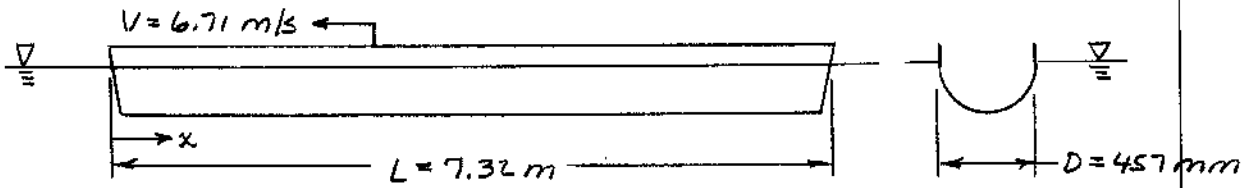
Problem 9.69

Given: Racing shell of Purdue crew, approximated as half a cylinder.



Find: (a) Location of transition in boundary layers on hull.
(b) Thickness of TBL at rear of hull.
(c) Total skin friction drag on hull.

Solution: Assume flow behaves as on a flat plate, with $Re_{x,t} = 500{,}000$.

$$Re_{x,t} = \frac{V x_t}{\nu} = 500{,}000 \; ; \; x_t = \frac{500{,}000\,\nu}{V} = 5\times10^5 \times 1\times10^{-6}\,\frac{m^2}{s} \times \frac{s}{6.71\,m} = 0.0745\,m$$ x_t

($\nu = 1\times10^{-6}\,m^2/s$ for water at 20°C, Table A.8). Thus LBL is only 1% of L.

For the turbulent boundary layer $\frac{\delta}{x} = \frac{0.382}{Re_x^{1/5}}$, so $\delta = \frac{0.382}{Re_L^{1/5}} L$

$$Re_L = \frac{VL}{\nu} = 6.71\,\frac{m}{s} \times 7.32\,m \times \frac{s}{1.00\times10^{-6}\,m^2} = 4.91\times10^7$$

$$\delta = 0.382 \times \frac{1}{(4.91\times10^7)^{1/5}} \times 7.32\,m = 0.0810\,m$$ δ

The drag force is $F_D = C_D A \frac{1}{2}\rho V^2$.

$$A \approx wL = \frac{\pi D}{2} L = \frac{\pi}{2} \times 0.457\,m \times 7.32\,m = 5.25\,m^2$$

Since $10^7 \le Re_L < 10^9$, then $C_D = \frac{0.455}{(\log Re_L)^{2.58}} = 0.00237$

Then

$$F_D = 0.00237 \times 5.25\,m^2 \times \frac{1}{2} \times 999\,\frac{kg}{m^3} \times (6.71)^2\,\frac{m^2}{s^2} \times \frac{N\cdot s^2}{kg\cdot m} = 280\,N$$ F_D

Note the rowers must produce an average power of

$$\mathcal{P} = F_D V = 280\,N \times 6.71\,\frac{m}{s} \times \frac{W\cdot s}{N\cdot m} = 1.88\,kW$$

to move the shell at this speed.