The exam is closed book and closed notes.

SAE 30 oil at 20°C flows at $U = 10$ ft/s over the upper side of a flat plate of which width $b = 2$ ft and length $L = 5$ ft and area $A = bL = 10$ ft$^2$. (a) What is the boundary layer thickness at the middle of the plate and (b) what is the friction drag $D_f$ acting on the plate? Transition to turbulent flow may occur at $Re = 5 \times 10^5$. ($\rho = 1.73$ slug/ft$^3$; $\mu = 0.00607$ slug/ft·s)

Reynolds number:

$$Re_L = \frac{UL}{\nu}, \quad Re_x = \frac{UX}{\nu}$$

Boundary layer thickness:

$$\delta = \begin{cases} \frac{5}{\sqrt{Re_x}} & \text{laminar} \\ 0.16 \frac{1}{\sqrt{Re_x}} & \text{turbulent} \end{cases}$$

Friction drag coefficient:

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

(a) Format (+3)

\[ Re_x = \frac{\rho U x}{\mu} \bigg|_{x=\frac{L}{2}} = \frac{(1.73)(10)(5/2)}{0.00607} = 7.125 \times 10^3 \text{ (Laminar)} \]

\[ \frac{\delta}{x} = \frac{5}{\sqrt{Re_x}} = \frac{5}{\sqrt{1.425 \times 10^4}} = 0.059 \]

\[ \therefore \delta = 0.059 \left(\frac{L}{2}\right) = (0.059)\left(\frac{5 \text{ ft}}{2}\right) = 0.148 \text{ ft} \quad (+3) \]

(b)

\[ Re_L = \frac{\rho U L}{\mu} = \frac{(1.73)(10)(5)}{0.00607} = 1.425 \times 10^4 \text{ (Laminar)} \]

\[ C_f = \frac{1.328}{\sqrt{Re_L}} = \frac{1.328}{\sqrt{1.425 \times 10^4}} = 0.0111 \]

\[ \therefore D_f = \frac{1}{2} \rho U^2 A C_f = \left(\frac{1}{2}\right)(1.73)(10)^2(10)(0.0111) = 9.6 \text{ lb} \quad (+4) \]