P7.63 For those who think electric cars are sissy, Keio University in Japan has tested a 22-ft long prototype whose eight electric motors generate a total of 590 horsepower. The “Kaz” cruises at 180 mi/h (see *Popular Science*, August 2001, p. 15). If the drag coefficient is 0.35 and the frontal area is 26 ft$^2$, what percent of this power is expended against sea-level air drag?

Solution: For air, take $\rho = 0.00237$ slug/ft$^3$. Convert 180 mi/h to 264 ft/s. The drag is

$$F = C_D \frac{\rho}{2} V^2 A_{\text{frontal}} = (0.35) \left( \frac{0.00237 \text{ slug/ft}^3}{2} \right) (264 \text{ ft/s})^2 (26 \text{ ft}^2) = 752 \text{ lbf}$$

$$Power = FV = (752 \text{ lbf})(264 \text{ ft/s})(550 \text{ ft-lbf/hp}) = 361 \text{ hp}$$

The horsepower to overcome drag is 61% of the total 590 horsepower available. Ans.
P7.64 A parachutist jumps from a plane, using an 8.5-m-diameter chute in the standard atmosphere. The total mass of chutist and chute is 90 kg. Assuming a fully open chute in quasisteady motion, estimate the time to fall from 2000 to 1000 m.

Solution: For the standard altitude (Table A-6), read $\rho = 1.112 \text{ kg/m}^3$ at 1000 m altitude and $\rho = 1.0067 \text{ kg/m}^3$ at 2000 meters. Viscosity is not a factor in Table 7.3, where we read $C_D \approx 1.2$ for a low-porosity chute. If acceleration is negligible,

$$W = C_D \frac{\rho}{2} U^2 \frac{\pi}{4} D^2, \quad \text{or:} \quad 90(9.81) N = 1.2 \left( \frac{\rho}{2} \right) U^2 \frac{\pi}{4} (8.5)^2, \quad \text{or:} \quad U^2 = \frac{25.93}{\rho}$$

Thus $U_{1000 \text{ m}} = \sqrt{\frac{25.93}{1.1120}} = 4.83 \text{ m/s}$ and $U_{2000 \text{ m}} = \sqrt{\frac{25.93}{1.0067}} = 5.08 \text{ m/s}$

Thus the change in velocity is very small (an average deceleration of only $-0.001 \text{ m/s}^2$) so we can reasonably estimate the time-to-fall using the average fall velocity:

$$\Delta t_{fall} = \frac{\Delta z}{V_{avg}} = \frac{2000 - 1000}{(4.83 + 5.08)/2} \approx 202 \text{ s} \quad \text{Ans.}$$
P7.69 Two baseballs, of diameter 7.35 cm, are connected to a rod 7 mm in diameter and 56 cm long, as in Fig. P7.69. What power, in W, is required to keep the system spinning at 400 r/min? Include the drag of the rod, and assume sea-level standard air.

Solution: For sea-level air, take $\rho = 1.225 \text{ kg/m}^3$ and $\mu = 1.78 \times 10^{-5} \text{ kg/m/s}$. Assume a laminar drag coefficient $C_D = 0.47$ from Table 7.3. Convert $\Omega = 400 \text{ rpm} \times 2\pi/60 = 41.9 \text{ rad/s}$. Each ball moves at a centerline velocity

$$V_b = \Omega r_b = (41.9)(0.28 + 0.0735/2) \approx 13.3 \text{ m/s}$$

Check $Re = 1.225(13.3)(0.0735)(1.78 \times 10^{-5}) \approx 67000$; Table 7.3: $C_D \approx 0.47$

Then the drag force on each baseball is approximately

$$F_b = C_D \frac{\rho}{2} V_b^2 \frac{\pi}{4} D^2 = 0.47 \left(\frac{1.225}{2}\right)(13.3)^2 \frac{\pi}{4} (0.0735)^2 \approx 0.215 \text{ N}$$

