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NAME

Fluids-ID

Quiz 11. Air at 20°C and 1 atm (ρ = 1.2 kg/m^3 and μ = 1.8 × 10-5 kg/m-s) flows at U = 3 m/s past a sharp flat plate of width b = 2 m and length L = 1 m. (a) Is the flow laminar or turbulent? (b) What is the local wall shear stress τ_w at the end of the plate? (c) What is the total friction drag D_f on both sides of the plate? (Use $Re_{cr} = 5 \times 10^5$)

Local friction coefficient:

$$c_f = \frac{\tau_w}{\frac{1}{2}\rho U^2} = \begin{cases} \dfrac{0.664}{\sqrt{Re_x}} & \text{(laminar)} \\ \dfrac{0.027}{Re_x^{\frac{1}{7}}} & \text{(turbulent)} \end{cases}$$

Friction drag coefficient:

$$C_f = \frac{D_f}{\frac{1}{2}\rho U^2 A} = \begin{cases} \dfrac{1.328}{\sqrt{Re_L}} & \text{(laminar)} \\ \dfrac{0.031}{Re_L^{\frac{1}{7}}} & \text{(turbulent)} \end{cases}$$

Solution:

(a) Check the Reynolds number to see if the flow is laminar or turbulent:

$$Re_L = \frac{\rho U L}{\mu} = \frac{\left(1.2\ \frac{\text{kg}}{\text{m}^3}\right)\left(3\ \frac{\text{m}}{\text{s}}\right)(1\ \text{m})}{1.8 \times 10^{-5}\ \frac{\text{kg}}{\text{m} \cdot \text{s}}} = 2 \times 10^5 < Re_{\text{cr}} \quad \text{(Laminar)} \qquad \text{(+2 points)}$$

(b) With $Re_x = Re_L = 2 \times 10^5$ at $x = L$,

$$c_f = \frac{0.664}{\sqrt{Re_x}} = \frac{0.664}{\sqrt{2 \times 10^5}} = 0.00148$$

$$\therefore \tau_w = c_f \frac{\rho}{2} U^2 = (0.00148)\left(\frac{1.2\ \frac{\text{kg}}{\text{m}^3}}{2}\right)\left(3\ \frac{\text{m}}{\text{s}}\right)^2 = 0.0080\ \text{Pa} \qquad \text{(+4 points)}$$

(b) Compute the drag for both sides of the plate, $A = 2bL$:

$$C_f = \frac{1.328}{\sqrt{Re_L}} = \frac{1.328}{\sqrt{2 \times 10^5}} = 0.00297$$

$$\therefore D_f = C_f \frac{\rho}{2} U^2 A = (0.00297)\left(\frac{1.2\ \frac{\text{kg}}{\text{m}^3}}{2}\right)\left(3\ \frac{\text{m}}{\text{s}}\right)^2 (2 \times 2\ \text{m} \times 1\ \text{m}) = 0.064\ \text{N} \qquad \text{(+4 points)}$$