Practice Problem set - 5

Question 1:

A reasonable approximation for the two-dimensional incompressible laminar boundary layer on the flat surface is given by the expression:

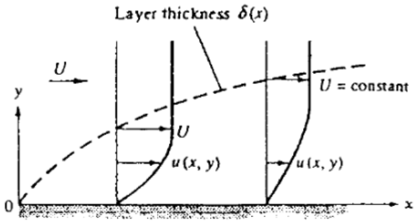


Fig. P4.17

$$u = U\left(\frac{2y}{\delta} - \frac{y^2}{\delta^2}\right) \quad \text{for } y \le \delta$$

where $\delta \approx Cx^{1/2}$, $C = \text{const}$

(a) Assuming a no-slip condition at the wall, find an expression for the velocity component $v(x, y)$ for $y \le \delta$.

Answer:

$$v = 2U\frac{d\delta}{dx}\left(\frac{y^2}{2\delta^2} - \frac{y^3}{3\delta^3}\right),$$

(b) Then find the maximum value of v at station $x = 1$ m, for the particular case of airflow when $U = 3$ m/s and $\delta = 1.1$ cm.

Answer:

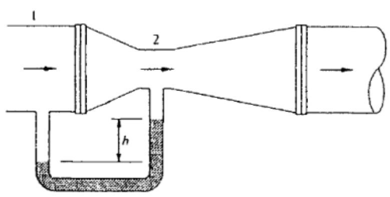
$$v_{max} = v|_{y=\delta} = \frac{U\delta}{6x} = \frac{(3\ m/s)(0.011\ m)}{6(1\ m)} = \mathbf{0.0055}\ \frac{\mathbf{m}}{\mathbf{s}}$$

(c) Sometimes, the laminar boundary-layer flow on a flat plate is given by a general sinusoidal velocity profile $u = A\sin(By) + C$. State the boundary conditions applicable to the specific problem. Also, determine the expression of u(y).

Answer: $u(y) = U\sin\left(\frac{\pi}{2}\frac{y}{\delta}\right)$

Question 2:

The pressure drop in a venturi meter varies only with the meter's fluid density, pipe approach velocity, and diameter ratio. A model venturi meter tested in water at 20°C shows a 5-kPa drop when the approach velocity is 4 m/s. A geometrically similar prototype meter measures gasoline at 20°C and a 9 m^3/min flow rate. If the prototype pressure gauge is most accurate at 15 kPa, what should the upstream pipe diameter be?



Answer: $D_p = 0.151$ m

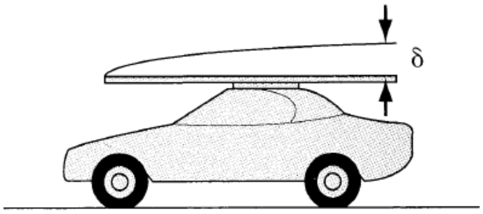
Question 3:

The flow rate of methanol at 20°C (ρ = 788.4 kg/m3 and $\mu = 5.857 \times 10^{-4}$ kg/(m · s)) through a 4-cm-diameter pipe is to be measured with a 3-cm-diameter orifice meter equipped with a mercury manometer across the orifice place. If the manometer's differential height is 11 cm, determine the flow rate of methanol through the pipe and the average flow velocity. (The discharge coefficient of the orifice meter is C_d = 0.61)

Answer: Flow rate = 3.09×10^{-3} m^3/s, Velocity = 2.46 m/s

Question 4:

Suppose you buy a 4 × 8-ft sheet of plywood and put it on your roof rack, as in the figure. You drive home at 35 mi/h. (a) If the board perfectly aligns with the airflow, how thick is the boundary layer at the end? (b) Estimate the drag if the flow remains laminar. (c) Estimate the drag for (smooth) turbulent flow.



