SOLUTIONS MANUAL TO ACCOMPANY

INTRODUCTION TO FLIGHT
8th Edition

By

John D. Anderson, Jr.

Chapter 2

2.1 $\rho = p/RT = (1.2)(1.01\times10^5)/(287)(300)$

$\rho = 1.41 \text{ kg/m}^2$

$v = 1/\rho = 1/1.41 = 0.71 \text{ m}^3/\text{kg}$

2.2 Mean kinetic energy of each atom $= \frac{3}{2}k\,T = \frac{3}{2}(1.38\times10^{-23})(500) = 1.035\times10^{-20}\text{J}$

One kg-mole, which has a mass of 4 kg, has 6.02×10^{26} atoms. Hence 1 kg has

$\frac{1}{4}(6.02\times10^{26}) = 1.505\times10^{26}$ atoms.

$$\text{Total internal energy} = (\text{energy per atom})(\text{number of atoms})$$

$$= (1.035\times10^{-20})(1.505\times10^{26}) = 1.558\times10^{6}\text{J}$$

2.3 $\rho = \frac{p}{RT} = \frac{2116}{(1716)(460+59)} = 0.00237\frac{\text{slug}}{\text{ft}^3}$

$$\text{Volume of the room} = (20)(15)(8) = 2400\,\text{ft}^3$$

$$\text{Total mass in the room} = (2400)(0.00237) = 5.688\,\text{slug}$$

$$\text{Weight} = (5.688)(32.2) = 183\,\text{lb}$$

2.4 $\rho = \frac{p}{RT} = \frac{2116}{(1716)(460-10)} = 0.00274\frac{\text{slug}}{\text{ft}^3}$

Since the volume of the room is the same, we can simply compare densities between the two problems.

$\Delta\rho = 0.00274 - 0.00237 = 0.00037\frac{\text{slug}}{\text{ft}^3}$

$\%\,\text{change} = \frac{\Delta\rho}{\rho} = \frac{0.00037}{0.00237}\times(100) = 15.6\%\text{ increase}$

2.5 First, calculate the density from the known mass and volume, $\rho = 1500/900 = 1.67\,\text{lb}_m/\text{ft}^3$

In consistent units, $\rho = 1.67/32.2 = 0.052\,\text{slug/ft}^3$. Also, $T = 70\ F = 70 + 460 = 530\ R$.

Hence,

$$p = \rho RT = (0.52)(1716)(530)$$

$$p = 47,290\,\text{lb/ft}^2$$

or $$p = 47,290/2116 = 22.3\,\text{atm}$$

2.6 $p = \rho RT$

$\ell np = \ell np + \ell nR + \ell nT$

Differentiating with respect to time,

$$\frac{1}{p}\frac{dp}{dt} = \frac{1}{\rho}\frac{d\rho}{dt} + \frac{1}{T}\frac{dT}{dt}$$

or, $$\frac{dp}{dt} = \frac{p}{\rho}\frac{d\rho}{dt} + \frac{p}{\mathrm{T}}\frac{dT}{dt}$$

or, $$\frac{dp}{dt} = RT\frac{d\rho}{dt} + \rho R\frac{dT}{dt} \qquad (1)$$

At the instant there is 1000 lb_m of air in the tank, the density is

$$\rho = 1000/900 = 1.11 \mathrm{lb_m/ft^3}$$
$$\rho = 1.11/32.2 = 0.0345 \mathrm{slug/ft^3}$$

Also, in consistent units, is given that

T = 50 + 460 = 510 *R*

and that

$$\frac{dT}{dt} = 1F/\mathrm{min} = 1R/\mathrm{min} = 0.016R/\mathrm{sec}$$

From the given pumping rate, and the fact that the volume of the tank is 900 ft^3, we also have

$$\frac{d\rho}{dt} = \frac{0.5 \mathrm{~lb_m/sec}}{900 \mathrm{~ft^3}} = 0.000556 \mathrm{~lb_m/(ft^3)(sec)}$$
$$\frac{d\rho}{dt} = \frac{0.000556}{32.2} = 1.73\times10^{-5} \mathrm{slug/(ft^3)(sec)}$$

