# 057:20 TEST # 3 Fall 2005

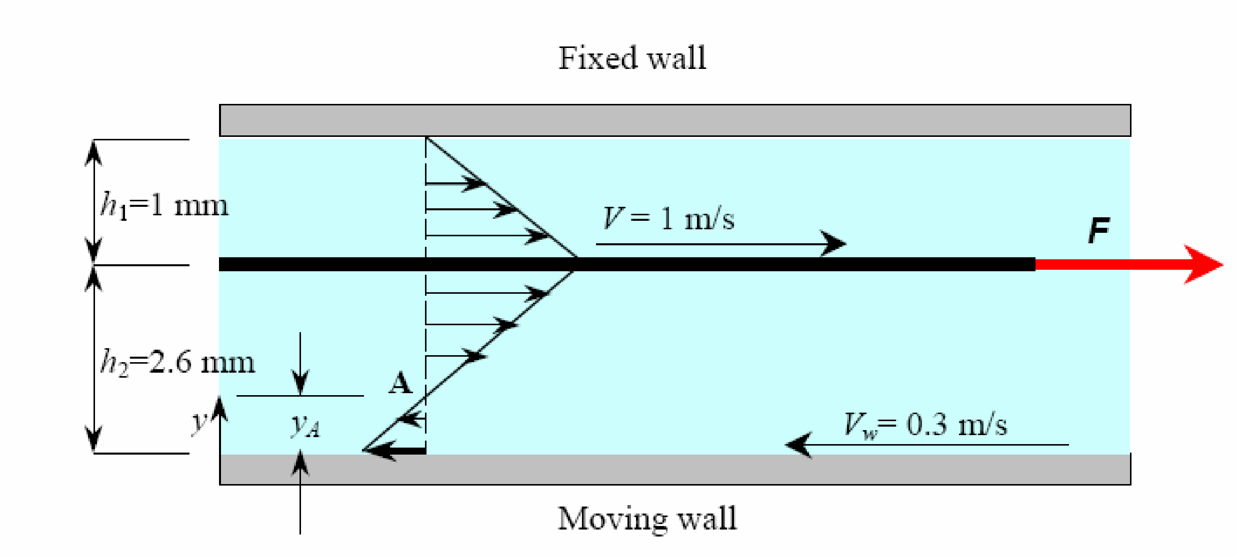
**Prob. 1**

**Information and assumptions**

**Find**

determine the force that needs to be applied on the plate to maintain this motion.

**Solution**




The magnitudes of shear forces acting on the upper and lower surfaces of the plate are

$$F_{shear} = \tau_w A_s = \mu A_s \left|\frac{du}{dy}\right| \quad (+5)$$

$$F_{\text{shear, upper}} = \tau_{w,\text{ upper}} A_s = \mu A_s \left|\frac{du}{dy}\right| = \mu A_s \frac{V-0}{h_1} = (0.027\ \text{N}\cdot\text{s/m}^2)(0.2\times 0.2\ \text{m}^2)\frac{1\ \text{m/s}}{1.0\times 10^{-3}\ \text{m}} = 1.08\ \text{N}$$

$$F_{\text{shear, lower}} = \tau_{w,\text{ lower}} A_s = \mu A_s \left|\frac{du}{dy}\right| = \mu A_s \frac{V-V_w}{h_2} = (0.027\ \text{N}\cdot\text{s/m}^2)(0.2\times 0.2\ \text{m}^2)\frac{[1-(-0.3)]\ \text{m/s}}{2.6\times 10^{-3}\ \text{m}} = 0.54\ \text{N} \quad (+2, +2)$$

$$F = F_{\text{shear, upper}} + F_{\text{shear, lower}} = 1.08 + 0.54 = \mathbf{1.62\ N} \quad (+1)$$

# 057:20 TEST # 3 Fall 2005

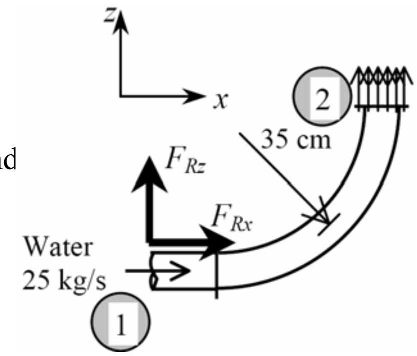
**Prob. 2**

**Information and assumptions**

Provided in problem statement

**Find**

(a) the gage pressure at the center of the inlet of the elbow and
(b) the anchoring force needed to hold the elbow in place.