Answer: Laminar δ = 0.3 in, F_{lam} = 0.73 N; **Turbulent** δ = 1.9 in, F_{turb} = 3.3 N

Question 5:

Air is flowing over a smooth plate With a velocity of 10 m/s. The plate length is 1.2 m, and the width is 0.8 m. If the **laminar boundary layer** exists up to a value of Re = 2 x 10^5, find the maximum distance from the leading edge up to which the laminar boundary layer exists. Take kinematic viscosity for air = 0.15 stokes.

Answer: 0.3 m

Question 6:

For the velocity profile $u/U = 2(y/\delta) — (y/\delta)^2$, find the thickness of the boundary layer at the end of the plate and the drag force on one side of a plate 1 m long and 0.8 m wide when placed in water flowing with a velocity of 150 mm per second. Calculate the value of the co-efficient of drag also. Take μ for water = 0.01 poise.

Answer: δ=14.15 mm, F_D = 0.0338 N, C_D = 0.00376

Question 7:

A 150 mm × 75 mm venturi meter measures oil (specific gravity = 0.9) flow rate. The reading shown by the U tube manometer connected to the venturi meter is 150 mm of mercury column. Calculate the discharge coefficient for the venturi meter if the flow rate is 1.7 m3/min. (Note: The size of the venturi meter is generally specified in terms of inlet and throat diameters)

Answer: $C_D = 0.963$

Question 8:

A student is to design an experiment involving dragging a sphere through a tank of fluid to illustrate (i) "creeping flow" ($Re_D \ll 1$) and (ii) flow for which the boundary layer becomes turbulent ($Re_D \approx 2.5 \times 10^5$). She proposes to use a smooth sphere of diameter 1 cm in SAE 10 oil at room temperature. Is this realistic for both cases? If either case is unrealistic, select an alternative reasonable sphere diameter and common fluid for that case (kinematic viscosity of SAE 10 = $1.1 \times 10^{-4}\ m^2 s^{-1}$).

Answer: There are numerous possible solutions. One such solution is to use a 10 cm sphere in water.

Question 9:

A) Assume laminar boundary-layer flow to estimate the drag on the triangular plate shown when it is parallel to a 15 m/s airflow. Take the kinematic viscosity of air as $1.51 \times 10^{-5}\ m^2\ s^{-1}$ and density of air as $1.2\ kg\ m^{-3}$. The drag coefficient of a flat plate parallel to the flow is given by the expression $C_f = \frac{0.73}{\sqrt{Re_x}}$.

Answer: 0.347 N

B) Determine the drag if the plate is parabolic, as shown in the figure. Compare the drag to that of the triangular plate.

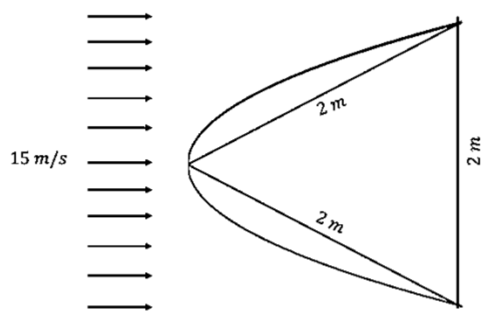


Figure 1Figure for Question 9

Answer: 0.713 N

C) In problem A), if the base rather than the tip faces the flow, would you expect the drag to be larger than, the same as, or lower than when the tip faces the flow? If not equal, how much does it change? How is this value compared to the one obtained in problem B)?

Answer: 0.694 N

Question 10:

Water at 10^{o}C flows steadily through a venturi. The pressure upstream from the throat is 200 kPa (gage). The throat diameter is 50 mm; the upstream diameter is 100 mm. Estimate this device's maximum flow rate if the downstream pressure is the same as water's vapor pressure at 10^{o}C i.e., 1.1 kPa. What will happen if the downstream pressure is maintained lower than this?

Answer: Assuming a discharge coefficient of 0.99, Q = 49.2 lps. A downstream pressure lower than the fluid's vapor pressure will lead to cavitation.