



# Chapter 1 – Fluid Properties

CE30460 - Fluid Mechanics

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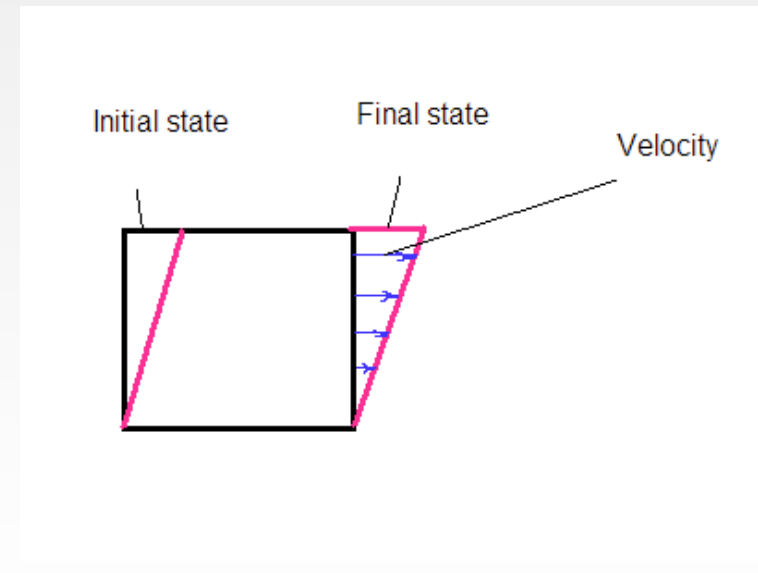
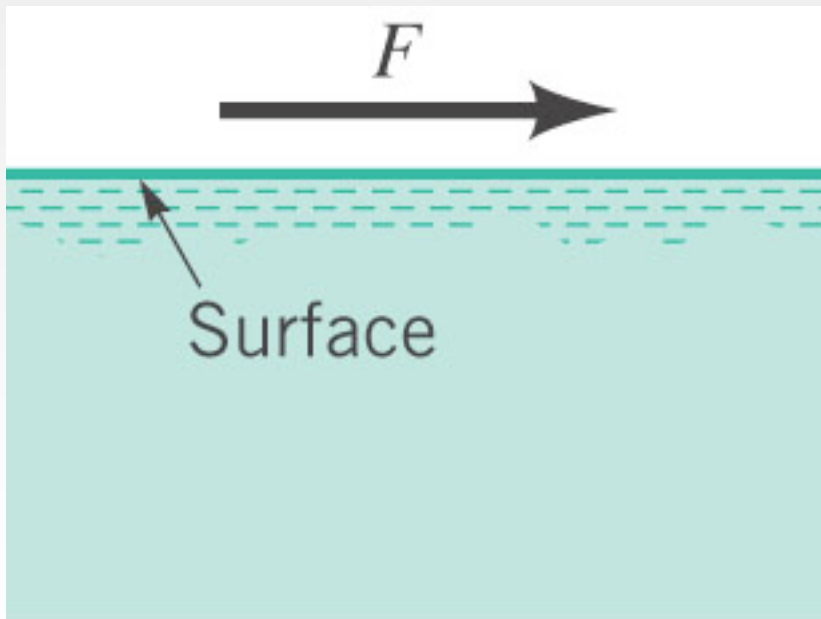


# What is a Fluid?

- A substance that deforms continuously when acted on by a shearing stress
- A solid will deform to a certain point for a given stress
- Liquids and Gases are fluids (water, oil, air)
- Some substances can act as solids and fluids (e.g. soil standing/ avalanche)



# What happens for a fluid/solid ?





# Units and Dimensions Important in Fluids

- Primary Dimensions
  - Length (L)
  - Time (T)
  - Mass (M)
  - Temperature ( $\Theta$ )
- For any relationship  $A=B$ 
  - Units (A)=Units (B)

Dimensional Homogeneity



# Systems of Units

British

Foot (ft)

Second (s)

Pound (lb)

Degree Rankine ( $^{\circ}\text{R}$ )  
related to Fahrenheit  
( $^{\circ}\text{F}+459.67$ )

SI (Systeme International)

Meter (m)

Second (s)

Kilogram (kg)

Degree Kelvin ( $^{\circ}\text{K}$ )  
related to Celsius  
( $^{\circ}\text{C}+273.15$ )



# Why are Units so Important

## Metric mishap caused loss of NASA orbiter

September 30, 1999

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CNN NASA lost a 125 million Mars orbiter because a Lockheed Martin engineering team used English units of measurement while the agency's team used the more conventional metric system for a key spacecraft operation, according to a review finding released Thursday.

