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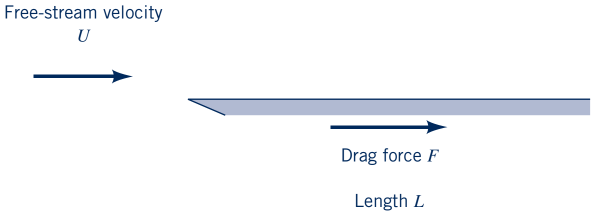
9.2C Water flows over two flat plates. The free-stream velocity is the same for both plates, the flow is laminar, and both plates have the same width. The length of the first plate is L_1, and that of the second plate is twice as long ($L_2 = 2\,L_1$).

The relation between the shear force F_2 for the plate of length $L_2 = 2\,L_1$ relative to the shear force F_1 for the plate of length L_1 is

a) $F_2 > 2\,F_1$. b) $F_2 = 2\,F_1$. c) $F_2 < F_1$.
d) $F_2 = \sqrt{2}\,F_1$. e) $F_2 = F_1$.



9.3C In two different experiments, air and water flow over an object that has the same shape in both experiments. It is found that the drag coefficient on each of the objects is the same for both the air and water flow. For the same velocity:

a) The drag force in the water flow is about equal to that for the airflow.
b) The drag force in the water flow is about 10 times that for the airflow.
c) The drag force in the water flow is about 100 times that for the airflow.
d) The drag force in the water flow is about 1000 times that for the airflow.

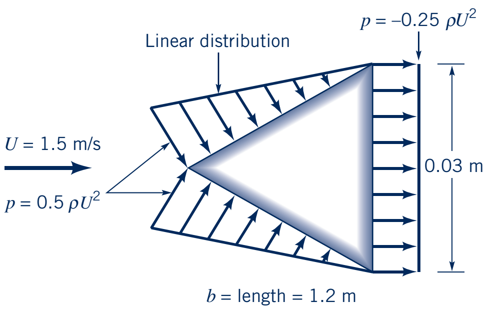
Additional conceptual questions are available in *WileyPLUS* at the instructor's discretion.

Problems

Note: Unless specific values of required fluid properties are given in the problem statement, use the values found in the tables on the inside of the front cover. Answers to the even-numbered problems are listed at the end of the book. The Lab Problems as well as the videos that accompany problems can be accessed in *WileyPLUS* or the book's website, www.wiley.com/college/munson.

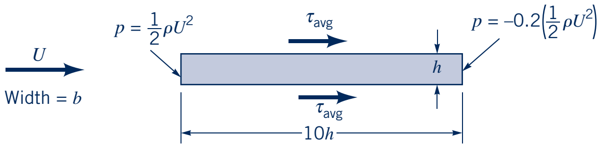
Section 9.1 General External Flow Characteristics

9.1 WILEY GO Assume that water flowing past the equilateral triangular bar shown in Fig. P9.1 produces the pressure distributions indicated. Determine the lift and drag on the bar and the corresponding lift and drag coefficients (based on frontal area). Neglect shear forces.



■ **Figure P9.1**

9.2 WILEY Fluid flows past the two-dimensional bar shown in Fig. P9.2. The pressures on the ends of the bar are as shown, and the average shear stress on the top and bottom of the bar is τ_{avg}. Assume that the drag due to pressure is equal to the drag due to viscous effects. **(a)** Determine τ_{avg} in terms of the dynamic pressure, $\rho U^2/2$. **(b)** Determine the drag coefficient for this object.

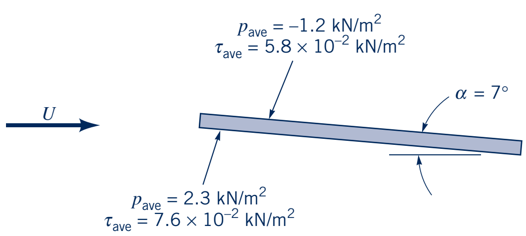


■ **Figure P9.2**

9.3 WILEY Repeat Problem 9.1 if the object is a cone (made by rotating the equilateral triangle about the horizontal axis through its tip) rather than a triangular bar.

9.4 WILEY A small 15 mm long fish swims with a speed of 20 mm/s. Would a boundary layer type flow be developed along the sides of the fish? Explain.

9.5 WILEY The average pressure and shear stress acting on the surface of the 1 m square flat plate are as indicated in Fig. P9.5. Determine the lift and drag generated. Determine the lift and drag if the shear stress is neglected. Compare these two sets of results.



■ **Figure P9.5**

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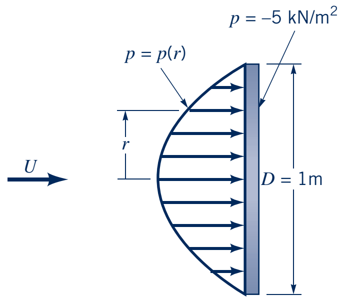
***9.6** WILEY The pressure distribution on the 1 m diameter circular disk in Fig. P9.6 is given in the table. Determine the drag on the disk.

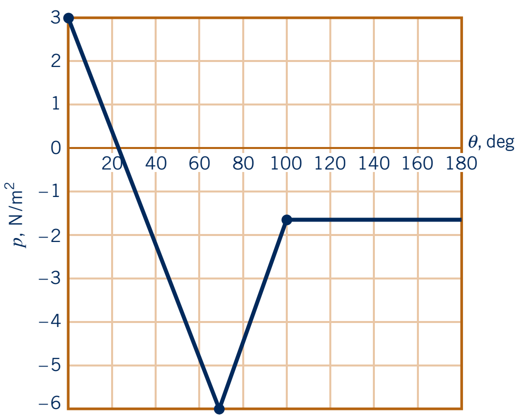
r **(m)**	***p*** **(kN/m²)**
0	4.34
0.05	4.28
0.10	4.06
0.15	3.72
0.20	3.10
0.25	2.78
0.30	2.37
0.35	1.89
0.40	1.41
0.45	0.74
0.50	0.0



■ **Figure P9.6**

9.7 When you walk through still air at a rate of 1 m/s, would you expect the character of the airflow around you to be most like that depicted in Fig. 9.6a, b, or c? Explain. (See **Video 9.3.**)

9.8 WILEY A 0.10 m diameter circular cylinder moves through air with a speed U. The pressure distribution on the cylinder's surface is approximated by the three straight-line segments shown in Fig. P9.8. Determine the drag coefficient on the cylinder. Neglect shear forces.



■ **Figure P9.8**

9.9 WILEY Typical values of the Reynolds number for various animals moving through air or water are listed below. For which cases is inertia of the fluid important? For which cases do viscous effects dominate? For which cases would the flow be laminar; turbulent? Explain.

Animal	**Speed**	**Re**
(a) large whale	10m /s	300,000,000
(b) flying duck	20m /s	300,000
(c) large dragonfly	7m /s	30,000
(d) invertebrate larva	1m m/s	0.3
(e) bacterium	0.01mm /s	0.00003

†9.10 Estimate the Reynolds numbers associated with the following objects moving through water: **(a)** a kayak, **(b)** a minnow, **(c)** a submarine, **(d)** a grain of sand settling to the bottom, **(e)** you swimming.

