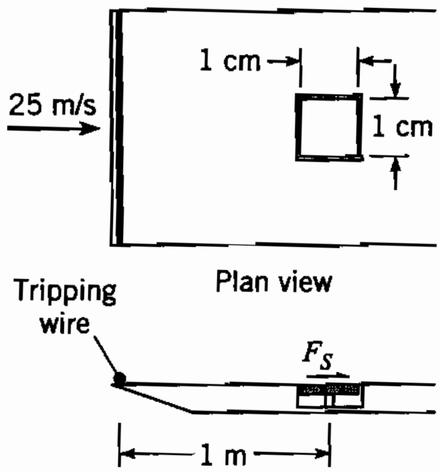
9.41 An element for sensing local shear stress is positioned in a flat plate 1 meter from the leading edge. The element simply consists of a small plate, 1 cm × 1 cm, mounted flush with the wall, and the shear force is measured on the plate. The fluid flowing by the plate is air with a free-stream velocity of 25 m/s, a density of 1.2 kg/m^3, and a kinematic viscosity of 1.5×10^{-5} m^2/s. The boundary layer is tripped at the leading edge. What is the magnitude of the force due to shear stress acting on the element?



PROBLEM 9.41

GIVEN: SHEAR STRESS SENSOR AS DESCRIBED ABOVE

FIND: THE TOTAL FORCE ACTING ON THE SENSOR

SOLUTION: $F_s = \int_{L_1}^{L_2} \tau_o B\, dx$

ASSUME THAT τ_o IS NEARLY CONSTANT OVER THE FACE OF THE SENSOR

$\Rightarrow F_s = \tau_o (L_2 - L_1) B = \tau_o (1\ cm^2)$ ← .0001 M²

CHECK Re AT $X = 1\ m$: $Re_x = \frac{(1\ m)(25\ m/s)}{1.5 \times 10^{-5}\ m^2/s}$

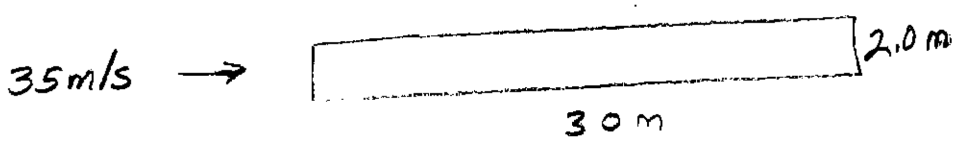
$R_x = 1.67 \times 10^6$ AND B.L. IS TRIPPED,

$\Rightarrow C_f = \frac{0.058}{Re_x^{1/5}}$, $\tau_o = C_f \frac{1}{2} \rho V_o^2$

$F_s = \frac{0.058}{(1.67 \times 10^6)^{1/5}} \left(\frac{1}{2}\right)(1.2)(25)^2(.0001)$

$F_s = 0.000124\ N$

9.61



GIVEN: SIGN TOWED THROUGH AIR ($T = 10°C$) AT 35 m/s

FIND: ESTIMATE OF POWER TO PULL SIGN.

SOLUTION: APPROXIMATE SIGN AS FLAT PLATE.

CALCULATE Re_L TO CHECK WHICH C_f TO USE.

$$Re_L = \frac{L U_0}{\nu} \qquad \nu = 1.41 \times 10^{-5}$$

$$Re_L = \frac{(35)(30)}{1.41 \times 10^{-5}} = 7.45 \times 10^{7}$$

$\Rightarrow$ USE EQN. 9.54 TO OBTAIN C_f.

$$C_f = \frac{0.523}{\ln^2(0.06\, Re_L)} - \frac{1520}{Re_L} = 0.00225$$

$$F_s = C_f \, B \, L \, \tfrac{1}{2} \rho U_0^2$$

$$F_s = (.00225)(2.0)(30)\tfrac{1}{2}(1.25)(35)^2 \, 2$$

← 2 SIDES

$$\boxed{F_s = 206.7\,N}$$

$$P = U_0 F_s$$

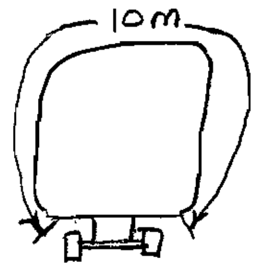
$$\boxed{P = 7235 \text{ WATTS}}$$

1 hp = 747 WATTS

$$P = 9.7 \text{ hp}$$

9.72 GIVEN: HIGH SPEED TRAIN AS SHOWN.

$L = 150\ m$ $\quad T_{AIR} = 10°C$



(a) $U_o = 100\ \frac{km}{HR}$

(b) $U_o = 200\ \frac{km}{HR}$

FIND: SURFACE RESISTANCE AND POWER TO OVERCOME IT

SOLUTION: $P = U_o \cdot F_s$

$$F_s = C_f\, B\, L\, \tfrac{1}{2} \rho\, U_o^2$$

FIND Re_L TO DECIDE WHICH C_f CORRELATION TO USE

$$Re_L = \frac{L\, U_o}{\nu} \qquad \nu = 1.41 \times 10^{-5}\ \frac{m^2}{s}$$

(a) $U_o = 100\ \frac{km}{HR}$ $\quad Re_L = 2.96 \times 10^8$

(b) $U_o = 200\ \frac{km}{HR}$ $\quad Re_L = 5.91 \times 10^8$

USE EQN. 9.54 $\quad C_f = \dfrac{0.523}{\ln^2(0.06\, Re_L)} - \dfrac{1520}{Re_L}$

(a) $C_f = .00187$ $\qquad$ (b) $C_f = .00173$

(a) $F_s = (.00187)(10)(150)(\tfrac{1}{2})(1.25)\left(\dfrac{100000}{3600}\right)^2$

$F_s = 1353\ N$

9.72 (2)

(b) $F_s = 5006$ N

$P = U_0 \cdot F_s$

(a) $P = 37.6$ kW

(b) $P = 278$ kW