



# GUJARAT TECHNOLOGICAL UNIVERSITY

Program Name: Master of Engineering

Level: PG

Subject Code : ME02000541

Subject Name : Advanced Fluid Mechanics

w. e. f. Academic Year:	2024-25
Semester:	2
Category of the Course:	Professional Elective Course

<b>Prerequisite:</b>	Basic knowledge of undergraduate-level Fluid Mechanics.
<b>Rationale:</b>	This course provides an in-depth understanding of fluid mechanics and gas dynamics principles for solving advanced engineering problems in aerospace, automotive, and energy industries.

### Course Outcome:

After Completion of the Course, Student will able to:

No	Course Outcomes	RBT level
1	Demonstrate fundamental kinematics and conservation principles of fluid systems	R,U
2	Apply Navier-Stokes equations to solve high and low Reynolds number flows	A
3	Analyze boundary layer formation, transition, and flow characteristics	A,N
4	Design and optimize systems involving turbulent flows using phenomenological theories	C
5	Evaluate the effects of shocks and compressibility in duct flows	E

### Teaching and Examination Scheme:

Teaching Scheme (in Hours)			Total Credits L+T+(PR/2)	Assessment Pattern and Marks				Total Marks
L	T	PR	C	Theory		Tutorial / Practical		
				ESE (E)	PA / CA (M)	PA/CA (I)	ESE (V)	
3	0	2	4	70	30	20	30	150

### Course Content:

Unit No.	Content	No. of Hours	% of Weightage
1.	<b>Unit 1: Fluid Mechanics Basics :</b> Review of Basic Concepts and Fluid Properties: <ul style="list-style-type: none"><li>Basic laws of fluid motion: Continuity, momentum, and</li></ul>	6	15



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	<p>energy equations.</p> <ul style="list-style-type: none"> <li>• Internal stresses and external forces on fluid elements.</li> <li>• Concepts of vorticity and circulation.</li> <li>• Velocity potential and stream function.</li> <li>• Analysis of irrotational flow.</li> </ul> <p>Governing Equations of Fluid Flow:</p> <ul style="list-style-type: none"> <li>• Navier-Stokes equations: Derivation and physical significance.</li> <li>• Exact solutions for simple flow cases: Plane Poiseuille and Couette flow.</li> <li>• Energy equation for fluid flows with thermal effects.</li> </ul>		
2.	<p><b>Unit 2: Dynamics of Ideal and Real Flows:</b></p> <p>Ideal Fluid Motion:</p> <ul style="list-style-type: none"> <li>• Euler's equation of motion: Derivation and applications.</li> <li>• Generalized Bernoulli equation: Interpretation and applications in ideal fluid flows.</li> <li>• Principle of superposition and its application in potential flows.</li> </ul> <p>Boundary Layer Theory:</p> <ul style="list-style-type: none"> <li>• Prandtl's boundary layer equations.</li> <li>• Laminar boundary layer over a flat plate: Blasius solution.</li> <li>• Approximation methods for boundary layer equations.</li> <li>• Momentum integral methods: Holstein and Bohlen method.</li> <li>• Thermal boundary layer theory and Reynolds analogy.</li> </ul>	8	20
3.	<p><b>Unit 3: Turbulence and Stability</b></p> <p>Transition to Turbulence:</p> <ul style="list-style-type: none"> <li>• Introduction to hydrodynamic stability theory.</li> <li>• Orr-Sommerfeld equation: Basic principles and results from stability studies.</li> <li>• Factors affecting transition from laminar to turbulent flow.</li> </ul> <p>Turbulent Flow Fundamentals:</p> <ul style="list-style-type: none"> <li>• Reynolds stress tensor: Definition and importance.</li> <li>• Phenomenological theories: Prandtl's mixing length and eddy viscosity concepts.</li> <li>• Universal velocity distribution: Logarithmic law of the wall and wake.</li> <li>• Energy cascade and Kolmogorov's theory.</li> </ul>	8	20
4.	<p><b>Unit 4: Gas Dynamics</b></p> <p>One-Dimensional Isentropic Flow:</p> <ul style="list-style-type: none"> <li>• Basic equations for isentropic flow in ducts.</li> </ul>	8	20



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	<ul style="list-style-type: none"> <li>• Choking phenomenon in isentropic flows.</li> <li>• Design and operation of nozzles and diffusers under varying pressure ratios.</li> <li>• Performance of real nozzles and applications.</li> </ul> <p>Normal Shocks:</p> <ul style="list-style-type: none"> <li>• Governing equations for shock waves: Conservation of mass, momentum, and energy.</li> <li>• Rankine-Hugoniot relations and Prandtl relations.</li> <li>• Weak and strong shocks: Thickness of shocks.</li> <li>• Effects of normal shocks on converging-diverging nozzle performance.</li> </ul> <p>Oblique Shocks and Expansion Waves:</p> <p style="padding-left: 20px;">Formation and analysis of oblique shocks.</p> <ul style="list-style-type: none"> <li>• Prandtl-Meyer expansion waves and applications.</li> </ul>		
5	<p><b>Unit 5: Advanced Applications in Fluid and Gas Dynamics:</b></p> <p>Flow in Constant Area Ducts with Friction (Fanno Flow):</p> <ul style="list-style-type: none"> <li>• Governing equations and working formulas.</li> <li>• Choking phenomena due to friction.</li> <li>• Effects on performance of long ducts.</li> </ul> <p>Flow in Constant Area Ducts with Heat Transfer (Rayleigh Flow):</p> <ul style="list-style-type: none"> <li>• Governing equations and thermodynamic implications.</li> <li>• Applications of Rayleigh flow in heat-exchanger designs.</li> </ul> <p>Case Studies and Advanced Applications:</p> <ul style="list-style-type: none"> <li>• Real-world applications in aerospace and automotive engineering.</li> <li>• Numerical techniques for solving compressible flow problems.</li> </ul>	5	15
<b>Total</b>		<b>45</b>	<b>100</b>