Make a similar approximate estimate for the drag of each rod:

$$V_r = \Omega r_{avg} = 41.9(0.14) \approx 5.86 \text{ m/s}, \quad Re = \frac{1.225(5.86)(0.007)}{1.78 \times 10^{-5}} \approx 2800, \quad C_D \approx 1.2$$

$$F_{rod} \approx C_D \left(\frac{\rho}{2}\right)V_r^2 D L = 1.2 \left(\frac{1.225}{2}\right)(5.86)^2 (0.007)(0.28) \approx 0.0495 \text{ N}$$

Then, with two balls and two rods, the total driving power required is

$$P = 2F_b V_b + 2F_r V_r = 2(0.215)(13.3) + 2(0.0495)(5.86) = 5.71 + 0.58 \approx 6.3 \text{ W} \quad \text{Ans.}$$
P7.73 A balloon is 4 m in diameter and contains helium at 125 kPa and 15° C. Balloon material and payload weigh 200 N, not including the helium. Estimate (a) the terminal ascent velocity in sea-level standard air; (b) the final standard altitude (neglecting winds) at which the balloon will come to rest; and (c) the minimum diameter (<4 m) for which the balloon will just barely begin to rise in sea-level air.

Solution: For sea-level air, take $\rho = 1.225 \text{ kg/m}^3$ and $\mu = 1.78 \times 10^{-5} \text{ kg/m} \cdot \text{s}$. For helium $R = 2077 \text{ J/kg} \cdot \text{K}$. Sea-level air pressure is 101350 Pa. For upward motion $V$,

$$\text{Net buoyancy} = \text{weight} + \text{drag}, \quad \text{or:} \quad (\rho_{\text{air}} - \rho_{\text{He}})g \frac{\pi}{6} D^3 = W + C_D \frac{\rho}{2} V^2 \frac{\pi}{4} D^2$$

$$\text{or:} \quad \left[ 1.225 - \frac{125000}{2077 \times 288} \right] (9.81) \frac{\pi}{6} (4)^3 = 200 + C_D \left( \frac{1.225}{2} \right) V^2 \frac{\pi}{4} (4)^2$$

Guess turbulent flow: $C_D \approx 0.2$: Solve for $V \approx 9.33 \text{ m/s}$ Ans. (a)

Check $Re_D = 2.6E6$: OK, turbulent flow.

(b) If the balloon comes to rest, buoyancy will equal weight, with no drag:

$$\left[ 1.225 - \frac{125000}{2077 \times 288} \right] (9.81) \frac{\pi}{6} (4)^3 = 200,$$

Solve: $\rho_{\text{air}} \approx 0.817 \frac{\text{kg}}{\text{m}^3}$, $Z_{\text{Table}\ A6} \approx 4000 \text{ m}$ Ans. (b)

(c) If it just begins to rise at sea-level, buoyancy will be slightly greater than weight:

$$\left[ 1.225 - \frac{125000}{2077 \times 288} \right] (9.81) \frac{\pi}{6} D^3 > 200, \quad \text{or:} \quad D > 3.37 \text{ m} \quad \text{Ans. (c)}$$
The largest flag in Rhode Island stands outside Herb Chambers’ auto dealership, on the edge of Route I-95 in Providence. The flag is 50 ft long, 30 ft wide, weighs 250 lbf, and takes four strong people to raise it or lower it. Using Prob. P7.40 for input, estimate (a) the wind speed, in mi/h, for which the flag drag is 1000 lbf; and (b) the flag drag when the wind is a low-end category 1 hurricane, 74 mi/h. [HINT: Providence is at sea level.]

Solution: Prob. P7.40 suggests a drag coefficient $C_D \approx 0.02 + 0.1(L/b)$, based on flag area $Lb$. Thus, for this big flag, $C_D = 0.02 + 0.1(50 \text{ ft})/(30 \text{ ft}) \approx 0.187$. From Table A.3, sea level density is $1.2255 \text{ kg/m}^3 = 0.00238 \text{ slug/ft}^3$. Then a drag of 1000 lbf occurs when

$$F = 1000 \text{lbf} = C_D \frac{\rho}{2} V^2 Lb = (0.187)\left(\frac{0.00238}{2}\right) V^2 (50 \text{ ft})(30 \text{ ft})$$

Solve for $V^2 = 2996 \frac{\text{ft}^2}{s^2}$, $V = 54.7 \text{ ft/s} = 37 \text{ mi/h}$ \hspace{1cm} \text{Ans.}(a)

