Announcements

1. **Exams will be returned at the end of class.**
   - **You may rework the exam for up to 10 extra credit points. Turn in your old exam and your new work (clearly indicated). Due 11/11/03.**
   - **You may sign up for presentations if there is sufficient interest.**
2. **Today's lecture – fluids – Chapter 15**
   - **Static fluids – buoyant force**
   - **Fluid flow**

The physics of fluids.

•Fluids include liquids (usually “incompressible) and gases (highly “compressible”).

•**Fluids obey Newton’s equations of motion**, but because they move within their containers, the application of Newton’s laws to fluids introduces some new forms.

- Pressure: P=force/area   1 (N/m^2) = 1 Pascal
- Density: ρ =mass/volume   1 kg/m^3 = 0.001 gm/ml

Note: In this chapter P≡pressure (NOT MOMENTUM)

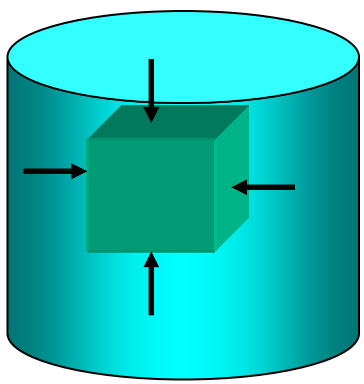
Pressure exerted by air at sea-level

$1 \text{ atm} = 1.013\text{x}10^5 \text{ Pa}$

Example: What is the force exerted by 1 atm of air pressure on a circular area of radius 0.08m?

$$F = PA = 1.013\text{x}10^5 \text{ Pa x } \pi(0.08\text{m})^2$$

$$= 2040 \text{ N}$$



Pressure exerted by a fluid acts in all directions.

Density: ρ =mass/volume

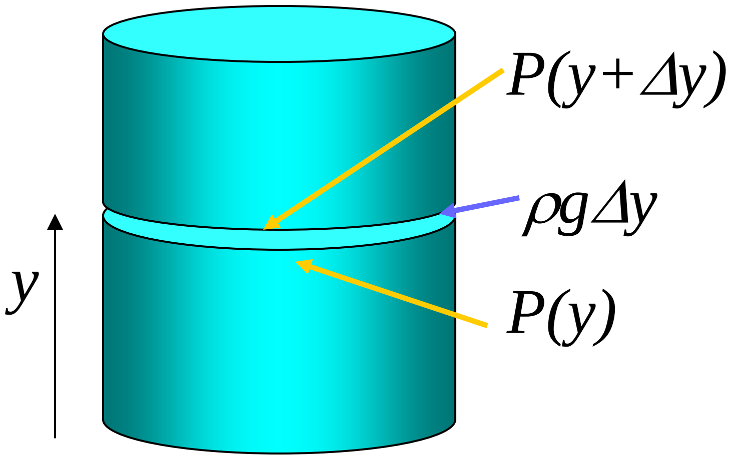
Effects of the weight of a fluid:

$$F(y) = F(y+\Delta y) + mg$$

$$\frac{F(y)}{A} = \frac{F(y+\Delta y)}{A} + \frac{mg}{A}$$

$$P(y) = P(y+\Delta y) + \rho g \Delta y$$

$$\lim_{\Delta y \to 0} \frac{P(y+\Delta y) - P(y)}{\Delta y} = \frac{dP}{dy}$$



$$\Rightarrow \frac{dP}{dy} = -\rho g$$

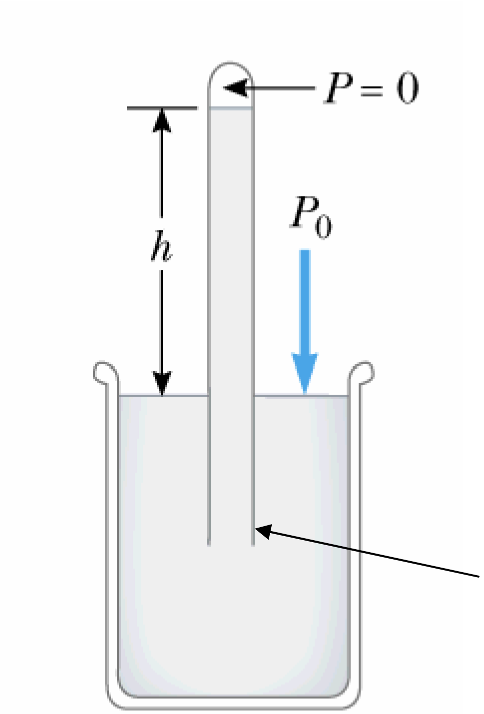
Note: In this formulation +y is defined to be in the up direction.

