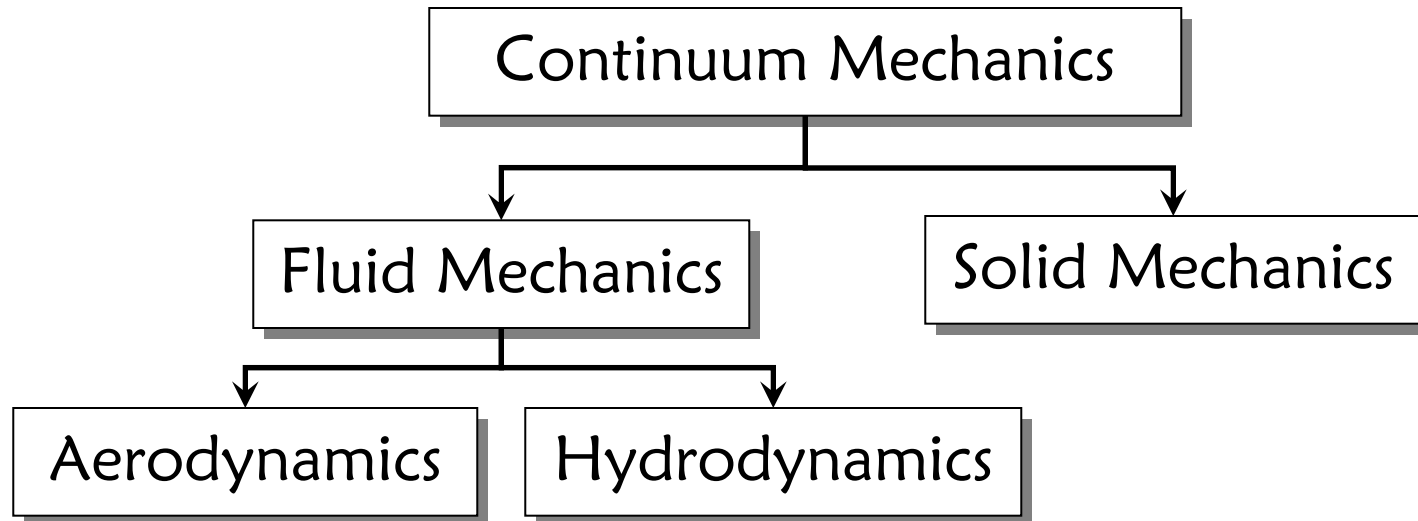


“A Flowing Gas”



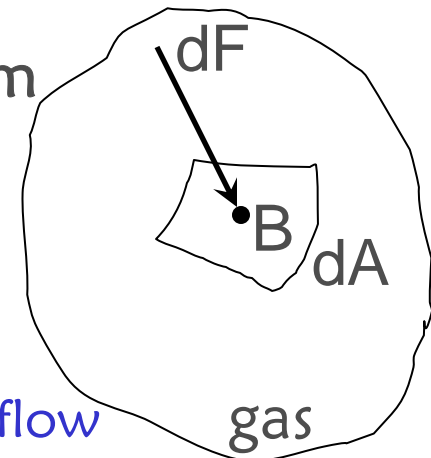
- Aerodynamics is a special subset of Fluid Mechanics, which in turn is a subset of Continuum Mechanics

Four Aerodynamic Quantities

- Pressure
Force per unit area: N/m^2 , lb/in^2 , lb/ft^2
- Density
Mass per unit volume: kg/m^3 , slug/ft^3
- Temperature
Measure of average kinetic energy
- Velocity
A vector quantity: ft/s , m/s , mi/hr , km/hr

Pressure

- “Pressure is the *normal* force per unit area exerted on a surface due to the time rate of change of momentum of the gas molecules impacting on that surface.”
- The concept of “force” arises from Newton’s 2nd Law:
 $F = m a$ or $F = d(mv)/dt$ or $F = m dv/dt$
- mv is the momentum or linear momentum
- Pressure varies from point to point
 $p = \lim dF/dA$ as $dA \rightarrow 0$
- Pressure depends on position and time:
 $p = p(x,y,z,t)$ where t -dependence \Rightarrow unsteady flow
 $p = p(x,y,z)$ where no t -dependence \Rightarrow steady flow



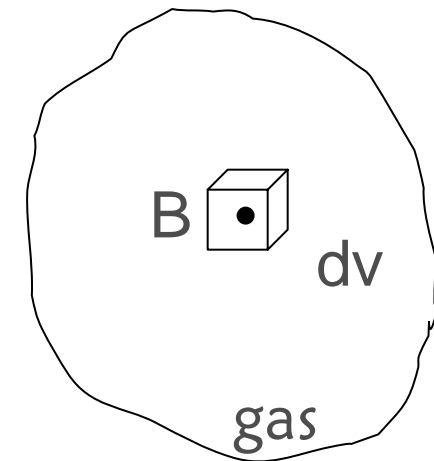
Density

- “The *density* of a substance (including a gas) is the mass of that substance per unit volume.”
- The concept of density obviously combines the concepts of *mass* and *volume*
- Density varies from point to point
- Density depends on position and time:

$$\rho = \lim (dm/dv) \text{ as } dv \rightarrow 0$$

$$\rho = \rho(x,y,z,t) \text{ where t-dependence } \Rightarrow \text{unsteady flow}$$

$$\rho = \rho(x,y,z) \text{ where no t-dependence } \Rightarrow \text{steady flow}$$