Section 9.2 Boundary Layer Characteristics (also see Lab Problems 9.1LP and 9.2LP.)

9.11 A 3.6 m long kayak moves with a speed of 1.5 m/s. Would a boundary layer type flow be developed along the sides of the boat? Explain.

9.12 WILEY Water flows past a flat plate that is oriented parallel to the flow with an upstream velocity of 0.5 m/s. Determine the approximate location downstream from the leading edge where the boundary layer becomes turbulent. What is the boundary layer thickness at this location?

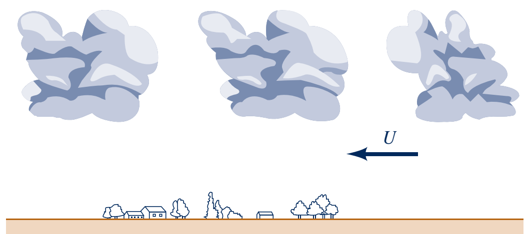
9.13 WILEY A viscous fluid flows past a flat plate such that the boundary layer thickness at a distance 1.3 m from the leading edge is 12 mm. Determine the boundary layer thickness at distances of 0.20, 2.0, and 20 m from the leading edge. Assume laminar flow.

9.14 WILEY If the upstream velocity of the flow in Problem 9.13 is $U = 1.5$ m/s, determine the kinematic viscosity of the fluid.

9.15 WILEY Water flows past a flat plate with an upstream velocity of $U = 0.02$ m/s. Determine the water velocity a distance of 10 mm from the plate at distances of $x = 1.5$ m and $x = 15$ m from the leading edge.

9.16 WILEY Approximately how fast can the wind blow past a 1 cm diameter twig if viscous effects are to be of importance throughout the entire flow field (i.e., Re < 1)? Explain. Repeat for a 0.01 cm diameter hair and a 2 m diameter smokestack.

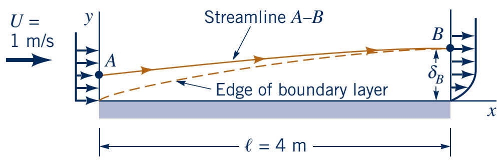
9.17 The typical shape of small cumulus clouds is as indicated in Fig. P9.17. Based on boundary layer ideas, explain why it is clear that the wind is blowing from right to left as indicated.



■ **Figure P9.17**

9.18 Consider flow past the flat plate described in Problem 9.15. Based on the nature of the boundary layer equations that govern this flow, Eqs. 9.8 and 9.9, explain why the answer to Problem 9.15 is independent of the plate length.

9.19 WILEY Because of the velocity deficit, $U - u$, in the boundary layer, the streamlines for flow past a flat plate are not exactly parallel to the plate. This deviation can be determined by use of the displacement thickness, δ^*. For air blowing past the flat plate shown in Fig. P9.19, plot the streamline $A-B$ that passes through the edge of the boundary layer ($y = \delta_B$ at $x = \ell$) at point B. That is, plot $y = y(x)$ for streamline $A-B$. Assume laminar boundary layer flow.



■ **Figure P9.19**

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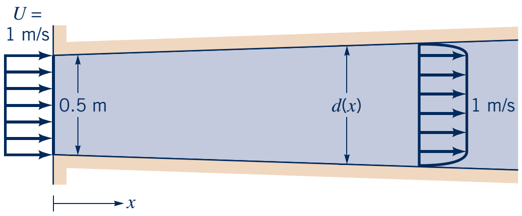
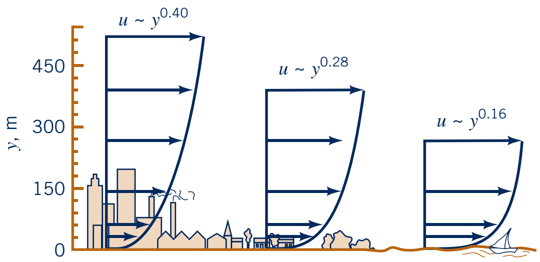
9.20 WILEY GO Air enters a square duct through a 0.3 m opening as is shown in Fig. P9.20. Because the boundary layer displacement thickness increases in the direction of flow, it is necessary to increase the cross-sectional size of the duct if a constant $U = 0.6$ m/s velocity is to be maintained outside the boundary layer. Plot a graph of the duct size, d, as a function of x for $0 \leq x \leq 3$ m if U is to remain constant. Assume laminar flow.



■ **Figure P9.20**

9.21 WILEY A smooth, flat plate of length $\ell = 6$ m and width $b = 4$ m is placed in water with an upstream velocity of $U = 0.5$ m/s. Determine the boundary layer thickness and the wall shear stress at the center and the trailing edge of the plate. Assume a laminar boundary layer.

9.22 WILEY An atmospheric boundary layer is formed when the wind blows over the Earth's surface. Typically, such velocity profiles can be written as a power law: $u = ay^n$, where the constants a and n depend on the roughness of the terrain. As is indicated in Fig. P9.22, typical values are $n = 0.40$ for urban areas, $n = 0.28$ for woodland or suburban areas, and $n = 0.16$ for flat open country (Ref. 23). **(a)** If the velocity is 6 m/s at the bottom of the sail on your boat ($y = 1.2$ m), what is the velocity at the top of the mast ($y = 9$ m)? **(b)** If the average velocity is 16 km/h on the tenth floor of an urban building, what is the average velocity on the sixtieth floor?



■ **Figure P9.22**

9.23 WILEY A 30-story office building (each story is 3.6 m tall) is built in a suburban industrial park. Plot the dynamic pressure, $\rho u^2/2$, as a function of elevation if the wind blows at hurricane strength (120 km/h) at the top of the building. Use the atmospheric boundary layer information of Problem 9.22.

9.24 Show that by writing the velocity in terms of the similarity variable η and the function $f(\eta)$, the momentum equation for boundary layer flow on a flat plate (Eq. 9.9) can be written as the ordinary differential equation given by Eq. 9.14.

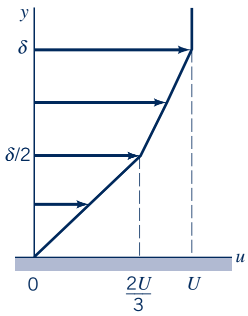
***9.25** Integrate the Blasius equation (Eq, 9.14) numerically to determine the boundary layer profile for laminar flow past a flat plate. Compare your results with those of Table 9.1.

9.26 WILEY GO An airplane flies at a speed of 640 km/h at an altitude of 3000 m. If the boundary layers on the wing surfaces behave as those on a flat plate, estimate the extent of laminar boundary layer flow along the wing. Assume a transitional Reynolds number of $Re_{xcr} = 5 \times 10^5$. If the airplane maintains its 640 km/h speed but descends to sea-level elevation, will the portion of the wing covered by a laminar boundary layer increase or decrease compared with its value at 3000 m? Explain.

