NAVAL HISTORY STEM-H LESSON PLAN

LESSON PLAN: SNAP, CRACKLE, POP: Submarine Buoyancy, Compression, and Rotational Equilibrium
DEVELOPED BY: Bill Sanford, Nansemond Suffolk Academy
2012 NAVAL HISTORICAL FOUNDATION TEACHER FELLOWSHIP

ACTIVITY 3: Bulk Deformation Problem

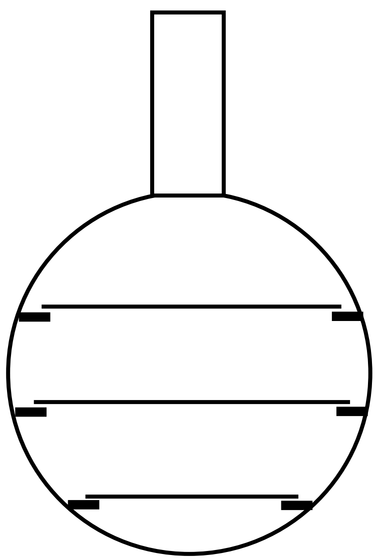
OBJECTIVE: Practice and Reinforce understanding of Deformation as it applies to a submarine at various depths

MATERIALS: None

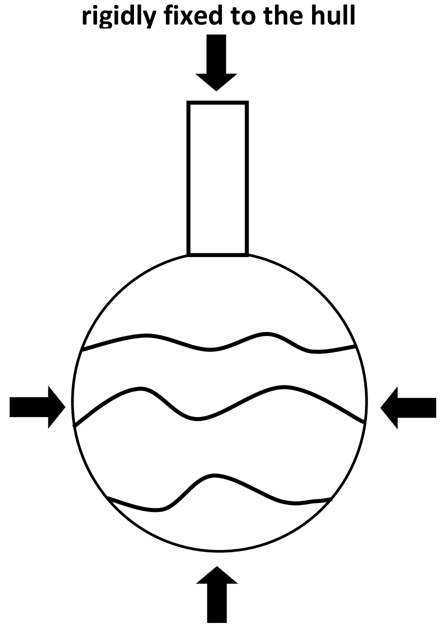
BACKGROUND:

- A submarine's hull actually compresses due to the water pressure it experiences.
    - To prove this, some crews have tied a string tightly between the bulkheads (walls) while on surface. After diving to a deep depth, the string hangs loosely.
- Similar to what is shown in the drawing below, the decks of a submarine "float" on the hull so they do not buckle when the hull compresses. As the submarine proceeds deeper and the cylindrical hull compresses, the decks stay the same width, so they tend to rub against their supports. Unless the deck/hull junctions are properly greased, this can cause creaking noises that could be detected by enemy submarines. The movies Das Boot and U-571 have relatively realistic depictions of World War II submarines at war.

"Floating" decks will not buckle when the submarine is compressed



Decks of a compressed submarine if they were rigidly fixed to the hull



To demonstrate this concept, Navy researchers have taken Styrofoam cups down deep in the ocean with research submarines. To be clear, nothing inside the submarine is crushed (Refer to Activity 1 of this lesson plan for calculations that prove that the air pressure inside the submarine does not increase just because the hull is exposed to extreme water pressure). The Styrofoam cup must be exposed to the high water pressure. The researchers put the cups in a small compartment on the outside of the submarine that is enclosed enough that the cups are not swept away, but with small holes that let water in.

The cup on the left is regular size.
Why do you suppose the one on the right so much smaller than the one in the middle?

Interesting Tidbit: An alloy is a mixture of metals, or a metal and other elements. For instance, various amounts of carbon are alloyed with iron to obtain steel with various characteristics: strength, flexibility, etc. Special steel alloys are used for submarine hulls. The trick for the metallurgist is to strike a compromise and use the correct ratio of alloy elements to create a hull plate with high compression strength (that maximizes its resistance to high water pressure, but also one that flexes (yields) enough to allow the hull to bend instead of break.

NAVAL HISTORICAL FOUNDATION

If you have not covered them in class, look up Hooke's Law as it applies to the concepts of Compression and Bulk Deformation. In physics books, they most often in the chapter about Springs. Now, consider a cube of Styrofoam taken to 750 feet below the surface of the ocean. Be sure to have the correct units for each answer.

1m = 3.281 feet density of seawater = 1025 kg/m^3

- Length of a side of the cube before being submerged: 6.0 inches
- Length of a side of the cube after being submerged at 750 ft: 2.0 inches

1. Explain which concept we should use to analyze what will happen to the Styrofoam: Compression or Bulk deformation?
   "Compression" describes 2-dimensional deformation involving a percentage change in length, that is caused by a force directed along one axis, like stretching a piece of fishing line, or shortening your spine by carrying heavy objects on your head. "Bulk" deformation describes 3-dimensional deformation involving a percentage change in volume, caused by a change in fluid pressure, such as changing your depth in water. Taking the Styrofoam cup deep below the surface of the ocean will involve Bulk Deformation.

2. Calculate the Stress in this situation.
   Stress is what causes Strain. In the case of Bulk deformation, the Stress is the change in fluid pressure.
   - Convert depth to meters: 725 ft * (1m / 3.281 ft) = 220.9692 m
   - Determine difference in pressure between the surface and at 725ft:
     - Change in Pressure = density of sea water * g * difference in depth
     - Change in pressure = 1000kg/m^3 * 9.8m/s^2 * 220.9692m = 2165498 Pascals

3. Calculate the Strain.

   Strain is not the change in length or the change in volume, but the percentage change. In this case, the strain is the %change in volume of the cup.
   - Convert original length to m: 6.0in * (1ft / 12in)(1m / 3.281 ft) = .152393m
   - Convert final length to m: 2.0in * (1ft / 12in) (1m / 3.281 ft) = .050798m
   - Original Volume = l_o^3 = $(.152393m)^3$ = .003539088 m^3
   - Final Volume = = l_f^3 = $(.050798m)^3$ = .000131077 m^3
   - percentage change in volume = [(V_{final} – $V_{original}$) / $V_{original}$]
   - = [(.000131077-.003539088) / .003539088]
   - = – .629630571
     - Note that the percentage change in volume is unitless and that it is negative. Being negative indicates that the volume of the cup decreased.

4. Determine the bulk modulus of Styrofoam in Pascals.

   Finding the Bulk Modulus
   - Stress = – Bulk Modulus * Strain
   - Change in Pressure = – Bulk Modulus * percentage change in volume
   - Bulk Modulus = – Change in Pressure / percentage change in volume
   - Bulk Modulus = – 2165498Pa / – .629630571

- Bulk Modulus = 3439315 Pa
- Note: This analysis is a little misleading, as Hooke's Law models materials that rebound to their original shape as you remove the stress. In this situation, the Styrofoam has undergone permanent deformation.

Note: This analysis is a little misleading, as Hooke's Law models materials that rebound to their original shape as you remove the stress. In this situation, the Styrofoam has undergone permanent deformation, as a submarine would if it ventured too deep! Only a few special research submarines are designed to explore the deepest depths of our oceans (~36,000 ft, almost 7 miles), which are deeper than Mount Everest is tall (~29,000 ft)!!!