The units mismatch prevented navigation information from transferring between the Mars Climate Orbiter spacecraft team in at Lockheed Martin in Denver and the flight team at NASA's Jet Propulsion Laboratory in Pasadena, California.





# Sample Problem 1 – Unit Homogeneity

- Consider the formula

$$F = K_a vt^{-1} + K_b lt^{-1} + K_c t^{-2}$$

- F – force, v – velocity, t – time, l – length
- What are the unites of the  $K_a$ ,  $K_b$  and  $K_c$  terms?



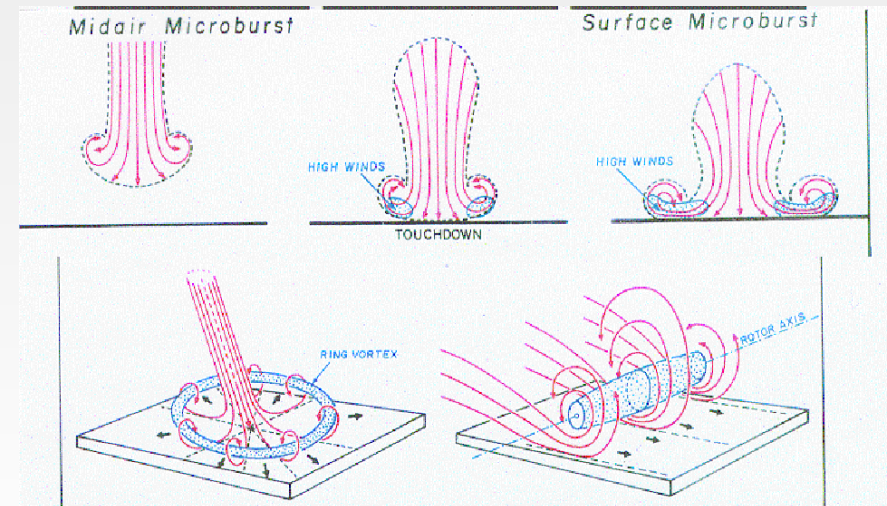
# Fluid Mass and Weight

- Density  $\rho$  [ $M L^{-3}$ ]
  - Varies with temperature and pressure
    - Liquid (often negligible changes)
    - Gasses (can be very important to account for changes)
- Specific Volume (inverse density)  $v$  [ $L^3 M^{-1}$ ]
- Specific Weight  $\gamma = \rho g$  [What are the units?]
- Specific gravity  $SG = \rho / \rho_{\text{water@4C}}$  (i.e. 1 for water at 4°C it equal to 1, for mercury 13.55, where the density of mercury would be  $13550 \text{ kg m}^{-3}$ ).



# Example 1 – Thunderstorm Fronts

Density Effects (called buoyancy) can be very very important in Environmental Flows



Also <http://video.google.com/videoplay?docid=8645834985308987314#>



## Sample Problem – Density

- A volume of  $1\text{m}^3$  is occupied by two fluids. Fluid 1 has a specific gravity of  $SG=2$ , while Fluid 2 has a density of  $800\text{ kgm}^{-3}$ ? There is three times as much mass of Fluid 2 as there is of Fluid 1.
- How much mass is there of each fluid?
- What volumetric fraction of the total volume does each fluid occupy?



# Ideal Gases

- Gases are much more compressible than liquids and their density is sensitive to changes in pressure and temperature. An ideal gas is one which follows the ideal gas law:

$$\rho = \frac{P}{RT}$$

- R – the gas constant depends on the particular gas in question.
- <http://intro.chem.okstate.edu/1314f00/laboratory/glp.htm>
- Pressure is a relative measurements and two common used measures in engineering are :  
Gauge vs. Absolute pressure (here we must use absolute)
  - Absolute is relative to absolute zero pressure
  - Gauge is measured relative to atmospheric (i.e. Absolute-Atmospheric)



# Pressure

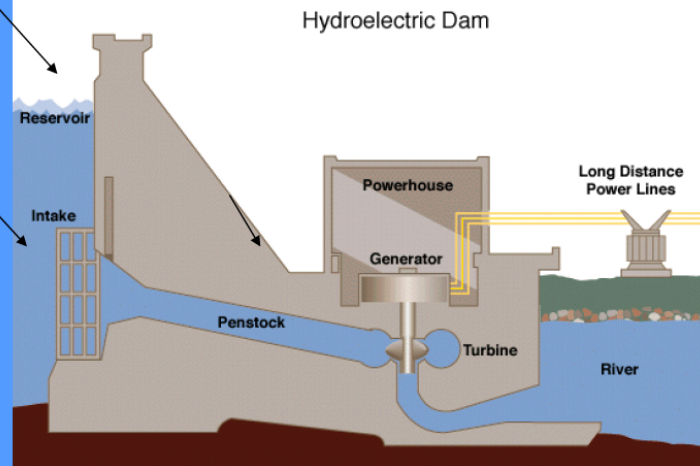
Zero absolute pressure (almost)



Zero gage pressure  
(Positive Absolute Pressure)

Positive gage pressure

•What is the minimum gage pressure possible?





