Problem 9.71

Given: Nuclear submarine, cruising submerged at \( V = 27 \text{ kt} \).
Assume hull is a circular cylinder; \( D = 11.0 \text{ m} \), and \( L = 107 \text{ m} \).

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: \( \text{Model plate:} \)

\[ \frac{W}{TLD} = 3.46 \text{ m} \]

Computing equations: \( Re_L = 500,000 \), \( \frac{C_D}{2.58} = \frac{0.455}{(\log_{10} Re_L)^2} \)

For seawater, \( V = 1.05 \times 10^{-6} \text{ m}^2/\text{sec} \) (Table A.12), so \( (T = 20^\circ \text{C}) \)

\[ Re_L = \frac{VL}{\nu} = 27 \text{ nm} \times 6076 \text{ ft} \times 0.305 \text{ m} \times \frac{\text{hr}}{3600 \text{ s}} \times 107 \text{ m} \times \frac{\text{m}}{1.25 \times 10^{-4} \text{ m}^2} = 1.42 \times 10^9 \]

Thus \( \frac{Re_L}{Re_L} = 500,000 \times 1.42 \times 10^9 = 3.55 \times 10^{-10} \) or \( \% L = 0.0352 \% \) of \( L \)

Neglect laminar BL; assume flow is completely turbulent.

\[ \frac{C_D}{2.58} = \frac{0.455}{(4.15)^2} = 0.00650 \]

\[ A = WL = 34.6 \text{ m} \times 107 \text{ m} = 3.70 \times 10^3 \text{ m}^2 \]

\[ q = \frac{1}{2} PV^2 = \frac{1}{2} \times 1025 \text{ kg/m} ^3 \times \left( \frac{27(6076)(0.305)}{3600} \right)^2 \text{ m}^2 \times \frac{\text{N} \cdot \text{m}}{\text{kg} \cdot \text{m}} = 99.0 \text{ kPa} \]

\[ F_D = C_D q A = 0.00650 \times 99.0 \times 10^3 \text{ N/m}^2 \times 3.70 \times 10^3 \text{ m}^2 = 5.49 \times 10^5 \text{ N} \]

\[ F = F_D V = 5.49 \times 10^5 \text{ N} \times 27 \text{ m/ hr} = 150 \text{ kft} \times 0.305 \text{ m} \times \frac{1 \text{ ft}}{3600 \text{ s}} = 7.58 \text{ MW} \]