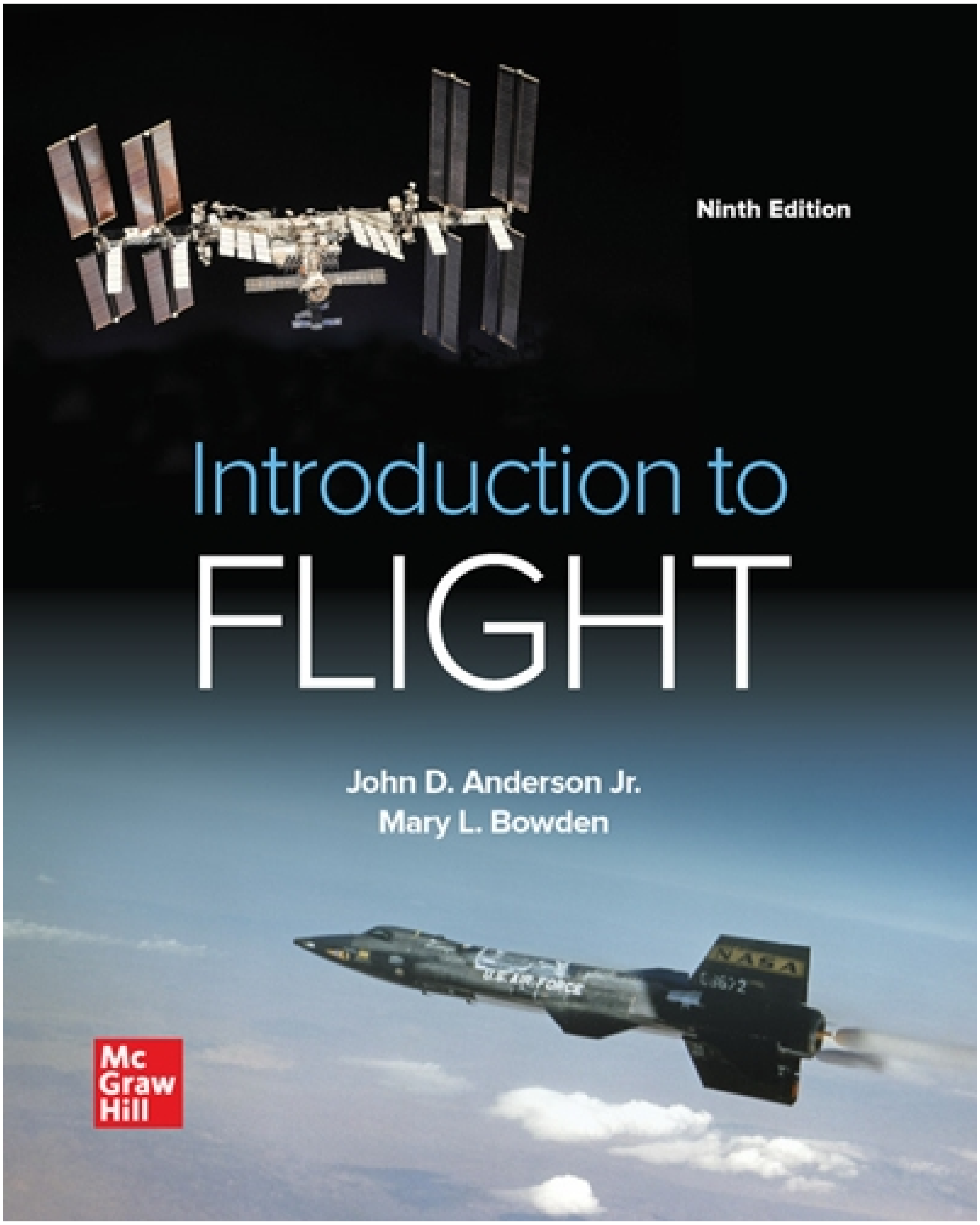
Solutions for Introduction to Flight 9th Edition by Anderson



Solutions

Chapter 2 – Introduction to Flight, 9th ed., Solutions

2.1 Consider the low-speed flight of the Space Shuttle as it is nearing a landing. If the air pressure and temperature at the nose of the shuttle are 1.2 atm and 300 K, respectively, what are the density and specific volume?

$$\rho = p/RT = (1.2)(1.01\times10^5)/(287)(300)$$
$$\rho = 1.41\ \text{kg/m}^2$$
$$v = 1/\rho = 1/1.41 = 0.71\ \text{m}^3/\text{kg}$$

2.2 Consider 1 kg of helium at 500 K. Assuming that the total internal energy of helium is due to the mean kinetic energy of each atom summed over all the atoms, calculate the internal energy of this gas. Note: The molecular weight of helium is 4. Recall from chemistry that the molecular weight is the mass per mole of gas; that is, 1 mol of helium contains 4 kg of mass. Also, 1 mol of any gas contains 6.02 x 10^{23} molecules or atoms (Avogadro's number).

