

Introduction to Aerodynamics

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Fundamentals, key concepts, and practical applications

1. What Is Aerodynamics?

- Definition:** The branch of fluid dynamics that studies the motion of air (or any gas) and its interaction with solid objects such as aircraft, automobiles, buildings, and sports equipment.
- Goal:** Predict and control forces (lift, drag, thrust, and moment) and flow behavior to improve performance, safety, and efficiency.

2. Basic Physical Quantities

Symbol	Quantity	Units	Typical Relevance
ρ	Air density	$\text{kg}\cdot\text{m}^{-3}$	Determines mass flow and aerodynamic forces
p	Static pressure	Pa ($\text{N}\cdot\text{m}^{-2}$)	Governs pressure distribution over surfaces
$\mathbf{V}$	Velocity (vector)	$\text{m}\cdot\text{s}^{-1}$	Primary driver of aerodynamic forces
T	Temperature	K	Affects density and speed of sound
μ	Dynamic viscosity	$\text{Pa}\cdot\text{s}$	Controls boundary layer thickness
$\nu = \mu/\rho$	Kinematic viscosity	$\text{m}^2\cdot\text{s}^{-1}$	Appears in Reynolds number

3. Governing Equations

1. **Continuity (mass conservation)** $\left[\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \right]$

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

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3. **Energy** $\left[\rho \left(\frac{\partial h}{\partial t} + \mathbf{V} \cdot \nabla h \right) = \frac{Dp}{Dt} + \Phi + \nabla \cdot (k \nabla T) \right]$ (h = specific enthalpy, Φ = viscous dissipation, k = thermal conductivity)

4. **Equation of State (ideal gas)** $[p = \rho R T]$

In most low-speed engineering work, the equations are simplified using incompressible flow assumptions (constant ρ).

4. Dimensionless Numbers

Number	Formula	Physical Meaning
Reynolds (Re)	$(Re = \frac{\rho V L}{\mu} = \frac{V L}{\nu})$	Ratio of inertial to viscous forces; predicts laminar vs. turbulent flow
Mach (M)	$(M = \frac{V}{a})$ (a = speed of sound)	Determines compressibility effects
Euler (Eu)	$(Eu = \frac{p}{\rho V^2})$	Relative importance of pressure forces
Froude (Fr)	$(Fr = \frac{V}{\sqrt{gL}})$	Role of gravity in free-surface flows
Strouhal (St)	$(St = \frac{fL}{V})$	Unsteady vortex shedding frequency

5. Aerodynamic Forces

| Force | Symbol | Typical Equation (2D airfoil) | Direction | |-----|