NAVAL HISTORY STEM-H LESSON PLAN

LESSON PLAN: SNAP, CRACKLE, POP: Submarine Buoyancy, Compression, and Rotational Equilibrium
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2012 Naval Historical Foundation STEM-H Teacher Fellowship

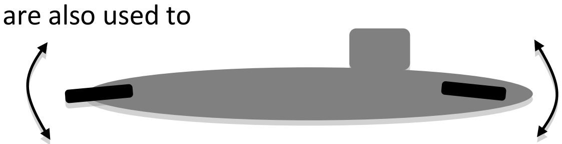
ACTIVITY 2: Balance of Torques using Submarine Trim Tanks

OBJECTIVE: Review and Practice the concepts of torque and rotational equilibrium by balancing the pitching (forward/aft) torques on a submarine.

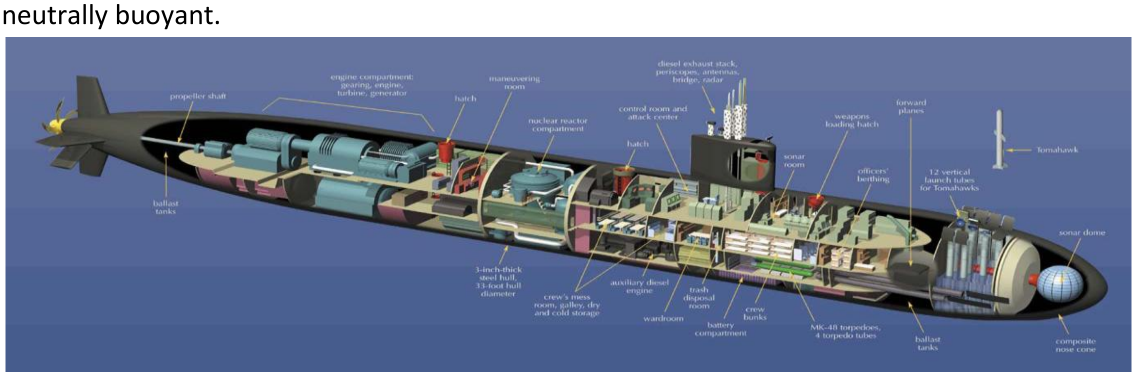
MATERIALS: How A Submarine Submerges - Video This clip "Buoyancy: Take 'Er Down" and many others are available on the Naval History and Heritage Command's U-Tube Channel and the Naval Historical Foundation's U-Tube Channel .

INSTRUCTIONS:

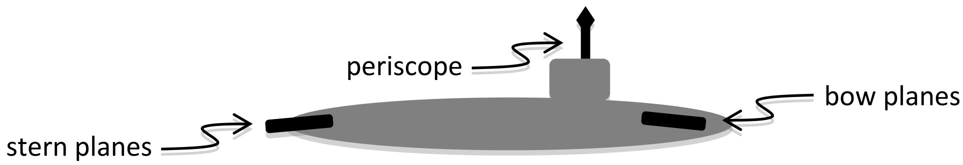
- Submarines are basically teardrop shaped, with a "sail": a rectangular protrusion on the top, from which the periscopes and antennas emerge (see the images throughout this lesson).
- Submarines have two sets of "planes" that can be angled so that the water flowing past them pushes them up or down. In this way, they are used to control the forward/aft angle of the submarine (its pitch). Similar to the wings of an airplane, they are also used to change forward motion into vertical motion. One set is near the rear (aft) end of the submarine, or its stern, on either side of its rudder. The other is either near the front (bow), or protruding from the sail. On some submarines, the Bow Planes are replaced by a set of planes sticking out from the sides of the sail, as seen on the picture on the next page.



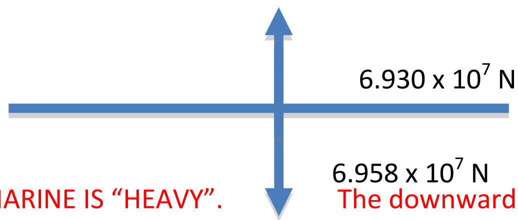
- For many reasons, a submarine routinely pumps water to/from forward and aft tanks, to help control the angle of the ship. For instance, consider the "sanitary" tanks (Note: sanitary is not a fitting term for what fills up these tanks). These tanks are forward of the center of the submarine, so as they fill up, the submarine's bow is heavier and tends to cause the sub to tilt downward. This can temporarily be controlled using the bow planes and stern planes, but after a while, it is useful to compensate by moving water from tank to tank, or adding/removing some water to/from a tank that is forward or aft of centerline. This would balance the forward/aft torque, but the sub would be "light" or "heavy" overall... in other words, it would no longer be neutrally buoyant.



1.



2. A)



B)

RIGHT NOW, THE SUBMARINE IS "HEAVY". The downward gravitational force exerted by the earth on the submarine is stronger than the upward buoyant force exerted by the water on the submarine. The COW must PUMP WATER OFF THE SUBMARINE INTO THE OCEAN

C)

Net Force on submarine = $6.958 \times 10^7 - 6.930 \times 10^7$ = 280000N downward, so… water that weighs that much must be pumped off.

mass = Net Force / g = 28571 kg of water must be pumped off

volume = mass / density = 28571kg / 1025 kg/m^3 = 27.8946 m^3 pumped off

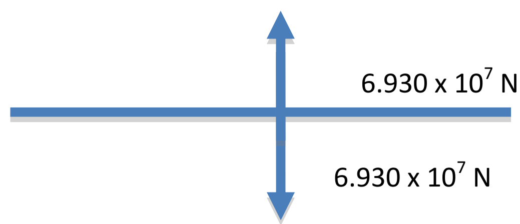
27.8946 m^3 (264.172 gallons/m^3) = 7363.7 gallons, or **7364 gallons pumped off** (4 digits of precision)

