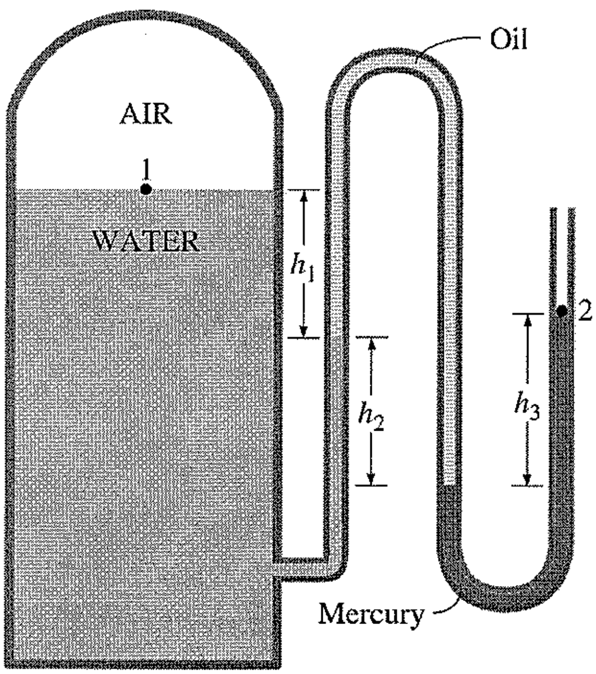
NAME:__________________

This is a closed book exam. 1 additional sheet of US-Letter paper with personal notes/equations on 1 side are allowed. Method of computation (calculator, nomograph, etc.) is up to you, but keep in mind that I cannot give partial credit if you used an equation solver in your calculator and come up with the wrong answer. Hence provide all necessary solving steps to follow through to the result. Show all work on attached pages and/or add additional pages if necessary.

1. (33.3 %) **Measuring Pressure with a Multi-fluid Manometer:**
The water in a tank is pressurized by air, and the pressure is measured by a multi-fluid manometer as shown in Figure below. The tank is located on a mountain at an altitude of 1400 m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank if $h_1 = 0.1$ m, $h_2 = 0.2$ m, and $h_3 = 0.35$ m. Take the densities of water, oil, and mercury to be 1000 kg/m3, 850 kg/m3, and 13,600 kg/m3, respectively.



1 1 1 1

$$P_1 + \rho_{WATER}\, g \cdot h_1 + \rho_{OIL} \cdot g \cdot h_2 - \rho_{mercury} \cdot g \cdot h_3 = P_{atm}$$

1

$$P_1 = P_{atm} - \rho_{WATER}\, g \cdot h_1 - \rho_{OIL} \cdot g \cdot h_2 + \rho_{mercury} \cdot g \cdot h_3$$

$$P_1 = P_{ATM} + g\left(\rho_{mercury} \cdot h_3 - \rho_{WATER} \cdot h_1 - \rho_{OIL} \cdot h_2\right)$$

$$P_1 = 85.6 \text{ kPa} + \left(9.81 \tfrac{m}{s^2}\right) \cdot \left[(13,600 \text{ kg/m}^3) \cdot (0.35 \text{ m}) - (1000 \text{ kg/m}^3)(0.1 \text{ m}) - \left(850 \tfrac{kg}{m^3}\right)(0.2 \text{ m})\right] \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \frac{m}{s^2}}\right)\left(\frac{1 \text{ kPa}}{1000 \frac{N}{m^2}}\right)$$

3

2 $\underline{P_1 = 130 \text{ kPa}}$

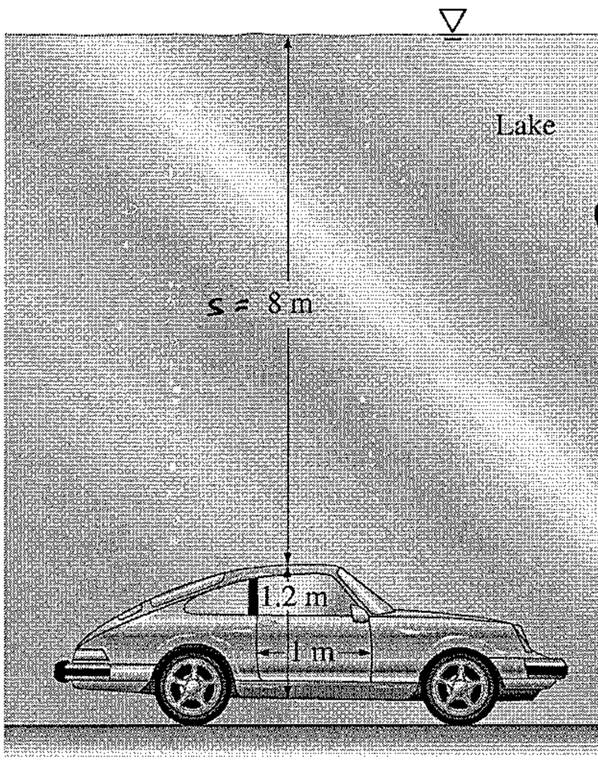
10 PTS TOTAL

2. (33.3 %) **Hydrostatic Force Acting on the Door of a Submerged Car:**

A heavy car plunges into a lake during an accident and lands at the bottom of the lake on its wheels (Figure below). The door is 1.2 m high and 1 m wide, and the top edge of the door is 8 m below the free surface of the water. Determine the hydrostatic force on the door and the location of the pressure center.