# Sample Problems – Ideal Gases

- A lab is conducting experiments. The temperature is  $27^{\circ}\text{C}$  and the pressure is 14 psia. What is the density of the air?
- Express your answers in both  $\text{slugs}/\text{ft}^3$  and  $\text{kg}/\text{m}^3$
- What happens if we conduct the same experiment at an altitude of 30000 feet. What are typical temperatures and pressures at that height. What will the density of air be up there?

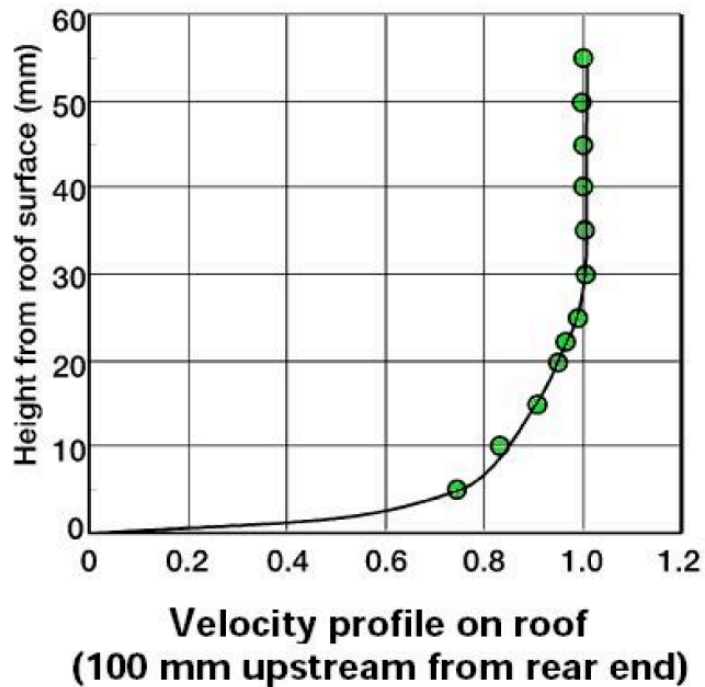


# Viscosity

- Viscosity is a measure of a fluid's resistance to shear – more viscous, more resistance
- Intrinsic property of a fluid (varies with temperature)
- Viscosity causes fluids to adhere to solid boundaries  
<http://www.youtube.com/watch?v=TADz6fqfXo0>
- Observations show shear stress is proportional to velocity gradient  $\tau \propto \frac{du}{dy}$
- (Dynamic) Viscosity ( $\mu$ ) is the constant or proportionality s.t.  $\tau = \mu \frac{du}{dy}$
- Kinematic Viscosity ( $\nu = \mu/\rho$ ) is also commonly used in formulas.



# Velocity profile of air over a car roof



Where is the region of maximum shear stress?



# Sample Problem – Shear Stress due to viscosity

- You measure a velocity profile for water at 15.6°C in the lab that can be fit with the polynomial

$$v(y) = -1.1y^3 + 12y^2 + 13.2y \quad 0 \leq y \leq 10$$

- Calculate an expression for the shear stress? Plot it.
- Where is it maximum? What is the value?
- Where is it minimum? What is the value?



# Compressibility

- How much does the volume of a fluid change for a given change in pressure
- Bulk Modulus

$$E_v = \frac{-\Delta p}{\Delta V / V} = \frac{\Delta p}{\Delta \rho / \rho}$$

- How is this different for gases and fluids?





# Compression of Gases

- Two common approaches are used
  - Isothermal (constant temperature) so from ideal gas law

$$\frac{P}{\rho} = \text{const}$$

- Isentropic (no change in entropy, frictionless with no exchange of heat to surroundings)

$$\frac{P}{\rho^k} = \text{const}$$

For many gases  $k \sim 1.4$

See table B3 and B4 in text



# Speed of Sound

- What is the speed of sound?
- <http://www.youtube.com/watch?v=QX04ySm4TTk>





# Speed of Sound

- What is the speed of sound?
  - A measure of how quickly small disturbances propagate

$$c = \sqrt{\frac{dp}{d\rho}} = \sqrt{\frac{E_v}{\rho}}$$



What does this mean for speed of sound in a liquid relative to a gas?



