EH 200	Ch 10	Prob 1, 2, 3

1. Why are submarines constructed with transverse framing system instead of longitudinal framing?

   To withstand hydrostatic pressure and force when submerged.

2. What is "out of roundness" and why is this significant in relation to submarine structures?

   - Submarine frames are perfectly circular for maximum resistance to compressive stresses.
   - 0.5% deviation from perfect circle reduces hydrostatic load carrying capacity be 35%.

3. Deep submergence research submarine capable of operating at depth of 2375 ft.

   Calculate hydrostatic pressure acting on hull.

   $$P_{hyd} = \rho g z = (64\ lb/ft^3)(2375\ ft)$$

   $$P_{hyd} = 152{,}000\ lb/ft^2 = 1055.6\ lb/in^2$$

   Factors involved in selecting material.

   - need low transition temperature so that hull remains ductile in cold water
   - high yield strength to withstand hydrostatic pressure and force without yielding.
   - large Elastic Modulus to reduce strain on material when subjected to large compressive stresses.
   - good endurance characteristics to withstand repeated dives and surfaces.

National® Brand 42-162 100 SHEETS Made in U.S.A.

4. Submarine pressure hull are constructed of high strength steel (σ_y = 80,000 - 100,000 psi) or titanium alloys (σ_y = 130,000 psi).

Why are hull made out of such material?

High yield strength allows material to withstand high pressures associated with submerged operations without suffering strain hardening.

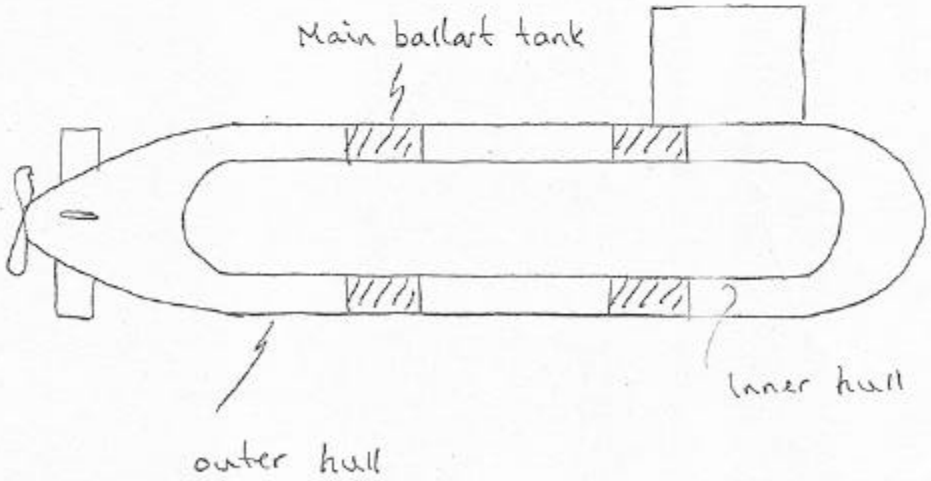
High yield strength also means less strain / compression when subjected to hydrostatic pressure.

5. What is the difference between hard and soft tanks?

Hard tanks must withstand hydrostatic pressure for full depth capability of the sub.

Soft tanks do not have to withstand hydrostatic pressure. Pressure in tank equals outside pressure.

6. Draw a diagram showing inner hull, outer hull and main ballast tanks. Which must be able to withstand hydrostatic pressure when submerged?



National® Brand 42-182 100 SHEETS Made in U.S.A.