Bonus question: Discuss if the driver can open the door assuming the strong driver can apply a push force of 1 kN at a point of driver choosing at 1 m from the door hinges.

Assume: The bottom surface of the lake is horizontal. The passenger cabin is well-sealed so that no water leaks inside. The door can be approximated as a vertical rectangular plate. The pressure in the passenger cabin remains at atmospheric value since there is no water leaking in, and thus no compression of the air inside.



2

$$P_{ave} = P_c = \rho g h_c = \rho \cdot g \cdot \left(s + \frac{b}{2}\right)$$

$$= \left(1000 \frac{kg}{m^3}\right)\left(9.81 \frac{m}{s^2}\right)\left(8m + \frac{1.2m}{2}\right) \cdot \left(\frac{1kN}{1000 \frac{kg\,m}{s^2}}\right)$$

1 $= 84.4\ kN/m^2$

2 $F_R = P_{ave} \cdot A = \left(84.4 \frac{kN}{m^2}\right)(1m \cdot 1.2m)$

$= 101.3\ kN$ 1

$$y_p = s + \frac{b}{2} + \frac{b^2}{12\left(s + \frac{b}{2}\right)}$$ 2

$$= 8 + \frac{1.2}{2} + \frac{1.2^2}{12(8 + 1.2/2)}$$ 1

$= 8.61\ m$ 1

TOTAL 10 PTS

BONUS: F_R acts 0.5 m from hinges

1 ⇒ MOMENT 50.65 kN · m

1 ⇒ >> 1 kN · 1m of driver

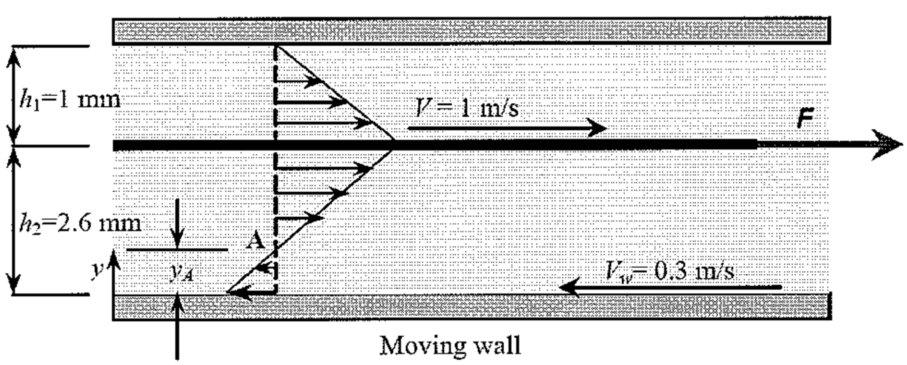
⇒ DRIVER NEEDS TO BE 50 x STRONGER

⇒ HE WILL NOT GET THE DOOR OPEN

(UNLESS OPENS WINDOW......)

MAX 2 PT BONUS

3. (33.3 %) A thin (thickness of the plate is negligible) 20-cm x 20-cm flat plate is pulled at 1 m/s horizontally through a 3.6-mm-thick oil layer sandwiched between two plates, one stationary and the other moving at a constant velocity of 0.3 m/s, as shown in Figure below. The dynamic viscosity of oil is $\mu = 0.027$ Pa·s = 0.027 N·s/m^2. Assuming the velocity in each oil layer to vary linearly: (*a*) find the location y_A where the oil velocity is zero and (*b*) determine the force that needs to be applied on the plate to maintain this motion.



a) $$\frac{2.6 - y_A}{y_A} = \frac{1}{0.3} \longrightarrow y_A = 0.6\ mm$$ 2

b) $$F_{\substack{SHEAR\\UPPER}} = \tau_{\substack{w\\UPPER}} \cdot A_S = \mu \cdot A_s \left|\frac{du}{dy}\right| = \mu \cdot A_S \frac{V-0}{h_1}$$ 2

$$= (0.027\ N\cdot s/m^2)(0.2 \times 0.2\ m^2)\frac{1\ m/s}{1.0 \times 10^{-3} m} = 1.08\ N$$ 1

$$F_{\substack{SHEAR\\LOWER}} = \tau_{\substack{w\\LOWER}} \cdot A_s = \mu \cdot A_s \left|\frac{du}{dy}\right| = \mu \cdot A_S \frac{V - V_w}{h_2}$$ 2

$$= \left(0.027 \frac{Ns}{m^2}\right)(0.2 \times 0.2\ m^2)\frac{[1-(-0.3)]\ \frac{m}{s}}{2.6 \cdot 10^{-3} m} = 0.54\ N$$ 1

$$F = F_{\substack{SHEAR\\UPPER}} + F_{\substack{SHEAR\\LOWER}} = 1.08 + 0.54\ N = 1.62\ N$$ 2

10 TOTAL