Thus, from equation (1) above,

$$\frac{d\rho}{dt} = (1716)(510)(1.73\times10^{-5}) + (0.0345)(1716)(0.0167)$$
$$= 15.1 + 0.99 = 16.1 \mathrm{~lb/(ft^2)(sec)} = \frac{16.1}{2116}$$
$$= 0.0076 \mathrm{~atm/sec}$$

2.7 In consistent units,

$$T = -10 + 273 = 263 \mathrm{~K}$$

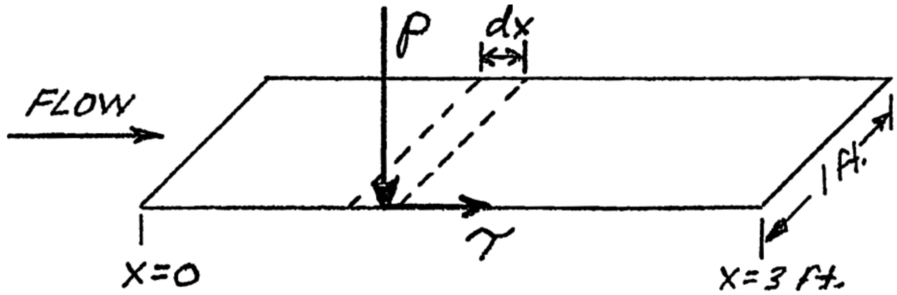
Thus,

$$\rho = p/RT = (1.7\times10^4)/(287)(263)$$
$$\rho = 0.225 \mathrm{~kg/m^3}$$

2.8 $\rho = p/RT = 0.5\times10^5/(287)(240) = 0.726 \mathrm{~kg/m^3}$

$v = 1/\rho = 1/0.726 = 1.38 \mathrm{~m^3/kg}$

2.9

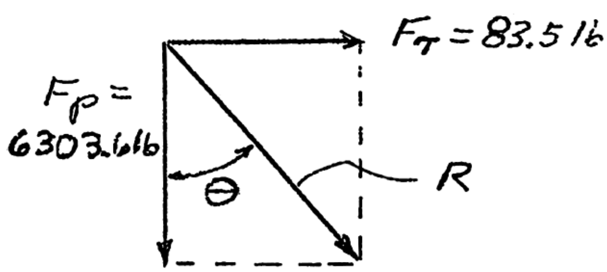


$$F_p = \text{Force due to pressure} = \int_0^3 p\,dx = \int_0^3 (2116 - 10x)\,dx$$

$$= [2116x - 5x^2]_0^3 = 6303 \text{ lb perpendicular to wall.}$$

$$F_\tau = \text{Force due to shear stress} = \int_0^3 \tau\,dx = \int_0^3 \frac{90}{(x+9)^{\frac{1}{2}}}\,dx$$

$$= [180\,(x+9)^{\frac{1}{2}}]_0^3 = 623.5 - 540 = 83.5 \text{ lb tangential to wall.}$$



Magnitude of the resultant aerodynamic force =

$$R = \sqrt{(6303)^2 + (835)^2} = 6303.6 \text{ lb}$$

$$\theta = \text{Arc Tan}\left(\frac{83.5}{6303}\right) = 0.76^\circ$$

2.10 $V = \dfrac{3}{2} V_\infty \sin\theta$

Minimum velocity occurs when sin $\theta = 0$, i.e., when $\theta = 0°$ and 180°.

$V_{min} = 0$ at $\theta = 0°$ and 180°, i.e., at its most forward and rearward points.

Maximum velocity occurs when sin $\theta = 1$, i.e., when $\theta = 90°$. Hence,

$$V_{max} = \frac{3}{2}(85)(1) = 127.5 \text{ mph at } \theta = 90^\circ,$$

i.e., the entire rim of the sphere in a plane perpendicular to the freestream direction.