†9.27 If the boundary layer on the hood of your car behaves as one on a flat plate, estimate how far from the front edge of the hood the boundary layer becomes turbulent. How thick is the boundary layer at this location?

9.28 WILEY A laminar boundary layer velocity profile is approximated by $u/U = [2 - (y/\delta)]\,(y/\delta)$ for $y \leq \delta$, and $u = U$ for $y > \delta$. **(a)** Show that this profile satisfies the appropriate boundary conditions. **(b)** Use the momentum integral equation to determine the boundary layer thickness, $\delta = \delta(x)$.

9.29 WILEY A laminar boundary layer velocity profile is approximated by the two straight-line segments indicated in Fig. P9.29. Use the momentum integral equation to determine the boundary layer thickness, $\delta = \delta(x)$, and wall shear stress, $\tau_w = \tau_w(x)$. Compare these results with those in Table 9.2.



■ **Figure P9.29**

9.30 A laminar boundary layer velocity profile is approximated by $u/U = 2(y/\delta) - 2(y/\delta)^3 + (y/\delta)^4$ for $y \leq \delta$, and $u = U$ for $y > \delta$. **(a)** Show that this profile satisfies the appropriate boundary conditions. **(b)** Use the momentum integral equation to determine the boundary layer thickness, $\delta = \delta(x)$.

***9.31** WILEY GO For a fluid of specific gravity $SG = 0.86$ flowing past a flat plate with an upstream velocity of $U = 5$ m/s, the wall shear stress on the flat plate was determined to be as indicated in the table below. Use the momentum integral equation to determine the boundary layer momentum thickness, $\Theta = \Theta(x)$. Assume $\Theta = 0$ at the leading edge, $x = 0$.

x (m)	τ_w (N/m^2)
0	—
0.2	13.4
0.4	9.25
0.6	7.68
0.8	6.51
1.0	5.89
1.2	6.57
1.4	6.75
1.6	6.23
1.8	5.92
2.0	5.26

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Section 9.3 Drag

9.32 Should a canoe paddle be made rough to get a "better grip on the water" for paddling purposes? Explain.

9.33 Two different fluids flow over two identical flat plates with the same laminar free-stream velocity. Both fluids have the same viscosity, but one is twice as dense as the other. What is the relationship between the drag forces for these two plates?

9.34 Fluid flows past a flat plate with a drag force $\mathcal{D}_1$. If the free-stream velocity is doubled, will the new drag force, $\mathcal{D}_2$, be larger or smaller than $\mathcal{D}_1$ and by what amount?

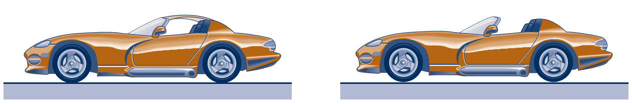
9.35 A model is placed in an airflow with a given velocity and then placed in water flow with the same velocity. If the drag coefficients are the same between these two cases, how do the drag forces compare between the two fluids?

9.36 The drag coefficient for a newly designed hybrid car is predicted to be 0.21. The cross-sectional area of the car is 3 m^2. Determine the aerodynamic drag on the car when it is driven through still air at 88 km/h.

9.37 A 5 m diameter parachute of a new design is to be used to transport a load from flight altitude to the ground with an average vertical speed of 3 m/s. The total weight of the load and parachute is 200 N. Determine the approximate drag coefficient for the parachute.

9.38 A 80 km/h wind blows against an outdoor movie screen that is 21 m wide and 6.0 m tall. Estimate the wind force on the screen.

9.39 The aerodynamic drag on a car depends on the "shape" of the car. For example, the car shown in Fig. P9.39 has a drag coefficient of 0.35 with the windows and roof closed. With the windows and roof open, the drag coefficient increases to 0.45. With the windows and roof open, at what speed is the amount of power needed to overcome aerodynamic drag the same as it is at 104 km/h with the windows and roof closed? Assume the frontal area remains the same. Recall that power is force times velocity.



Windows and roof closed: $C_D = 0.35$ Windows open; roof open: $C_D = 0.45$

Figure P9.39

9.40 A rider on a bike with the combined mass of 100 kg attains a terminal speed of 15 m/s on a 12% slope. Assuming that the only forces affecting the speed are the weight and the drag, calculate the drag coefficient. The frontal area is 0.9 m^2. Speculate whether the rider is in the upright or racing position.

9.41 A baseball is thrown by a pitcher at 150 km/h through standard air. The diameter of the baseball is 7 cm. Estimate the drag force on the baseball.

9.42 A logging boat is towing a log that is 2 m in diameter and 8 m long at 4 m/s through water. Estimate the power required if the axis of the log is parallel to the tow direction.

9.43 A sphere of diameter D and density ρ_s falls at a steady rate through a liquid of density ρ and viscosity μ. If the Reynolds number, $\text{Re} = \rho DU/\mu$, is less than 1, show that the viscosity can be determined from $\mu = gD^2(\rho_s - \rho)/18\,U$.

9.44 Determine the drag on a small circular disk of 0.3 cm diameter moving 3×10^{-3} m/s through oil with a specific gravity of 0.87 and a viscosity 10,000 times that of water. The disk is oriented normal to the upstream velocity. By what percent is the drag reduced if the disk is oriented parallel to the flow?

9.45 The square, flat plate shown in Fig. P9.45*a* is cut into four equal-sized pieces and arranged as shown in Fig. P9.45*b*. Determine the ratio of the drag on the original plate [case **(a)**] to the drag on the plates in the configuration shown in **(b)**. Assume laminar boundary flow. Explain your answer physically.

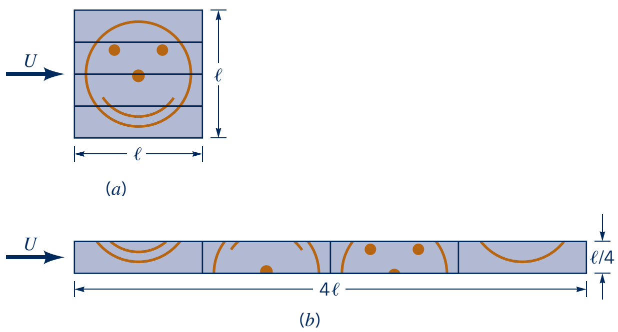


Figure P9.45

9.46 If the drag on one side of a flat plate parallel to the upstream flow is $\mathcal{D}$ when the upstream velocity is U, what will the drag be when the upstream velocity is $2U$; or $U/2$? Assume laminar flow.

9.47 Water flows past a triangular flat plate oriented parallel to the free stream as shown in Fig. P9.47. Integrate the wall shear stress over the plate to determine the friction drag on one side of the plate. Assume laminar boundary layer flow.

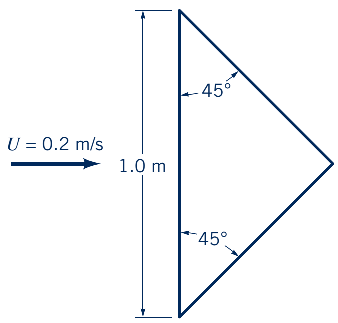


Figure P9.47

9.48 For small Reynolds number flows, the drag coefficient of an object is given by a constant divided by the Reynolds number (see Table 9.4). Thus, as the Reynolds number tends to zero, the drag coefficient becomes infinitely large. Does this mean that for small velocities (hence, small Reynolds numbers) the drag is very large? Explain.