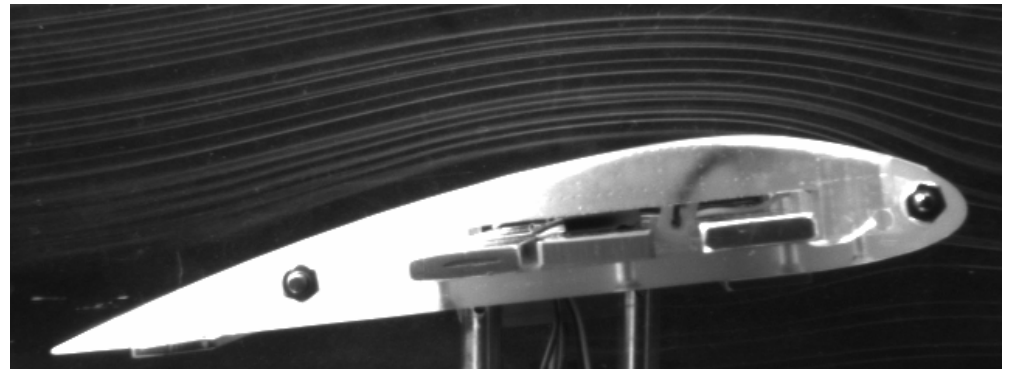
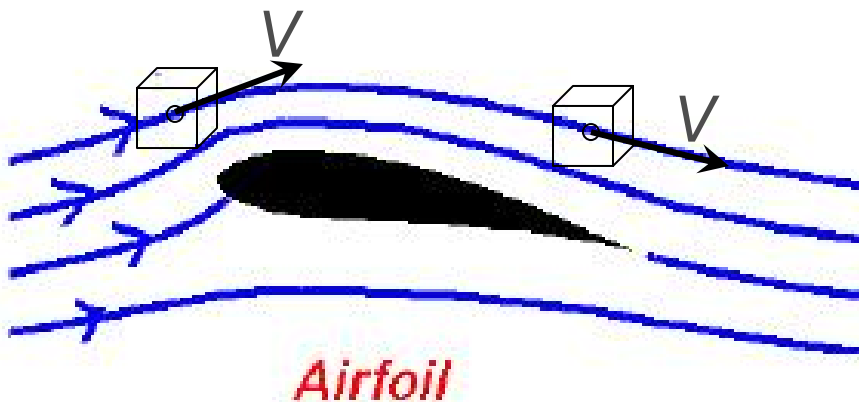


Temperature

- “*Temperature* is a measure of the average kinetic energy of the particles in the gas. If KE is the mean molecular kinetic energy, then temperature is given by $KE = (3/2)kT$, where k is the Boltzmann constant.
- The Boltzmann constant has the value:
 $k = 1.38 \times 10^{-23}$ J/K (Joules per Kelvin)
- Temperature depends on position and time:
 $T = T(x,y,z,t)$ where t-dependence \Rightarrow unsteady flow
 $T = T(x,y,z)$ where no t-dependence \Rightarrow steady flow
- Typical units:
Kelvin (K), degree Celsius ($^{\circ}\text{C}$)
degree Rankine ($^{\circ}\text{R}$), degree Fahrenheit ($^{\circ}\text{F}$)

Flow Velocity

- “The *velocity* at any fixed point B in a flowing gas is the velocity of an infinitesimally small fluid element as it sweeps through B.”
- Velocity is a *vector* quantity: it has *magnitude* and *direction*
- If the flow is *steady* (not t-dependent), then a moving fluid element traces out a fixed path or *streamline*



Flow Field

- The four aerodynamic quantities

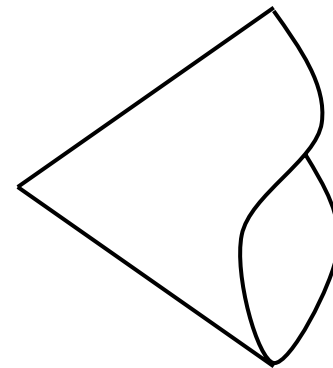
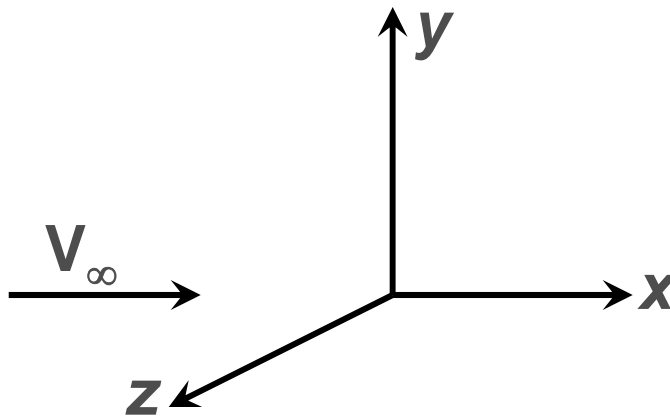
Pressure $p = p(x,y,z,t)$, (a scalar)