**Solution**

(a) The mean inlet and outlet velocities of water are

$$V_1 = V_2 = V = \frac{\dot{m}}{\rho A} = \frac{\dot{m}}{\rho(\pi D^2/4)} = \frac{25\ \text{kg/s}}{(1000\ \text{kg/m}^3)[\pi(0.1\,\text{m})^2/4]} = 3.18\ \text{m/s}$$ (+1)

The Bernoulli equation for a streamline going through the center of the reducing elbow is

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 \rightarrow P_1 - P_2 = \rho g(z_2 - z_1) \rightarrow P_{1,\,\text{gage}} = \rho g(z_2 - z_1)$$ (+2, +1)

$$P_{1,\,\text{gage}} = (1000\,\text{kg/m}^3)(9.81\,\text{m/s}^2)(0.35\,\text{m})\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right) = 3.434\,\text{kN/m}^2 = \mathbf{3.434\ kPa}$$ (+1)

(b) Then the momentum equations

$$\sum \vec{F} = \sum_{\text{out}} \beta\dot{m}\vec{V} - \sum_{\text{in}} \beta\dot{m}\vec{V}$$ (+3)

$$F_{Rx} + P_{1,\text{gage}}A_1 = 0 - \beta\dot{m}(+V_1) = -\beta\dot{m}V$$
$$F_{Rz} = \beta\dot{m}(+V_2) = \beta\dot{m}V$$

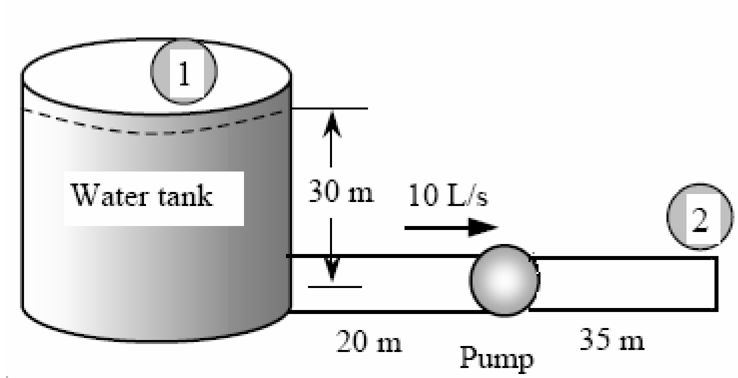
$$F_{Rx} = -\beta\dot{m}V - P_{1,\,\text{gage}}A_1$$
$$= -1.03(25\,\text{kg/s})(3.18\,\text{m/s})\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right) - (3434\ \text{N/m}^2)[\pi(0.1\,\text{m})^2/4]$$
$$= -109\ \text{N}$$

$$F_{Ry} = \beta\dot{m}V = 1.03(25\,\text{kg/s})(3.18\,\text{m/s})\left(\frac{1\,\text{N}}{1\,\text{kg}\cdot\text{m/s}^2}\right) = 81.9\ \text{N}$$ (+1)

$$F_R = \sqrt{F_{Rx}^2 + F_{Ry}^2} = \sqrt{(-109)^2 + 81.9^2} = \mathbf{136\ N}, \quad \theta = \tan^{-1}\frac{F_{Ry}}{F_{Rx}} = \tan^{-1}\frac{81.9}{-109} = -37° = \mathbf{143°}$$ (+1)

