical awareness, recognition of limitations, or justified compromises.
(iv)To award the full10 marks in the excellent category, the student must demonstrate reasonably good performance across all six criteria; otherwise, proportionally lower marks may be given.

GAS DYNAMICS LAB			
Course Code	1MASL107D	Scheme	2026
Type of course	PCCL	Semester	I
Teaching Hours/Week (L:T:P)	0: 0 :2	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	30 (0: 0 : 28 :2)	SEE Marks	50
Credits	1	Total Marks	100
Type of Examination	Practical	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Apply gas dynamics principles to conduct experiments and determine compressible flow properties.
CO2: Analyse subsonic, sonic, and supersonic flows, including shock waves and expansion phenomena, using experimental and theoretical methods.
CO3: Design and validate compressible flow experiments by evaluating system performance using experimental data and modern engineering tools.

Note:

1. The laboratory syllabus consists of PART-A and PART-B. While PART-A has 6-8 conventional experiments, PART-B has 6 typical open-ended experiments. The maximum marks for the laboratory course are 100.
2. Both PART-A and PART-B are considered for CIE and SEE.
3. Students have answer 1(one) question from PART-A and 1(one) question from PART-B.
   a. The questions set for SEE shall be from among the experiments under PART-A. It is evaluated for **80 marks** out of the maximum 100 marks.
   b. The open-ended question set for SEE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for **20 marks.**
4. For Continuous Internal Evaluation (CIE) during the semester, classwork shall typically include open-ended questions from **Part-B**, along with other similar questions designed to enhance the students' skills.

PART – A
List of experiments

1. Calibration of pressure measuring instruments for compressible flow applications.
2. Experimental investigation of flow through a convergent-divergent nozzle.
3. Determination of critical pressure ratio and verification of choking phenomenon in compressible flow.
4. Determination of Mach number and pressure distribution in compressible flow.
5. Experimental investigation of normal shock characteristics in a convergent-divergent nozzle.
6. Experimental investigation of oblique shock and expansion wave phenomena in supersonic flow.
7. Performance evaluation of convergent-divergent nozzle under varying pressure ratios.
8. Computational and experimental analysis of compressible flow using CFD.

PART – B
OPEN ENDED EXPERIMENTS

Open-ended experiments are a type of laboratory activity where the outcome is not predetermined and students are given the freedom to explore, design, and conduct the experiment based on the problem statements as per the concepts defined by the course coordinator. It encourages creativity, critical thinking, and inquiry-based learning.

1. Design and optimize a convergent-divergent nozzle for a specified exit Mach number using analytical and CFD approaches.
2. Investigate the influence of back pressure on nozzle flow regimes, choking, and shock location.

3. Evaluate the effect of nozzle geometry (throat diameter, divergence angle, and area ratio) on nozzle performance.
4. Develop and validate a CFD model for normal shock and oblique shock phenomena through comparison with experimental observations.
5. Design and experimentally investigate compressible flow characteristics of aerospace propulsion nozzles.
6. Analyze transient compressible flow phenomena using experimental measurements or numerical simulation and validate theoretical predictions.

Textbooks:

1. Anderson, J. D., Modern Compressible Flow: With Historical Perspective, 4th Edition, McGraw-Hill Education, 2021.
2. Yahya, S. M., Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion, 6th Edition, New Age International Publishers, 2019.
3. Liepmann, H. W. and Roshko, A., Elements of Gas dynamics, Dover Publications, New York, 2001 (Indian Reprint).

Reference books / Manuals:

1. Shapiro, A. H., The Dynamics and Thermodynamics of Compressible Fluid Flow, Volumes I & II, CBS Publishers & Distributors (Indian Reprint).
2. Oosthuizen, P. H. and Carscallen, W. E., Compressible Fluid Flow, 2nd Edition, CRC Press, Taylor & Francis Group, 2014.
3. Zucker, R. D. and Biblarz, O., Fundamentals of Gas Dynamics, 2nd Edition, John Wiley & Sons,2002.
4. Gas Dynamics Laboratory Manual, C. G. Patel Institute of Technology, Bardoli..

