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$\mu_{water} = 2.34\text{x}10^{-5}\ \frac{lbf \cdot s}{ft^2}$

$1\ mile = 5280\ ft$

$1\ \frac{slug \cdot ft}{s^2} = 1\ lbf$

$g = 32.2\ \frac{ft}{s^2}$

1. European Intercity Express trains operate at speeds of up to 280 *km/h*. Suppose that a train is 120 *m* long. Treat the sides and top of the train as one smooth flat plate 9 *m* wide. When the train moves through still air at sea level, calculate
   a. the possible length of the laminar boundary layer, [5 pts]

$\because\ V = 280\ km/h = \frac{280000\ m}{h} \cdot \frac{1\ h}{60\ min} \cdot \frac{1\ min}{60\ s} = 77.78\ m/s$

$\rho_{air} = 1.225\ kg/m^3,\ \mu_{air} = 1.789 \times 10^{-5}\ Pa \cdot s$

$\therefore\ Re = \frac{\rho V \cdot L}{\mu} < 5\times10^5$

$L < \frac{2300 \cdot \mu}{\rho V}$

$L < 0.094\ m$

5

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b. the thickness of this laminar layer at its down-stream end, [5 pts]

for laminar flow: $\frac{\delta}{x} = \frac{5}{\sqrt{Re_x}}$, $Re_x = 5\times10^5$, $x = 0.094\ m$

$\rightarrow \delta_{end} = \frac{5 \times 0.094\ m}{\sqrt{5\times10^5}} = \cancel{6.647 \times 10^{-4}}\ m$

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c. the thickness of the boundary layer at the rear end of the train, [10 pts]

for turbulent flow: $\frac{\delta}{x} = \frac{0.382}{Re_x^{\frac{1}{5}}}$, $x = 120\ m = L$

$Re_x = \frac{\rho_{air} V \cdot L}{\mu_{air}} = \frac{1.225\ kg/m^3 \times 77.78\ m/s \times 120\ m}{1.789\times10^{-5}\ Pa \cdot s}$

$= 6.391 \times 10^8$

10

$\rightarrow \delta = \frac{0.382 \times 120\ m}{(6.391\times10^8)^{\frac{1}{5}}} = 0.795\ m$

d. the viscous drag force on the train in *kN*. [5 pts]

$\because\ Re_x = 6.391\times10^8$, $A = 120\ m \times 9\ m = 1080\ m^2$

$\therefore\ C_D = \cancel{\frac{0.455}{(\log Re_x)^{2.58}} - \frac{1610}{Re_x}} = 1.66\times10^{-3}$

2

$\rightarrow F_D = \frac{1}{2}\rho_{air} V^2 \cdot A \cdot C_D = \frac{1}{2} \times 1.225\ kg/m^3 \times (77.78\ m/s)^2 \times 1080\ m^2 \times 1.66\times10^{-3}$

$= 6639.6\ N$

$= 6.\cancel{6396\ kN}$

10

]

2. Water flows through a 2-*in*-diameter tube that suddenly contracts to 1 *in* diameter. The pressure drop across the contraction is 0.5 *psi*. Determine the volume flow rate in ft^3/min. [25pts]

assume there is no head loss, incompressible flow, $z_1 = z_2$

$$\because \frac{P_1}{\rho_{water}} + \frac{V_1^2}{2} + g z_1 = \frac{P_2}{\rho_{water}} + \frac{V_2^2}{2} + g z_2$$

$$\frac{d}{dt}\int_{cv} \rho d\forall + \int_{cs} \rho \vec{V} \cdot d\vec{A} = 0$$

$$\rightarrow Q_1 = Q_2, \quad A_1V_1 = A_2V_2, \quad A_1 = \frac{(\frac{2}{12} ft)^2 \pi}{4} \quad A_2 = \frac{(\frac{1}{12} ft)^2 \pi}{4}$$

[10

$$\because \rho_{water} = 1.938 \ slug/ft^3 \quad z_1 = z_2 \qquad \rightarrow \frac{A_2}{A_1} = \frac{1}{4}$$

