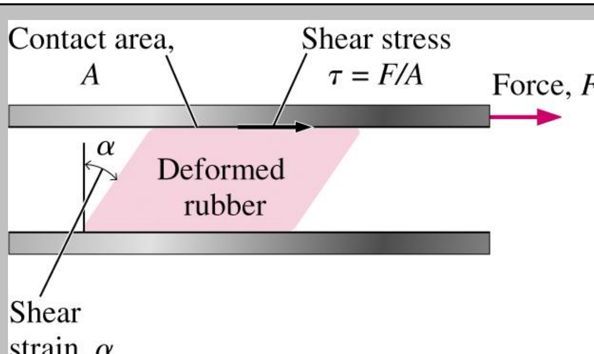
Additional Lecture No. 1 – Basic Concepts

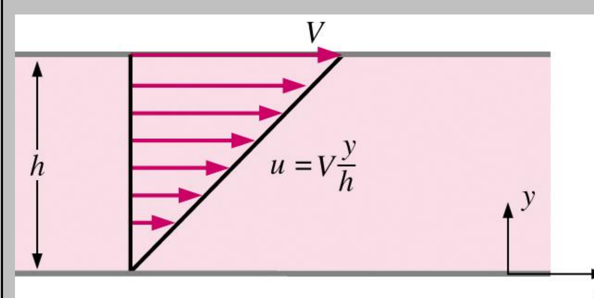
What is a fluid?

- A fluid is a substance in the gaseous or liquid form
- Distinction between solid and fluid?
  - Solid: can resist an applied shear by deforming. Stress is proportional to strain
  - Fluid: deforms continuously under applied shear. Stress is proportional to strain rate

