Appendix L
Odd-numbered Homework Problems

Chapter 1

Section 1.2 Dimensions, Dimensional Homogeneity, and Units

1.1 Verify the dimensions, in both the *FLT* and *MLT* systems, of the following quantities, which appear in Table 1.1: **(a)** angular velocity, **(b)** energy, **(c)** moment of inertia (area), **(d)** power, and **(e)** pressure.

1.3 If V is a velocity, ℓ a length, and ν a fluid property having dimensions of L^2T^{-1}, which of the following combinations are dimensionless: **(a)** $V\ell\nu$, **(b)** $V\ell/\nu$, **(c)** $V^2\nu$, **(d)** $V/\ell\nu$?

1.5 If V is a velocity, determine the dimensions of Z, α, and G, which appear in the dimensionally homogeneous equation

$$V = Z(\alpha - 1) + G$$

1.7 The volume rate of flow, Q, through a pipe containing a slowly moving liquid is given by the equation

$$Q = \frac{\pi R^4 \Delta p}{8\mu\ell}$$

where R is the pipe radius, Δp the pressure drop along the pipe, μ a fluid property called viscosity $(FL^{-2}T)$, and ℓ the length of pipe. What are the dimensions of the constant $\pi/8$? Would you classify this equation as a general homogeneous equation? Explain.

1.9 According to information found in an old hydraulics book, the energy loss per unit weight of fluid flowing through a nozzle connected to a hose can be estimated by the formula

$$h = (0.04 \text{ to } 0.09)(D/d)^4V^2/2g$$

where h is the energy loss per unit weight, D the hose diameter, d the nozzle tip diameter, V the fluid velocity in the hose, and g the acceleration of gravity. Do you think this equation is valid in any system of units? Explain.

1.11 A formula to estimate the volume rate of flow, Q, flowing over a dam of length, B, is given by the equation

$$Q = 3.09\, BH^{3/2}$$

where H is the depth of the water above the top of the dam (called the head). This formula gives Q in ft^3/s when B and H are in feet. Is the constant, 3.09, dimensionless? Would this equation be valid if units other than feet and seconds were used?

1.13 Make use of Table 1.2 to express the following quantities in SI units: **(a)** 10.2 in./min, **(b)** 4.81 slugs, **(c)** 3.02 lb, **(d)** 73.1 ft/s^2, **(e)** 0.0234 lb·s/ft^2.

1.15 Water flows from a large drainage pipe at a rate of 1200 gal/min. What is this volume rate of flow in **(a)** m^3/s, **(b)** liters/min, and **(c)** ft^3/s?

Section 1.4 Measures of Fluid Mass and Weight

1.17 Obtain a photograph/image of a situation in which the density or specific weight of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

1.19 The density of a certain liquid is 2.15 slugs/ft^3. Determine its specific weight and specific gravity.

†1.21 Estimate the number of pounds of mercury it would take to fill your bathtub. List all assumptions and show all calculations.

†1.23 The presence of raindrops in the air during a heavy rainstorm increases the average density of the air–water mixture. Estimate by what percent the average air–water density is greater than that of just still air. State all assumptions and show calculations.

***1.25** The variation in the density of water, ρ, with temperature, T, in the range of 20 °C $\le T \le$ 50 °C, is given in the following table.

Density (kg/m^3)	998.2	997.1	995.7	994.1	992.2	990.2	988.1
Temperature (°C)	20	25	30	35	40	45	50

Use these data to determine an empirical equation of the form $\rho = c_1 + c_2T + c_3T^2$, which can be used to predict the density over the range indicated. Compare the predicted values with the data given. What is the density of water at 42.1 °C?

1.27 A mountain climber's oxygen tank contains 1 lb of oxygen when he begins his trip at sea level where the acceleration of gravity is 32.174 ft/s^2. What is the weight of the oxygen in the tank when he reaches the top of Mt. Everest where the acceleration of gravity is 32.082 ft/s^2? Assume that no oxygen has been removed from the tank; it will be used on the descent portion of the climb.

