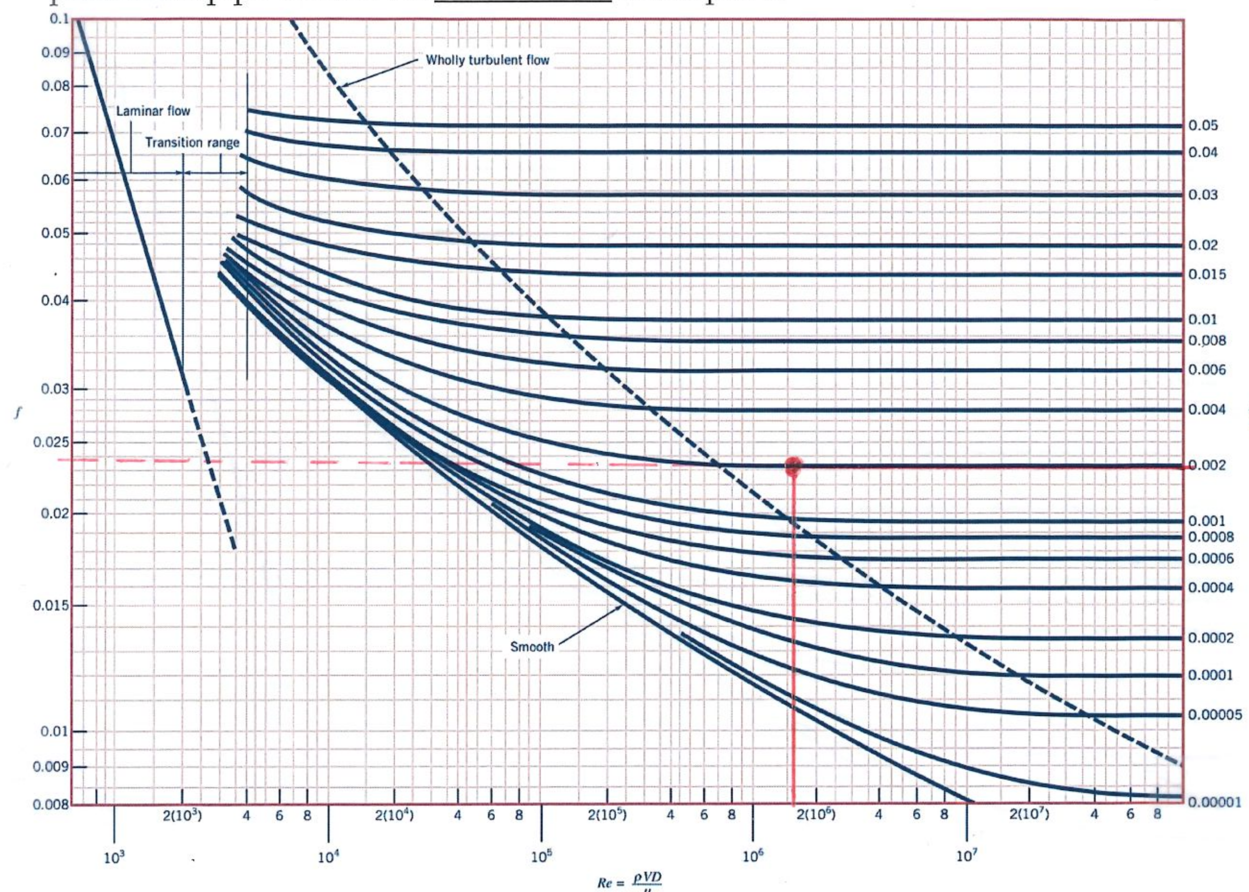
## PROBLEM 2 (39 points)

A pump is being sized for a large fountain that is placed 500 ft off-shore in a lake ($\rho = 1.94$ slugs/ft$^3$ and $\mu = 3.732 \times 10^{-5}$ lbf-s/ft$^2$). The fountain should create a jet of water with a maximum height above the water level of 55 ft. The pump efficiency is 75% and the volumetric flow rate of the pump is 47 ft$^3$/s. The pipes are all 2 ft in diameter and have a roughness of 0.004 ft and all elbows are regular and flanged.