Solid

$$\tau = \frac{F}{A} \propto \alpha$$

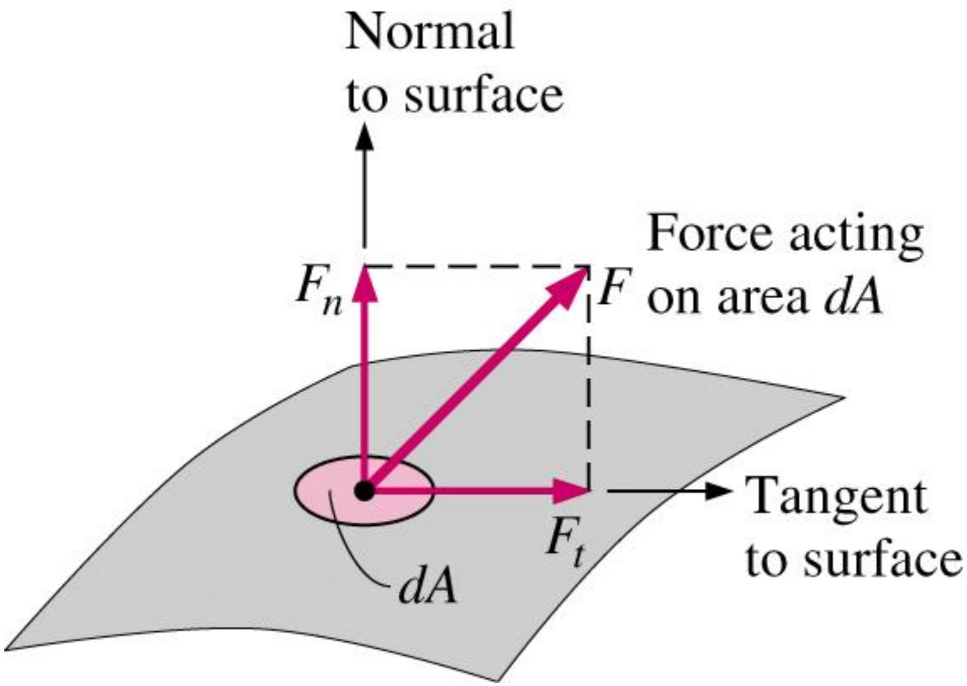




Fluid

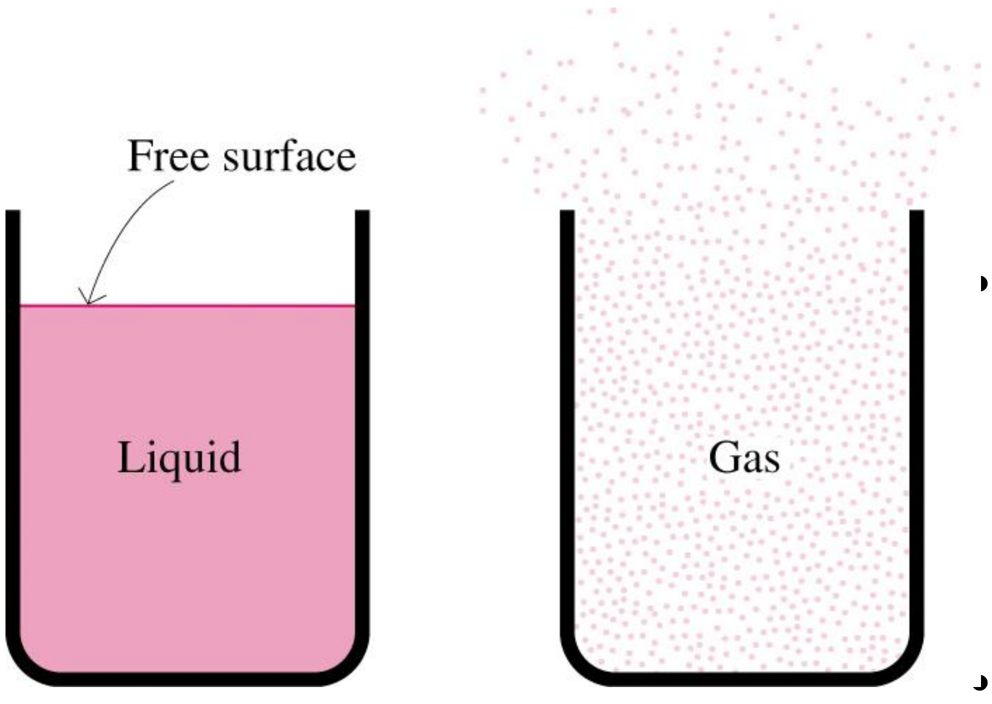
$$\tau = \frac{F}{A} \propto \mu \frac{V}{h}$$

What is a fluid?



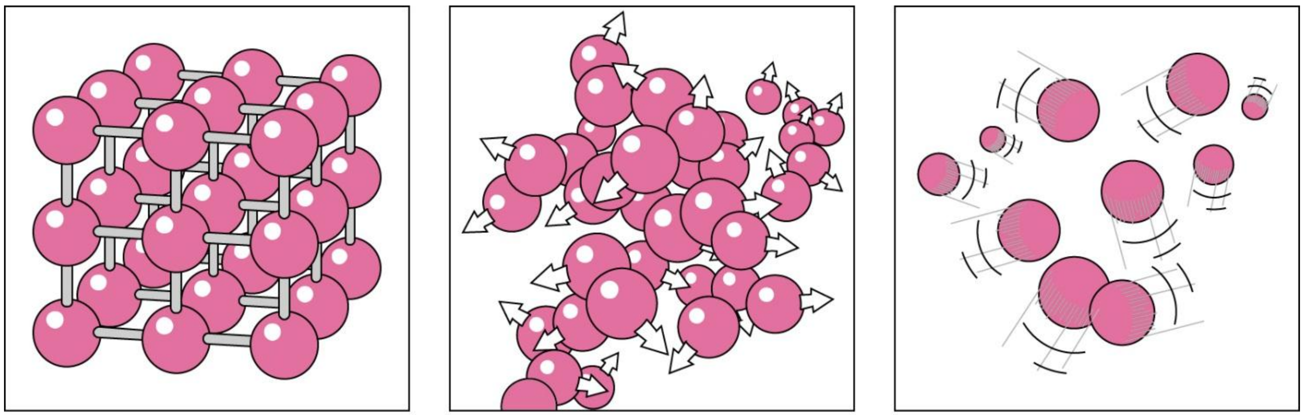
- Stress is defined as the force per unit area.
- Normal component: normal stress
  - In a fluid at rest, the normal stress is called **pressure**
- Tangential component: shear stress

What is a fluid?