Web links and Video Lectures (e-Resources):

1. NPTEL – Fundamentals of Compressible Flow (IIT Guwahati)
   https://nptel.ac.in/courses/112103294
2. NASA Glenn Research Center – Beginner's Guide to Compressible Flow and Nozzle Flow
   https://www.grc.nasa.gov
3. ANSYS Innovation Courses – Compressible Flow in a Nozzle (CFD Tutorial)
   https://innovationspace.ansys.com/product/compressible-flow-in-a-nozzle/
4. MIT OpenCourseWare – Fluid Mechanics and Compressible Flow Resources
   https://ocw.mit.edu
5. OpenFOAM Official Documentation and Tutorials (Compressible Flow Solvers)
   https://www.openfoam.com/documentation

Sl. No.	Self-Learning (SL) Activity	Number of Hours / Semester
1	Online Tutorials / Subject Videos etc.	2 (minimum)

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation (CIE):

For the Professional Core Course Laboratory, the maximum marks prescribed are 100. Out of these, 50 marks are allotted for Continuous Internal Evaluation (CIE) and 100 marks for the Semester End Examination (SEE). The SEE marks obtained out of 100 shall be proportionately scaled down to 50 marks. The final result shall be declared based on the aggregate of the CIE marks (50) and the scaled-down SEE marks (50), totalling 100 marks."

Out of 50 marks, 40 marks shall be assigned for assessment of regular laboratory PART -A classwork, and 10 marks for Part – B. (Table 1)

Out of 40 marks, 25 marks shall be based on the regular classwork and allotment of marks shall be as per rubrics listed in Table 1.

The remaining 15 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table 1.

The open-ended question set for CIE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for 10 marks. The allotment of marks shall be as per rubrics listed in Table 2

Table – 1 Distribution of marks corresponding to laboratory component		
Component	**Description**	**Marks**
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	10 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	15 marks
	Subtotal	**25**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	10marks
	Subtotal	**15**
	Total	**40**

Table 2 Distribution of marks corresponding to PART -B of the laboratory component				
Evaluation Rubrics for continuous internal evaluation CIE). Maximum marks:10				
Criteria and Guiding factors	**Students' Level and Rubrics**			
	Excellent: E, Good: G, Fair: F Needs Improvements: NI			
	E	**G**	**F**	**NI**

(1) Problem Understanding **Criteria:** Is the problem understood correctly and framed appropriately? (i)Clarity in interpreting the given problem. (ii)Identification of relevant concepts and constraints. (iii) Ability to rephrase or model the problem logically.	2.0	1.5	1.0	0.5
(2) Conceptual Knowledge **Criteria**: Are the chosen methods or concepts valid for this type of problem? (i)Application of appropriate theories, principles, or laws. (ii)Integration of multiple concepts where necessary. (iii)Accuracy in stating relevant equations or models.	2.0	1.5	1.0	0.5
(3) Approach and Strategy **Criteria**: Is the approach well thought out and methodical? (i)Logical structure and progression. (ii)Use of diagrams, sketches, or flowcharts if applicable. (iii)Identification of assumptions and boundary conditions.	2.0	1.5	1.0	0.5
(4) Execution and Accuracy **Criteria**: Are the calculations correct? Is the final solution reasonable? (i) Correct application of formulas/methods. (ii)Accuracy of calculations or simulations (if any). (iii)Unit consistency and result verification.	2.0	1.5	1.0	0.5
(5) Innovation or Depth **Criteria**: Has the student shown original thinking or alternative methods? (i)Novel or efficient solutions. (ii)Consideration of alternate approaches. (iii)Interdisciplinary integration or practical extensions.	1	0.75	0.5	0.25
(6) Presentation and Clarity **Criteria**: Is the answer easy to follow and professionally written? (i)Organization and neatness. (ii)Clarity of explanation, labelling, and steps. (iii) Use of proper technical terminology.	1	0.75	0.5	0.25
Total	10	7.5	5.0	2.5
Note: (i)The marks shown for *Excellent, Good, Fair, Needs Improvement* are indicative. The evaluator may also assign intermediate scores depending on the quality of work. (ii)If the total score results in a fraction, it should be rounded off to the next higher integer. (iii)The listed criteria are guidelines; evaluators may also consider other authentic dimensions (e.g., depth of insight, critical thinking, and practical awareness, recognition of limitations, or justified compromises. (iv)To award the full10 marks in the excellent category, the student must demonstrate reasonably good performance across all six criteria; otherwise, proportionally lower marks may be given.				

COMPUTATION AND FLIGHT SIMULATION LAB			
Course Code	1MASL107E	Scheme	2026
Type of course	PCCL	Semester	I
Teaching Hours/Week (L:T:P)	0: 0 :28	CIE Marks	50
Total Hours of Pedagogy L:T:P:SL:TW	0: 0 : 0 :02	SEE Marks	50
Credits	1	Total Marks	100
Type of Examination	Practical	Exam Hours	03

Course outcome (Course Skill Set)

At the end of the course, the student will be able to:
CO1: Develop computational models of aircraft dynamic systems using MATLAB and Simulink to study flight stability and control.
CO2: Analyse the dynamic and structural performance of aircraft systems using numerical simulations and ANSYS.
CO3: Design computational solutions for aerospace engineering problems by integrating simulation tools and engineering principles.

