Given: Stabilizing fin on Bonneville land speed record auto.

\[ z = 1.340 \text{ m} \]

\[ V = 560 \text{ km/hr} \]

\[ L = 1.65 \text{ m} \]

\[ H = 0.785 \text{ m} \]

Find: (a) Evaluate \( \text{Re}_L \)
(b) Location of \( x_t \)
(c) Power to overcome skin friction drag on fin.

Solution: Assume standard atmosphere, so \( T = 279 \text{ K} \), \( \rho / \rho_0 = 0.877 \)
(Table A.3); \( \mu = 1.79 \times 10^{-5} \text{ kg/m/s} \) (Table A.7). Then

\[
\text{Re}_L = \frac{\rho VL}{\mu} = \frac{(0.877)(1.23 \text{ kg/m}^3)(560 \times 10^3 \text{ m/hr})}{1.65 \text{ m} \times 1.79 \times 10^{-5} \text{ kg/m s} \times 3600 \text{ s/hr}}
\]

\[ \text{Re}_L = 1.55 \times 10^7 \]

Assume transition occurs at \( \text{Re}_x = 500,000 \). Then

\[
\frac{x_t}{L} = \frac{\text{Re}_xt}{\text{Re}_L} = \frac{500,000}{1.55 \times 10^7} = 0.0323
\]

\[ x_t = 0.0323 \times L = 0.0323 \times 1.65 \text{ m} = 0.0532 \text{ m} = 53.2 \text{ mm} \]

Calculate drag force using \( C_D \) from Fig. 9.8: \( F_D = C_D A \frac{1}{2} \rho V^2 \)

\[ C_D = 0.0029 \) (Fig. 9.8); \( A = 2 \text{ L}_x H = 2 \times 1.65 \text{ m} \times 0.785 \text{ m} = 2.59 \text{ m}^2 \) (2 sides)

\[
\frac{1}{2} \rho V^2 = \frac{1}{2} \times (0.877)(1.23 \text{ kg/m}^3)(560 \times 10^3 \text{ m/hr})^2 \times (3600 \text{ s/hr}) \times 5 \times 1.31 \times 10^4 \text{ N/m}^2 \]

\[ F_D = 0.0029 \times 2.59 \text{ m}^2 \times 1.31 \times 10^4 \text{ N/m}^2 = 98.4 \text{ N} \] (skin friction drag on fin)

The power required is

\[ P = F_D V = 98.4 \text{ N} \times 560 \times 10^3 \text{ m/hr} \times \frac{\text{hr}}{3600 \text{ s}} \times \frac{\text{W} \cdot \text{s}}{\text{N} \cdot \text{m}} = 15.3 \text{ kW} \]

Check using Eq. 9.37b:

\[ C_D = \frac{0.455}{(\log \text{Re}_L)^{2.58}} = \frac{1610}{\text{Re}_L} = 0.00270 \]

This is slightly less than from the graph, but reasonable agreement.
Given: F-4 aircraft slowed by dual parachutes, each 12 ft in diameter. Craft weighs 32,000 lb, lands at 160 kt. Neglect drag of aircraft; brakes not applied.

Find: Time required to decelerate to 100 kt.

Solution: Apply Newton's second law of motion, definition of $C_D$.

Basic equations: $\Sigma F_x = ma$,

$$C_D = \frac{F_D}{\frac{1}{2} \rho V^2 A}$$

Then

$$\Sigma F_x = -2F_D = -C_D \rho V^2 A = ma = \frac{W}{g}\frac{dv}{dt}$$

or

$$\frac{dv}{V_i} = -\frac{C_D \rho g A}{W} dt$$

Integrating,

$$\int_{V_i}^{V_f} \frac{dv}{V_i} = -\frac{1}{V_i} \int_{V_i}^{V_f} = \frac{1}{V_f} - \frac{1}{V_i} = \int_0^t -\frac{C_D \rho g A}{W} dt = -\frac{C_D \rho g A}{W} t$$

or

$$t = \frac{W}{C_D \rho g A} \left[ \frac{1}{V_f} - \frac{1}{V_i} \right]$$

Since two chutes (assume hemispheres), $A = \pi R^2 = \frac{1}{2} \pi D^2$

From Table 9.3, $C_D = 1.42$ for hemisphere facing stream. For standard air, $\rho g = 8.33 \times 0.075 \text{lb/ft}^3$ and

$$t = \frac{32,000 \text{lb} \times 1}{1.42 \times 0.075 \text{lb/ft}^3 \times \frac{2}{\pi} \times \frac{1}{100} \text{hr} \times \frac{3600 \text{ sec}}{\text{hr}} \times 6080 \text{ ft}}$$

or

$$t = 2.45 \text{ s}$$

To find distance, set: $ax = \frac{dv}{dx} = V \frac{dv}{dx}$. Then, from Eq. 1,

$$-2C_D \frac{V^3}{2} A = \frac{W}{g} V \frac{dv}{dx}$$

and

$$\frac{dv}{V} = -\frac{C_D \rho g A}{W} \frac{dx}{dx}$$

Integrating,

$$\int_{V_i}^{V_f} \frac{dv}{V} = \ln \frac{V_f}{V_i} = \ln \frac{V_i}{V_i} = -\frac{C_D \rho g A}{W} x$$

or

$$x = -\frac{W}{C_D \rho g A} \ln \frac{V_f}{V_i}$$

Thus

$$x = \frac{1}{1.42} \times 32,000 \text{ lb} \times \frac{2}{\pi (12)^2 \text{ ft}^2} \times \frac{8.33}{0.075 \text{ lb/ft}^3} \times \text{ln} \frac{100}{160} = 624 \text{ ft}$$
Given: Ford "Probe" driven along level highway at 100 km/hr in standard air. Frontal area, \( A = 1.8 \, \text{m}^2 \), and \( C_d = 0.31 \)