7. Describe changes that occur to a surfaced submarine's displacement and buoyant force as it moves from fresh water to salt water.

on the surface: $\Delta_{FW} = \Delta_{SW}$

for static equilibrium: $F_{BFW} = F_{BSW}$

or, $\rho_{FW}\, g\, \nabla_{FW} = \rho_{SW}\, g\, \nabla_{SW}$

$\rho_{FW}\, \nabla_{FW} = \rho_{SW}\, \nabla_{SW}$

$\frac{\nabla_{FW}}{\nabla_{SW}} = \frac{\rho_{SW}}{\rho_{FW}}$

buoyant force does not change on the surface

only ∇ changes

but, $\rho_{FW} < \rho_{SW}$ for any given temperature

$\therefore \frac{\nabla_{FW}}{\nabla_{SW}} = \frac{\rho_{SW}}{\rho_{FW}} > 1 \rightarrow \nabla_{FW} > \nabla_{SW}$

8. Describe changes in submerged submarine's displacement and buoyant force as it moves from fresh water to salt water.

$\rho_{FW} < \rho_{SW}$

displacement in Fresh water = displacement in salt water

$\therefore \nabla_{FW} = \nabla_{SW}$ (submarine shape doesn't change)

$F_B = \rho g \nabla$

$F_{BFW} = \rho_{FW}\, g\, \nabla$ $\quad F_{BSW} = \rho_{SW}\, g\, \nabla$

and $\rho_{FW} < \rho_{SW}$

$\therefore F_{BFW} < F_{BSW}$

Buoyant force in salt water is greater ... will want to push sub to surface. Add water to BCT

9. How does increasing depth affect submarine buoyancy?

- temperature decreases as depth increases → density increases → buoyant force increases

- pressure increases as depth increases, causing hull to compress slightly. compression of hull results in slight reduction in displaced volume causing slight decrease in buoyant force

SEAWOLF class submarine displaces 8060 LT when surfaced, and 9,150 LT when submerged. What accounts for difference when surfaced and submerged?

for equilibrium $F_B = \Delta = \rho g \nabla$

- when surfaced, a portion of the submarine is above water, therefore ∇ when surfaced is less than when submerged.
- in order to submerge, submarine adds ballast water and increases its weight. Therefore submerged Δ is greater than surfaced Δ.

National® Brand 42-182 100 SHEETS Made in U.S.A.

LOS ANGELES class submarine is neutrally buoyant at $\Delta = 6900$ LT in salt water at 45°F. Sub moves into water 1 deg warmer.

How many pounds of water must be added or removed from DCT to maintain neutral buoyancy.

45°F: $\rho = 1.9933 \ lb\,s^2/ft^4$

46°F: $\rho = 1.9931 \ lb\,s^2/ft^4$

in 45°F water, $F_B = \Delta$.

$$\nabla = \frac{\Delta}{\rho g} = \frac{(6900 \text{ LT})(2240 \text{ lb})}{(1.9933)(32.17 \ ft/s^2) \text{ LT}} = 241031 \ ft^3$$

in 46° water:

$$F_B = \rho_{46}\, g\, \nabla = (1.9931 \ lb\,s^2/ft^4)(32.17 \ ft/s^2)(241031 \ ft^3)$$

$$F_B = 6899.3 \text{ LT}$$

Buoyant force in 46°F water is less than buoyant force in 45°F water, causing sub to slowly sink

∴ remove water from DCT

weight of water = 6900 LT − 6899.3 LT = 0.7 LT

$$\boxed{\text{weight} = 1568 \text{ lb removed}}$$

OHIO class sub enroute to its patrol area. Sub is in Gulf Stream and is neutrally buoyant at $\Delta = 18{,}700$ LT. Sub exits Gulf Stream and enters North Atlantic.

How many pounds of water to add or subtract from DCT to maintain neutral buoyancy.

Gulf Stream: $T = 70°F$, $\rho = 1.9876 \ lb\,s^2/ft^4$

North Atlantic: $T = 50°F$, $\rho = 1.9924 \ lb\,s^2/ft^4$

In Gulf Stream, neutrally buoyant so $F_B = \Delta$.

$$\nabla = \frac{\Delta}{\rho g} = \frac{(18700 \text{ LT})(2240 \text{ lb})}{(1.9876)(32.17 \text{ ft/s}^2)\text{ LT}} = 655103 \text{ ft}^3$$

In North Atlantic, find F_B:

$$F_B = \rho g \nabla = (1.9924 \ lb\,s^2/ft^4)(32.17 \text{ ft/s}^2)(655103 \text{ ft}^3)\left(\frac{1 \text{ LT}}{2240 \text{ lb}}\right)$$

$$F_B = 18745 \text{ LT}$$

Buoyant force in North Atlantic is greater than Gulf Stream, and sub will rise to surface.