- A liquid takes the shape of the container it is in and forms a free surface in the presence of gravity
- A gas expands until it encounters the walls of the container and fills the entire available space. Gases cannot form a free surface
- Gas and vapor are often used as synonymous words

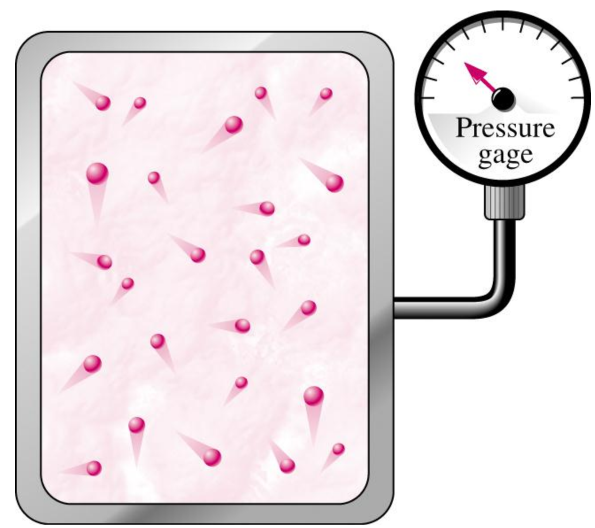
What is a fluid?



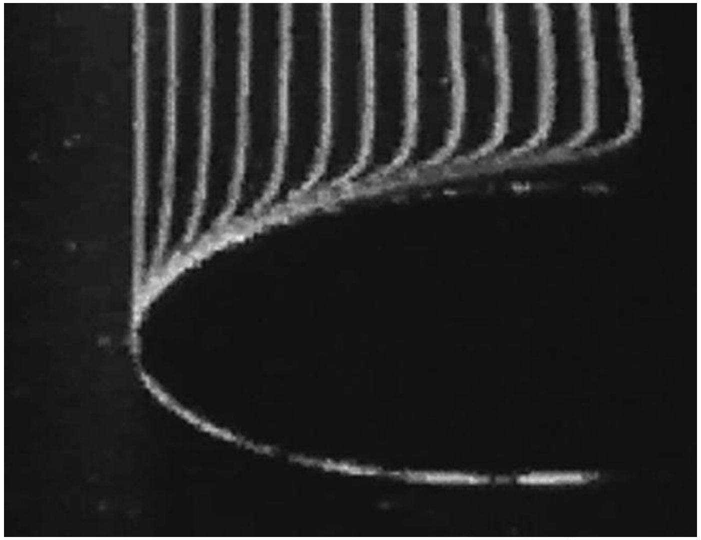
(a) solid

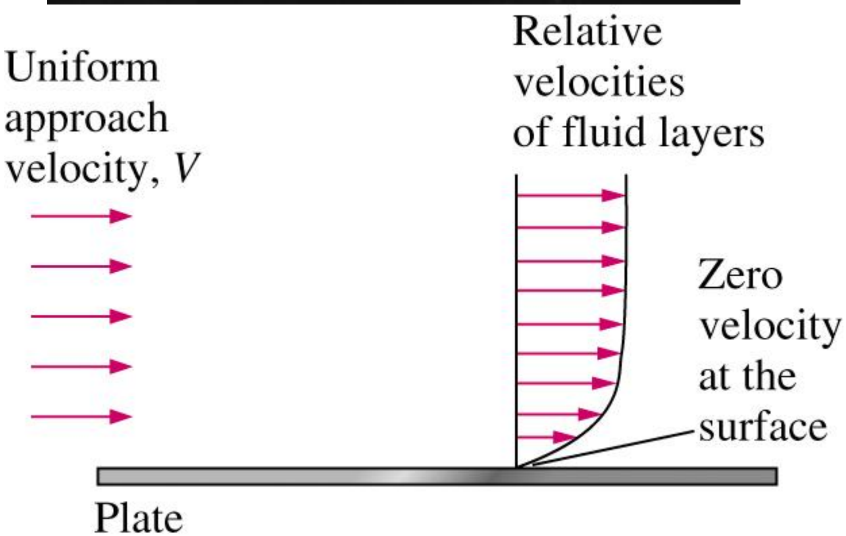
(b) liquid

(c) gas



No-slip condition





- No-slip condition: A fluid in direct contact with a solid ``sticks'' to the surface due to viscous effects
- Responsible for generation of wall shear stress τ_w, surface drag $D= \int\tau_w \, dA$, and the development of the boundary layer
- The fluid property responsible for the no-slip condition is **viscosity**
- Important boundary condition in formulating initial boundary value problem (IBVP) for analytical and computational fluid dynamics analysis