9.49 A rectangular cartop carrier of 0.5 m height, 1.5 m length (front to back), and 1.3 m width is attached to the top of a car. Estimate the additional power required to drive the car with the carrier at 100 km/h through still air compared with the power required to drive only the car at 100 km/h.

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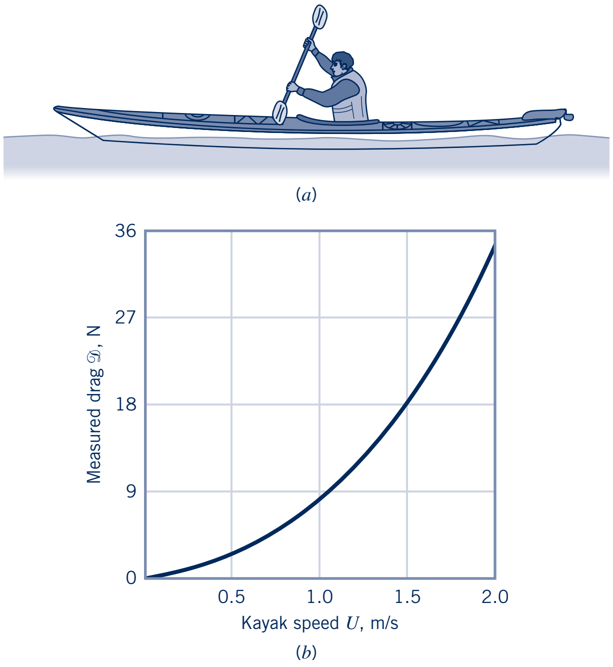
9.50 As shown in **Video V9.2** and Fig. P9.50*a*, a kayak is a relatively streamlined object. As a first approximation in calculating the drag on a kayak, assume that the kayak acts as if it were a smooth, flat plate 5 m long and 0.5 m wide. Determine the drag as a function of speed and compare your results with the measured values given in Fig. P9.50*b*. Comment on reasons why the two sets of values may differ.

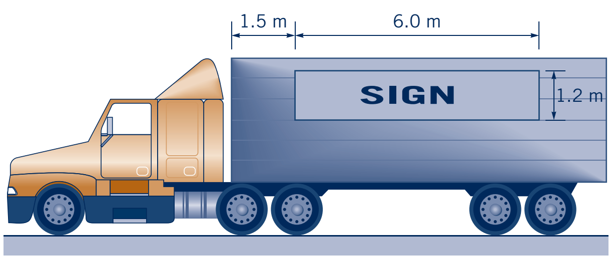


■ **Figure P9.50**

9.51 A three-bladed helicopter blade rotates at 200 rpm. If each blade is 3.6 m long and 0.5 m wide, estimate the torque needed to overcome the friction on the blades if they act as flat plates.

9.52 A ceiling fan consists of five blades of 0.80 m length and 0.10 m width which rotate at 100 rpm. Estimate the torque needed to overcome the friction on the blades if they act as flat plates.

9.53 A thin smooth sign is attached to the side of a truck as is indicated in Fig. P9.53. Estimate the friction drag on the sign when the truck is driven at 88 km/h.

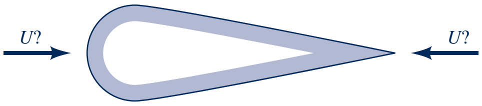


■ **Figure P9.53**

9.54 A 38.1 mm diameter, 0.0245 N table tennis ball is released from the bottom of a swimming pool. With what velocity does it rise to the surface? Assume it has reached its terminal velocity.

9.55 A hot-air balloon roughly spherical in shape has a volume of 2000 m^3 and a weight of 2.2 kN (including passengers, basket, balloon fabric, etc.). If the outside air temperature is 27 °C and the temperature within the balloon is 74 °C, estimate the rate at which it will rise under steady-state conditions if the atmospheric pressure is 101 kPa.

9.56 It is often assumed that "sharp objects can cut through the air better than blunt ones." Based on this assumption, the drag on the object shown in Fig. P9.56 should be less when the wind blows from right to left than when it blows from left to right. Experiments show that the opposite is true. Explain.



■ **Figure P9.56**

9.57 An object falls at a rate of 30 m/s immediately prior to the time that the parachute attached to it opens. The final descent rate with the chute open is 3 m/s. Calculate and plot the speed of falling as a function of time from when the chute opens. Assume that the chute opens instantly, that the drag coefficient and air density remain constant, and that the flow is quasisteady.

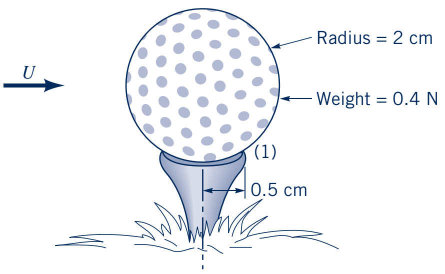
9.58 Estimate the velocity with which you would contact the ground if you jumped from an airplane at an altitude of 1500 m and **(a)** air resistance is negligible, **(b)** air resistance is important, but you forgot your parachute, or **(c)** you use a 7.6 m diameter parachute.

9.59 As is discussed in Section 9.3, the drag on a rough golf ball is less than that on an equal-sized smooth ball. Does it follow that a 10 m diameter spherical water tank resting on a 20 m tall support should have a rough surface so as to reduce the moment needed at the base of the support when a wind blows? Explain.

9.60 A 12 mm diameter cable is strung between a series of poles that are 50 m apart. Determine the horizontal force this cable puts on each pole if the wind velocity is 30 m/s.

9.61 How fast do small water droplets of 0.06 μm (6×10^{-8} m) diameter fall through the air under standard sea-level conditions? Assume the drops do not evaporate. Repeat the problem for standard conditions at 5000 m altitude.

9.62 A strong wind can blow a golf ball off the tee by pivoting it about point 1 as shown in Fig. P9.62. Determine the wind speed necessary to do this.



■ **Figure P9.62**

9.63 A 56 cm by 86 cm speed limit sign is supported on a 7.6 cm wide, 1.5 m long pole. Estimate the bending moment in the pole at ground level when a 48 km/h wind blows against the sign. (See **Video V9.14.**) List any assumptions used in your calculations.

9.64 Determine the moment needed at the base of a 20 m tall, 0.12 m diameter flag pole to keep it in place in a 20 m/s wind.

9.65 Repeat Problem 9.64 if a 2 m by 2.5 m flag is attached to the top of the pole. See Fig. 9.30 for drag coefficient data for flags.

