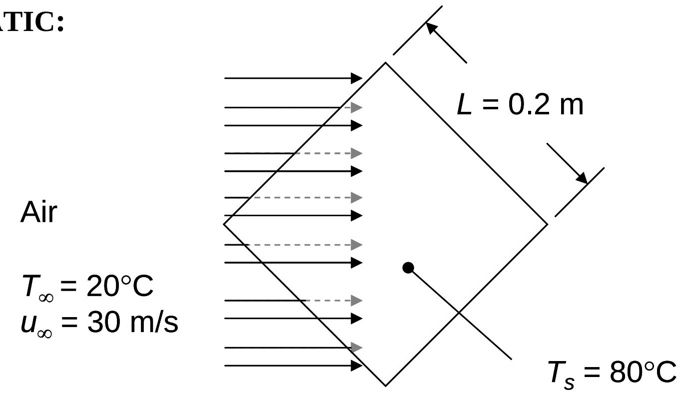
PROBLEM 6.49

KNOWN: Dimensions and temperature of a thin, rough plate. Velocity of air flow parallel to plate (at an angle of 45° to a side). Heat transfer rate from plate to air.

FIND: Drag force on plate.

SCHEMATIC:



ASSUMPTIONS: (1) The modified Reynolds analogy holds, (2) Constant properties.

PROPERTIES: Table A-4, Air (50°C = 323 K): c_p = 1008 J/kg·K, Pr = 0.704.

ANALYSIS: The modified Reynolds analogy, Equation 6.38, combined with the definition of the Stanton number, Equation 6.36, yields

$$C_f/2 = (Nu/Re)Pr^{-1/3} \tag{1}$$

The drag force is related to the friction coefficient according to

$$F_D = \tau_s A_s = C_f \cdot \rho u_\infty^2 A_s / 2 \tag{2}$$

Combining Equations (1) and (2)

$$F_D = \frac{Nu}{Re} Pr^{-1/3} \rho u_\infty^2 A_s$$

Substituting the definitions of Nu and Re, we find

$$F_D = \frac{hL_c}{k}\frac{\nu}{u_\infty L_c} Pr^{-1/3}\rho u_\infty^2 A_s = \frac{h}{c_p}\frac{\nu}{\alpha} Pr^{-1/3} u_\infty A_s = \frac{h}{c_p} Pr^{2/3} u_\infty A_s$$

Where L_c is a characteristic length used to define Nu and Re. With $hA_s = q/\Delta T$ we have

$$F_D = \frac{q u_\infty Pr^{2/3}}{c_p \Delta T} = \frac{2000\ \text{W} \times 30\ \text{m/s} \times (0.704)^{2/3}}{1008\ \text{J/kg}\cdot\text{K} \times 60\ \text{K}} = 0.785\ \text{N}$$ <

COMMENTS: (1) Heat transfer or friction coefficient correlations for this simple configuration apparently do not exist. (2) Experiments to measure the drag force would be relatively simple to implement and measured drag forces could be used to determine the heat transfer coefficients using the Reynolds analogy. (3) The solution demonstrates advantages associated with working the problem symbolically and only introducing numbers at the end. First, the length scale in Nu and Re did not have to be defined because it cancelled out. Second, the properties k, ν, and ρ also cancelled out.