A vertical stabilizing fin on a land-speed-record car is 1.65 m long and 0.785 m tall. The automobile is to be driven at the Bonneville Salt Flats in Utah, where the elevation is 1340 m and the summer temperature reaches 50 degC. The car speed is 560 km/hr. Calculate the power required to overcome skin friction drag on the fin.

SOLUTION:

At a temperature of 313 K, the kinematic viscosity of air is $\nu = 2.0*10^{-5}$ m^2/s. Thus, the Reynolds number at the trailing edge of the vertical fin is:

$$\mathrm{Re}_L = \frac{UL}{\nu} = \frac{\left(560*10^3\ \frac{\text{m}}{\text{hr}}\cdot\frac{\text{hr}}{3600\ \text{s}}\right)(1.65\ \text{m})}{\left(1.7*10^{-5}\ \frac{\text{m}^2}{\text{s}}\right)} \Rightarrow \mathrm{Re}_L = 1.51*10^7 \tag{1}$$

Clearly the flow is turbulent at the trailing edge of the vertical fin. At what distance from the leading edge of the fin does the flow transition from laminar to turbulent? To answer this question, calculate the distance at the transition Reynolds number,

$$\mathrm{Re}_{\text{crit}} = 500{,}000 = \frac{Ux}{\nu} = \frac{\left(560*10^3\ \frac{\text{m}}{\text{hr}}\cdot\frac{\text{hr}}{3600\ \text{s}}\right)x}{\left(1.7*10^{-5}\ \frac{\text{m}^2}{\text{s}}\right)} \Rightarrow x = 5.5\ \text{cm} \tag{2}$$

Thus, most of the flow over the fin is turbulent. Since this is the case, approximate the entire flow over the fin as being turbulent. The drag coefficient for a turbulent boundary layer over a flat plate is,

$$C_D = \frac{0.0742}{\mathrm{Re}_L^{1/5}} \Rightarrow \frac{D_{\text{1-side}}}{\frac{1}{2}\rho U^2 LH} = \frac{0.0742}{\mathrm{Re}_L^{1/5}} \Rightarrow D_{\text{2-sides}} = 2D_{\text{1-side}} = 2\cdot\frac{0.0742}{\mathrm{Re}_L^{1/5}}\cdot\frac{1}{2}\rho U^2 LH \tag{3}$$

The power is given by,

$$P = UD_{\text{2-sides}} \Rightarrow \boxed{P = \frac{0.0742}{\mathrm{Re}_L^{1/5}}\cdot\rho U^3 LH} \tag{4}$$

Using the given data,

ρ = 1.075 kg/m^3 (standard atmosphere at an altitude of 1340 m)
Re_L = $1.51*10^7$
U = 560 km/hr = 155.6 m/s
L = 1.65 m
H = 0.785 m
$\Rightarrow \boxed{P = 14.3\ \text{kW}}$

Note that a speed of 540 km/hr at a temperature of 50 degC result in a Mach number of 0.43. Thus, a more accurate approach to solving this problem would assume relations for a compressible boundary layer, rather than the incompressible relations assumed in the previous solution.