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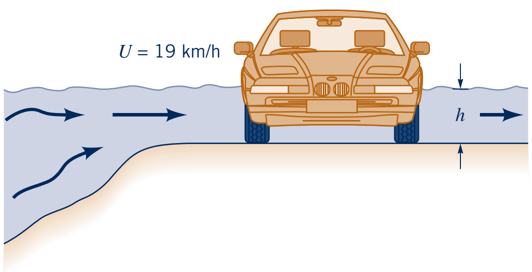
†9.66 During a flash flood, water rushes over a road as shown in Fig. P9.66 with a speed of 19 km/h. Estimate the maximum water depth, h, that would allow a car to pass without being swept away. List all assumptions and show all calculations.



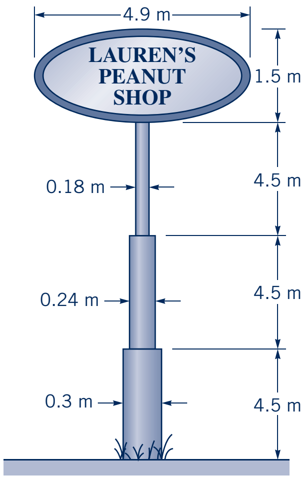
■ **Figure P9.66**

9.67 How much more power is required to pedal a bicycle at 24 km/h into a 32 km/h headwind than at 24 km/h through still air? Assume a frontal area of 0.4 m^2 and a drag coefficient of $C_D = 0.88$.

†9.68 Estimate the wind velocity necessary to knock over a 88 N garbage can that is 0.9 m tall and 0.6 m in diameter. List your assumptions.

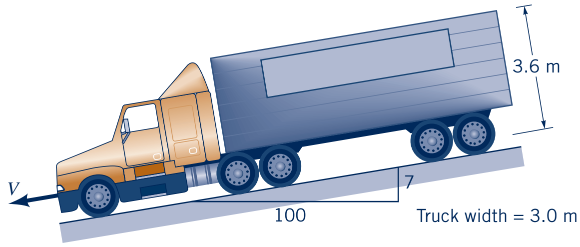
9.69 On a day without any wind, your car consumes x liters of gasoline when you drive at a constant speed, U, from point A to point B and back to point A. Assume that you repeat the journey, driving at the same speed, on another day when there is a steady wind blowing from B to A. Would you expect your fuel consumption to be less than, equal to, or greater than x liters for this windy round-trip? Support your answer with appropriate analysis.

9.70 The structure shown in Fig. P9.70 consists of three cylindrical support posts to which an elliptical flat plate sign is attached. Estimate the drag on the structure when an 80 km/h wind blows against it.



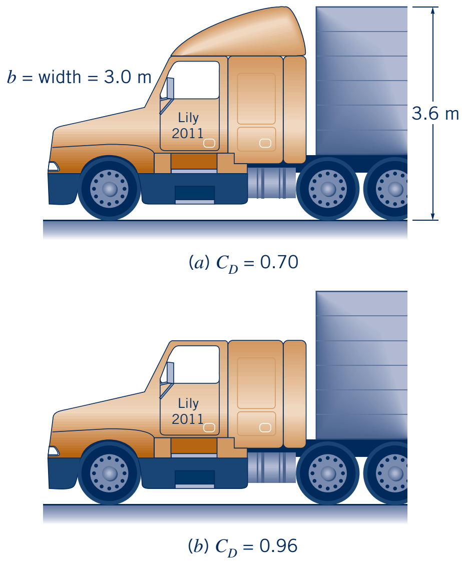
■ **Figure P9.70**

9.71 A 25000 kg truck coasts down a steep 7% mountain grade without brakes, as shown in Fig. P9.71. The truck's ultimate steady-state speed, V, is determined by a balance between weight, rolling resistance, and aerodynamic drag. Determine V if the rolling resistance for a truck on concrete is 1.2% of the weight and the drag coefficient based on frontal area is 0.76.



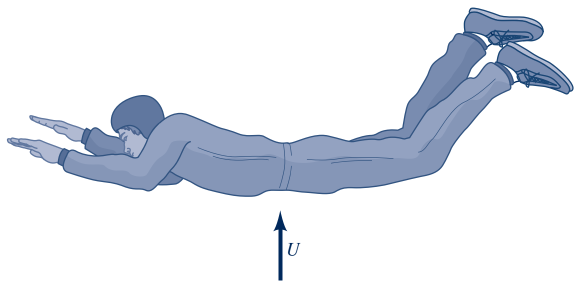
■ **Figure P9.71**

9.72 As shown in **Video V9.19** and Fig. P9.72, the aerodynamic drag on a truck can be reduced by the use of appropriate air deflectors. A reduction in drag coefficient from $C_D = 0.96$ to $C_D = 0.70$ corresponds to a reduction of how many horsepower needed at a highway speed of 104 km/h?



■ **Figure P9.72**

9.73 As shown in **Video V9.11** and Fig. P9.73, a vertical wind tunnel can be used for skydiving practice. Estimate the vertical wind speed needed if a 670 N person is to be able to "float" motionless when the person **(a)** curls up as in a crouching position or **(b)** lies flat. See Fig. 9.30 for appropriate drag coefficient data.



■ **Figure P9.73**

9.74 Compare the rise velocity of a 0.3 cm diameter air bubble in water to the fall velocity of a 0.3 cm diameter water drop in air. Assume each to behave as a solid sphere.

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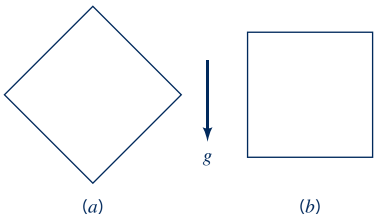
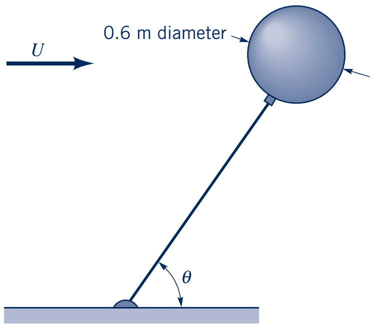
9.75 A 222 N box shaped like a 0.3 m cube falls from the cargo hold of an airplane at an altitude of 9000 m. If the drag coefficient of the falling box is 1.2, determine the time it takes for the box to hit the ocean. Assume that it falls at the terminal velocity corresponding to its current altitude and use a standard atmosphere (see Table C.1).

9.76 WILEY GO A 500 N cube of specific gravity $SG = 1.8$ falls through water at a constant speed U. Determine U if the cube falls **(a)** as oriented in Fig. P9.76*a*, **(b)** as oriented in Fig. P9.76*b*.



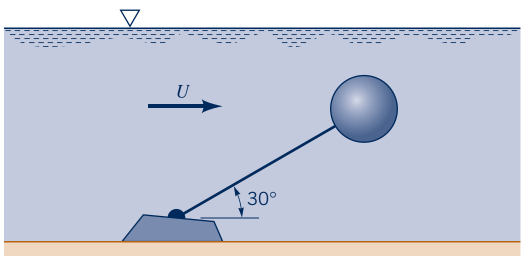
■ **Figure P9.76**

***9.77** WILEY The helium-filled balloon shown in Fig P9.77 is to be used as a wind-speed indicator. The specific weight of the helium is $\gamma = 1.7\ \text{N/m}^3$, the weight of the balloon material is 0.9 N, and the weight of the anchoring cable is negligible. Plot a graph of θ as a function of U for $1 \leq U \leq 80$ km/h. Would this be an effective device over the range of U indicated? Explain.