(a) [10 pts] On the Moody diagram provided below, draw a point which indicates the operating point in the pipe. What is the friction factor at this point?




$$Re = \frac{\rho V D}{\mu} = \left[1.94\ \frac{slug}{ft^3} \cdot 15\ ft/s \cdot 2\ ft\right] \Big/ \left[3.732 \times 10^{-5}\ (lbf \cdot s/ft^2)\right] \cdot \left(\frac{slug \cdot ft}{s^2 \cdot lbf}\right)$$

$$V = \dot{V}/A = \dot{V} \cdot 4/\pi D^2 = \frac{47\ ft^3/s \cdot 4}{\pi\ (2^2)\ ft^2} = 15.0\ ft/s$$

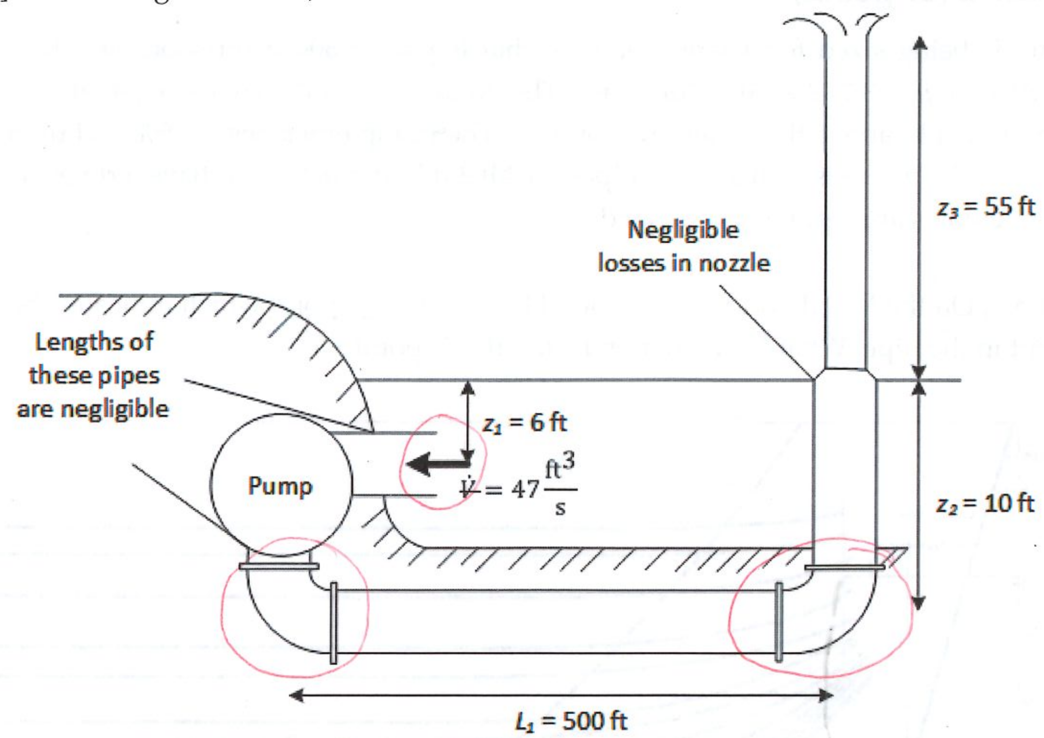
$$Re = 1{,}560{,}000$$

$$\varepsilon/D = \frac{0.004\ ft}{2.0\ ft} = 0.002$$

$$f \approx 0.024$$

ANS

(b) [5 pts] On the diagram below, circle all the sources of minor loss.




(c) [25 pts] Determine the electric power required by the pump (in hp).

3 1 2

MEE (1) to (2)

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} + g z_1 + w_{IN} - loss = \frac{P_3}{\rho} + \frac{V_3^2}{2} + g z_3$$

$$w_{IN} = g z_3 - loss_{major} - loss_{minor}$$

$$= g z_3 + f \frac{L}{D} \frac{V^2}{2} + \Sigma K \frac{V^2}{2} \qquad K_{REENT} = 0.8$$

$$= g z_3 + f \frac{L}{D} \frac{V^2}{2} + (K_{REENT} + 2K_{ELB}) \frac{V^2}{2} \qquad K_{ELBOW} = 0.3$$

$$= 32.2 \frac{ft}{s^2} \cdot 55\, ft + 0.024 \left( \frac{510\, ft}{2\, ft} \right) \frac{1}{2} \frac{15^2\, ft^2}{s^2} + (0.8 + 2 \cdot 0.3) \frac{1}{2} \left( \frac{15^2\, ft^2}{s^2} \right)$$

1771

$$= 2617 \; ft^2/s^2$$

$$\dot{W} = \dot{m} w = \rho \dot{V} w = 1.94 \frac{slug}{ft^3} \cdot 47 \frac{ft^3}{s} \cdot 2617 \frac{ft^2}{s^2} \left( \frac{lbf \cdot s^2}{slug \cdot ft} \right)$$

$$= 238{,}618 \frac{ft \cdot lbf}{s} \left( \frac{s \cdot HP}{550\, ft \cdot lbf} \right) = 434\, HP$$

PROBLEM 2 (cont'd)