Density $\rho = \rho(x,y,z,t)$, (a scalar)

Temperature $T = T(x,y,z,t)$, (a scalar)

Velocity $\mathbf{V} = \mathbf{V}(x,y,z,t)$ (a vector)

define the *flow field*

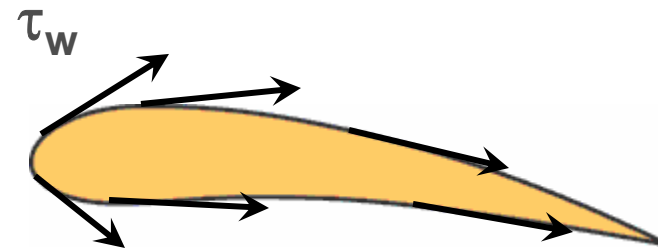
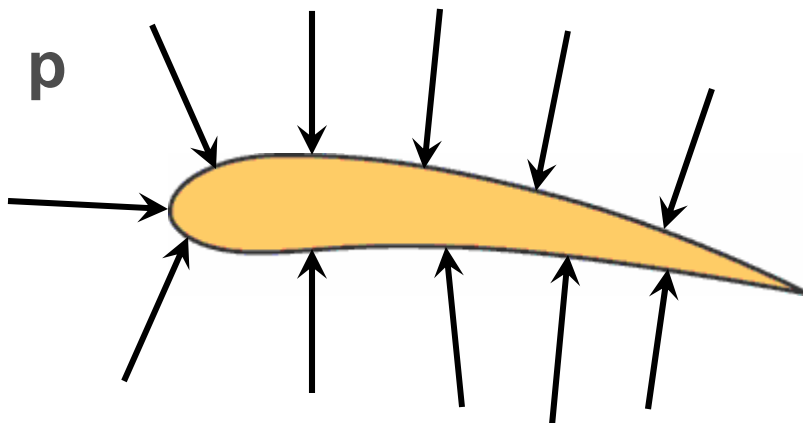


Aerodynamic Forces

- “Theoretical and experimental aerodynamicists labor to calculate and measure flow fields of many types.”
- ... because “the aerodynamic force exerted by the airflow on the surface of an airplane, missile, *etc.*, stems from only two simple natural sources:

Pressure distribution on the surface (normal to surface)

Shear stress (friction) on the surface (tangential to surface)



Aerodynamic Forces

- “A primary function of theoretical and experimental aerodynamics is to predict and measure the aerodynamic forces on a body.”
- Usually means prediction and measurement of ρ and τ_w
- Prediction and measurement of usually requires knowledge of the flow field:
 ρ , ρ , T , and \mathbf{V} which generally depend on position (x,y,z) and time (t)

Mystery Vehicle



Mystery Vehicle



Mystery Vehicle



Perfect Gas

- In reality, a gas is not a continuum, but is a collection of particles (molecules, atoms, ...)
- These particles are moving with essentially random motion (recall that Temperature is a measure of that random motion)
- There are intermolecular forces due to the electromagnetic properties of the particles
- “A *perfect gas* is one in which intermolecular forces are negligible.”
- In both subsonic and supersonic flows, air behaves essentially as a perfect gas

Equation of State for Perfect Gas

- Relationship between pressure, density, and temperature:
 $p = \rho RT$
where R is the specific gas constant (gas-dependent)
- For normal air
 $R = 287 \text{ J}/(\text{kg K}) = 1716 \text{ ft lb} / (\text{slug } ^\circ\text{R})$
- Another useful quantity is *specific volume*:
 $v = 1/\rho$ (typical units are m^3/kg and ft^3/slug)
- Equation of state can be written
 $p v = RT$

Sample Problem

The air pressure and density at a point on the wing of a Boeing 747 are $1.10 \times 10^5 \text{ N/m}^2$ and 1.20 kg/m^3 , respectively. What is the temperature at that point?

Solution: From equation of state $p = \rho RT$;
hence $T = p/(\rho R)$, or

$$T = 1.10 \times 10^5 \text{ N/m}^2 / [1.20 \text{ kg/m}^3 \times 287 \text{ J/(kg K)}]$$

$$T = 319 \text{ K}$$

