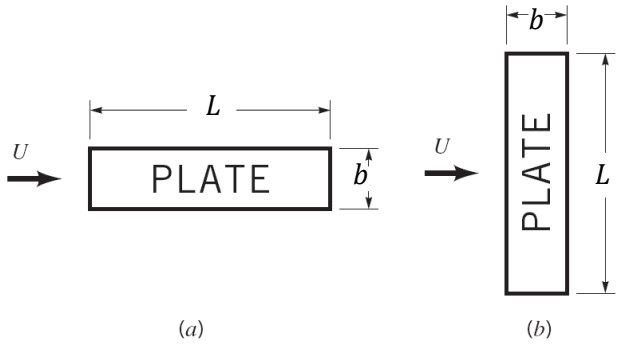
December 3, 2012

NAME

Fluids-ID

Quiz 15. A thin flat plate 55 by 110 cm is immersed in a 6-m/s stream of SAE 10 oil at 20°C. Compute the boundary layer thickness δ at the end of the plate and the total friction drag D_f if the stream is parallel to (a) the long side and (b) the short side. Transition to turbulent flow may occur at Re = 5×10^5. (ρ = 891 kg/m^3, μ = 0.29 kg/m·s)



Boundary later thickness:

$$\frac{\delta}{x} = \begin{cases} \frac{5}{\sqrt{Re_x}} \text{ (laminar)} \\ \frac{0.37}{Re_x^{1/5}} \text{ (turbulent)} \end{cases}$$

Friction drag coefficient:

$$C_f = \frac{D_f}{\frac{1}{2}\rho U^2 A} = \begin{cases} \frac{1.328}{\sqrt{Re_\ell}} \text{ (laminar)} \\ \frac{0.072}{Re_\ell^{1/5}} \text{ (turbulent)} \end{cases}$$

Solution:

(a) Long side

$$Re_L = \frac{\rho UL}{\mu} = \frac{(891)(6)(1.1)}{(0.29)} = 20{,}300 \text{ (laminar)}$$ (+2 points)

$$\delta = \frac{5L}{\sqrt{Re_L}} = \frac{(5)(1.1)}{\sqrt{20300}} = \mathbf{0.039\ m}$$ (+2 points)

$$D_f = \frac{1}{2}\rho U^2 A C_f = \frac{1}{2}\rho U^2 (2Lb)\frac{1.328}{\sqrt{Re_L}}$$

$$= \left(\frac{1}{2}\right)(891)(6)^2(2\times1.1\times0.55)\left(\frac{1.328}{\sqrt{20300}}\right) = \mathbf{181\ N}$$ (+3 points)

(b) Short side

$$Re_L = \frac{\rho Ub}{\mu} = \frac{(891)(6)(0.55)}{(0.29)} = 10{,}140 \text{ (laminar)}$$

$$\delta = \frac{5b}{\sqrt{Re_L}} = \frac{(5)(0.55)}{\sqrt{10140}} = \mathbf{0.027\ m}$$

$$D_f = \frac{1}{2}\rho U^2 A C_f = \frac{1}{2}\rho U^2 (2Lb)\frac{1.328}{\sqrt{Re_L}}$$

$$= \left(\frac{1}{2}\right)(891)(6)^2(2\times1.1\times0.55)\left(\frac{1.328}{\sqrt{10140}}\right) = \mathbf{256\ N}$$ (+3 points)

Note: The drag is 41% *more* if we align the flow with the short side.