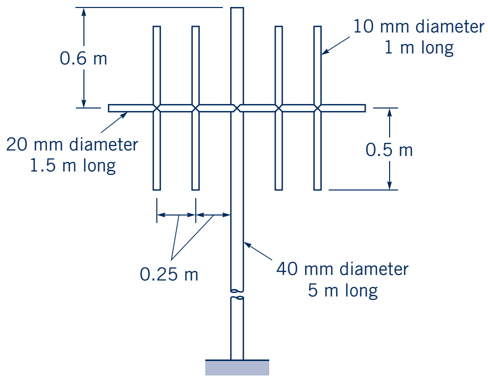
■ **Figure P9.77**

9.78 WILEY A 0.30 m diameter cork ball ($SG = 0.21$) is tied to an object on the bottom of a river as is shown in Fig. P9.78. Estimate the speed of the river current. Neglect the weight of the cable and the drag on it.



■ **Figure P9.78**

9.79 WILEY A shortwave radio antenna is constructed from circular tubing, as is illustrated in Fig. P9.79. Estimate the wind force on the antenna in a 100 km/h wind.



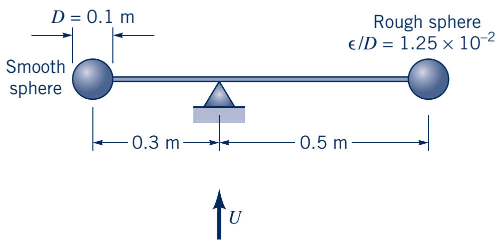
■ **Figure P9.79**

†9.80 WILEY Estimate the wind force on your hand when you hold it out of your car window while driving 88 km/h. Repeat your calculations if you were to hold your hand out of the window of an airplane flying 880 km/h.

†9.81 Estimate the energy that a runner expends to overcome aerodynamic drag while running a complete marathon race. This expenditure of energy is equivalent to climbing a hill of what height? List all assumptions and show all calculations.

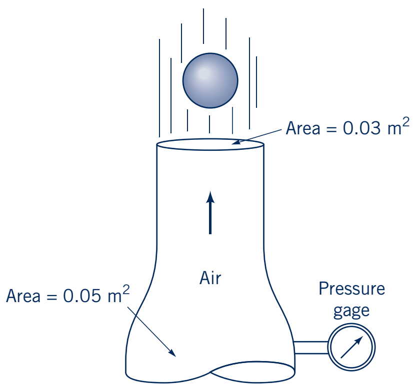
9.82 WILEY A 2 mm diameter meteor of specific gravity 2.9 has a speed of 6 km/s at an altitude of 50,000 m where the air density is $1.03 \times 10^{-3}\ \text{kg/m}^3$. If the drag coefficient at this large Mach number condition is 1.5, determine the deceleration of the meteor.

9.83 WILEY Air flows past two equal sized spheres (one rough, one smooth) that are attached to the arm of a balance as is indicated in Fig. P9.83. With $U = 0$ the beam is balanced. What is the minimum air velocity for which the balance arm will rotate clockwise?



■ **Figure P9.83**

9.84 WILEY A 5 cm diameter sphere weighing 0.6 N is suspended by the jet of air shown in Fig. P9.84 and **Video V3.2.** The drag coefficient for the sphere is 0.5. Determine the reading on the pressure gage if friction and gravity effects can be neglected for the flow between the pressure gage and the nozzle exit.



■ **Figure P9.84**

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9.85 A 96 km/h wind blows against a football stadium scoreboard that is 11 m tall, 24 m wide, and 2.4 m thick (parallel to the wind). Estimate the wind force on the scoreboard. See Fig. 9.28 for drag coefficient data.

9.86 The United Nations Building in New York is approximately 87.5 m wide and 154 m tall. **(a)** Determine the drag on this building if the drag coefficient is 1.3 and the wind speed is a uniform 20 m/s. **(b)** Repeat your calculations if the velocity profile against the building is a typical profile for an urban area (see Problem 9.22) and the wind speed halfway up the building is 20 m/s.

9.87 A regulation football is 17.2 cm in diameter and weighs 4 N. If its drag coefficient is $C_D = 0.2$, determine its deceleration if it has a speed of 6 m/s at the top of its trajectory.

9.88 An airplane tows a banner that is $b = 0.8$ m tall and $\ell =$ 25 m long at a speed of 150 km/h. If the drag coefficient based on the area $b\ell$ is $C_D = 0.06$, estimate the power required to tow the banner. Compare the drag force on the banner with that on a rigid flat plate of the same size. Which has the larger drag force and why?

9.89 The paint stirrer shown in Fig. P9.89 consists of two circular disks attached to the end of a thin rod that rotates at 80 rpm. The specific gravity of the paint is $SG = 1.1$ and its viscosity is $\mu = 96 \times 10^{-2}\ \text{N} \cdot \text{s/m}^2$. Estimate the power required to drive the mixer if the induced motion of the liquid is neglected.

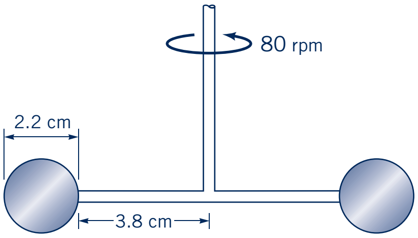

Figure P9.89

†9.90 If the wind becomes strong enough, it is "impossible" to paddle a canoe into the wind. Estimate the wind speed at which this will happen. List all assumptions and show all calculations.

9.91 A fishnet consists of 0.25 cm diameter strings tied into squares 10 cm per side. Estimate the force needed to tow a 4.5 m by 9 m section of this net through seawater at 1.5 m/s.

9.92 It is suggested that the power, $\mathcal{P}$, needed to overcome the aerodynamic drag on a vehicle traveling at a speed U varies as $\mathcal{P} \sim U^n$. What is an appropriate value for the constant n? Explain.

9.93 Estimate the power needed to overcome the aerodynamic drag of a person who runs at a rate of 90 m^2 in 10 s in still air. Repeat the calculations if the race is run into a 32 km/h headwind; a 32 km/h tailwind. Explain.

9.94 By appropriate streamlining, the drag coefficient for an airplane is reduced by 12% while the frontal area remains the same. For the same power output, by what percentage is the flight speed increased?

9.95 Two bicycle racers ride 30 km/h through still air. By what percentage is the power required to overcome aerodynamic drag for the second cyclist reduced if she drafts closely behind the first cyclist rather than riding alongside her? Neglect any forces other than aerodynamic drag. (See Fig. 9.30.)