2.11 The mass of air displaced is

$$M = (2.2)(0.002377) = 5.23 \times 10^{-3} \text{ slug}$$

The weight of this air is

$$W_{air} = (5.23 \times 10^{-3})(32.2) = 0.168 \text{ lb}$$

This is the lifting force on the balloon due to the outside air. However, the helium inside the balloon has weight, acting in the downward direction. The weight of the helium is less than that of air by the ratio of the molecular weights

$$W_{H_c} = (0.168)\frac{4}{28.8} = 0.0233 \text{ lb.}$$

Hence, the maximum weight that can be lifted by the balloon is

0.168 – 0.0233 = 0.145 lb.

2.12 Let p_3, ρ_3, and T_3 denote the conditions at the beginning of combustion, and p_4, ρ_4, and T_4 denote conditions at the end of combustion. Since the volume is constant, and the mass of the gas is constant, then $p_4 = \rho_3 =$ 11.3 kg/m^3. Thus, from the equation of state,

$$p_4 = \rho_4 RT_4 = (11.3)(287)(4000) = 1.3 \times 10^7 \text{ N/m}^2$$

or,

$$p_4 = \frac{1.3 \times 10^7}{1.01 \times 10^5} = \boxed{129 \text{ atm}}$$

2.13 The area of the piston face, where the diameter is 9 cm = 0.09 m, is

$$A = \frac{\pi(0.09)^2}{4} = 6.36 \times 10^{-3} \text{m}^2$$

(a) The pressure of the gas mixture at the beginning of combustion is

$$p_3 = \rho_3 RT_3 = 11.3(287)(625) = 2.02 \times 10^6 \text{ N/m}^2$$

The force on the piston is

$$F_3 = p_3 A = (2.02 \times 10^6)(6.36 \times 10^{-3}) = 1.28 \times 10^4 \text{N}$$

Since 4.45 N = l lb*f*,

$$F_3 = \frac{1.28 \times 10^4}{4.45} = \boxed{2876 \text{ lb}}$$

(b) $p_4 = \rho_4 RT_4 = (11.3)(287)(4000) = 1.3 \times 10^7 \text{N/m}^2$

The force on the piston is

$$F_4 = p_4 A = (1/3 \times 10^7)(6.36 \times 10^{-3}) = \boxed{8.27 \times 10^4 \text{N}}$$

$$F_4 = \frac{8.27 \times 10^4}{4.45} = \boxed{18{,}579 \text{ lb}}$$

2.14 Let p_3 and T_3 denote conditions at the inlet to the combustor, and T_4 denote the temperature at the exit.

Note: $p_3 = p_4 = 4 \times 10^6 \text{ N/m}^2$

(a) $$\rho_3 = \frac{p_3}{RT_3} = \frac{4 \times 10^6}{(287)(900)} = \boxed{15.49 \text{ kg/m}^3}$$

(b) $$\rho_4 = \frac{p_4}{RT_4} = \frac{4 \times 10^6}{(287)(1500)} = \boxed{9.29 \text{ kg/m}^3}$$

2.15 1 mile = 5280 ft, and 1 hour = 3600 sec.

So:

$$\left(60 \frac{\text{miles}}{\text{hour}}\right)\left(\frac{5280 \text{ ft}}{\text{mile}}\right)\left(\frac{1 \text{ hour}}{3600 \text{ sec}}\right) = 88 \text{ ft/sec.}$$

A very useful conversion to remember is that

$$\boxed{60 \text{ mph} = 88 \text{ ft/sec}}$$

also, 1 ft = 0.3048 m

$$\left(88 \frac{\text{ft}}{\text{sec}}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 26.82 \frac{\text{m}}{\text{sec}}$$

Thus $$\boxed{88 \frac{\text{ft}}{\text{sec}} = 26.82 \frac{\text{m}}{\text{sec}}}$$

2.16 $$692 \frac{\text{miles}}{\text{hour}}\left(\frac{88 \text{ ft/sec}}{60 \text{ mph}}\right) = \boxed{1015 \text{ ft/sec}}$$

$$692 \frac{\text{miles}}{\text{hour}}\left(\frac{26.82 \text{ m/sec}}{60 \text{ mph}}\right) = \boxed{309.3 \text{ m/sec}}$$

2.17 On the front face

$$F_f = p_f A = (1.0715 \times 10^5)(2) = 2.143 \times 10^5 \text{ N}$$

On the back face

$$F_b = p_b A = (1.01 \times 10^5)(2) = 2.02 \times 10^5 \text{ N}$$

The net force on the plate is

$$F = F_f - F_b = (2.143 - 2.02) \times 10^5 = 0.123 \times 10^5 \text{ N}$$

From Appendix C,

$$1\ lb_f = 4.448 \text{ N.}$$

So,

$$F = \frac{0.123 \times 10^5}{4.448} = \boxed{2765 \text{ lb}}$$

This force acts in the same direction as the flow (i.e., it is aerodynamic drag.)