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 Calculate the weight of air (in pounds) contained within a room 20 ft long, 15 ft wide, and 8 ft high. Assume standard atmospheric pressure and temperature of 2116 lb/ft² and 59°F, respectively.

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

$$\text{Volume of the room} = (20)(15)(8) = 2400\,\text{ft}^3$$
$$\text{Total mass in the room} = (2400)(0.00237) = 5.688\,\text{slug}$$
$$\text{Weight} = (5.688)(32.2) = 183\,\text{lb}$$

2.4 Comparing with the case of Prob. 2.3, calculate the percentage change in the total weight of air in the room when the air temperature is reduced to −10°F (a very cold winter day), assuming that the pressure remains the same at 2116 lb/ft².

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

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 If 1500 lbm of air is pumped into a previously empty 900 ft^3 storage tank and the air temperature in the tank is uniformly 70°F, what is the air pressure in the tank in atmospheres?

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 In Prob. 2.5, assume that the rate at which air is being pumped into the tank is 0.5 lbm/s. Consider the instant in time at which there is 1000 lbm of air in the tank. Assume that the air temperature is uniformly 50°F at this instant and is increasing at the rate of 1°F/min. Calculate the rate of change of pressure at this instant.

$$p = \rho RT$$

$$\ell n p = \ell n p + \ell n R + \ell n T$$

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

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

$$\rho = 1000/900 = 1.11 \,\text{lb}_m/\text{ft}^3$$
$$\rho = 1.11/32.2 = 0.0345 \,\text{slug/ft}^3$$

Also, in consistent units, is given that

$T = 50 + 460 = 510\ R$

and that

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

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

$$\frac{d\rho}{dt} = \frac{0.5 \,\text{lb}_m/\text{sec}}{900 \,\text{ft}^3} = 0.000556 \,\text{lb}_m/(\text{ft}^3)(\text{sec})$$

$$\frac{d\rho}{dt} = \frac{0.000556}{32.2} = 1.73\times10^{-5}\,\text{slug/(ft}^3\text{)(sec)}$$

Thus, from equation (1) above,

$$\frac{dp}{dt} = (1716)(510)(1.73\times10^{-5}) + (0.0345)(1716)(0.0167)$$

$$= 15.1 + 0.99 = 16.1\ \text{lb/(ft}^2\text{)(sec)} = \frac{16.1}{2116}$$

$$= 0.0076\ \text{atm/sec}$$

2.7 Assume that, at a point on the wing of the Concorde supersonic transport, the air temperature is −10°C and the pressure is 1.7 x 10⁴ N/m². Calculate the density at this point.

In consistent units,

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

Thus,

$$\rho = p/RT = (1.7\times10^4)/(287)(263)$$

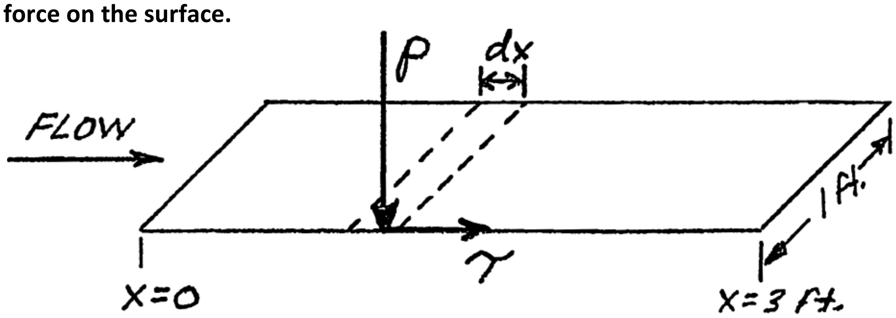
$$\rho = 0.225\ \text{kg/m}^3$$

2.8 At a point in the test section of a supersonic wind tunnel, the air pressure and temperature are 0.5 x 10⁵ N/m² and 240 K, respectively. Calculate the specific volume.

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

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

2.9 Consider a flat surface in an aerodynamic flow (say a flat sidewall of a wind tunnel). The dimensions of this surface are 3 ft in the flow direction (the x direction) and 1 ft perpendicular to the flow direction (the y direction). Assume that the pressure distribution (in pounds per square foot) is given by p = 2116 − 10 x and is independent of y . Assume also that the shear stress distribution (in pounds per square foot) is given by $\tau_w = 90/(x + 9)^{1/2}$ and is independent of y as shown in figure below. In these expressions, x is in feet, and x = 0 at the front of the surface. Calculate the magnitude and direction of the net aerodynamic force on the surface.