9.96 As indicated in Fig. P9.96, the orientation of leaves on a tree is a function of the wind speed, with the tree becoming "more streamlined" as the wind increases. The resulting drag coefficient for the tree (based on the frontal area of the tree, HW) as a function of Reynolds number (based on the leaf length, L) is approximated as

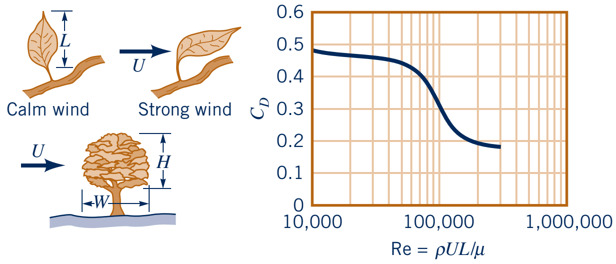

Figure P9.96

shown. Consider a tree with leaves of length $L = 0.09$ m. What wind speed will produce a drag on the tree that is 6 times greater than the drag on the tree in a 4.5 m/s wind?

9.97 The blimp shown in Fig. P9.97 is used at various athletic events. It is 39 m long and has a maximum diameter of 10 m. If its drag coefficient (based on the frontal area) is 0.060, estimate the power required to propel it **(a)** at its 56 km/h cruising speed, or **(b)** at its maximum 88 km/h speed.

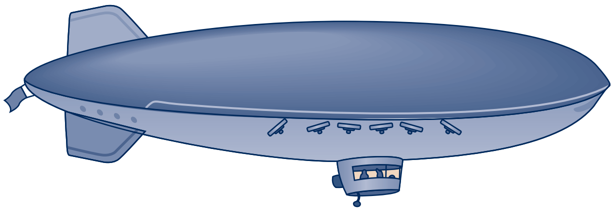

Figure P9.97

9.98 If for a given vehicle it takes 14920 W to overcome aerodynamic drag while being driven at 104 km/h, estimate the horsepower required at 120 km/h.

9.99 (See Fluids in the News article "Dimpled Baseball Bats," Section 9.3.3.) How fast must an 8.9 cm diameter, dimpled baseball bat move through the air in order to take advantage of drag reduction produced by the dimples on the bat? Although there are differences, assume the bat (a cylinder) acts the same as a golf ball in terms of how the dimples affect the transition from a laminar to a turbulent boundary layer.

9.100 (See Fluids in the News article "At 5333 km/L It Doesn't Cost Much to 'Fill 'er Up,'" Section 9.3.3.) **(a)** Determine the power it takes to overcome aerodynamic drag on a small (0.5 m^2 cross section), streamlined ($C_D = 0.12$) vehicle traveling 24 km/h. **(b)** Compare the power calculated in part (a) with that for a large (3.34 m^2 cross-sectional area), nonstreamlined ($C_D =$ 0.48) SUV traveling 104 km/h on the interstate.

Section 9.4 Lift

9.101 A rectangular wing with an aspect ratio of 6 is to generate 4448 N of lift when it flies at a speed of 61 m/s. Determine the length of the wing if its lift coefficient is 1.0.

9.102 A 5.3 N kite with an area of 0.5 m^2 flies in a 6 m/s wind such that the weightless string makes an angle of 55° relative to the horizontal. If the pull on the string is 6.7 N, determine the lift and drag coefficients based on the kite area.

9.103 A Piper Cub airplane has a gross weight of 7784 N, a cruising speed of 184 km/h, and a wing area of 17 m^2. Determine the lift coefficient of this airplane for these conditions.

9.104 A light aircraft with a wing area of 19 m^2 and a weight of 8896 N has a lift coefficient of 0.40 and a drag coefficient of 0.05. Determine the power required to maintain level flight.

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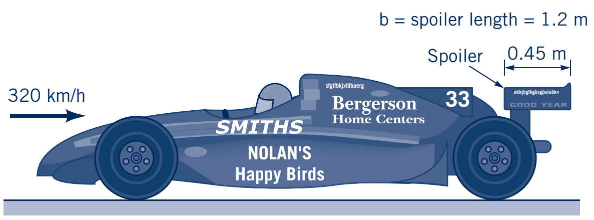
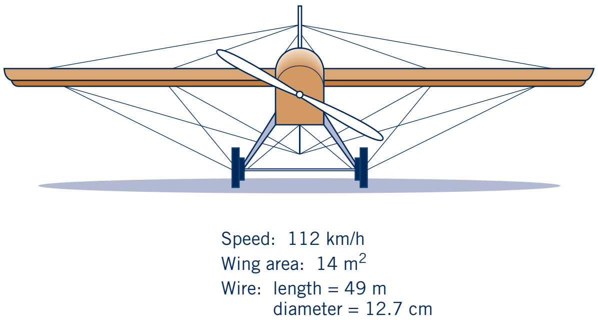
9.105 As shown in **Video V9.25** and Fig. P9.105, a spoiler is used on race cars to produce a negative lift, thereby giving a better tractive force. The lift coefficient for the airfoil shown is $C_L = 1.1$, and the coefficient of friction between the wheels and the pavement is 0.6. At a speed of 320 km/h, by how much would use of the spoiler increase the maximum tractive force that could be generated between the wheels and ground? Assume the airspeed past the spoiler equals the car speed and that the airfoil acts directly over the drive wheels.



■ **Figure P9.105**

9.106 The wings of old airplanes are often strengthened by the use of wires that provided cross-bracing as shown in Fig. P9.106. If the drag coefficient for the wings was 0.020 (based on the planform area), determine the ratio of the drag from the wire bracing to that from the wings.

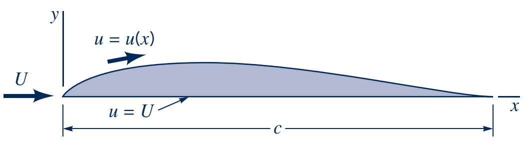


■ **Figure P9.106**

9.107 For a given airplane, compare the power to maintain level flight at a 1500 m altitude with that at 9000 m at the same velocity. Assume C_D remains constant.

9.108 A wing generates a lift $\mathscr{L}$ when moving through sea-level air with a velocity U. How fast must the wing move through the air at an altitude of 10,000 m with the same lift coefficient if it is to generate the same lift?

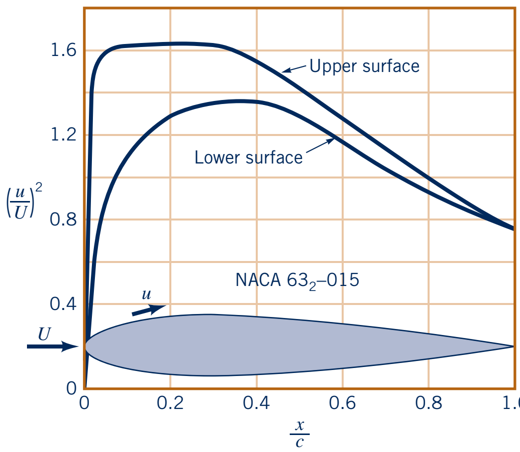
9.109 Air blows over the flat-bottomed, two-dimensional object shown in Fig. P9.109. The shape of the object, $y = y(x)$, and the fluid speed along the surface, $u = u(x)$, are given in the table. Determine the lift coefficient for this object.