Classification of Flows

- We classify flows as a tool in making simplifying assumptions to the governing partial-differential equations, which are known as the Navier-Stokes equations
  - Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0$$

  - Conservation of Momentum

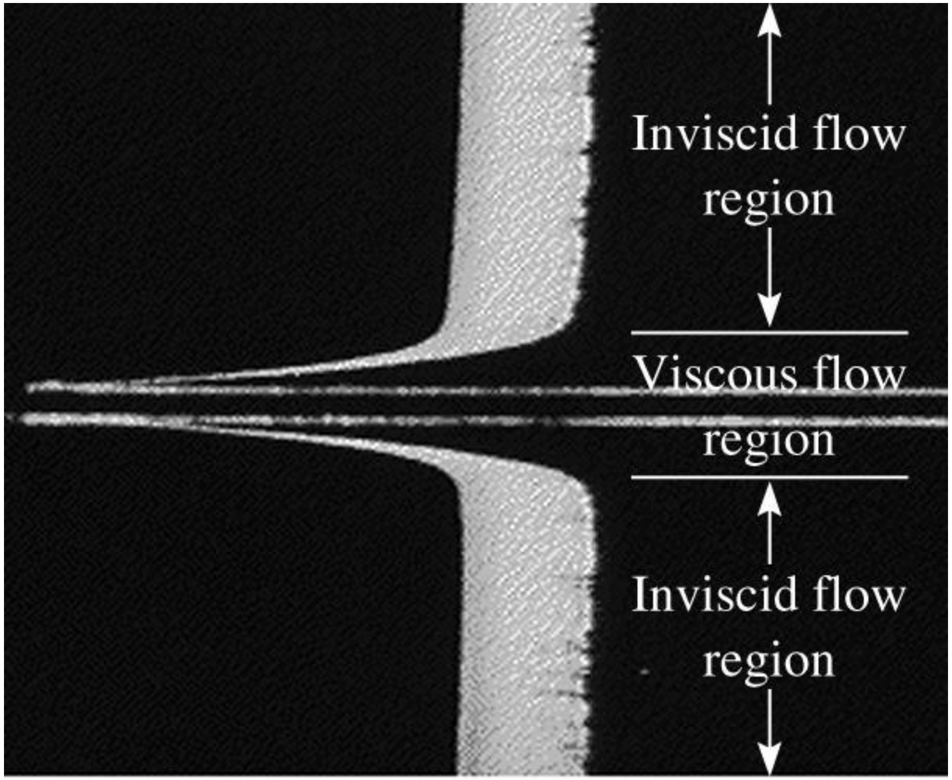
$$\rho \frac{\partial \mathbf{U}}{\partial t} + (\mathbf{U} \cdot \nabla)\, \mathbf{U} = -\nabla p + \rho \mathbf{g} + \mu \nabla^2 \mathbf{U}$$

Viscous vs. Inviscid Regions of Flow

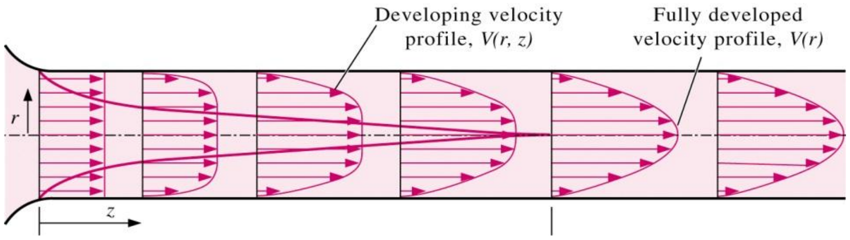
- Regions where frictional effects are significant are called viscous regions. They are usually close to solid surfaces.
- Regions where frictional forces are small compared to inertial or pressure forces are called inviscid