$\therefore$ add water to DCT

weight added $= 18745 \text{ LT} - 18700 \text{ LT}$

$\boxed{\text{add 45 LT or 100800 lb to DCT}}$

National® Brand 42-182 100 SHEETS Made in U.S.A.

Submerged SSN-688, $\Delta = 6900$ LT has been patrolling arctic ice pack, and is moving into North Atlantic.

Under the ice, trim was based on water being 70% salt water, 30% fresh water at $T = 30°F$.

In North Atlantic, water is 100% salt water and $T = 35°F$

$T = 30°F$: $\rho_{FW} = 1.9399 \ lb\,s^2/ft^4$ $\quad \rho_{SW} = 1.9947 \ lb\,s^2/ft^4$

$T = 35°F$: $\rho_{FW} = 1.9400 \ lb\,s^2/ft^4$ $\quad \rho_{SW} = 1.9945 \ lb\,s^2/ft^4$

Find: what action must be taken to maintain neutral buoyancy in North Atlantic?

$$\rho_{arctic} = 70\% \ \rho_{SW} + 30\% \ \rho_{FW} \qquad (30°F)$$

$$= (.7)(1.9947 \ lb\,s^2/ft^4) + (.3)(1.9399 \ lb\,s^2/ft^4)$$

$$\rho_{arctic} = 1.9783 \ lb\,s^2/ft^4$$

$$\nabla_{arctic} = \frac{\Delta}{\rho_{arctic}\, g} = \frac{(6900 \ LT)(2240 \ lb)}{(1.9783 \ lb\,s^2/ft^4)(32.17 \ ft/s^2) \ LT} = 242859 \ ft^3$$

also, $\nabla_{arctic} = \nabla_{atl}$

$$F_{B_{atl}} = \rho_{atl}\, g\, \nabla = (1.9945 \ lb\,s^2/ft^4)(32.17 \ ft/s^2)(242859 \ ft^3)\left(\frac{LT}{2240 \ lb}\right)$$

$$F_{B_{atl}} = 6957 \ LT$$

in arctic @ neutral buoyancy $F_{B_{arct}} - \Delta = 6900$ LT

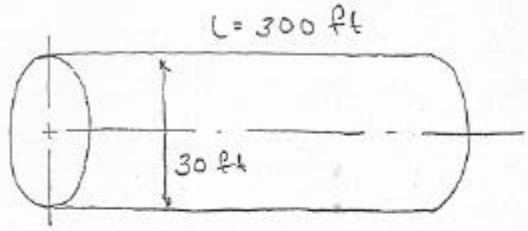
$$F_{B_{arctic}} = 6900 \ LT < F_{B_{atl}} = 6957 \ LT$$

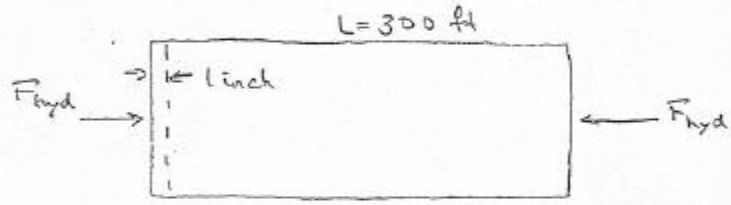
since F_B in atlantic is greater than arctic, submarine will rise toward surface.

$\therefore$ add 57 LT of water.

A surface submarine's pressure hull is a right cylinder 30 ft in diameter and 300 ft in length. At depth, hydrostatic force compresses the hull's length by 1 inch.