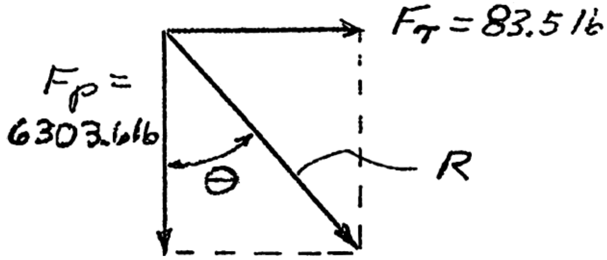


$$F_p = \text{Force due to pressure} = \int_0^3 p\,dx = \int_0^3 (2116 - 10x)\,dx$$

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

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

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



Magnitude of the resultant aerodynamic force =

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

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

2.10 A pitcher throws a baseball at 85 miles per hour. The flow field over the baseball moving through the stationary air at 85 miles per hour is the same as that over a stationary baseball in an airstream that approaches the baseball at 85 miles per hour. (This is the principle of wind tunnel testing, as will be discussed in Ch. 4.) This picture of a stationary body with the flow moving over it is what we adopt here. Neglecting friction, the theoretical expression for the flow velocity over the surface of a sphere (like the baseball) is $V = (3/2)\,V_\infty \sin\theta$. Here V_∞ is the airstream velocity (the free-stream velocity far ahead of the sphere). An arbitrary point on the surface of the sphere is located by the intersection of the radius of the sphere with the surface, and θ is the angular position of the radius measured from a line through the center in the direction of the free stream (i.e., the most forward and rearward points on the spherical surface correspond to θ = 0° and 180°, respectively). The velocity V is the flow velocity at that arbitrary point on the surface. Calculate the values of the minimum and maximum velocity at the surface and the location of the points at which these occur.

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

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,

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

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

2.11 Consider an ordinary, helium-filled party balloon with a volume of 2.2 ft 3 . The lifting force on the balloon due to the outside air is the net resultant of the pressure distribution exerted on the exterior surface of the balloon. Using this fact, we can derive Archimedes' principle, namely that the upward force on the balloon is equal to the weight of the air displaced by the balloon. Assuming that the balloon is at sea level, where the air density is 0.002377 slug/ft^3, calculate the maximum weight that can be lifted by the balloon. Note: The molecular weight of air is 28.8 and that of helium is 4.

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 In the four-stroke, reciprocating, internal combustion engine that powers most automobiles as well as most small general aviation aircraft, combustion of the fuel–air mixture takes place in the volume between the top of the piston and the top of the cylinder. (Reciprocating engines are discussed in Ch. 9.) The gas mixture is ignited when the piston is essentially at the end of the compression stroke (called top dead center), when the gas is compressed to a relatively high pressure and is squeezed into the smallest volume that exists between the top of the piston and the top of the cylinder. Combustion takes place rapidly before the piston has much time to start down on the power stroke. Hence, the volume of the gas during combustion stays constant; that is, the combustion process is at constant volume. Consider the case where the gas density and temperature at the instant combustion begins are 11.3 kg/m^3 and 625 K, respectively. At the end of the constant-volume combustion process, the gas temperature is 4000 K. Calculate the gas pressure at the end of the constant-volume combustion. Assume that the specific gas constant for the fuel–air mixture is the same as that for pure air.

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 For the conditions of Prob. 2.12, calculate the force exerted on the top of the piston by the gas at (a) the beginning of combustion and (b) the end of combustion. The diameter of the circular piston face is 9 cm.

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

$$p_3 = \rho_3 R T_3 = 11.3(287)(625) = 2.02 \times 10^6\ \text{N/m}^2$$

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) $p_4 = \rho_4 R T_4 = (11.3)(287)(4000) = 1.3 \times 10^7\,\text{N/m}^2$

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 In a gas turbine jet engine, the pressure of the incoming air is increased by flowing through a compressor; the air then enters a combustor that looks vaguely like a long can (sometimes called the combustion can). Fuel is injected in to the combustor and burns with the air, and then the burned fuel–air mixture exits the combustor at a higher temperature than the air coming into the combustor. (Gas turbine jet engines are discussed in Ch. 9.) The pressure of the flow through the combustor remains relatively constant; that is, the combustion process is at constant pressure . Consider the case where the gas pressure and temperature entering the combustor are 4 x 10^6 N/m^2 and 900 K, respectively, and the gas temperature exiting the combustor is 1500 K. Calculate the gas density at (a) the inlet to the combustor and (b) the exit of the combustor. Assume that the specific gas constant for the fuel–air mixture is the same as that for pure air.