Note:

1. The laboratory syllabus consists of PART-A and PART-B. While PART-A has 6-8 conventional experiments, PART-B has 6 typical open-ended experiments. The maximum marks for the laboratory course are 100.
2. Both PART-A and PART-B are considered for CIE and SEE.
3. Students have answer 1(one) question from PART-A and 1(one) question from PART-B.
    a. The questions set for SEE shall be from among the experiments under PART-A. It is evaluated for **80 marks** out of the maximum 100 marks.
    b. The open-ended question set for SEE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for **20 marks.**
4. For Continuous Internal Evaluation (CIE) during the semester, classwork shall typically include open-ended questions from **Part-B**, along with other similar questions designed to enhance the students' skills.

PART – A
List of experiments

1. Modeling and Analysis of Aircraft Dynamic Systems using MATLAB
2. Frequency Response Analysis of Aircraft Control Systems
3. Simulation of Aircraft Longitudinal Motion using SIMULINK
4. Simulation of Aircraft Lateral-Directional Motion using SIMULINK
5. Modeling and Simulation of Aircraft Flight Trajectory
6. Finite Element Analysis of an Aircraft Wing using ANSYS to evaluate its stability

PART – B
OPEN ENDED EXPERIMENTS

Open-ended experiments are a type of laboratory activity where the outcome is not predetermined and students are given the freedom to explore, design, and conduct the experiment based on the problem statements as per the concepts defined by the course coordinator. It encourages creativity, critical thinking, and inquiry-based learning.

1. Design and simulate a Stability Augmentation System (SAS) for improving aircraft pitch or roll stability under varying flight conditions.
2. Investigate the influence of aircraft design parameters (mass, CG location, static margin, wing loading, etc.) on dynamic stability and flying qualities.
3. Develop a flight simulation model for a user-defined mission profile and analyze aircraft performance under different environmental conditions.

4. Optimize an aircraft wing structure using ANSYS by modifying geometric or material parameters to reduce deformation while maintaining structural integrity.
5. Study the influence of different loading conditions (distributed lift, point loads, fuel loading, gust loading, etc.) on aircraft wing structural behavior using ANSYS.
6. Develop an integrated MATLAB–SIMULINK computational model to simulate aircraft dynamics with a suitable controller and compare the performance for different controller parameters or flight conditions.

Textbooks:

1. Brian L. Stevens, Frank L. Lewis and Eric N. Johnson, Aircraft Control and Simulation, 3rd Edition, Wiley, 2015.
2. John H. Blakelock, Automatic Control of Aircraft and Missiles, 2nd Edition, Wiley, 1991.
3. Dean C. Karnopp, Donald L. Margolis and Ronald C. Rosenberg, System Dynamics: Modeling, Simulation and Control of Mechatronic Systems, 5th Edition, Wiley, 2012.

Reference books / Manuals:

1. Nelson, R. C., Flight Stability and Automatic Control, 2nd Edition, McGraw-Hill, 1998.
2. Etkin, B. and Reid, L. D., Dynamics of Flight: Stability and Control, 3rd Edition, Wiley, 1996.
3. Cook, M. V., Flight Dynamics Principles, 3rd Edition, Butterworth-Heinemann, 2013.
4. ANSYS Mechanical User's Guide, ANSYS Inc., Latest Edition.
5. MATLAB and Simulink Documentation, MathWorks Inc., Latest Release.

Web links and Video Lectures (e-Resources):

1. MATLAB Documentation – https://www.mathworks.com/help/
2. Simulink Documentation – https://www.mathworks.com/help/simulink/
3. Aerospace Blockset Documentation - https://www.mathworks.com/products/aerospace-blockset.html
4. ANSYS Learning Resources – https://www.ansys.com/academic
5. NASA Technical Reports Server (NTRS) – https://ntrs.nasa.gov/

Assessment Structure (both CIE and SEE)

The weightage assigned to Continuous Internal Evaluation (CIE) and Semester End Examination (SEE) shall be 50% each. A student shall secure a minimum of 50% of the maximum marks prescribed for CIE and a minimum of 40% of the maximum marks prescribed for SEE to be eligible for a pass in the course.

