

Introduction to Fluid Mechanics

Introduction to Fluid Mechanics

(A concise, structured overview for beginners)

1. What Is Fluid Mechanics?

- **Definition:** The branch of physics that studies the behavior of fluids (liquids and gases) at rest and in motion.
- **Why It Matters:**
 - Designs aircraft, automobiles, pipelines, and hydraulic systems.
 - Predicts weather patterns, ocean currents, and blood flow.
 - Supports many engineering disciplines (mechanical, civil, chemical, biomedical).

2. Fundamental Concepts

Concept	Description	Typical Units
Fluid	Substance that continuously deforms under shear stress; cannot sustain a static shear force.	—
Continuum Hypothesis	Treats fluids as continuous matter, ignoring molecular discreteness. Valid when characteristic length $\gg$ mean free path.	—
Control Volume	A fixed region in space through which fluid may flow; used for applying conservation laws.	m^3
Particle (or Fluid Element)	An infinitesimally small mass of fluid that moves with the flow.	kg
Density (ρ)	Mass per unit volume.	$kg \cdot m^{-3}$
Viscosity (μ, ν)	Internal friction; resistance to relative motion of adjacent layers.	$Pa \cdot s$ (dynamic) or $m^2 \cdot s^{-1}$ (kinematic)
Pressure (p)	Normal force per unit area exerted by the fluid.	Pa ($N \cdot m^{-2}$)
Surface Tension (σ)	Force acting along a fluid surface that minimizes surface area.	$N \cdot m^{-1}$

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3. Governing Principles

3.1 Conservation Laws

1. Mass (Continuity Equation)

$$\left[\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \right]$$

- For incompressible flow ($\rho = \text{const}$): $(\nabla \cdot \mathbf{V}) = 0$.

2. Momentum (Navier–Stokes Equations)

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

- Captures inertial, pressure, viscous, and body force effects.

3. Energy

$$\left[\rho \left(\frac{\partial e}{\partial t} + \mathbf{V} \cdot \nabla e \right) = - p \nabla \cdot \mathbf{V} + \Phi + \nabla \cdot (k \nabla T) + \dot{q} \right]$$

- (e): internal energy per unit mass, (Φ): viscous dissipation, (k): thermal conductivity.

3.2 Dimensionless Numbers (Quick Reference)

Number	Formula	Physical Meaning
Reynolds (Re)	$Re = \frac{\rho V L}{\mu}$	