2.18 Wing loading $= \frac{W}{s} = \frac{10{,}100}{233} = \boxed{43.35 \text{ lb/ft}^2}$

In SI units:

$$\frac{W}{s} = \left(43.35 \frac{\text{lb}}{\text{ft}^2}\right)\left(\frac{4.448 \text{ N}}{1 \text{ lb}}\right)\left(\frac{1 \text{ ft}}{0.3048 \text{ m}}\right)^2$$

$$\frac{W}{s} = \boxed{2075.5 \frac{\text{N}}{\text{m}^2}}$$

In terms of kilogram force,

$$\frac{W}{s} = \left(2075.5 \frac{\text{N}}{\text{m}^2}\right)\left(\frac{1 \text{ k}_f}{9.8 \text{ N}}\right) = \boxed{211.8 \frac{\text{kg}_f}{\text{m}^2}}$$

2.19 $V = \left(437 \frac{\text{miles}}{\text{hr}}\right)\left(\frac{5280 \text{ ft}}{\text{mile}}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 7.033 \times 10^5 \frac{\text{m}}{\text{hr}} = \boxed{703.3 \frac{\text{km}}{\text{hr}}}$

$$\text{Altitude} = (25{,}000 \text{ ft})\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 7620 \text{ m} = \boxed{7.62 \text{ km}}$$

2.20 $V = \left(26{,}000 \frac{\text{ft}}{\text{sec}}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 7.925 \times 10^3 \frac{\text{m}}{\text{sec}} = \boxed{7.925 \frac{\text{km}}{\text{sec}}}$

2.21 From Fig. 2.16,

length of fuselage = 33 ft, 4.125 inches = 33.34 ft

$$= 33.34 \text{ ft}\left(\frac{0.3048 \text{ m}}{\text{ft}}\right) = \boxed{10.16 \text{ m}}$$

wing span = 40 ft, 11.726 inches = 40.98 ft

$$= 40.98 \text{ ft}\left(\frac{0.3048 \text{ m}}{\text{ft}}\right) = \boxed{12.49 \text{ m}}$$

2.22 **(a)** From App. C 1 ft. = 0.3048 m.

Thus,

354,200 ft = (354,000)(0.3048) = 107,960 m = 107.96 km

(b) From Example 2.6: 60 mph = 26.82 m/sec

Thus,

$$4520 \frac{\text{miles}}{\text{hr}} = 4520 \frac{\text{miles}}{\text{hr}} = \frac{\left(26.82 \frac{\text{m}}{\text{sec}}\right)}{60\left(\frac{\text{mi}}{\text{hr}}\right)} 2020.4 \text{ m/sec}$$

2.23

$$m = \frac{34,000 \text{ lb}}{32.2 \text{ lb/slug}} = 1055.9 \text{ slug}$$

From Newton's 2nd Law

$$F = ma$$

$$a = \frac{F}{M} = \frac{57,000}{1055.9} = 53.98 \text{ ft/sec}^2$$

2.24

$$\text{\# of g's} = \frac{53.98}{32.2} = 1.68$$

2.25 From Appendix C, one pound of force equals 4.448 N. Thus, the thrust of the Rolls-Royce Trent engine in pounds is

$$T = \frac{373.7 \times 10^3 \text{ N}}{4.448 \text{ N/lb}} = 84,015 \text{ lb}$$

2.26

(a) $F = (690,000)(9.8) = \boxed{6.762 \times 10^6 \text{ N}}$

(b) $F = 6.762 \times 10^6 / 4.448 = \boxed{1.5 \times 10^6 \text{ lb}}$