Find: (a) power required to overcome aerodynamic drag  
(b) estimate maximum speed if engine is rated at 145 hp.

Solution:  

\[ P = F_d V \]

Computing equation:  
\[ F_d = C_d \frac{1}{2} \rho V^2 A \]

\[ P = F_d V = C_d \frac{1}{2} \rho V^3 A \]

\[ P = 0.31 \times \frac{1}{2} \times 1.23 \frac{\text{kg}}{\text{m}^3} \times \left( \frac{100 \, \text{km}}{\text{hr}} \times \frac{10^3 \, \text{m}}{\text{km}} \times \frac{1 \, \text{hr}}{3600 \, \text{s}} \right)^3 \times 1.8 \, \text{m}^2 \times \frac{1 \, \text{hp}}{746 \, \text{W}} \times \frac{W \cdot \text{m}}{N \cdot \text{m}} = 9.86 \, \text{hp} \]

Since  \( P = C_d \frac{1}{2} \rho V^3 A \), then

\[ V = \left( \frac{2P}{C_d \rho A} \right)^{1/3} \]

If we assume 100% drive train efficiency and neglect rolling resistance, then the 145 hp overcomes aero-dynamic drag at maximum speed.

\[ V_{\text{max}} = \left( \frac{2 \times 145 \, \text{hp} \times 746 \, \text{N} \cdot \text{m}}{0.31 \times 1.23 \, \text{kg} \cdot \frac{1}{1.8 \, \text{m}^2} \cdot \frac{1}{\text{m}^2}} \right)^{1/3} \]

\[ V_{\text{max}} = 68.1 \, \text{m/s} \quad (245 \, \text{km/hr}, 152 \, \text{mph}) \]
Given: Water tower as shown.

Standard day.

Find: Estimate bending moment
at base of tower.

Solution: Apply definition of \( C_D \),
sum moments about base.

Computing equations: \( C_D = \frac{F_D}{2 \rho V^2 A} \)
\( \Sigma M = \Sigma F \times L \)

Assumptions: (1) \( F_D \) acts at center of sphere; \( F_{De} \) at center of cylinder
(2) Neglect interference between sphere and cylinder.

Then \( M = F_D \left( h + \frac{D}{2} \right) + F_{De} \left( \frac{h}{2} \right) \)
\( A_S = \frac{\pi D^2}{4} = \frac{\pi}{4} (12)^2 \text{m}^2 = 113 \text{ m}^2 \)
\( A_C = h d = 30 \text{ m} \times 2 \text{ m} = 60 \text{ m}^2 \)

\( V = 100 \text{ km/hr} = 100 \frac{\text{m}}{\text{hr}} \times \frac{1000 \text{ m}}{\text{km}} \times \frac{1.23 \text{ km}}{\text{m}^3} \times \frac{3600 \text{ s}}{\text{hr}} = 27.8 \text{ m/s} \)

\( \rho = \frac{1}{2} \rho V^2 = \frac{1}{2} \times 1.23 \frac{\text{kg}}{\text{m}^3} \times (27.8)^2 \frac{\text{m}^2}{\text{s}^2} \times \frac{N \cdot \text{s}^2}{\text{kg} \cdot \text{m}} = 475 \frac{\text{N}}{\text{m}^2} \)

\( C_D = C_D (Re) \). For standard air (Table A.10), \( V = 1.46 \times 10^{-5} \text{ m}^3/\text{s} \), so

\( Re_S = \frac{VD}{\nu} = \frac{27.8 \text{ m} \times 12 \text{ m} \times \frac{2}{1.46 \times 10^{-5} \text{ m}^2}}{2.23 \times 10^{-7}} = 2.29 \times 10^7 \)

This \( Re \) is too large for Fig. 9.11. Thus guess \( C_{DS} = 0.18 \) (Problem 9.125).

\( F_{DS} = C_{DS} g A_S = 0.18 \times 475 \frac{\text{N}}{\text{m}^2} \times 113 \text{ m}^2 = 9.66 \text{ KN} \)

\( Re_C = \frac{VD}{\nu} = \frac{27.8 \text{ m} \times 2.0 \text{ m} \times \frac{2}{1.46 \times 10^{-5} \text{ m}^2}}{2.23 \times 10^{-7}} = 3.81 \times 10^6 \)

This \( Re \) is too large for Fig. 9.13. Thus guess \( C_{De} = 0.4 \).