■ **Figure P9.109**

x(% c)	y(% c)	u/U
0	0	0
2.5	3.72	0.971
5.0	5.30	1.232
7.5	6.48	1.273
10	7.43	1.271
20	9.92	1.276
30	11.14	1.295
40	11.49	1.307
50	10.45	1.308
60	9.11	1.195
70	6.46	1.065
80	3.62	0.945
90	1.26	0.856
100	0	0.807

***9.110** When air flows past the airfoil shown in Fig. P9.110, the velocity just outside the boundary layer, u, is as indicated. Estimate the lift coefficient for these conditions.



■ **Figure P9.110**

9.111 A Boeing 747 aircraft weighing 2,579,840 N when loaded with fuel and 100 passengers takes off with an airspeed of 224 km. With the same configuration (i.e., angle of attack, flap settings, etc.), what is its takeoff speed if it is loaded with 372 passengers? Assume each passenger with luggage weighs 890 N.

9.112 Show that for unpowered flight (for which the lift, drag, and weight forces are in equilibrium) the glide slope angle, θ, is given by $\tan\theta = C_D/C_L$.

9.113 A sail plane with a lift-to-drag ratio of 25 flies with a speed of 80 km/h. It maintains or increases its altitude by flying in thermals, columns of vertically rising air produced by buoyancy effects of nonuniformly heated air. What vertical airspeed is needed if the sail plane is to maintain a constant altitude?

9.114 If the lift coefficient for a Boeing 777 aircraft is 15 times greater than its drag coefficient, can it glide from an altitude of 9000 m to an airport 130 km away if it loses power from its engines? Explain. (See Problem 9.112.)

9.115 On its final approach to the airport, an airplane flies on a flight path that is 3.0° relative to the horizontal. What lift-to-drag ratio is needed if the airplane is to land with its engines idled back to zero power? (See Problem 9.112.)

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9.116 Over the years there has been a dramatic increase in the flight speed (U), altitude (h), weight ($\mathcal{W}$), and wing loading ($\mathcal{W}/A$ = weight divided by wing area) of aircraft. Use the data given in the table below to determine the lift coefficient for each of the aircraft listed.

Aircraft	Year	$\mathcal{W}$, N	U, km/h	$\mathcal{W}$/A, N/m^2	h, m
Wright Flyer	1903	3336	56	72.0	0
Douglas DC-3	1935	111,200	288	1197	3048
Douglas DC-6	1947	467,040	504	3447	4572
Boeing 747	1970	3,558,400	912	7182	9144

9.117 If the takeoff speed of a particular airplane is 192 km/h at sea level, what will it be at Denver (elevation 1500 m)? Use properties of the U.S. Standard Atmosphere.

9.118 The landing speed of an airplane such as the Space Shuttle is dependent on the air density. (See **Video V9.1.**) By what percent must the landing speed be increased on a day when the temperature is 43 °C compared to a day when it is 10 °C? Assume that the atmospheric pressure remains constant.

9.119 Commercial airliners normally cruise at relatively high altitudes (9000 to 10,500 m). Discuss how flying at this high altitude (rather than 3000 m, for example) can save fuel costs.

9.120 A pitcher can pitch a "curve ball" by putting sufficient spin on the ball when it is thrown. A ball that has absolutely no spin will follow a "straight" path. A ball that is pitched with a very small amount of spin (on the order of one revolution during its flight between the pitcher's mound and home plate) is termed a knuckle ball. A ball pitched this way tends to "jump around" and "zig-zag" back and forth. Explain this phenomenon. *Note*: A baseball has seams.

9.121 For many years, hitters have claimed that some baseball pitchers have the ability to actually throw a rising fastball. Assuming that a top major leaguer pitcher can throw a 152 km/h pitch and impart an 1800 rpm spin to the ball, is it possible for the ball to actually rise? Assume the baseball diameter is 7.4 cm and its weight is 1.45 N.

9.122 (See Fluids in the News article "Learning from Nature," Section 9.4.1.) As indicated in Fig. P9.122, birds can significantly alter their body shape and increase their planform area, A, by spreading their wing and tail feathers, thereby reducing their flight speed. If during landing the planform area is increased by 50% and the lift coefficient increased by 30% while all other parameters are held constant, by what percent is the flight speed reduced?

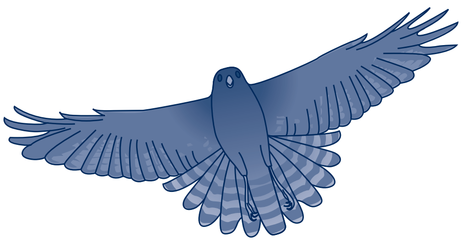

Figure P9.122

9.123 (See Fluids in the News article "Why Winglets?," Section 9.4.2.) It is estimated that by installing appropriately designed winglets on a certain airplane the drag coefficient will be reduced by 5%. For the same engine thrust, by what percent will the aircraft speed be increased by use of the winglets?

Lab Problems

9.1LP This problem involves measuring the boundary layer profile on a flat plate. To proceed with this problem, go to Appendix H, which is located in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

9.2LP This problem involves measuring the pressure distribution on a circular cylinder. To proceed with this problem, go to Appendix H, which is located in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

Lifelong Learning Problems

9.1LL One of the "Fluids in the News" articles in this chapter discusses pressure-sensitive paint—a new technique of measuring surface pressure. There have been other advances in fluid measurement techniques, particularly in velocity measurements. One such technique is particle image velocimetry, or PIV. Obtain information about PIV and its advantages. Summarize your findings in a brief report.

9.2LL For typical aircraft flying at cruise conditions, it is advantageous to have as much laminar flow over the wing as possible because there is an increase in friction drag once the flow becomes turbulent. Various techniques have been developed to help promote laminar flow over the wing, both in airfoil geometry configurations as well as active flow control mechanisms. Obtain information on one of these techniques. Summarize your findings in a brief report.

9.3LL We have seen in this chapter that streamlining an automobile can help to reduce the drag coefficient. One of the methods of reducing the drag has been to reduce the projected area. However, it is difficult for some road vehicles, such as a tractor-trailer, to reduce this projected area due to the storage volume needed to haul the required load. Over the years, work has been done to help minimize some of the drag on this type of vehicle. Obtain information on a method that has been developed to reduce drag on a tractor-trailer. Summarize your findings in a brief report.

FE Exam Problems

Sample FE (Fundamentals of Engineering) exam questions for fluid mechanics are provided in *WileyPLUS* or on the book's website, www.wiley.com/college/munson.

Computational Fluid Dynamics (CFD)

The CFD problems associated with this chapter have been developed for use with the ANSYS Academic CFD software package that is associated with this text. See *WileyPLUS* or the book's website (www.wiley.com/college/munson) for additional details.

9.1CFD This CFD problem involves simulating the pressure distribution for flow past a cylinder and investigating the differences between inviscid and viscous flows. To proceed with this problem, go to *WileyPLUS* or the book's website, www.wiley.com/college/munson.

There are additional CFD problems located in *WileyPLUS*.

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