Department of Space Engineering and Rocketry

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

Institute Vision

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

Institute Mission

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

Department Vision

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

Department Mission

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

Program Educational Objectives (PEO)

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

Program Outcomes (PO)

PO 1: An ability to independently carry out research and development work to solve practical problems in Aerodynamics
PO 2: An ability to write and present substantial technical report and research article
PO 3: Students should be able to demonstrate a degree of mastery over and above the bachelor program in the areas of Aerodynamics
PO 4: Ability to design, perform and interpret data from experiments and correlate them with numerical and theoretical solutions
PO 5: Students should be committed to professional ethics, responsibilities and norms of practices.
PO 6: An ability to recognize the need for continuous learning throughout his professional career in the context of technological challenges and advancements

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

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

Course Objectives

This course enables the students to:

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

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

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

Syllabus

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

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

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

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

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

Textbooks:

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

Reference books:

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

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

List of the Experiments:

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

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

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

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

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

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

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

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

References :

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

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

Module I:

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

Module II:

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

Module I:

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

Module II:

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

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

Course Objectives

This course enables the students:

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

Course Outcomes

After the completion of this course, students will be:

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

Syllabus

Module I:

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

Module II:

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

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

Course Objectives

This course enables the students:

1.	To know fundamental of hypersonic flow and its importance.
2.	To learn hypersonic shock, expansion-wave relations.
3.	To analyze the hypersonic inviscid flowfields using approximate and exact methods.
4.	To comprehend basic aspects boundary layer and aerodynamic heating in viscous hypersonic flow.
5.	To apply computational fluid dynamics in hypersonic viscous flow.

Course Outcomes

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

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

Syllabus

Module I:

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

Module II:

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

Course code: SR 581
Course title: Missile Aerodynamics
Pre-requisite(s): Elements of Aerodynamics
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech
Semester / Level: II/05
Branch: Space Engineering & Rocketry
Name of Teacher:

Course Objectives

This course enables the students:

1.	To understand the static stability of a missile.
2.	To learn the fundamental concept of dynamic stability and its characteristics of a missile.
3.	To analyze the air loads and component load distribution of a missile.
4.	To learn aerodynamic launching problems.
5.	To understand dispersion of a missile and its design consideraoin.

Course Outcomes

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

CO1	Learn the static longitudinal, directional and lateral stability of a missile.
CO2	Apply the fundamental concept of dynamic stability for longitudinal and lateral dynamic stability analysis.
CO3	Analyze the air loads, component load distribution and aerodynamic hinge moments of a missile.
CO4	Learn the aerodynamic launching problems in air, ground and underwater launch.
CO5	Understand the free flight dispersion and its consideration in design.

Syllabus

Module I:
Introduction to Missiles and Static Stability : Introduction, Forces and Moments for Two Degree of Freedom in Static Longitudinal Stability; Derivation of Forces, Moments and Static Margin; Load Factors for Complete Missile, Canard, Wing and Tail Controls; Interference Factors; Methods to Alter the Stability of Missile; Relation between Angles

in Pitch and Yaw Plane with Total Angle of Attack; Methods to Estimate the Stability of Missile in Yaw Plane; Effect of Different Control Surfaces; Induced Rolling; Roll Damping. [12 L]

Module II:

Dynamic Stability : Introduction, Equation of Motion for Six Degrees of Freedom, Oscillating and Non Oscillating Motion; Short and Long Period, Phugoid Motion, Longitudinal Dynamic Stability with Two and Three Degree of Freedom, Time- to- Half and Time- to- Double, Effect due to Angular Velocity, Lateral Dynamic Stability, Response Characteristics of Missile. [8 L]

Module III:

Air Loads : Introduction, Design Criteria for Forward and Rear Control, Component Air Loads on Body and Aerodynamic Surfaces, Component Load Distribution on Body and Aerodynamic Surfaces, Aerodynamic Hinge Moments, Aerodynamic Heating. [8 L]

Module IV:

Aerodynamic Launching Problems : Introduction, Safety of Parent Aircraft in Air Launch, Launch Boundaries in Air Launch, Consideration to Parent-aircraft Performance, Problems in Ground Launch, Range Safety, Shipboard and Underwater Launches. [8 L]

Module V:

Free-flight Dispersion : Introduction, Dispersion During Launch or Boost Phase of Missiles, Dispersions During Power-off Flight of a Ballistic Missile, Dispersion-sensitivity Factors in Vacuum, Reentry-body Design Considerations. [8 L]

Text books:

1. Missile Configuration Design, Chin, S. S., McGraw-Hill, 1982. **(T1)**

Reference books:

1. Fundamental of Aerodynamics, Anderson, John D., McGraw-Hill, 2001. **(R1)**

2. Missile Aerodynamics, Jack N. Nielson, McGraw-Hill, 1960. **(R2)**

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

Course Objectives

This course enables the students:

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

Course Outcomes

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

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

Syllabus

Module I:
Introduction: Computational Fluid Dynamics; Classification of Partial Differential Equations; Linear and Non- linear Partial Differential Equations – Model Equation, Elliptic Equation, Parabolic Equation and Hyperbolic Equation; System of 1st order Partial Differential Equations; System of 2nd order Partial Difference Equations; Initial Conditions; Boundary Conditions. [8L]
Module II:
Finite Difference Formulations: Introduction; Taylor Series Expansion; Finite Difference by Polynomial; Finite Difference Equations; Higher Order Derivatives; Multidimensional

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

Module III:

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

Module IV:

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

Module V:

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

Text books:

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

Reference books:

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

Course code: SR 614
Course title: Turbulence Modeling in CFD
Pre-requisite(s): Fluid Mechanics, Numerical Analysis, Computational Fluid Dynamics
Co- requisite(s): Nil
Credits: L:3 T:0 P:0
Class schedule per week: 03
Class: M. Tech.
Semester / Level: III/6
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students:

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

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

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

Syllabus

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

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

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

Module IV:

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

Module V:

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

Text books:

1. Wilcox, D. C., Turbulence Modeling for CFD, DCW Industries, 1994. (**T1**)

2. Versteeg, H. K., and Malalasekera, W., An Introduction to Computational Fluid Dynamics, Pearson Education Limited, 2007. (**T2**)

Reference books:

1. Blazek, J., Computational Fluid Dynamics: Principles and Applications, Elsevier, 2001. (**R1**)

2. Hoffmann, K. A. and Chiang, S. T., Computational Fluid Dynamics (Vol. III), Engineering Education System, 2000. (**R2**)

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

Oblique Shock and Expansion Wave : Introduction and Source of Oblique Waves; Mach Wave; Mach Cone; Oblique Shock Relations for Pressure, Temperature and Mach

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

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

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

Text books:

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

Reference books:

4. Gas Dynamics - Rathakrishnan, E.

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

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

Layer; Forced and Natural Flows; Adiabatic Wall; Effect of Prandlt's Number. Relation between Velocity and Temperature Fields – Adiabatic Wall and Heat Transfer; Recovery Factor. [9]

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

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

Text books:

1. Boundary Layer Theory –H. Schlichting

2. Fundamental of Aerodynamics – John D. Anderson

Reference books:

1.. Viscous Fluid Flow – Frank M. White

Course code: SR 579
Course title: Experimental Aerodynamics
Pre-requisite(s): Engineering Mathematics
Co- requisite(s): NA
Credits: L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: II/5
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives
This course enables the students to:

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

Course Outcomes

After the completion of this course, students will be:

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

Syllabus

SR 579 : EXPERIMENTAL AERODYNAMICS

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

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

Pressure, Velocity, Force and Moment Measurement: Pitot Static Probe; Laser Doppler Velocimeter; Mechanical System for Pressure Measurement; Water and Mercury Manometers; Principle of Pressure Transducer; Different Types of Pressure

Transducers; Mechanical Pressure Scanner, Electronic Pressure Scanner; Pressure Sensitive Paint; Calibration of Pressure Measuring Units, Definition of Forces and Moments on Aerospace Vehicles; Basic Principle of Mechanical Balance and Strain Gage Balance; Interaction between Different Components of Forces and Moments; Major Components for Force and Moment Measuring Systems. [9]