# 057:20 TEST # 3 Fall 2005

**Prob. 3**




**Information and assumptions**

Provided in problem statement

**Find**

The required pumping head

**Solution**

The energy equation:

$$\frac{P_1}{\rho g}+\alpha_1\frac{V_1^2}{2g}+z_1+h_{\text{pump, u}}=\frac{P_2}{\rho g}+\alpha_2\frac{V_2^2}{2g}+z_2+h_{\text{turbine, e}}+h_L \rightarrow z_1+h_{\text{pump, u}}=\alpha_2\frac{V_2^2}{2g}+h_L$$ (+4)

where $\alpha_2 = 1$ and

$$h_L=h_{L,\text{total}}=h_{L,\text{major}}+h_{L,\text{minor}}=\sum\left(f\frac{L}{D}+\sum K_L\right)\frac{V^2}{2g}$$ (+1)

**Pipe 1**: $$V_1=\frac{\dot V}{A_{c1}}=\frac{\dot V}{\pi D_1^2/4}=\frac{0.018\ \text{m}^3/\text{s}}{\pi(0.06\ \text{m})^2/4}=6.366\ \text{m/s}$$

$$\text{Re}_1=\frac{\rho V_1 D_1}{\mu}=\frac{(999.1\ \text{kg/m}^3)(6.366\ \text{m/s})(0.06\ \text{m})}{1.138\times10^{-3}\ \text{kg/m}\cdot\text{s}}=335{,}300$$ (+1)

$$\varepsilon/D_1=\frac{0.00026\ \text{m}}{0.06\ \text{m}}=0.00433$$

From Moody Chart, $f = 0.0294$. From Table 8-4, $K_L = 0.5$ (+1)

$$h_{L1}=\left(f_1\frac{L_1}{D_1}+\sum K_L\right)\frac{V_1^2}{2g}=\left((0.02941)\frac{20\ \text{m}}{0.06\ \text{m}}+0.5\right)\frac{(6.366\ \text{m/s})^2}{2(9.81\ \text{m/s}^2)}=21.3\ \text{m}$$ (+1)

**Pipe2**

$$V_2=V_1=6.366\,m/s$$

$$h_{L2}=f\frac{L_2}{D_2}\frac{V_2^2}{2g}=(0.02941)\frac{35m}{0.06m}\frac{(6.366\,m/s)^2}{2(9.81\,m/s^2)}=35.4m$$ (+1)

$$h_L=h_{L1}+h_{L2}=21.3m+35.4m=56.7m$$

The required pumping head

$$h_{pump,u}=\alpha_2\frac{V_2^2}{2g}+h_L-z_1=(1)\frac{(6.366\,m/s)^2}{2(9.81\,m/s^2)}+56.7-30=28.7m$$ (+1)

# 057:20 TEST # 3 Fall 2005

**Prob. 4**

**Information and assumptions**

Provided in problem statement

**Find**

Estimate the boundary layer thickness, the displacement thickness, and the momentum thickness of the boundary layer at the end of the test section.

**Solution**

The Reynolds number at the downstream end of the wall

$$\mathrm{Re}_x = \frac{VL}{\nu} = \frac{(7.5\ \mathrm{ft/s})(1.5\ \mathrm{ft})}{1.697\times10^{-4}\ \mathrm{ft^2/s}} = 6.63\times10^4$$

(+3)

So the boundary layer remains laminar. (+1)

*Boundary layer thickness:* $\delta = \frac{4.91x}{\sqrt{\mathrm{Re}_x}} = \frac{4.91(1.5\ \mathrm{ft})}{\sqrt{6.63\times10^4}} = 0.0286\ \mathrm{ft} \approx 0.34\ \mathrm{in}$

and

*Displacement thickness:* $\delta^* = \frac{1.72x}{\sqrt{\mathrm{Re}_x}} = \frac{1.72(1.5\ \mathrm{ft})}{\sqrt{6.63\times10^4}} = 0.0100\ \mathrm{ft} \approx 0.12\ \mathrm{in}$

and

*Momentum thickness:* $\theta = \frac{0.664x}{\sqrt{\mathrm{Re}_x}} = \frac{0.664(1.5\ \mathrm{ft})}{\sqrt{6.63\times10^4}} = 0.00387\ \mathrm{ft} \approx 0.046\ \mathrm{in}$