For an "incompressible" fluid (such as mercury):

ρ = 13.585 x 10^3 kg/m^3 (constant)

$$\frac{dP}{dy} = -\rho g \quad \Rightarrow P = P_0 - \rho g(y - y_0)$$

Example:



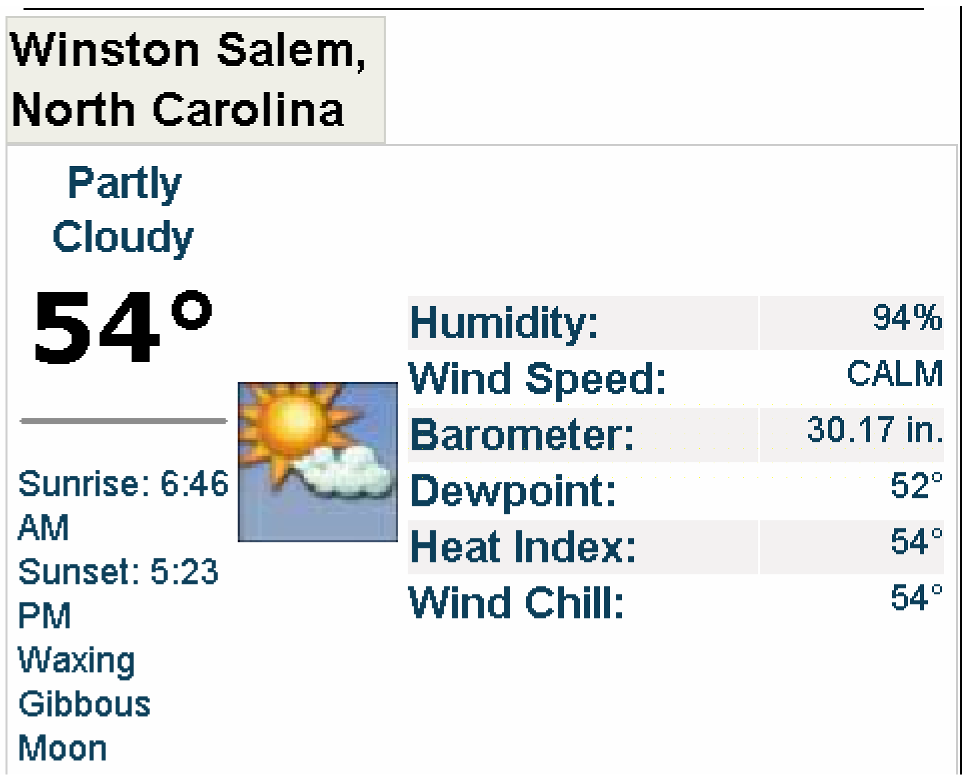
$$h = y - y_0 = \frac{P_0}{\rho g}$$

$$= \frac{1.013 \times 10^5 \text{ Pa}}{13.595 \times 10^3 \text{ kg/m}^3 \cdot 9.8 \text{ m/s}^2}$$

