Problem 11.26

Given: A schlieren photograph taken in the NTF shows a Mach angle, $\alpha = 57°$, at a location where $T = -270°F$ and $p = 1.3$ psia.

Find: (a) the local Mach number and flow speed
(b) the unit Reynolds number for the flow

Solution:

$$\sin\alpha = \frac{1}{M} \quad \therefore \quad M = \frac{1}{\sin\alpha} = \frac{1}{\sin 57°} = 1.19 \qquad M$$

$$c = \sqrt{kRT} = \left[1.4 \times 53.3 \frac{ft \cdot lbf}{lbm \cdot °R} \times 32.2 \frac{lbm}{slug} \times 190°R \times \frac{slug \cdot ft}{lbf \cdot s^2}\right]^{1/2} = 676 \text{ ft/s}$$

$$V = Mc = 1.19(676 \text{ ft/s}) = 804 \text{ ft/s} \qquad V$$

$$Re_x = \frac{\rho V x}{\mu}$$

$$\rho = \frac{p}{RT} = 1.3 \frac{lbf}{in^2} \times 53.3 \frac{lbm°R}{ft \cdot lbf} \times \frac{1}{190°R} \times \frac{144 in^2}{ft^2} = 0.0185 \text{ lbm/ft}^3$$

From Eq. A.1 (Appendix A)

$$\mu = \frac{bT^{1/2}}{1 + S/T}$$

$b = 1.458 \times 10^{-6}$ kg/m·s·K$^{1/2}$

$S = 110.4$ K

T in K

$T = -270F = -167C = 106$ K.

$$\mu = 1.458 \times 10^{-6} \frac{kg}{m \cdot s \cdot K^{1/2}} (106K)^{1/2} \times \frac{1}{1 + \frac{110.4}{106}} = 7.35 \times 10^{-6} \text{ kg/m·s}$$

$$\mu = 7.35 \times 10^{-6} \frac{kg}{m \cdot s} \times \frac{N \cdot s^2}{kg \cdot m} \times \frac{2.089 \times 10^{-2} lbf \cdot s/ft^2}{1 N \cdot s}$$

$$\mu = 1.54 \times 10^{-7} \text{ lbf·s/ft}^2$$

$$\therefore \quad Re_x = \frac{\rho V}{\mu} x = 0.0185 \frac{lbm}{ft^3} \times 804 \frac{ft}{s} \times \frac{ft^2}{1.54 \times 10^{-7} lbf \cdot s} \times \frac{slug}{32.2 lbm} \times \frac{lbf \cdot s^2}{slug \cdot ft} \cdot$$

$$Re_x = 3.00 \times 10^6 \text{ ft}^{-1} = 9.84 \times 10^6 \text{ m}^{-1} \qquad Re/x$$