CHAPTER 1

1.1 $$\rho = \frac{p}{RT} = \frac{(5.6)(2116)}{(1716)(850)} = \boxed{0.00812\ \text{slug/ft}^3}$$

$$v = \frac{1}{\rho} = \boxed{123\ \text{ft}^3/\text{slug}}$$

1.2 $$\rho = \frac{p}{RT} = \frac{(10)(1.01\ \text{x}\ 10^5)}{(287)(320)} = \boxed{11.0\ \text{kg/m}^3}$$

$$n = \frac{p}{RT} = \frac{(10)(1.01\ \text{x}\ 10^5)}{(1.38\ \text{x}\ 10^{-23})(320)} = \boxed{2.87\ \text{x}\ 10^{26}/\text{m}^3}$$

$$\eta = \frac{pv}{RT} = \frac{p}{\rho RT} = \frac{(10)(1.01\ \text{x}\ 10^5)}{(11.0)(8314)(320)} = \boxed{0.0345\ \frac{\text{kg} - \text{mole}}{\text{kg}}}$$

1.3 From the definition of enthalpy,

$$h = e + p\,v = e + RT \qquad \text{(A1)}$$

For a calorically perfect gas, this becomes

$$c_p\,T = c_v\,T + RT, \text{ or } \boxed{c_p - c_v = R}$$

For a thermally perfect gas, Eq. (A1) is first differentiated

$$dh = de + Rdt$$

or,

$$c_p\,dT = c_v\,dT = Rdt$$

or,

$$\boxed{c_p - c_v = R}$$

1.4 $$s_2 - s_1 = c_p \ \ell n \frac{T_2}{T_1} - R \ell n \ \frac{p_2}{p_1}$$

(a) R = 1716 ft-lb/slug°R

$$c_p = \frac{\gamma R}{\gamma - 1} = \frac{(1.4)(1716)}{0.4} = 6006 \text{ ft-lb/slug°R}$$

$$s_2 - s_1 = (6006) \ \ell n \ (1.687) - (1716) \ \ell n \ 4.5$$

$$s_2 - s_1 = \boxed{559.9 \text{ ft-lb/slug°R}}$$

(b) R = 287 joule/kg°K

$$c_p = \frac{\gamma R}{\gamma - 1} = \frac{(1.4)(287)}{0.4} = 1004.5 \text{ joule/kg°K}$$

$$s_2 - s_1 = (1004.5) \ \ell n \ (1.687) - 287 \ \ell n \ (4.5)$$

$$s_2 - s_1 = \boxed{93.6 \text{ joule/kg°K}}$$

1.5 $$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$p_2 = p_1 \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = 1800 \ (400/500)^{\frac{1.4}{0.4}}$$

$$p_2 = \boxed{824.3 \text{ lb/ft}_2}$$

$$\rho_2 = \frac{p_2}{RT_2} = \frac{824.3}{(1716)(400)} = \boxed{0.0012 \text{ slug/ft}^3}$$

1.6 Volume of room = (20)(15)(8) = 2400 ft^3

Standard sea level density = 0.002377 $slug/ft^3$

Mass of air = (0.002377)(2400) = $\boxed{5.70 \text{ slug}}$

Weight = Mass x acceleration of gravity = (5.7)(32.2) = $\boxed{184 \text{ lb}}$

1.7

(a) $dp = -\rho V dV$

and $d\rho = \rho \tau dp$, or $dp = \frac{d\rho}{\rho\tau}$

Combining:

$$\frac{d\rho}{\rho\tau} = -\rho V dV$$

$$d\rho = -\tau p^2 V dV$$

$$\frac{d\rho}{\rho} = -\tau \rho V dV$$

$$\boxed{\frac{d\rho}{\rho} = -\tau \rho V^2 \frac{dV}{V}}$$

(b) $\tau_s = \frac{1}{\gamma p} = \frac{1}{(1.4)(1.01 \times 10^5)} = 7.07 \times 10^{-6}\ m^2/N$

$$\frac{d\rho}{\rho} = \tau_s \rho V^2 \frac{dV}{V} = -(7.07 \times 10^{-6})(1.23)(10)^2(0.01)$$

$$\frac{d\rho}{\rho} = \boxed{-8.7 \times 10^{-6}}$$

(c) Here, $\frac{d\rho}{\rho}$ will be larger by the ratio $\left(\frac{1000}{10}\right)^2$.

$$\frac{d\rho}{\rho} = (-8.7 \times 10^{-6})\left(\frac{1000}{10}\right)^2 = \boxed{-8.7 \times 10^{-2}}$$

<u>Comment</u>: By increasing the velocity of a factor of 100, the fractional change in density is increased by factor of 10^4. This is just another indication of why high-speed flows must be treated as compressible.

CHAPTER 2

2.1 Consider a two-dimensional body in a flow, as sketched in Figure A. A control volume is drawn around this body, as given in the dashed lines in Figure A. The control volume is bounded by:

1. The upper and lower streamlines far above and below the body (ab and hi, respectively.)
2. Lines perpendicular to the flow velocity far ahead of and behind the body (ai and bh, respectively).
3. A cut that surrounds and wraps the surface of the body (cdefg).

The entire control volume is abcdefhia. The width of the control volume in the z direction (perpendicular to the page) is unity. Stations 1 and 2 are inflow and outflow stations, respectively.

Assume that the contour abhi is far enough from the body such that the pressure is everywhere the same on abhi and equal to the freestream pressure $p = p_\infty$. Also, assume that the inflow velocity u_1 is uniform across ai (as it would be in a freestream, or a test section of a wind tunnel.) The outflow velocity u_2 is not uniform across bh, because the presence of the body has created a wake at the outflow station. However, assume that both u_1 and u_2 are in the x direction; hence, u_1 = constant and $u_2 = f(y)$.

Consider the surface forces on the control volume shown in Figure A. They stem from two contributions:

1. The pressure distribution over the surface, abhi,

$$-\iint_{abhi} p\, dS$$