Neglecting changes in diameter due to hydrostatic force, calculate the change in buoyancy due to hull compression.





buoyancy decreases due to buoyant volume lost due to compression.

$$V_{lost} = \left(\pi \frac{d^2}{4}\right)(1 \text{ inch})$$

$$= \frac{\pi}{4}(30 \text{ ft})^2 (1 \text{ inch})\left(\frac{\text{ft}}{12 \text{ in}}\right)$$

$$V_{lost} = 58.9 \text{ ft}^3$$

assuming seawater @ 59°F, lost buoyant force:

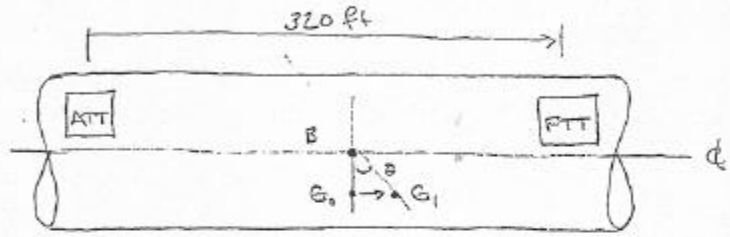
$$F_{lost} = \rho g V_{lost} = (64 \text{ lb/ft}^3)(58.9 \text{ ft}^3)\left(\frac{\text{LT}}{2240 \text{ lb}}\right)$$

$$\boxed{F = 1.68 \text{ LT}}$$

Submerged submarine neutrally buoyant at $\Delta = 6850$ LT and zero trim. $KB = 16.5$ ft, $KG = 13.5$ ft.

To detect mines, sub must trim 4 deg down by bow. Trim tanks located 320 ft apart.

How many pounds water must be transferred between trim tanks?



$\theta = 4°$

$$w\ell = \Delta_s \overline{BG_0} \tan\theta$$

$$w = \frac{\Delta_s \overline{BG_0} \tan\theta}{\ell} = \frac{(6850 \text{ LT})(\overbrace{16.5 \text{ ft} - 13.5 \text{ ft}}^{3 \text{ ft}})(\tan 4°)}{320 \text{ ft}}$$

$$\boxed{w = 4.49 \text{ LT} = 10059 \text{ lb}}$$

$$\text{gallons} = \frac{w}{\rho g} = \left(\frac{10059 \text{ lb}}{64 \text{ lb/ft}^3}\right)\left(7.4805 \text{ gal/ft}^3\right) = 1176 \text{ gal}$$

How does trim affect sub's center of buoyancy and center of gravity?

No change to B (sub is submerged)

G moves forward.

SEAWOLF class sub operating at neutral buoyancy and zero trim at $\Delta = 9100$ LT. $KB = 20$ ft, $KG = 16.5$ ft.

8 torpedoes (3434 lb each) loaded into torpedo tubes. Each torpedo moved forward a distance of 30 ft.

a) How does loading torpedoes affect sub's LCG?

LCG moves forward and sub trims down by bow.

b) Calculate resulting trim angle.

$$wl = \Delta \overline{BG_o} \tan\phi$$

$$\tan\phi = \frac{wl}{\Delta \overline{BG_o}}$$

$$w = 8(3434 \text{ lb})\left(\frac{\text{LT}}{2240 \text{ lb}}\right) = 12.26 \text{ LT}$$

$$\phi = \tan^{-1}\left[\frac{wl}{\Delta(KB-KG)}\right] = \tan^{-1}\left[\frac{(12.26 \text{ LT})(30 \text{ ft})}{(9100 \text{ LT})(20 \text{ ft} - 16.5 \text{ ft})}\right]$$

$$\boxed{\phi = 0.62^\circ}$$

c) If trim tanks are located 310 ft apart, how many pounds of water must be transferred to restore level trim?