A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to a subject /course only if he/she secures not less than 50% of the aggregate marks obtained in CIE and SEE taken together.

Continuous Internal Evaluation (CIE):

For the Professional Core Course Laboratory, the maximum marks prescribed are 100. Out of these, 50 marks are allotted for Continuous Internal Evaluation (CIE) and 100 marks for the Semester End Examination (SEE). The SEE marks obtained out of 100 shall be proportionately scaled down to 50 marks. The final result shall be declared based on the aggregate of the CIE marks (50) and the scaled-down SEE marks (50), totalling 100 marks."

Out of 50 marks, 40 marks shall be assigned for assessment of regular laboratory PART -A classwork, and 10 marks for Part – B. (Table 1)

Out of 40 marks, 25 marks shall be based on the regular classwork and allotment of marks shall be as per rubrics listed in Table 1.

The remaining 15 marks shall be based on the practical test conducted by two Internal examiners appointed by the HoD. The allotment of marks shall be as per the rubrics defined for the practical test as indicated in the Table 1.
The open-ended question set for CIE shall be any other open-ended question and not selected from the experiments under PART-A. It shall be evaluated for 10 marks. The allotment of marks shall be as per rubrics listed in Table 2

Table – 1 Distribution of marks corresponding to laboratory component		
Component	**Description**	**Marks**
Allotment of marks for regular classwork		
Ability in Conducting Experiments	Initiative, skill, safety practices, teamwork, and independent handling of equipment during regular lab sessions.	10 marks
Laboratory Record / Journal	Regular and neat maintenance of lab record, accuracy of results, and timely submission.	15 marks
	Subtotal	**25**
Allotment of marks for CIE practical test		
Laboratory Test / Experiment Performance	Ability to set up apparatus, follow procedure, take observations, and obtain correct results in the test experiment.	5 marks
Viva-Voce	Understanding of theory, concepts, and experimental procedure; ability to explain results and answer related questions.	10marks
	Subtotal	**15**
	Total	**40**

Table 2 Distribution of marks corresponding to PART -B of the laboratory component				
Evaluation Rubrics for continuous internal evaluation CIE). Maximum marks:10				
Criteria and Guiding factors	**Students' Level and Rubrics**			
	Excellent: E, Good: G, Fair: F **Needs Improvements: NI**			
	E	**G**	**F**	**NI**
(1) Problem Understanding **Criteria:** Is the problem understood correctly and framed appropriately? (i)Clarity in interpreting the given problem. (ii)Identification of relevant concepts and constraints. (iii) Ability to rephrase or model the problem logically.	2.0	1.5	1.0	0.5
(2) Conceptual Knowledge **Criteria**: Are the chosen methods or concepts valid for this type of problem? (i)Application of appropriate theories, principles, or laws. (ii)Integration of multiple concepts where necessary. (iii)Accuracy in stating relevant equations or models.	2.0	1.5	1.0	0.5

(3) Approach and Strategy **Criteria**: Is the approach well thought out and methodical? (i)Logical structure and progression. (ii)Use of diagrams, sketches, or flowcharts if applicable. (iii)Identification of assumptions and boundary conditions.	2.0	1.5	1.0	0.5
(4) Execution and Accuracy **Criteria**: Are the calculations correct? Is the final solution reasonable? (i) Correct application of formulas/methods. (ii)Accuracy of calculations or simulations (if any). (iii)Unit consistency and result verification.	2.0	1.5	1.0	0.5
(5) Innovation or Depth **Criteria**: Has the student shown original thinking or alternative methods? (i)Novel or efficient solutions. (ii)Consideration of alternate approaches. (iii)Interdisciplinary integration or practical extensions.	1	0.75	0.5	0.25
(6) Presentation and Clarity **Criteria**: Is the answer easy to follow and professionally written? (i)Organization and neatness. (ii)Clarity of explanation, labelling, and steps. (iii) Use of proper technical terminology.	1	0.75	0.5	0.25
Total	10	7.5	5.0	2.5

Note:
(i)The marks shown for *Excellent, Good, Fair, Needs Improvement* are indicative. The evaluator may also assign intermediate scores depending on the quality of work.
(ii)If the total score results in a fraction, it should be rounded off to the next higher integer.
(iii)The listed criteria are guidelines; evaluators may also consider other authentic dimensions (e.g., depth of insight, critical thinking, and practical awareness, recognition of limitations, or justified compromises.
(iv)To award the full10 marks in the excellent category, the student must demonstrate reasonably good performance across all six criteria; otherwise, proportionally lower marks may be given.