$$= 0.76 \text{ m}$$

ρ = 13.595 x 10^3 kg/m^3

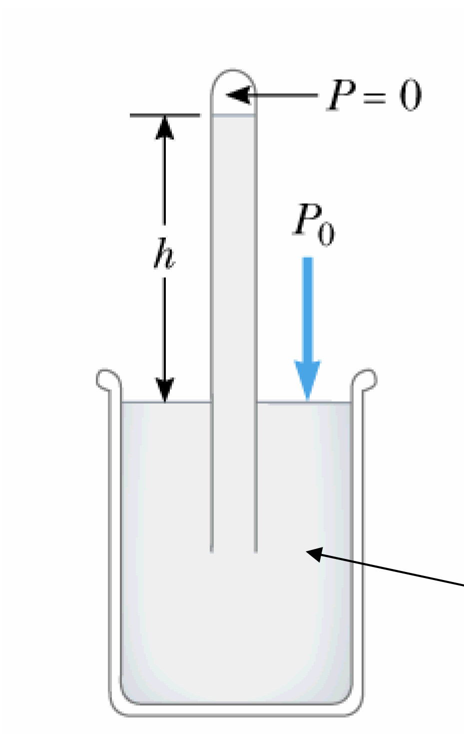
Weather report:



$$30.17\text{in} = 30.17\text{in}\,\frac{0.0254\text{m}}{\text{in}} = 0.766\text{m}$$

Question: Consider the same setup, but replace fluid with water ($\rho = 1000$ kg/m^3). What is h?

$$\frac{dP}{dy} = -\rho g \quad \Rightarrow P = P_0 - \rho g (y - y_0)$$



$$h = y - y_0 = \frac{P_0}{\rho g}$$

$$= \frac{1.013\times10^5 \text{ Pa}}{1000\,\text{kg/m}^3 \cdot 9.8\,\text{m/s}^2}$$

$$= 10.34\text{m}$$

$\rho = 1000\,\text{kg/m}^3$

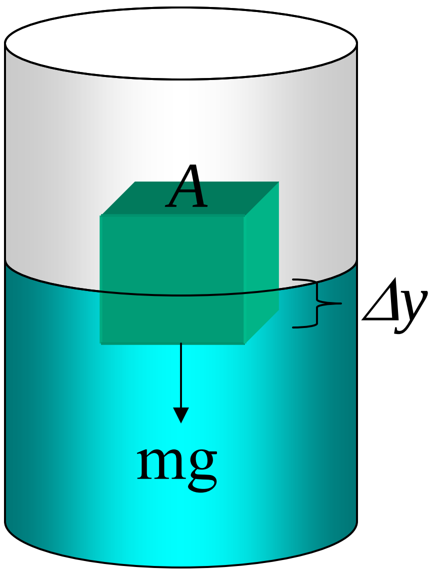
Buoyant force for fluid acting on a solid:

$$F_B = \rho_{fluid} V_{displaced} g$$

$$P(y) = P(y+\Delta y) + \rho_{\text{fluid}} g \Delta y$$

Buoyant force: $F_B = F_{bottom} - F_{top}$

$$F_B = \{P(y) - P(y+\Delta y)\}A = \rho_{\text{fluid}} g \Delta y A = \rho_{\text{fluid}} g V_{submerged}$$



$$F_B - mg = 0$$

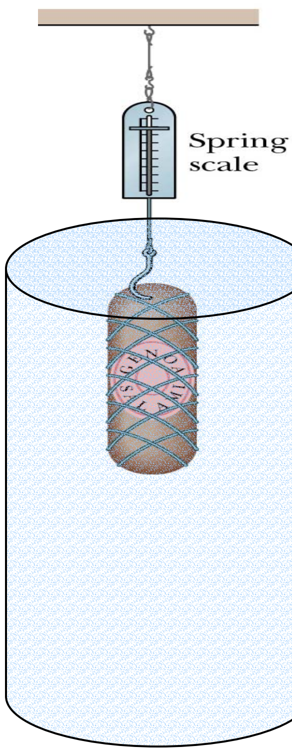
$$\rho_{fluid} V_{submerged} g - \rho_{solid} V_{solid} g = 0$$

$$\frac{V_{submerged}}{V_{solid}} = \frac{\rho_{solid}}{\rho_{fluid}}$$

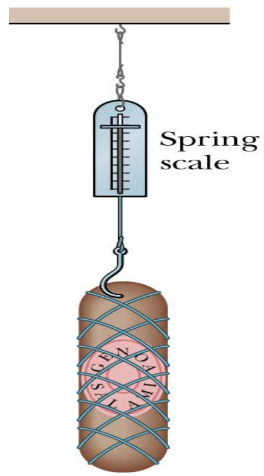
Suppose you have a boat which floats in a fresh water lake, with 50% of it submerged below the water. If you float in the same boat in salt water, which of the following would be true?