=L

$$\rightarrow \frac{P_1 - P_2}{\rho_{water}} = \frac{V_2^2 - V_1^2}{2} = \frac{(1 - \frac{A_2^2}{A_1^2})V_2^2}{2}$$

$$V_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho_{water}(1 - \frac{A_2^2}{A_1^2})}} = \sqrt{\frac{2 \times 0.5 \ lbf/in^2 \cdot (\frac{12 \ in}{1 ft})^2}{1.938 \ slug/ft^3 (1 - \frac{1}{4^2})}}$$

$$= 8.904 \ ft/s$$

$$\rightarrow A_2V_2 = Q = \frac{(\frac{1}{12} ft)^2 \pi}{4} \times 8.904 \ ft/s = 15.48 \times 10^{-3} \ ft^3/s$$

$$= \frac{15.48 \times 10^{-3} \ ft^3}{s} \times \frac{60 s}{1 min}$$

$$= 0.9288 \ ft^3/min$$

om^2

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3. The unsteady lift force F_L on a cylinder is a function of the diameter D, the cylinder length l, the vortex shedding frequency f, the free stream velocity V_∞, the free stream density ρ, the free stream speed of sound c_∞, and the viscosity μ. Use D, V_∞, and ρ as the repeating parameters.
   a) What is the dependent parameter? [3pts]
   b) What is the total number of variables? [3pts]
   c) What is the number of fundamental (primary) dimensions? [3pts]
   d) How many dimensionless parameters will result? [3pts]
   e) Obtain the π parameter that contains the frequency, f. Note: dimension for f is 1/time. [13pts]

$D \quad l \quad f \quad V_\infty \quad \rho \quad c_\infty \quad \mu \rightarrow n=7$

repeating parameter : D, V_∞, ρ

(a) dependent parameters : $\cancel{l, f, c_\infty, \mu}$ 0

(b) total number of variables : $\cancel{n=7}$ 0

(c) $\because D \rightarrow L \quad V_\infty \rightarrow L/t \quad \rho \rightarrow M/L^3$

$\rightarrow$ primary dimensions : $M, L, t \rightarrow r=3$ 3

(d) $\because$ $\begin{array}{cccc} l & f & c_\infty & \mu \\ L & \frac{1}{t} & \frac{L}{t} & \frac{M}{Lt} \end{array}$ $\therefore m=r=3$ 3

$\rightarrow n-m=\cancel{4}$ So, four dimensionless parameters will result.

(e) $\Pi=\rho^a V_\infty^b D^c f \rightarrow \left(\frac{M}{L^3}\right)^a \left(\frac{L}{t}\right)^b (L)^c \cdot \left(\frac{1}{t}\right) = M^0 L^0 t^0$

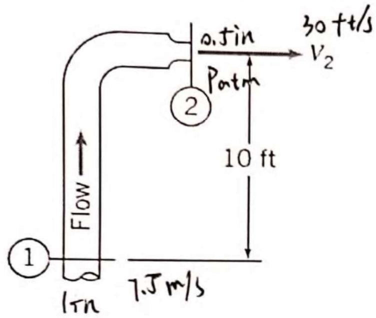
$\rightarrow M: \; a=0, \quad L: \; b+c-3a=0, \quad t: \; -b-1=0$

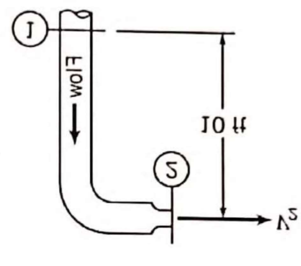
$\Rightarrow a=0, \; b=-1, \; c=1 \quad \therefore$ So, $\Pi=\frac{Df}{V_\infty}$ 13

15

4. Fill-in the blank questions: [5pts each]

Water flows steadily up the vertical 1-*in*-diameter pipe and out the nozzle, which is 0.5 *in* in diameter, discharging to atmospheric pressure. The stream velocity at the nozzle exit must be 30 *ft/s*. From here:





inverted

5

i. the velocity at section ① is 7.5 *ft/s*,

0

ii. the minimum gage pressure required at section ① is 1441.63 *psi*,

iii. if the device were inverted, the required minimum gage pressure at section ① would be 193.56 *psi*.

0

Your car runs out of gas unexpectedly and you siphon gas from another car. The height difference for the siphon is 1 ft. The hose diameter is 0.5 in. Assume the tank free surface is decreasing very slowly and is exposed to the atmosphere. V≈0

5

iv. The flow velocity at the syphon exit is 8.025 *ft/s*.

v. The gasoline flow rate is 0.011 ft^3/s.

5