D)

Net Vertical Force = 0

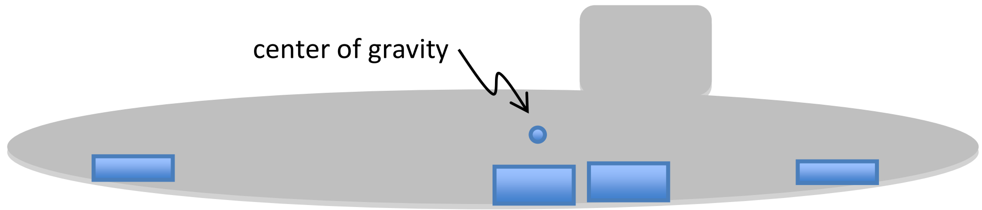
Vertical Equilibrium

Vertical Acceleration = 0



3.

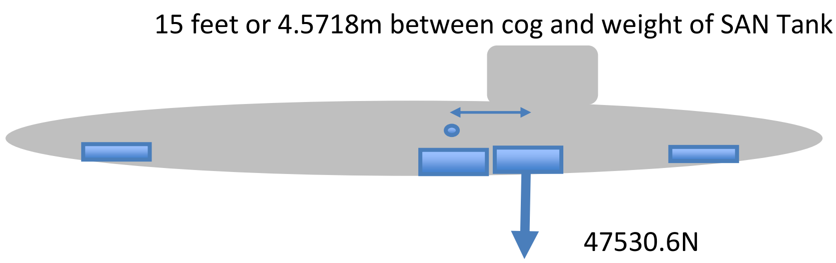
A.



B. Rotational Equilibrium is a state in which the net torque on an object is zero (no torques or all the torques exerted on the object cancel each other out). This results in the object having zero rotational acceleration.

C. 1250 gallons (264.172 gallons/m^3) = 4.7318 m^3 of waste liquid were added.

D.



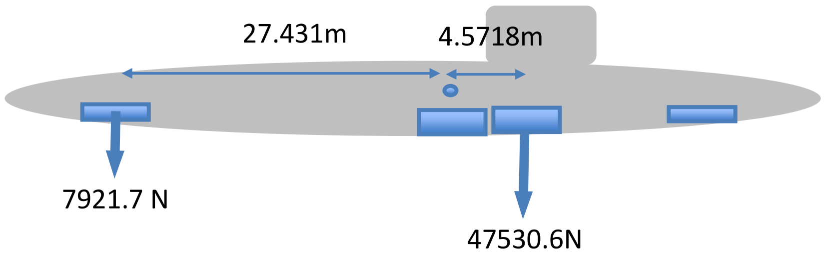
E. See Diagram, above. 15 feet (1m / 3.281 ft) = 4.5718m

F. torque = force * lever arm
torque = weight of San. Tank * 4.5718m
torque = 47530.6N * 4.5718m = 217299.3 Nm

G. Having the Sanitary Tank close to the forward/aft centerline reduces the lever arm of the weight of its contents, minimizing the inevitable variations in torque as this tank repeatedly fills and is emptied.

H.

- Allow seawater into the submarine and put it in the aft trim tank.



Note: by convention, clockwise torque is defined as positive

We want the sub back in rotational equilibrium, in other words, we want:
Net torque = 0
torque of water in Aft Trim + torque of liquid in Sanitary Tank = 0
torque of water in Aft Trim = – torque of liquid in Sanitary Tank
27.431 m * weight of water added to Aft Trim = – (–) 4.5718m * 47530.6N
Weight of water that must be added to Aft Trim = 7921.7 N
mass = Net Force / accel. = weight of water / g = 7921.7 N / 9.8 m/s^2
mass of water added to Aft Trim Tank = 808.344 kg
Using conversions similar to those seen above, we find that

.78863 m^3 or 208.35 gallons of water must be added to the Aft Trim Tank

I.

- Pump water from the fwd trim tank off the submarine into the ocean
- The torque caused by the weight of the Sanitary Tank is clockwise. In the previous solution, we balanced this torque with an equal but opposite (counter-clockwise) torque created by adding water to the Aft Trim Tank.
- In this solution, we analyze another way to counter the clockwise torque of the sanitary tank: removing water from the forward trim tank, thus reducing the clockwise torque caused by it.
- 15.239 m * weight of water removed from Fwd Trim = 4.5718m * 47530.6N
- **Weight of water that must be removed Fwd Trim = 14259 N**
- mass = Net Force / accel. = weight of water / g = 14259 N / 9.8 m/s^2
- **mass of water added to Aft Trim Tank = 1455 kg**
- Using conversions similar to those seen above, we find that
  - **1.4195 m^3 or 375 gallons of water must be removed the Fwd Trim Tank**

J.

a. Since the sub began in a state of neutral buoyancy, and the COW took on additional water, it will tend to **Sink**. In other words, the COW allowed water into a tank that was previously filled with air, so the submarine's mass has increased, while its volume remained the same, thus the submarine is more dense than it was before.
b. To regain neutral buoyancy, the COW could pump water from the Centerline Trim Tank off the submarine, thus decreasing its weight, while not affecting its rotational equilibrium (since there is no affect on torque, since the tank is at the fwd/aft centerline of the sub, thus the lever arm of its weight is zero).