A.More than 50% of the boat will be below the salt water.
B.Less than 50% of the boat will be below the salt water.
C.The submersion fraction depends upon the boat's total mass and volume.
D.The submersion fraction depends upon the barometric pressure.

Archimede’s method of finding the density of the King’s “gold” crown



W_{water}



W_{air}

$$W_{water} = mg - F_B = \rho_{object} V_{object}\, g - \rho_{water} V_{object}\, g$$

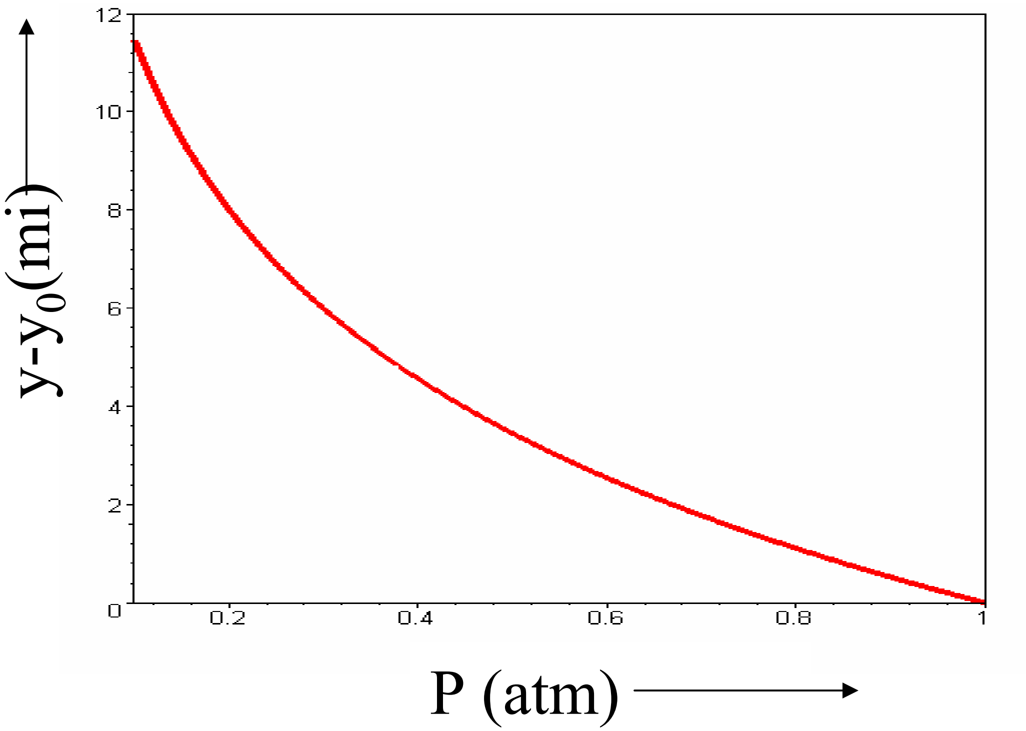
$$W_{air} = mg = \rho_{object} V_{object}\, g$$

$$\rho_{object} = \rho_{water} \frac{W_{air}}{W_{air} - W_{water}}$$

Effects of the weight of a "compressible" fluid on pressure.

$$\frac{dP}{dy} = -\rho g \qquad \text{For a gas, } \rho = P\frac{\rho_0}{P_0}$$

$$\frac{dP}{dy} = -P\left(\frac{\rho_0 g}{P_0}\right) \qquad \text{Solution:} \quad P(y) = P_0 e^{-\frac{\rho_0 g}{P_0}(y-y_0)} \approx P_0 e^{-\frac{y-y_0}{8000m}} \approx P_0 e^{-\frac{y-y_0}{5mi}}$$



Summary:

Application of Newton's second law to fluid (near Earth's surface)

$$\frac{dP}{dy} = -\rho g$$

Incompressible fluid: $P = P_0 - \rho g (y - y_0)$

example: $\rho = 1000 \text{kg/m}^3$ (water)