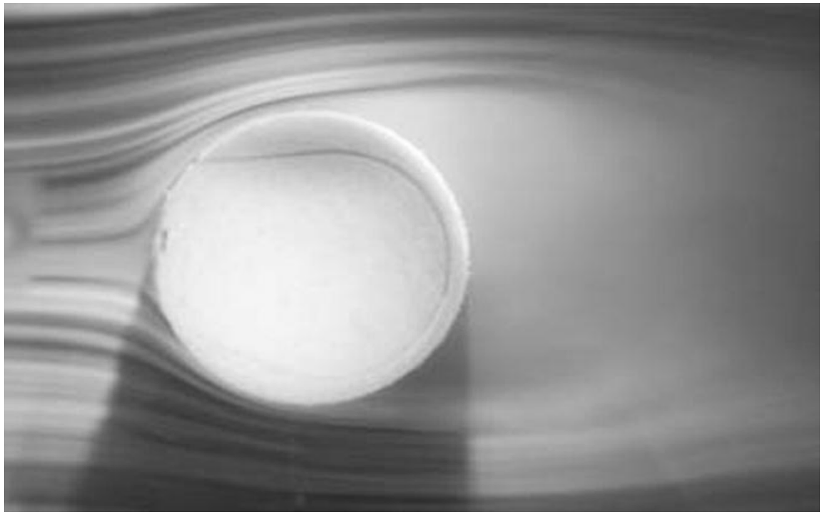
For inviscid flows:

$$\rho\frac{\partial \mathbf{U}}{\partial t} + (\mathbf{U}\cdot\nabla)\,\mathbf{U} = -\nabla p + \rho\mathbf{g} + \cancelto{0}{\mu\nabla^2\mathbf{U}}$$



Internal vs. External Flow





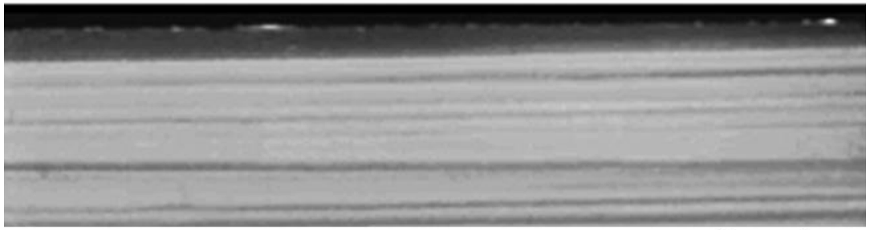
- Internal flows are dominated by the influence of viscosity throughout the flowfield
- For external flows, viscous effects are limited to the boundary layer and wake.

Compressible vs. Incompressible Flow

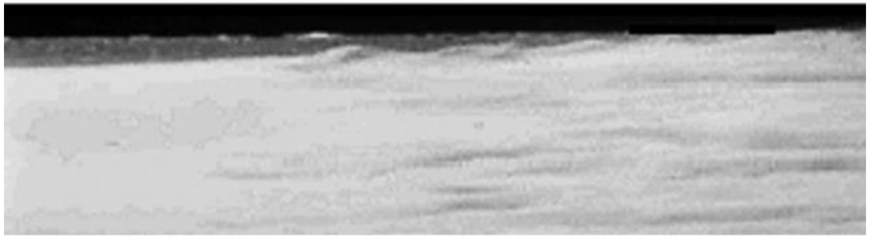
- A flow is classified as incompressible if the density remains nearly constant.
- Liquid flows are typically incompressible.
- Gas flows are often compressible, especially for high speeds.
- Mach number, Ma = V/c is a good indicator of whether or not compressibility effects are important.
  - Ma < 0.3 : Incompressible
  - Ma < 1 : Subsonic
  - Ma = 1 : Sonic
  - Ma > 1 : Supersonic
  - Ma >> 1 : Hypersonic

Laminar vs. Turbulent Flow

- Laminar: highly ordered fluid motion with smooth streamlines.
- Turbulent: highly disordered fluid motion characterized by velocity fluctuations and eddies.
- Transitional: a flow that contains both laminar and turbulent regions
- Reynolds number, Re= $\rho UL/\mu$ is the key parameter in determining whether or not a flow is laminar or turbulent.



