

Introduction to Fluid Mechanics

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(A concise, organized overview for quick study and reference)

1. What Is Fluid Mechanics?

- **Definition:** The branch of physics that studies the behavior of fluids (liquids and gases) at rest (fluid statics) and in motion (fluid dynamics).
 - **Why It Matters:** Applications span aerospace, automotive, civil engineering, biomedical devices, environmental science, and everyday phenomena (e.g., weather, blood flow).
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2. Fundamental Concepts

Concept	Description	Typical Units
Fluid	Substance that continuously deforms under shear stress; cannot sustain a static shear force.	—
Continuum Hypothesis	Treats fluid as a continuous medium, ignoring molecular discreteness. Valid when the characteristic length $\gg$ mean free path.	—
Control Volume (CV)	Imaginary region in space through which fluid may flow; used for applying conservation laws.	m ³
Control Surface (CS)	The boundary of a control volume.	m ²
Reference Frame	Inertial (non-accelerating) or non-inertial (accelerating/rotating) frames; equations are simplest in inertial frames.	—

3. Governing Equations

3.1 Conservation of Mass – Continuity Equation

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- **Differential form (incompressible fluid):**

$$[\nabla \cdot \mathbf{V} = 0]$$

- **Integral form (general):**

$$\left[\frac{d}{dt} \int_{CV} \rho \, dV + \int_{CS} \rho \mathbf{V} \cdot \mathbf{n} \, dA = 0 \right]$$

3.2 Conservation of Momentum – Navier-Stokes Equations

- **General vector form:**

$$\left[\rho \left(\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V} \right) = - \nabla p + \mu \nabla^2 \mathbf{V} + \rho \mathbf{g} \right]$$

- **Key terms:**

- Inertia (left side)
- Pressure gradient, viscous diffusion, body forces (right side)

3.3 Conservation of Energy – Energy Equation

- **Simplified for incompressible flow (steady, no heat generation):**

$$\left[h + \frac{V^2}{2} + gz = \text{constant along a streamline} \right]$$

- **Full form includes:** internal energy, heat conduction, viscous dissipation, work of pressure forces.

4. Fluid Properties

Property	Symbol	Typical Units	Physical Meaning
Density	(ρ)	kg/m^3	Mass per unit volume
Viscosity (dynamic)	(μ)	$\text{Pa}\cdot\text{s}$ ($\text{kg/m}\cdot\text{s}$)	Internal friction
Kinematic Viscosity	($\nu = \mu/\rho$)	m^2/s	Diffusivity of momentum
Pressure	(p)	Pa (N/m^2)	Normal force per area
Temperature	(T)	K or $^{\circ}\text{C}$	Thermal state
Surface Tension	(σ)	N/m	Cohesive force at fluid interface

5. Dimensionless Numbers

| Number | Definition |