December 6, 2013

NAME

Fluids-ID

Quiz 14. Suppose you buy a 1- by 1-ft sheet of plywood and put it on your roof rack of a toy car. You drive the toy car at 1 mi/h. Assuming the airflow ($\nu = 1.57 \times 10^{-4}$ ft^2/s and $\rho = 2.38 \times 10^{-3}$ slugs/ft^3) over the board is laminar 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 and 1 lb = 1 slug·ft/s^2)

Boundary layer thickness:

$$\delta(x) = \frac{5x}{\sqrt{Re_x}}$$

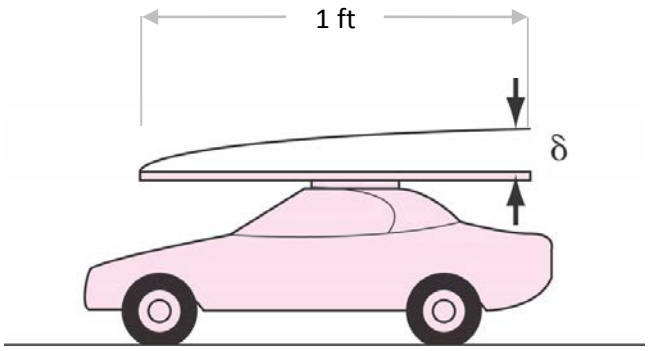
Local friction coefficient:

$$c_f(x) = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2} = \frac{0.664}{\sqrt{Re_x}}$$

Friction drag coefficient:

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

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,

$$\delta(L) = \frac{5x}{\sqrt{Re_x}}\Bigg)_{x=L}$$

Where,

$$Re_{x=L} = Re_L = \frac{U_\infty L}{\nu} = \frac{(1 * 1.4667\,\text{ft/s})(1\text{ft})}{1.57 * 10^{-4}\,\text{ft}^2/\text{s}} = 9.34 * 10^3$$

Thus,

$$\delta = \frac{5 * (1\text{ ft})}{(9.34 \times 10^3)^{1/2}} = 0.0517\ ft$$

(+2 points)

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

$$c_f(L) = \frac{0.664}{\sqrt{Re_x}}\Big)_{x=L} = \frac{0.664}{\sqrt{Re_L}} = \frac{0.664}{\sqrt{9.34 * 10^3}} = 0.00687$$

(+1 point)

(c) Shear stress at the end of the board

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

or

$$\tau_w(L) = \left(\frac{1}{2}\right)\left(2.38 * 10^{-3}\right) * (1 * 1.4667)^2 * (0.00687) = 1.76 * 10^{-5} lb/ft^2$$

(+1 point)

(d) Friction drag coefficient

$$C_f = \frac{1.328}{\sqrt{Re_L}} = \frac{1.328}{\sqrt{9.34 * 10^3}} = 0.0137$$

(+1 point)

(e) Friction drag force

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

Thus,

$$D_f = (0.0137)\frac{1}{2}(2.38 * 10^{-3})(1 * 1.4667)^2(1) = 3.5 * 10^{-5}\ lb$$

(+2 point)