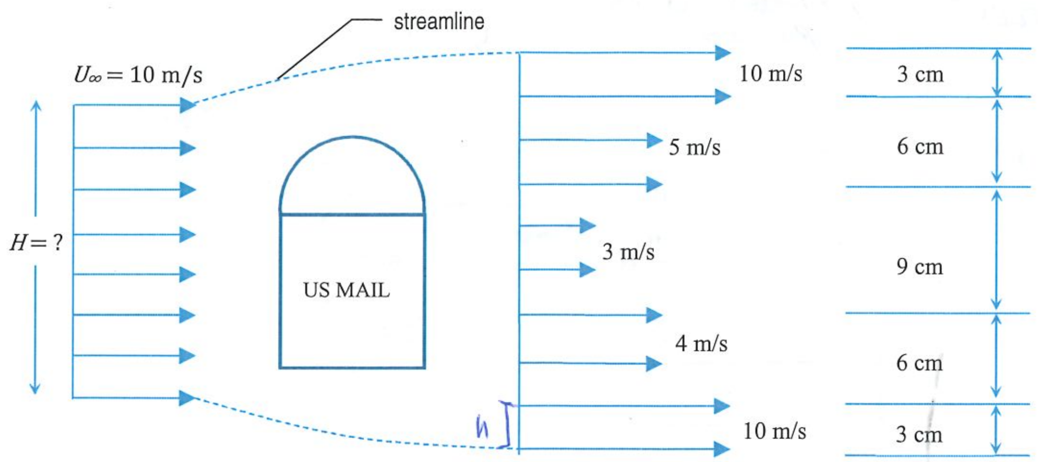
$$\eta_p = \frac{\dot{W}}{\dot{W}_{ELEC}}$$

$$\dot{W}_{ELEC} = \dot{W} / \eta_p = \frac{434\, HP}{0.75} = 578\, HP$$

ANS

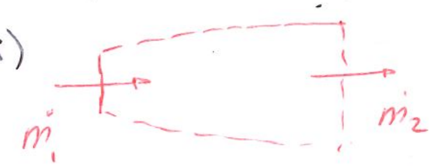
## PROBLEM 3 (37 points)

A mailbox has a $U_\infty$=10 m/s wind blowing against its side. Downstream of the mailbox the wind speed varies as shown below. Assume the flow is uniform from the front to the back of the mailbox (i.e., into the page), and that the mailbox is $w$=50 cm long from front to back. The density of air is $\rho$=1.2 kg/m³.




(a) Find the height $H$ upstream of the mailbox for the system outlined in the figure.
(b) Find the momentum flow rate of air on the downstream side.
(c) Find the net drag force the wind exerts on the mailbox.

(a)




CoM

$$\dot{L}_0 = \dot m_1 - \dot m_2 = \rho w H V_\infty - \rho w \sum h_i V_i$$

$$H = \frac{\sum h_i V_i}{V_\infty} = \big(2\times[3\,cm][10\,m/s] + [6\,cm][5\,m/s] + [9\,cm][3\,m/s] + [6\,cm][4\,m/s]\big)/10\,[m/s]$$

$= 14.1$ cm ← ANS

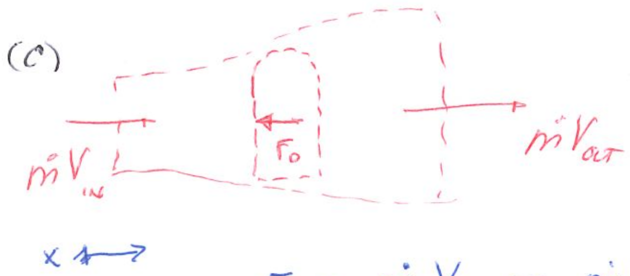
(b) "$\dot m V_{out}$" $= \sum_i \dot m V = \sum_i (\rho w h_i V_i) V_i = \sum \rho w h_i V_i^2 = \rho w \sum h_i V_i^2$

$= 1.2\ \frac{kg}{m^3} \cdot (0.50\ m)\left[2\times 0.03\times 10^2 + 0.06\times 5^2 + 0.09\times 3^2 + 0.06\times 4^2\right] \frac{m^3}{s^2} \left\langle \frac{N\cdot s^2}{kg\cdot m} \right\rangle$

$= 5.56$ N ← ANS

## PROBLEM 3 (cont'd)

(c)




CoLM, x dir

$$\dot L_0 = -F_D + \dot m V_{in,x} - \dot m V_{out,x}$$

$$F_D = \dot m V_{in,x} - \dot m V_{out,x}$$

$$= (\rho w H \cdot V_\infty)(U_\infty) - \dot m V_{out,x}$$

$$= 1.2\ \frac{kg}{m^3}\ 0.50\ m \cdot 0.141\ m \cdot 10^2\ \frac{m^2}{s^2} - 5.56\ N$$

$= 2.90$ N ← ANS