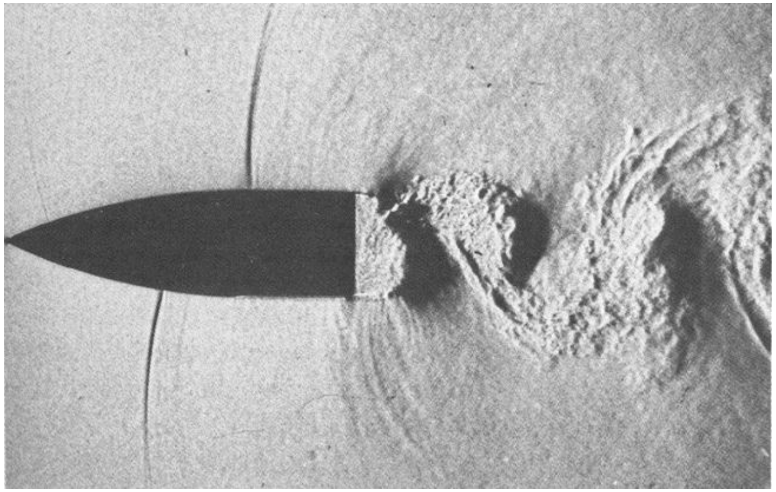
Laminar

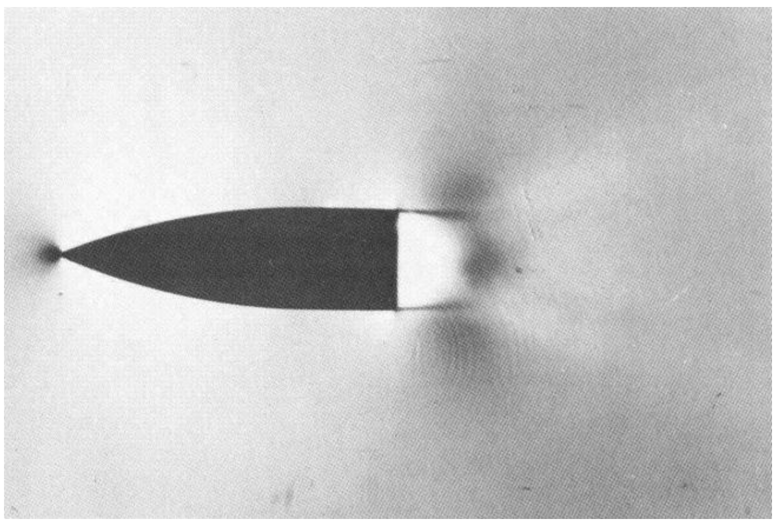


Transitional

Turbulent

Steady vs. Unsteady Flow

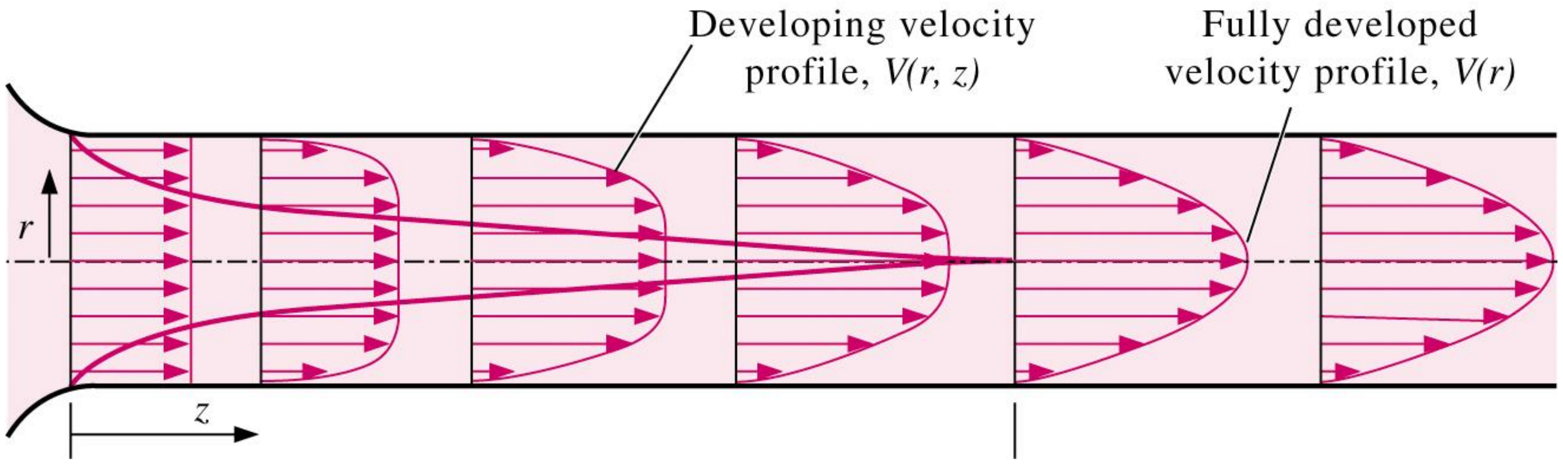




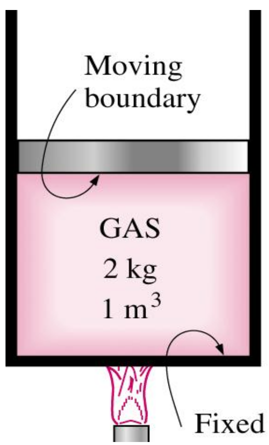
- Steady implies no change at a point with time. Transient terms in N-S equations are zero $\frac{\partial \mathbf{U}}{\partial t} = \frac{\partial \rho}{\partial t} = 0$
- Unsteady is the opposite of steady.
  - Transient usually describes a starting, or developing flow.
  - Periodic refers to a flow which oscillates about a mean.
- Unsteady flows may appear steady if "time-averaged"

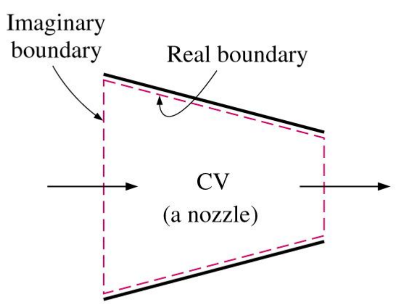
One-, Two-, and Three-Dimensional Flows

- N-S equations are 3D vector equations.
- Velocity vector, $\boldsymbol{U}(x,y,z,t) = [U_x(x,y,z,t), U_y(x,y,z,t), U_z(x,y,z,t)]$
- Lower dimensional flows reduce complexity of analytical and computational solution
- Change in coordinate system (cylindrical, spherical, etc.) may facilitate reduction in order.
- Example: for fully-developed pipe flow, velocity *V(r)* is a function of radius *r* and pressure *p(z)* is a function of distance *z* along the pipe.

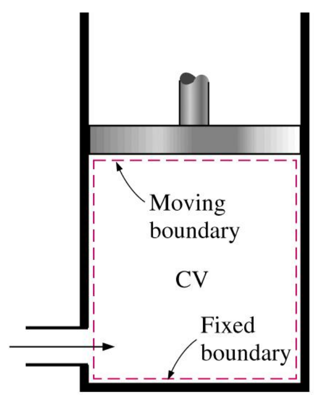


System and Control Volume





(*a*) A control volume (CV) with real and imaginary boundaries



(*b*) A control volume (CV) with fixed and moving boundaries

- A system is defined as a quantity of matter or a region in space chosen for study.
- A closed system consists of a fixed amount of mass.
- An open system, or control volume, is a properly selected region in space.
- We'll discuss control volumes in more detail in Chapter 6.

Dimensions and Units

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to dimensions are called **units**.
- Primary dimensions include: mass *m*, length *L*, time *t*, and temperature *T*.
- Secondary dimensions can be expressed in terms of primary dimensions and include: velocity *V*, energy *E*, and volume *V*.
- Unit systems include metric SI (International System).
- **Dimensional homogeneity** is a valuable tool in checking for errors. Make sure every term in an equation has the same units.

Accuracy, Precision, and Significant Digits

Engineers must be aware of three principals that govern the proper use of numbers.

1. ***Accuracy error :*** Value of one reading minus the true value. Closeness of the average reading to the true value. Generally associated with repeatable, fixed errors.
2. ***Precision error :*** Value of one reading minus the average of readings. Is a measure of the fineness of resolution and repeatability of the instrument. Generally associated with random errors.
3. ***Significant digits :*** Digits that are relevant and meaningful. When performing calculations, the final result is only as precise as the least precise parameter in the problem. When the number of significant digits is unknown, the accepted standard is 3.