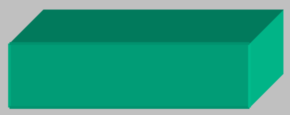
Compressible fluid: $P = P_0 e^{-\frac{\rho_0 g}{P_0}(y - y_0)}$

$$\approx P_0 - \rho_0 g (y - y_0) \quad \left(\text{for } \frac{\rho_0 g}{P_0}(y - y_0) << 1\right)$$

example: $\rho = 1.29 \text{kg/m}^3$ (air)

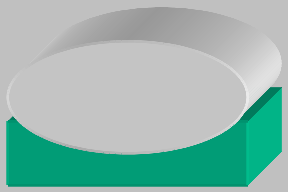
Peer instruction question

Suppose that a caterer packed some food in an air tight container with a flexible top at sea-level. This food was loaded on to an airplane with a cruising altitude of ~6 mi above the earth's surface. Assuming that the airplane cabin is imperfectly pressurized, what do you expect the container to look like during the flight?



(A)

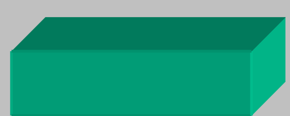
(B)



(C)

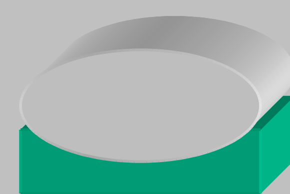
Peer instruction question

Suppose that a caterer packed some food in an air tight container with a flexible top at sea-level. This food was loaded on to a submarine which typically submerges at 200m below sea level. Assuming that the submarine cabin is imperfectly pressurized, what do you expect the container to look like during the submersion?



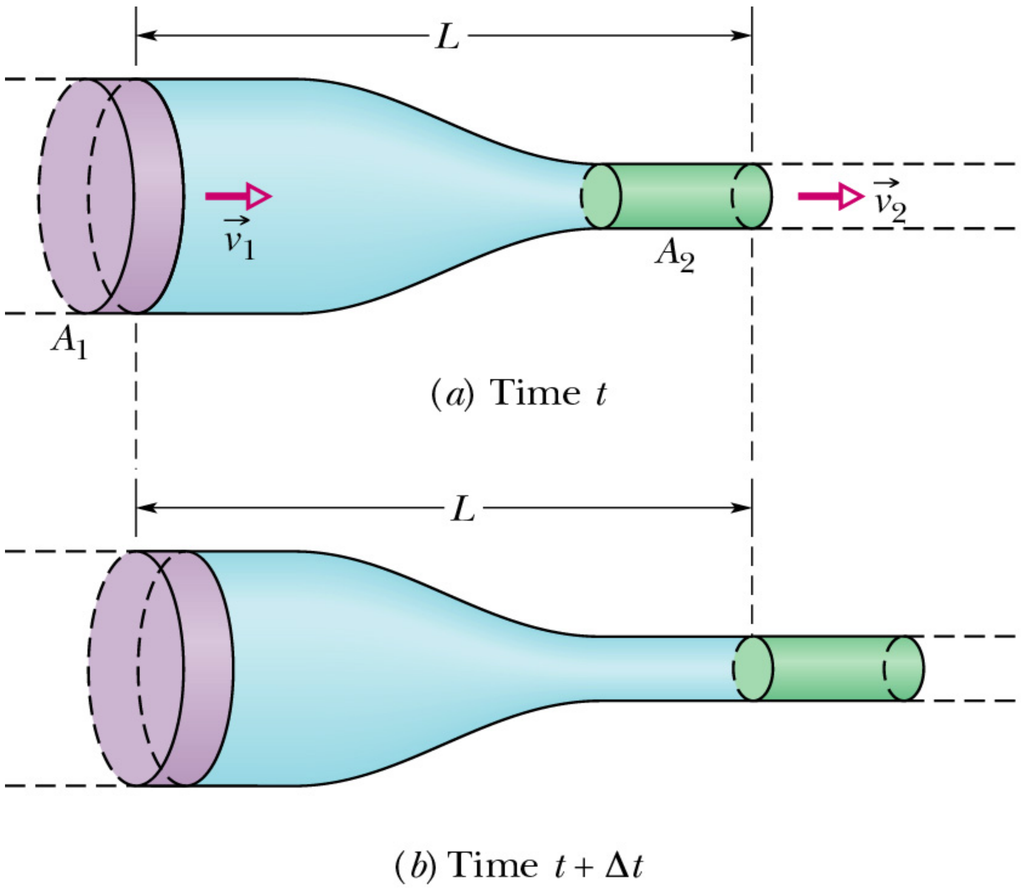
(A)