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 Throughout this book, you will frequently encounter velocities in terms of miles per hour. Consistent units in the English engineering system and the SI are ft/sec and m/sec, respectively. Consider a velocity of 60 mph. What is this velocity in ft/sec and m/sec?

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 You might find it convenient to remember the results from Prob. 2.15. If you do, then you can almost instantly convert velocities in mph to ft/sec or m/sec. For example, using just the results of Prob. 2.15 for a velocity of 60 mph, quickly convert the maximum flight velocity of the F-86H (shown in Fig. 2.15) of 692 mph at sea level to ft/sec and m/sec.

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

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

2.17 Consider a stationary, thin, flat plate with area of 2 m^2 for each face oriented perpendicular to a flow. The pressure exerted on the front face of the plate (facing into the flow) is 1.0715 x 10^5 N/m^2, and is constant over the face. The pressure exerted on the back face of the plate (facing away from the flow) is 1.01 x 10^5 N/m^2, and is constant over the face. Calculate the aerodynamic force in pounds on the plate. Note: The effect of shear stress is negligible for this case.

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,

$$F = \frac{0.123\times10^5}{4.448} = \boxed{2765 \text{ lb}}$$

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

2.18 The weight of the North American P-51 Mustang shown in Fig. 2.12b is 10,100 lb and its wing planform area is 233 ft². Calculate the wing loading in both English engineering and SI units. Also, express the wing loading in terms of the non-consistent unit kgf.

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

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 The maximum velocity of the P-51 shown in Fig. 2.12b is 437 mph at an altitude of 25,000 ft. Calculate the velocity in terms of km/hr and the altitude in terms of km.

$$V = \left(437\frac{\text{miles}}{\text{hr}}\right)\left(\frac{5280 \text{ ft}}{\text{mile}}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 7.033\times10^5\frac{\text{m}}{\text{hr}} = \boxed{703.3\ \frac{\text{km}}{\text{hr}}}$$

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

2.20 The velocity of the Space Shuttle (Fig. 2.24) at the instant of burnout of the rocket booster is 26,000 ft/sec. What is this velocity in km/sec?

$$V = \left(26{,}000\ \frac{\text{ft}}{\text{sec}}\right)\left(\frac{0.3048 \text{ m}}{1 \text{ ft}}\right) = 7.925\times10^3\ \frac{\text{m}}{\text{sec}} = \boxed{7.925\ \frac{\text{km}}{\text{sec}}}$$

2.21 By examining the scale drawing of the F4U-1D Corsair in Fig. 2.16, obtain the length of the fuselage from the tip of the propeller hub to the rear tip of the fuselage, and also the wingspan (linear distance between the two wing tips), in meters.

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 The X-15 (see Fig. 5.92) was a rocket-powered research airplane designed to probe the mysteries of hypersonic flight. In 2014, the X-15 still holds the records for the fastest and highest flying piloted airplane (the Space Shuttle and Spaceship One, in this context, are space ships, not airplanes). On August 22, 1963, pilot Joseph Walker set the unofficial world altitude record of 354,200 feet. On October 3, 1967, pilot William J. Knight set the world speed record of 4520 mph (Mach 6.7). (a) Convert Walker's altitude record to meters and kilometers. (b) Convert Knight's speed record to meters per second.

(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 The X-15 is air-launched from under the wing of a B-52 mother ship. Immediately after launch, the pilot starts the XLR-99 rocket engine, which provides 57,000 lb of thrust. For the first moments, the X-15 accelerates in horizontal flight. The gross weight of the airplane at the start is 34,000 lb. Calculate the initial acceleration of the airplane.

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

From Newton's 2nd Law

$$F = ma$$

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

2.24 Frequently the acceleration of high-speed airplanes and rocket-powered space vehicles is quoted in "g's," which is the acceleration relative to the acceleration of gravity. For example, an acceleration of 32.2 ft/sec² is one "g." From the results of Problem 2.23, calculate the number of g's experienced by the X-15 pilot during the initial acceleration.

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

2.25 In the United States, the thrust of a jet engine is usually quoted in terms of pounds of thrust. Elsewhere, the thrust is generally stated in terms of kilo-newtons. The thrust of the Rolls-Royce Trent 900 engine turbofan is rated at 373.7 kN. What is the thrust in pounds?

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 The first stage of the Saturn rocket booster used to send the Apollo astronauts to the moon was powered by five F-1 rocket engines. The thrust of rocket engines is sometimes given in terms of kg force. For example, the thrust of the F-1 engine is sometimes quoted as 690,000 kg. Calculate the F-1 thrust in the consistent units of (a) newtons, and (b) pounds.

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

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