**Suggested Specification Table with Marks (Theory):**

Distribution of Theory Marks					
R Level	U Level	A Level	N Level	E Level	C Level
15	25	30	20	10	--

*Where R: Remember; U: Understanding; A: Application, N: Analyze and E: Evaluate C: Create (as per Revised Bloom's Taxonomy)*

**References/Suggested Learning Resources:**

**(a) Books:**

1. Yunus Cengel and John Cimbala, Fluid Mechanics, McGraw Hill.



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2. F. M. White, Viscous Fluid Flow, McGraw Hill.
3. H. Schlichting, Boundary Layer Theory, McGraw Hill.
4. J. D. Anderson, Computational Fluid Dynamics, McGraw Hill.
5. S. M. Yahya, Fundamentals of Compressible Flow, New Age Publishers.

## (b) Open-source software and website:

1. OpenFOAM: CFD software for flow simulations.  
- [www.openfoam.com](https://www.openfoam.com)
2. SimScale: Cloud-based simulation platform.  
- [www.simscale.com](https://www.simscale.com)
3. NASA Technical Reports Server (NTRS): Research and technical papers.  
- [ntrs.nasa.gov](https://ntrs.nasa.gov)
4. NPTEL: Free video lectures and notes.  
- [nptel.ac.in](https://nptel.ac.in)
5. CFD Onlin: Tutorials and discussion forums for CFD.  
- [www.cfd-online.com](https://www.cfd-online.com)
6. GitHub: Source code repositories for fluid mechanics projects.  
- [github.com](https://github.com)
7. NIST Chemistry WebBook: Fluid properties database.  
- [webbook.nist.gov](https://webbook.nist.gov)

## Suggested Course Practical List: If any

1. Measure the effect of angle of attack on lift and drag forces using a wind tunnel.
2. Study the energy loss in wake regions behind different models (car, bus, etc.).
3. Plot the velocity distribution over NACA aerofoils for various flow conditions.
4. Measure boundary layer thickness using analytical and numerical solutions.
5. Visualize flow patterns around objects using Hele-Shaw apparatus.
6. Create a gas dynamics table (isentropic flow, normal shocks, etc.) for different  $\gamma$  values.
7. Analyze the efficiency and operational characteristics of a converging-diverging nozzle.
8. Derive the velocity profile for flow through an elliptical duct by solving Navier-Stokes equations.

## List of Laboratory/Learning Resources Required:

### Laboratory Resources

1. Wind Tunnel (Subsonic and Supersonic)
2. Hele-Shaw Apparatus
3. Boundary Layer Measurement Apparatus
4. Flow Visualization Tools
5. Pressure Measurement Instruments



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6. Computational Resources
7. Nozzle Performance Testing Apparatus
8. Shock Tube Apparatus
9. Thermal Boundary Layer Testing Setup
10. Fanno and Rayleigh Flow Demonstrators

## Learning Resources

### 1. Online Simulation Platforms

- SimScale: Cloud-based CFD simulations.
- CFD Online: Tutorials and forums for CFD problems.
- OpenFOAM Training: Online courses and user guides for OpenFOAM.

### 2. Online Learning Platforms

- MIT OpenCourseWare: Lectures on fluid mechanics and gas dynamics., <https://ocw.mit.edu>
- NPTEL Courses: Comprehensive fluid mechanics modules., <https://nptel.ac.in>

## Suggested Project List:

1. Wake Region Analysis Behind Objects: Study energy losses and wake patterns using a wind tunnel (models: car, bus, or cylinder).
2. CFD Analysis of Flow Over Aerofoils: Simulate flow around various aerofoil shapes using OpenFOAM or ANSYS Fluent and calculate lift/drag forces.
3. Performance Evaluation of Aerofoils: Experimentally analyze lift and drag characteristics of different NACA aerofoils in a wind tunnel.
4. Shock Tube Experimentation: Investigate normal shock propagation, strength, and its effects on pressure and temperature.
5. Thermal Boundary Layer Development: Develop temperature distribution over a flat plate and analyze the impact of thermal conductivity.
6. Supersonic Flow in Nozzles: Simulate flow behavior in converging-diverging nozzles under different pressure ratios and analyze shock formation.
7. Boundary Layer Analysis Over a Flat Plate: Solve boundary layer equations numerically and validate results with Blasius or Falkner-Skan solutions.



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8. Hydrodynamic Lubrication Analysis: Study lubrication effects in journal bearings using low Reynolds number approximations.

## Suggested Activities for Students:

1. Seminar Presentations: Deliver presentations on advanced topics like turbulence modeling, boundary layer theory, or gas dynamics applications.
2. Case Studies: Analyze real-world applications such as aerodynamic optimization of vehicles or nozzle design for rockets.
3. CFD Simulations: Perform flow simulations using tools like OpenFOAM or ANSYS Fluent.
4. Experimental Workshops: Conduct experiments on wind tunnels, Hele-Shaw apparatus, and shock tube setups.
5. Research Paper Reviews: Critically analyze and present findings from reputed journals in fluid mechanics.
6. Group Discussions: Engage in discussions on emerging trends like rarefied gas dynamics or hypersonic flows.
7. Open-Ended Problem Solving: Tackle unsolved problems in compressible flows, turbulent mixing, or flow visualization.
8. Data Analysis: Work on experimental or simulated data to identify patterns and validate theories.

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