trimming moment = restoring moment

$$(8)(3434 \text{ lb})(30 \text{ ft}) = w(310 \text{ ft})$$

$$w = \frac{(8)(3434 \text{ lb})(30 \text{ ft})}{310 \text{ ft}}$$

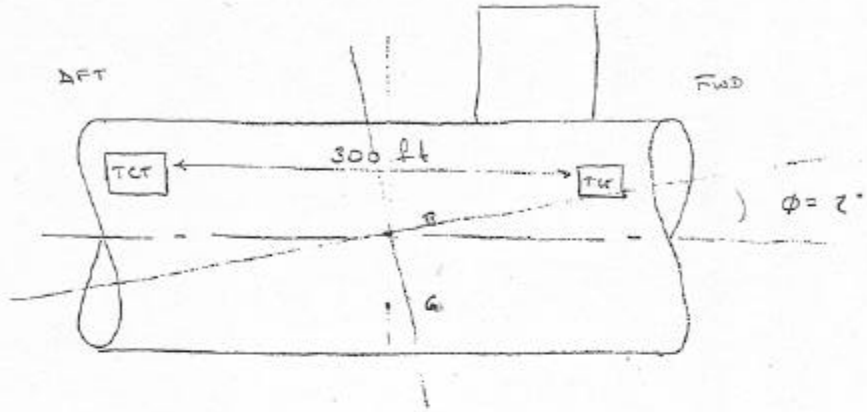
$$\boxed{w = 2659 \text{ lb}}$$

d) If KG increases, how does this affect sub's tendency to trim?

If KG increases, distance $\overline{BG}$ decreases and sub is more likely to trim.

Submerged submarine has trim angle of 2° up. Desire to correct trim by pumping water between fwd and aft trim tanks, and correct trim to zero.

Trim tanks are 300 ft apart. KG = 13.5 ft, KB = 15.7 ft, Δ = 7500 LT

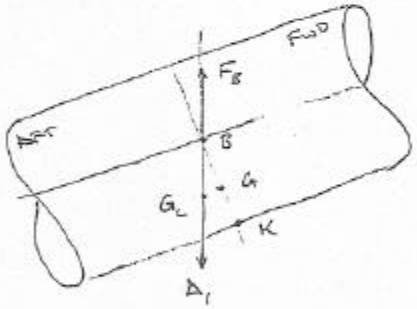


a) to correct 2° up angle, pump water from aft to forward.

b) LCG will move forward slightly

c) show relationship between LCB and LCG in each case.

initial 2° up trim: (sub is at static equilibrium)



note G is aft of LCB

- when sub returns to level trim, G shifts forward to location under B (same longitudinal location)

d) how many pounds water must be pumped to correct trim.

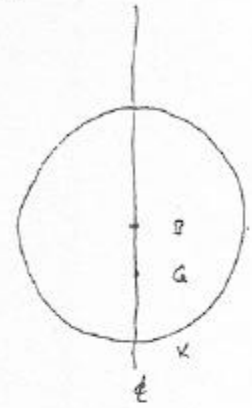
$$\tan \phi = \frac{w l}{\Delta \overline{GB}}$$

$\phi = 2°$ $\quad l = 300$ ft, $\quad \overline{GB} = KB - KG = 15.7$ ft $- 13.5$ ft $= 2.2$?

$$w = \frac{\Delta \overline{GB} \tan \phi}{l} = \frac{(7500 \text{ LT})(2.2 \text{ ft})}{300 \text{ ft}} \frac{(\tan 2°)}{\text{LT}} (2240 \text{ lb})$$

$$\boxed{w = 4302 \text{ lb}}$$

For a submarine, $\Delta = 6500$ LT, $KB = 14.5$ ft, $KG = 13$ ft



a) write curve of intact static stability.