(B)



(C)

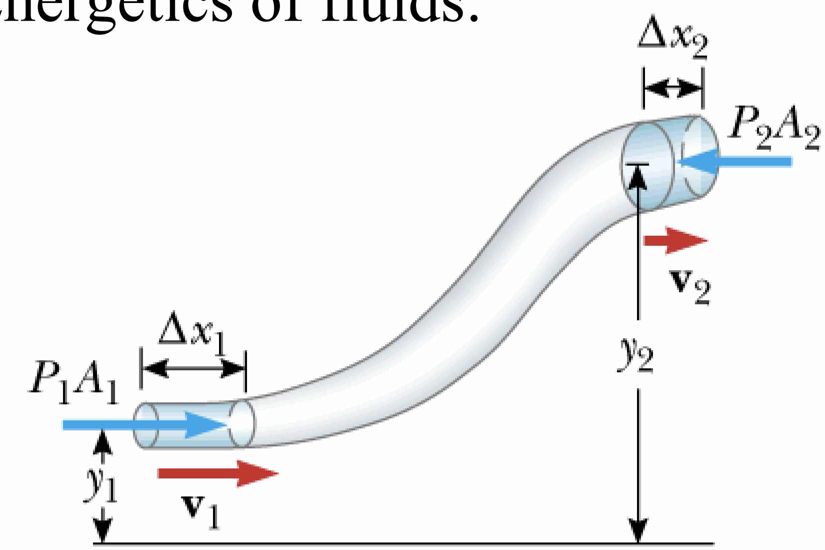
Physics of flowing (incompressible)* fluids



$$A_1 v_1 \Delta t = A_2 v_2 \Delta t$$

*Later will generalize to compressible fluids in "streamline" flow.

Energetics of fluids:



$\Delta x_1 = v_1 \Delta t$

$\Delta x_2 = v_2 \Delta t$

$A_1 \Delta x_1 = A_2 \Delta x_2$

$m = \rho A_1 \Delta x_1$

$K_2 + U_2 = K_1 + U_1 + W_{12}$

$\frac{1}{2} m v_2^2 + mgh_2 = \frac{1}{2} m v_1^2 + mgh_1 + (P_1 A_1 \Delta x_1 - P_2 A_2 \Delta x_2)$

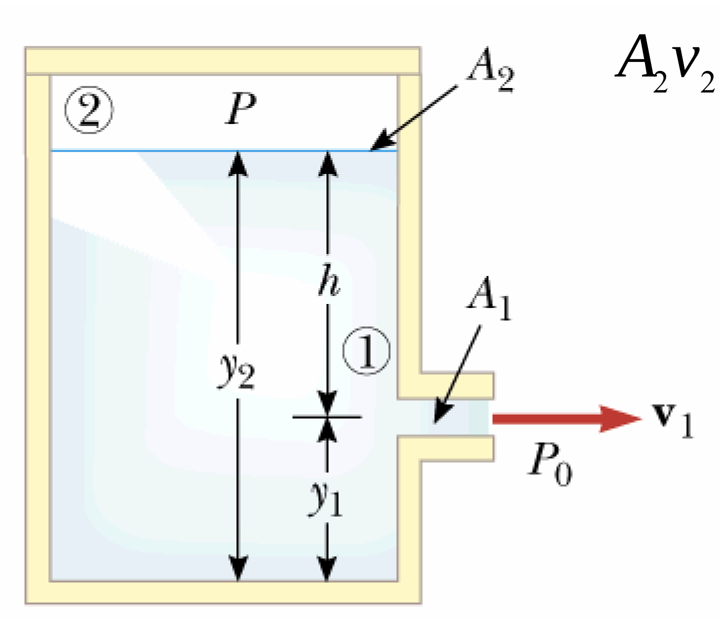
$\Rightarrow P_2 + \frac{1}{2} \rho v_2^2 + \rho g h_2 = P_1 + \frac{1}{2} \rho v_1^2 + \rho g h_1$