Unsteady Measurement: Introduction to Unsteady data; Introduction to Turbulent measurements; Basic Principle of Hot Wire Anemometer; Constant Current and Constant Temperature Anemometer, Measurement of Unsteady Velocities Using Hot Wire Anemometers; Measurement of Turbulent Stresses; Single and Multiple Hot Wire Probes; Basic Principles of Unsteady Pressure Transducers; Calibration of Steady and Unsteady Pressure Transducers. [9]

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

Text books:

1. High Speed Wind Tunnel Testing – Roe, W. H. and Pope, A.
2. Low Speed Wind Tunnel Testing – Pope, A. and Goin, L.

Reference books:

3. Random Data: Analysis and Measurement Procedures – Bendat, J. S. and Piersol. A.G.

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

List of the Experiments:

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

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

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

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

List of the Experiments:

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

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

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

supersonic flow with M=2.0

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

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

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

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

References :

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

Course code: SR 611
Course title: Fundamental of Turbulence
Pre-requisite(s): Fundamental of Aerodynamics
Co- requisite(s):
Credits: 3 L:03 T: P:
Class schedule per week: 03
Class: M. TECH.
Semester / Level: III/6
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

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

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

5. **Statistical description, Turbulent Transport, Spectral Dynamics:** Probability density, Effect of spikes and discontinuities, Correlations, Transport in stationary, homogenous turbulence, Diffusion equation, Uniform shear flow, Grid turbulence, one and three

dimensional spectra, Three dimensional spectrum, Isotropic relations, effect of production and dissipation. [9]

Text books:

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

Reference books:

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

Course code: SR 612
Course title: Aerodynamics of Internal Flows
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M. Tech.
Semester / Level: III/06
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

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

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

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

Text books:

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

Reference books:

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

Course code: MSR 613
Course title: Basics of Measurement
Pre-requisite(s): NA
Co- requisite(s): NA
Credits: 3 L:3 T:0 P:0
Class schedule per week: 3 Lectures
Class: M.Engg
Semester / Level: III / 6
Branch: Space Engg. & Rocketry
Name of Teacher:

Course Objectives

This course enables the students to:

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

Course Outcomes

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

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

Syllabus

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

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

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

Measurement of Pressure, Flow and Temperature: Static and Dynamic pressure; Pressure measuring system and transducers; Dynamic characteristics of pressure measuring system; Calibration method; Obstruction meter; Flow meters; Pressure probes;

Thermal anemometer; Calibration of flow measuring devices; Pressure thermometer; Thermo resistive elements; Thermocouple; Errors; Measurement of temperature in fluid flow; Measurement of heat flux. [9L]

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

Text books:

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

Reference books:

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

Course code: SR 615
Course title: Data Acquisition and Processing Lab
Pre-requisite(s): NA
Co- requisite(s):
Credits: 2 L:0 T:0 P:4
Class schedule per week: 03
Class: ME
Semester / Level: III/06
Branch: Space Engg. and Rocketry
Name of Teacher:

Course Objectives
This course enables the students to:

1.	Understand the need the data acquisition in the aerospace application.
2.	Remember and recognize the software used in the Data acquisition systems.
3.	Use the hardware and software for simple problems of DAQ.
4.	Analyze the obtained data through various post processing methods.
5.	Design the program for various data acquisition problems.

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

CO1	Recognizing the need of data acquisition systems.
CO2	Able to understand the basics of software to be used for DAQ
CO3	Solving simple problems of data acquisition.
CO4	Able to execute programs and examine the obtained data for DAQ.
CO5	Able to design the programs for complex problems of DAQ.

Syllabus

Data Acquisition Lab :

1. Introduction to the Data Acquisition system and Labview.
2. Overview of front and back panel. Simple programming using Labview such as creation of mathematical calculators, obtaining the sine curve in front panel, etc.
3. Introduction to DAQ Assistant, hardware and program to obtain DC voltage from a given source.
4. Obtaining DC voltages from multiple sources, its tabulation and recording.
5. Acquisition of signals in time and frequency domain for single source.
6. Acquire the signals in time and frequency domain for multiple sources.
7. Introduction to Signal conditioning and acquisition of data from strain gages.
8. Post processing of the data using spectral methods.
9. Introduction to output voltages from DAQ (trigger, pulse, continuous source).
10. Controlled operation of DC/ Stepper motor/ PID control using DAQ and Labview.

Text books:

Reference books: