Problem 9.71

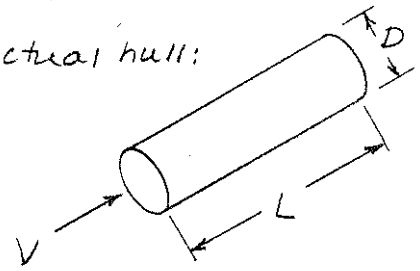
Given: Nuclear submarine, cruising submerged at $V = 27$ kt.

Assume hull is a circular cylinder, $D = 11.0$ m, and $L = 107$ m.

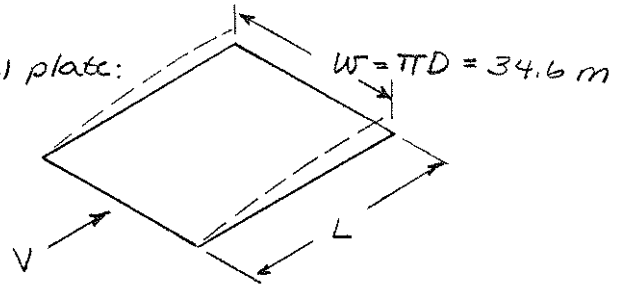
Find: (a) Estimate percentage of hull length with laminar BL.
(b) Calculate drag due to skin friction.
(c) Estimate power consumed

Solution: Treat hull as a flat plate with same wetted area.

Actual hull:



Model plate:



Computing equations: $Re_{x_t} = 500{,}000$ $\quad C_D = \dfrac{0.455}{(\log_{10} Re_L)^{2.58}}$

For seawater, $\nu = 1.05 \times 10^{-6}\ m^2/sec$ (Table A.2), so $\quad (T = 20°C)$

$$Re_L = \frac{VL}{\nu} = 27\frac{nm}{hr} \times 6076\frac{ft}{nm} \times 0.305\frac{m}{ft} \times \frac{hr}{3600\,s} \times 107\,m \times \frac{s}{1.05\times10^{-6}\,m^2} = 1.42\times10^9$$

Thus $\dfrac{x_t}{L} = \dfrac{Re_{x_t}}{Re_L} = \dfrac{500{,}000}{1.42\times10^9} = 3.52\times10^{-4}$ or $x_t = 0.0352\%$ of L $\quad \%L$ ←

Neglect laminar BL; assume flow is completely turbulent.

$$C_D = \frac{0.455}{(\log_{10} Re_L)^{2.58}} = \frac{0.455}{(9.15)^{2.58}} = 0.00150 \;;\; A = WL = 34.6\,m \times 107\,m = 3.70\times10^3\,m^2$$

$$q = \tfrac{1}{2}\rho V^2 = \tfrac{1}{2} \times 1025\frac{kg}{m^3}\left(\frac{27(6076)(0.305)}{3600}\right)^2\frac{m^2}{s^2} \times \frac{N\cdot s^2}{kg\cdot m} = 99.0\ kPa$$

$$F_D = C_D\, q\, A = 0.00150 \times 99.0\times10^3\frac{N}{m^2} \times 3.70\times10^3\,m^2 = 5.49\times10^5\ N \qquad F_D$$ ←

$$\mathcal{P} = F_D V = 5.49\times10^5\,N \times 27\frac{nm}{hr} \times 6076\frac{ft}{nm} \times 0.305\frac{m}{ft} \times \frac{hr}{3600\,s} = 7.63\ MW$$