$$\overline{GZ} = \overline{BG} \sin\phi$$

$$BG = KB - KG = 1.5 \text{ ft}$$

$$\overline{GZ} = 1.5 \text{ ft} \sin\phi$$

b) compute maximum righting moment

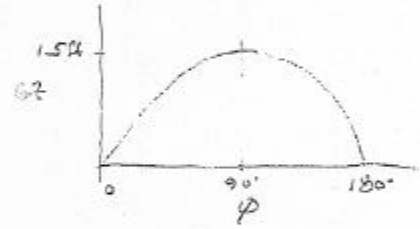
$$RM_{max} = \overline{GZ}_{max} \Delta_s$$

$$\overline{GZ}_{max} = 1.5 \text{ ft}$$

$$RM_{max} = (1.5 \text{ ft})(6500 \text{ LT}) = 9750 \text{ LT}\cdot\text{ft}$$

c) maximum righting moment occurs at 90°

d) range of stability is 0-180°



e) compute dynamic stability

$$\text{dynamic stability} = \int RM$$

$$= \int \Delta_s \, GZ(\phi) \, d\phi$$

$$= \Delta_s \int \overline{BG} \sin\phi \, d\phi$$

$$= \Delta_s \overline{BG} \int_0^{180} \sin\phi \, d\phi$$

$$= 2 \Delta_s \overline{BG} = 2 (6500 \text{ LT})(1.5 \text{ ft})$$

$$= \boxed{19500 \text{ LT}\cdot\text{ft}}$$

f) compute same for $KG = 14$ ft $\Rightarrow BG = .5$ ft

$$GZ = .5 \text{ ft} \sin\phi$$

$$RM_{max} = (.5 \text{ ft})(6500 \text{ LT}) = 3250 \text{ LT}\cdot\text{ft}$$

$$\text{Dynamic Stability} = 2 \Delta_s \overline{BG} = 2 (6500 \text{ LT})(.5 \text{ ft}) = 6500 \text{ LT}\cdot\text{ft}$$

EN 200	Ch 10	Prob 19

A surfaced sub travelling at full power can achieve a speed of 15 kts, yet when submerged at depth of 400 ft can achieve 25 kts.

Why?

Increase in speed when submerged is due to lack of wave making resistance. As submarine submerges, wave making effects decrease until only viscous resistance contributes to total hull resistance.

National® Brand 42-182 100 SHEETS Made in U.S.A.

20. Why does it make sense to use odd number of blades on sub propeller?

- reduce propeller / wake interaction
- reduce vibration

21. Name 2 advantages & disadvantages of highly skewed propeller.

Advantages

- reduced vibration
- reduced cavitation

Disadvantages

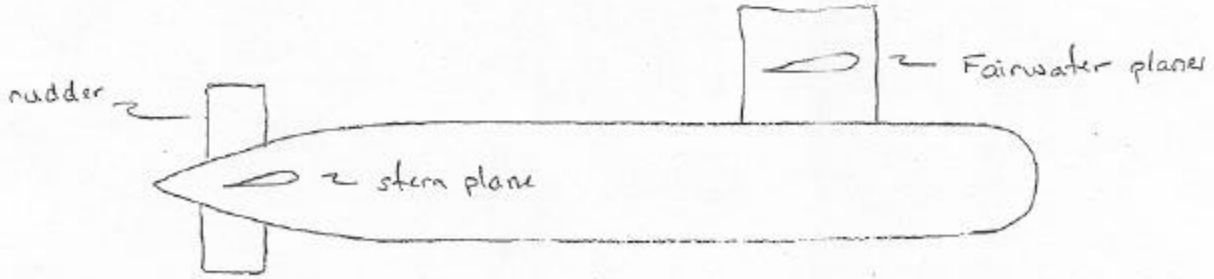
- poor backing efficiency
- blade strength problems
- difficult to manufacture & expensive

22. Describe 2 sources of surface suction

Water surface effect: velocity of water between sub & surface is greater than below submarine. Increased velocity produces low pressure.

Wave effects: - water velocities in waves decrease with depth.
- water velocity on top of sub greater than below sub, produces lower pressure.

23. Draw diagram showing rudder, fairwater, and stern planes. What are each used for?



rudder - turning
fairwater planes - depth control
stern planes - trim control