(+2, +2, +2)

**Prob. 5**

**Information and assumptions**

Provided in problem statement

**Find**

Drag force acting on the top and side surfaces and the power required to overcome this drag

**Solution**

The Reynolds number is

$$Re_L = \frac{VL}{\upsilon} = \frac{[65 \times 1.4667 \text{ ft/s}](20 \text{ ft})}{1.697 \times 10^{-4} \text{ ft}^2/\text{s}} = 1.124 \times 10^7$$ (+2)

Then the friction coefficient:

$$C_f = \frac{0.074}{Re_L^{1/5}} = \frac{0.074}{(1.124 \times 10^7)^{1/5}} = 0.002878$$ (+2)

The area of the top and side surfaces of the truck is

$$A = A_{top} + 2A_{side} = 9\times20+2\times8\times20 = 500 \text{ ft}^2$$ (+1)

The drag force acting on these surfaces becomes

$$F_D = C_f A \frac{\rho V^2}{2} = 0.002878 \times (500 \text{ ft}^2) \frac{(0.07350 \text{ lbm/ft}^3)(65 \times 1.4667 \text{ ft/s})^2}{2} \left( \frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) = \mathbf{14.9 \text{ lbf}}$$ (+3)

Noting that power is force times velocity, the power needed to overcome this drag force is

$$\dot{W}_{drag} = F_D V = (14.9 \text{ lbf})(65 \times 1.4667 \text{ ft/s}) \left( \frac{1 \text{ kW}}{737.56 \text{ lbf} \cdot \text{ft/s}} \right) = \mathbf{1.93 \text{ kW}}$$ (+2)

# 057:20 TEST # 3 Fall 2005

**Prob. 6**

**Information and assumptions**

Provided in problem statement

**Find**

Drag on cooling tower

**Solution**

The drag coefficient for an ellipsoid with L/D = 25/5 = 5 is CD = 0.1 in turbulent flow (from table 11-2) (+2)

Noting that 1 m/s = 3.6 km/h, the velocity of the submarine is equivalent to V = 40/3.6 = 11.11 m/s. The frontal area of an ellipsoid is $A = \pi D^2/4$.

Then the drag force acting on the submarine becomes

*In water:* $$F_D = C_D A \frac{\rho V^2}{2} = (0.1)[\pi(5\text{ m})^2/4]\frac{(1025\text{ kg/m}^3)(11.11\text{ m/s})^2}{2}\left(\frac{1\text{ kN}}{1000\text{ kg}\cdot\text{m/s}^2}\right) = 124.2\text{ kN}$$

*In air:* $$F_D = C_D A \frac{\rho V^2}{2} = (0.1)[\pi(5\text{ m})^2/4]\frac{(1.30\text{ kg/m}^3)(11.11\text{ m/s})^2}{2}\left(\frac{1\text{ kN}}{1000\text{ kg}\cdot\text{m/s}^2}\right) = 0.158\text{ kN}$$

(+2, +2)

Noting that power is force times velocity, the power needed to overcome this drag force is

*In water:* $$\dot{W}_{\text{drag}} = F_D V = (124.2\text{ kN})(11.11\text{ m/s})\left(\frac{1\text{ kW}}{1\text{ kN}\cdot\text{m/s}}\right) = \mathbf{1380\ kW}$$

*In air:* $$\dot{W}_{\text{drag}} = F_D V = (0.158\text{ kN})(11.11\text{ m/s})\left(\frac{1\text{ kW}}{1\text{ kN}\cdot\text{m/s}}\right) = \mathbf{1.75\ kW}$$

(+2, +2)