\( F_{De} = C_{De} g A_C = 0.4 \times 475 \frac{\text{N}}{\text{m}^2} \times 60 \text{ m}^2 = 11.4 \text{ KN} \)

The moment is

\( M = 9.66 \text{ KN} \left( 30 \text{ m} + \frac{12 \text{ m}}{2} \right) + 11.4 \text{ KN} \left( 30 \text{ m} \right) = 519 \text{ KN} \cdot \text{m} \)
The takeoff speed must increase about 8 percent.

\[
V_0 = V_0(\frac{W}{W_0})^{1/2} = 150 \text{ Kmph}(1/0.855)^{1/2} = 122 \text{ Kmph}
\]

At the same gross mass, the lift force remains the same. Thus, when the aircraft is on the verge of stalling, it attains the same lift force, but the gross mass in Denver is 16 km. From Table A.3, at 16 km, \( C_{L0} = 0.855 \).

In Denver, \( g = 161 \text{ Kmph} \) or \( gV_0^2 = gV_0^2 \) or \( \frac{gV_0^2}{g} = \frac{gV_0^2}{g} \).

\[
F_0 = C_{L0}A\rho V_0^2 = \frac{2.5}{25} \times 1210 \times 1210 \times 0.855 = 25 \text{ Kmph}
\]

\[
m_{\text{max}} = \frac{2.5}{g} \times 25 \times 1210 \times 1210 \times 0.855 = 7260 \text{ Kg}
\]

The maximum mass of the aircraft in Denver is 7260 Kg.

From Fig. 9.23, \( C_{max} = 2.07 \) for condition 2. Then for standard:

\[
C_{max} = \frac{F}{\rho g V_0^2} = \frac{F}{\rho g V_0^2} = \frac{F}{\rho g V_0^2}
\]

\[
m_{\text{max}} = \frac{2.5}{g} \times 25 \times 1210 \times 1210 \times 0.855 = 7260 \text{ Kg}
\]

Solution: Apply definition of lift coefficient.

Given: Aircraft with NACA 23012 section airfoils and effective lift area, \( A = 25 \text{ m}^2 \). Maximum flap setting corresponds to condition 2 in Fig. 9.23. Takeoff speed is 160 Kmph.

Find: Maximum gross mass at takeoff, speed in Denver (\( g = 161 \text{ Kmph} \)). Neglect added lift due to ground effect.

The lift force must equal gravity force at takeoff.

Assumption: Lift force must equal gravity force at takeoff.
Given: Hydrofoil craft with effective foil area, \( A = 0.7 \, m^2 \) and mass, \( m = 1800 \, kg \). Foils have \( C_L = 1.6 \) and \( C_D = 0.5 \). Neglect induced drag.

Find: (a) Minimum speed to support craft on foils.  
(b) Power required at this speed.  
(c) Maximum speed if 110 kW is available.

**Solution:** Apply definitions of lift, drag coefficients and power.

Computing equations: \( C_L = \frac{F_L}{\frac{1}{2} \rho V^2 A} \); \( C_D = \frac{F_D}{\frac{1}{2} \rho V^2 A} \); \( P = F_D V \)

**Assumptions:**  
(1) Lift force equals gravity force.  
(2) Neglect induced drag.

Then \( F_L = mg = C_L A \frac{1}{2} \rho V^2 \)  
so \( V = \left( \frac{2 mg}{C_L A} \right)^{1/2} \)

Minimum speed is \( V_{min} = \left[ \frac{2}{1.6} \times 1800 \, kg \times 9.81 \, m/s^2 \times \frac{m^3}{999 \, kg \times 0.7 \, m^2} \right]^{1/2} = 5.12 \, m/s \) \( (10.9 \, kt) \) \( V_{min} \)

The drag force at any speed is \( F_D = C_D A \frac{1}{2} \rho V^2 \)  
so \( F_D = \frac{C_D}{C_L} F_L = \frac{C_D}{C_L} mg \)

and \( P = F_D V = \frac{C_D}{C_L} mg V \)

The minimum power is \( P_{min} = \frac{C_D}{C_L} mg V_{min} = \left( \frac{0.5}{1.6} \times 1800 \, kg \times 9.81 \, m/s^2 \times 5.12 \, m/s \right) \frac{N \cdot m^2}{kg \cdot m} \)

\( P_{min} = 31.0 \times 10^3 \frac{N \cdot m}{s} \times \frac{W \cdot s}{N \cdot m} = 31.0 \, kW \)

As speed increases, the craft will ride higher in the water, decreasing the lifting area such that \( F_L = mg \). Thus \( P_{max} = \frac{C_D}{C_L} mg V_{max} \) or \( V_{max} = \frac{C_L}{C_D} \frac{P_{max}}{mg} \)

Assuming \( C_D/C_L \) remains constant,

\( V_{max} = \frac{1.6}{0.5} \times 110 \times 10^3 \frac{W}{1800 \, kg \times 9.81 \, m/s} \frac{N \cdot m}{W \cdot s} \frac{kg \cdot m}{N \cdot s^2} = 9.9 \, m/s \) \( (38.7 \, kt) \) \( V_{max} \)