(b) Convert $74 \text{ mi/h} = 108.5 \text{ ft/s}$. Then compute the hurricane drag:

$$F = C_D \frac{\rho}{2} V^2 Lb = (0.187)\left(\frac{0.00238}{2}\right)(108.5)^2 (50)(30) \approx 3900 \text{ lbf} \hspace{1cm} \text{Ans.}(b)$$
The world record for automobile mileage, 12,665 miles per gallon, was set in 2005 by the PAC-CAR II in Fig. P7.109, built by students at the Swiss Federal Institute of Technology in Zurich [52]. This little car, with an empty weight of 64 lbf and a height of only 2.5 ft, traveled a 21-km course at 30 km/hr to set the record. It has a reported drag coefficient of 0.075 (comparable to an airfoil), based upon a frontal area of 3 ft$^2$. (a) What is the drag of this little car when on the course? (b) What horsepower is required to propel it? (c) Do a bit of research and explain why a value of miles per gallon is completely misleading in this particular case.

Solution: For air, assuming sea-level, take $\rho = 0.00238$ slug/ft$^3$. Convert $V = 30$ km/h to 27.34 ft/s. (a) Then the car’s drag on the course, in lbf, is

$$F = C_D \frac{\rho}{2} V^2 A = (0.075) \frac{0.00238 \text{slug/ft}^3}{2} (27.34 \text{ft}/s)^2 (3 \text{ft}^2) = 0.20 \text{lbf} \quad \text{Ans.}(a)$$

Pretty small! Probably the rolling resistance is larger than this.

(b) The power required to overcome drag is simply

$$P = F V = (0.20 \text{lbf})(27.34 \text{ft}/s) = 5.47 \frac{\text{ft-lbf}}{s} \div 550 = 0.010 \text{hp} \quad \text{Ans.}(b)$$

Pretty small! Not much of an engine is required. (c) The actual propulsor for this car was a very small hydrogen fuel cell. Thus “miles per gallon” does not make much sense.
P7.116 An airplane weighs 180 kN and has a wing area of 160 m² and a mean chord of 4 m. The airfoil properties are given by Fig. 7.25. If the plane is designed to land at \( V_0 = 1.2V_{\text{stall}} \), using a split flap set at 60°, (a) What is the proper landing speed in mi/h? (b) What power is required for takeoff at the same speed?

Solution: For air at sea level, \( \rho \approx 1.225 \text{ kg/m}^3 \). From Fig. 7.24 with the flap, \( C_{L,\text{max}} \approx 1.75 \) at \( \alpha \approx 6° \). Compute the stall velocity:

\[
V_{\text{stall}} = \sqrt{\frac{2W}{\rho C_{L,\text{max}} A_p}} = \sqrt{\frac{2(180000 \text{ N})}{(1.225 \text{ kg/m}^3)(1.75)(160 \text{ m}^2)}} = 32.4 \text{ m/s}
\]

Then \( V_{\text{landing}} = 1.2V_{\text{stall}} = 38.9 \text{ m/s} = 87 \text{ mi/h} \quad \text{Ans. (a)} \)

\[
C_L = \frac{C_{L,\text{max}}}{(V_{\text{land}}/V_{\text{stall}})^2} = \frac{1.75}{(1.2)^2} = 1.22
\]

For take-off at the same speed of 38.9 m/s, we need a drag estimate. From Fig. 7.25 with a split flap, \( C_{D,\infty} \approx 0.04 \). We don’t have a theory for induced drag with a split flap, so we just go along with the usual finite wing theory, Eq. (7.71). The aspect ratio is \( b/c = (40 \text{ m})/(4 \text{ m}) = 10 \).

\[
C_D = C_{D,\infty} + \frac{C_L^2}{\pi AR} = 0.04 + \frac{(1.22)^2}{\pi(10)} = 0.087,
\]

\[
F_{\text{drag}} = (0.087)\left(\frac{1.225}{2}\right)(38.9)^2(160) = 12900 \text{ N}
\]

Power required = \( FV = (12900 \text{ N})(38.9 \text{ m/s}) = 501000 \text{ W} = 672 \text{ hp} \quad \text{Ans. (b)} \)