# Sample Problem – Speed of Sound in Water vs. Air

- Which do you think is greater?
- Calculate them.....



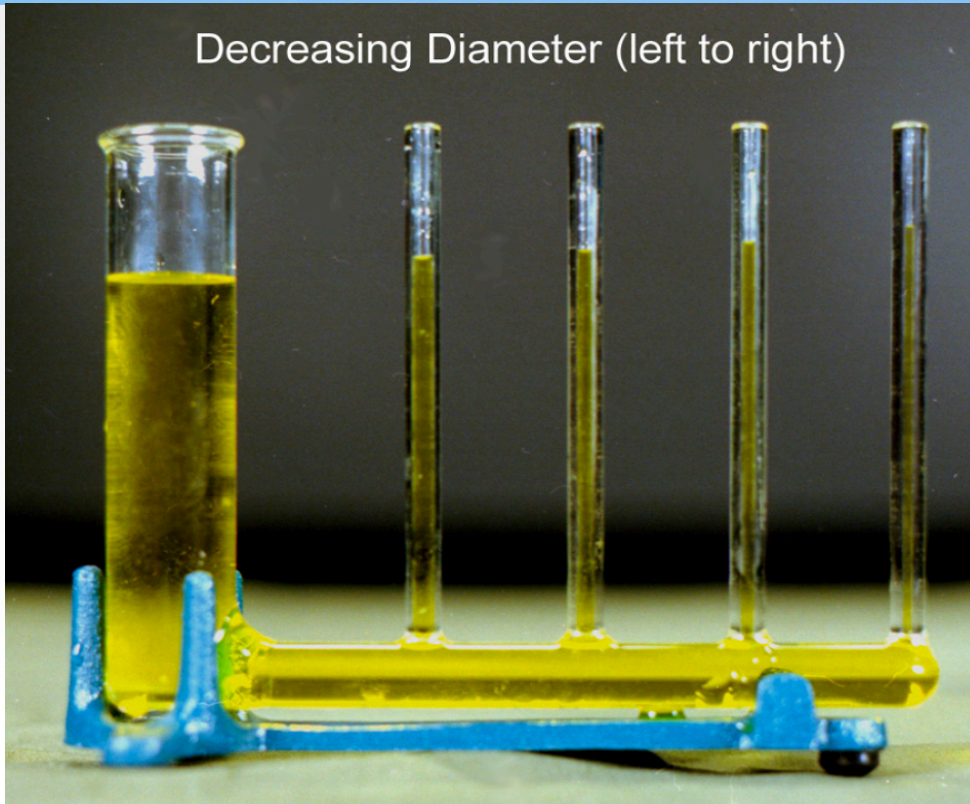
# Surface Tension

- Surface tension is a property of fluid that is important at interfaces between different fluids. The different molecular dynamics on each side of the interface lead to surface tension
- How insects walk on water; how droplets form in a specific shape
- Sensitive to changes in chemical composition (i.e. you can change surface tension easily by dissolving a solute in a fluid)
- For a capillary rise  $\gamma\pi R^2 h = 2\pi R\sigma \cos(\theta)$



# Capillary Rise

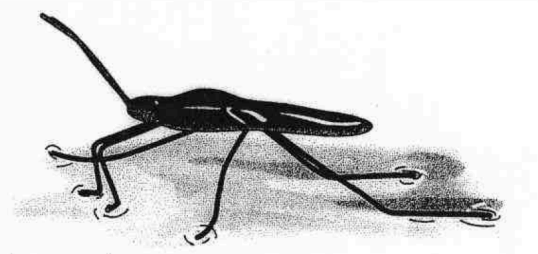
Decreasing Diameter (left to right)





## Sample Question – Walking on Water...

- A water strider is supported on the surface of a pond by surface tension acting along the interface between the water and the bugs' legs. Determine the minimum length of the interface needed to support the bug
- Assume the bug weighs  $10^{-4}$  N and that surface tension acts only vertically upwards
- Repeat the calculation for an average human weighing 750N





# Important Equations

- Specific Weight

$$\gamma = \rho g$$

- Ideal Gas Law

$$p = \rho RT$$

- Newtonian Fluid Shear Stress

$$\tau = \mu \, du/dy$$

- Bulk Modulus

$$E_v = \frac{-\Delta p}{\Delta V/V} = \frac{-\Delta p}{\Delta \rho/\rho}$$

- Speed of Sound

$$c = \sqrt{\frac{dp}{d\rho}} = \sqrt{\frac{E_v}{\rho}}$$

- Capillary Rise in a Tube

$$\gamma \pi R^2 h = 2\pi R \sigma \cos(\theta)$$