Bernoulli's equation:

$$P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g h_2 = P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g h_1$$

Example: Suppose we know A_1, A_2, ρ, P, y_1, y_2

$$P + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 = P_0 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1$$



$$A_2 v_2 = A_1 v_1$$

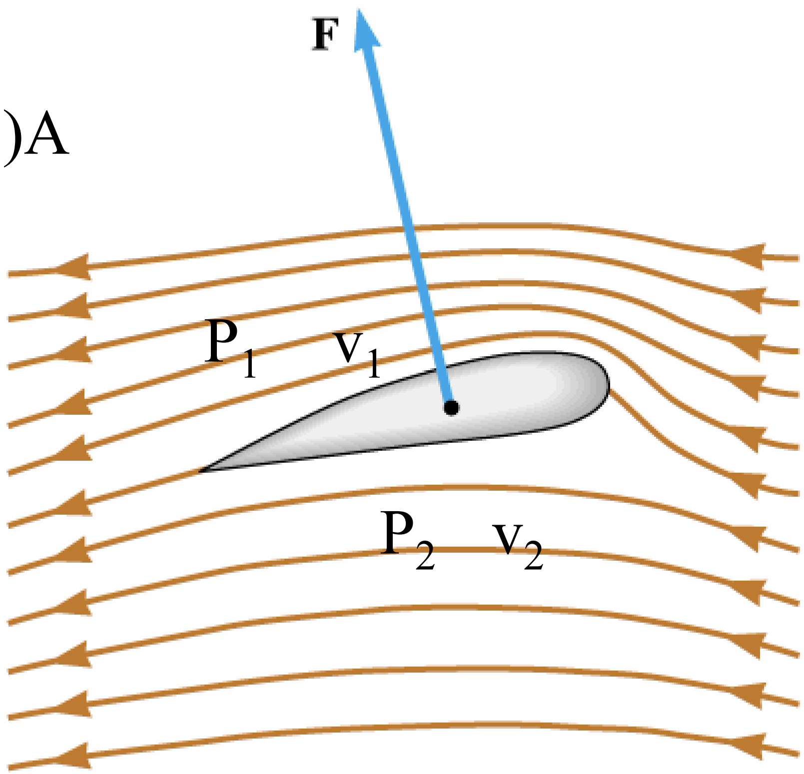
$$v_1 = \sqrt{\frac{2\left(gh - (P_0 - P)/\rho\right)}{1 - \left(A_1/A_2\right)^2}}$$

Streamline flow of air around an airplane wing:

Serway, Physics for Scientists and Engineers, 5/e
Figure 15.24

$$P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g h_2 = P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g h_1$$

$F_{lift}=(P_2-P_1)A$



Harcourt, Inc.

$$h_1 \approx h_2$$

$$v_1 > v_2$$

$$P_2 = P_1 + \tfrac{1}{2}\rho\left(v_1^2 - v_2^2\right)$$

Example:

$v_1 = 270$ m/s

$v_2 = 260$ m/s

$\rho = 0.6$ kg/m^3

$A = 40$ m^2

$F_{lift} = 63{,}600$ N

http://www.grc.nasa.gov/WWW/K-12/airplane/foil2.html

Peer instruction question

Suppose you see a tornado coming toward your house. Assuming that you have enough time, which of the following should you do before entering your shelter?

(A) Open all of the windows and doors.

(B) Make sure that all of the windows and doors are tightly shut.

Homework problem: A hypodermic syringe contains a medicine with the density of water. The barrel of the syringe has a cross-sectional area $A=2.5x10^{-5}m^2$, and the needle has a cross-sectional area $a= 1.0x10^{-8}m^2$. In the absence of a force on the plunger, the pressure everywhere is 1 atm. A force F of magnitude 2 N acts on the plunger, making the medicine squirt horizontally from the needle. Determine the speed of the medicine as leave the needle's tip.