December 8, 2014

NAME

Fluids-ID

Quiz 13. Suppose you buy a 4- by 8-ft sheet of plywood and put it on your roof rack. You drive the car at 35 mi/h. The flow is turbulent from the leading edge of the board and the board is perfectly aligned with the airflow. Find (a) the boundary layer thickness δ, (b) the local friction coefficient c_f, and (c) the wall shear stress τ_w at the end of the board and (d) the friction drag coefficient C_f and (e) the friction drag D_f on the upper side of the plywood. (Note: 1 mi/h = 1.4667 ft/s, 1 lb = 1 slug·ft/s^2, $\nu = 1.57 \times 10^{-4}$ ft^2/s and $\rho = 2.38 \times 10^{-3}$ slugs/ft^3)

Boundary layer thickness:

$$\delta(x) = \frac{0.16x}{Re_x^{1/7}}$$

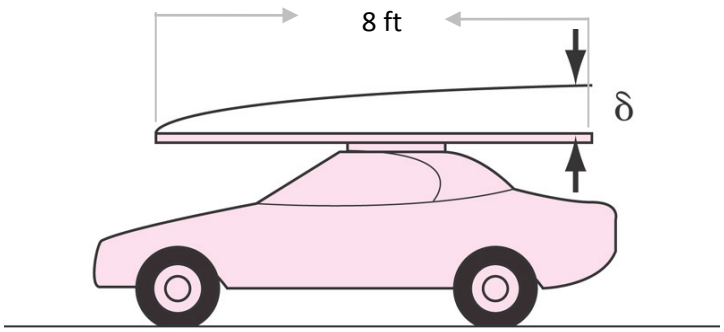
Local friction coefficient:

$$c_f(x) = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2} = \frac{0.027}{Re_x^{1/7}}$$

Friction drag coefficient:

$$C_f = \frac{D_f}{\frac{1}{2}\rho U_\infty^2 A} = \frac{0.031}{Re_L^{1/7}}$$

where, $Re_x = {U_\infty x}/{\nu}$ and $Re_L = {U_\infty L}/{\nu}$



Note: Attendance (+2 points), format (+1 point)

Solution:

(a) Boundary layer thickness at the end of the board,

$$\delta(L) = \frac{0.16x}{Re_x^{1/7}}\Bigg)_{x=L}$$

Where,

$$Re_{x=L} = Re_L = \frac{U_\infty L}{\nu} = \frac{(35 * 1.467\ \text{ft/s})(8\ \text{ft})}{1.57 * 10^{-4}\ \text{ft}^2/\text{s}} = 2.62 * 10^6$$

(+1 points)

Thus,

$$\delta = \frac{0.16 * 8\ \text{ft}}{(2.62 * 10^6)^{1/7}} = 0.155\ ft$$

(+1 points)

(b) Local friction coefficient at the end of the board,

$$c_f(L) = \frac{0.027}{Re_x^{1/7}}\Big)_{x=L} = \frac{0.027}{Re_L^{1/7}} = \frac{0.027}{\left(2.62 * 10^6\right)^{1/7}} = 0.00327$$

(+1 point)

(c) Shear stress at the end of the board

$$\tau_w(L) = \frac{1}{2}\rho U_\infty^2 c_f(L)$$

or

$$\tau_w(L) = \left(\frac{1}{2}\right)\left(2.38 * \ 10^{-3}\right) * (35 * 1.4667)^2 * (0.00327) = 1.03 * 10^{-2} lb/ft^2$$

(+1 point)

(d) Friction drag coefficient

$$C_f = \frac{0.031}{Re_L{}^{1/7}} = \frac{0.031}{\left(2.6 * 10^6\right)^{1/7}} = 3.754 * 10^{-3}$$

(+1 point)

(e) Friction drag force

$$D_f = C_f \cdot \frac{1}{2}\rho U^2 A$$

Where,

$$A = 4\ \text{ft} * 8\ \text{ft} = 32\ \text{ft}^2$$

(+1 point)

Thus,

$$D_f = (3.754 \times 10^{-3})\frac{1}{2}(2.38 \times 10^{-3}\ \text{slug/ft}^3)(51.345\ \text{ft/s})^2(32\ \text{ft}^2) = 0.377\ lb$$

(+1 point)