Section 1.5 Ideal Gas Law

1.29 Some experiments are being conducted in a laboratory in which the air temperature is 27 °C and the atmospheric pressure is 14.3 psia. Determine the density of the air. Express your answers in slugs/ft^3 and in kg/m^3.

1.31 Nitrogen is compressed to a density of 4 kg/m^3 under an absolute pressure of 400 kPa. Determine the temperature in degrees Celsius.

1.33 A tire having a volume of 3 ft^3 contains air at a gage pressure of 26 psi and a temprature of 70 °F. Determine the density of the air and the weight of the air contained in the tire.

Section 1.6 Viscosity (also see Lab Problems 1.74 and 1.75)

1.35 Obtain a photograph/image of a situation in which the viscosity of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

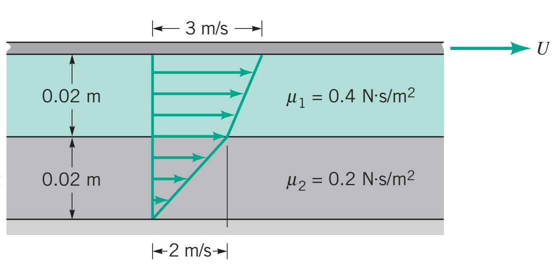
1.37 A liquid has a specific weight of 59 lb/ft^3 and a dynamic viscosity of 2.75 lb·s/ft^2. Determine its kinematic viscosity.

1.39 The time, t, it takes to pour a liquid from a container depends on several factors, including the kinematic viscosity, ν, of the liquid. (See **Video V1.3.**) In some laboratory tests, various oils having the same density but different viscosities were poured at a fixed tipping rate from small 150-ml beakers. The time required to pour 100 ml of the oil was measured, and it was found that an approximate equation for the pouring time in seconds was $t = 1 + 9 \times 10^2\nu + 8 \times 10^3\nu^2$ with ν in m^2/s. **(a)** Is this a general homogeneous equation? Explain. **(b)** Compare the time it would take to pour 100 ml of SAE 30 oil from a 150-ml beaker at 0 °C to the corresponding time at a temperature of 60 °C. Make use of Fig. B.2 in Appendix B for viscosity data.

1.41 The viscosity of a certain fluid is 5×10^{-4} poise. Determine its viscosity in both SI and BG units.

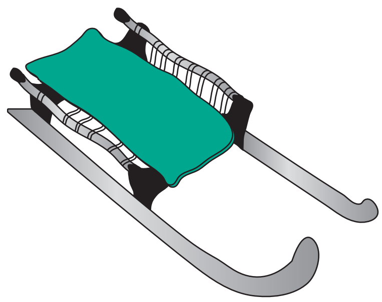
1.43 Calculate the Reynolds number for the flow of water and for air through a 3-mm-diameter tube if the mean velocity is 2 m/s and the temperature is 30 °C in both cases (see Example 1.3). Assume the air is at standard atmospheric pressure.

1.45 As shown in **Video V1.4**, the no-slip condition means that a fluid "sticks" to a solid surface. This is true for both fixed and moving surfaces. Let two layers of fluid be dragged along by the motion of an upper plate as shown in Fig. P1.45. The bottom plate is stationary. The top fluid puts a shear stress on the upper plate, and the lower fluid puts a shear stress on the botton plate. Determine the ratio of these two shear stresses.



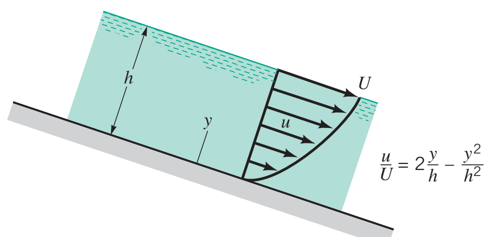
■ **FIGURE P1.45**

1.47 The sled shown in Fig. P1.47 slides along on a thin horizontal layer of water between the ice and the runners. The horizontal force that the water puts on the runners is equal to 1.2 lb when the sled's speed is 50 ft/s. The total area of both runners in contact with the water is 0.08 ft^2, and the viscosity of the water is 3.5×10^{-5} lb·s/ft^2. Determine the thickness of the water layer under the runners. Assume a linear velocity distribution in the water layer.



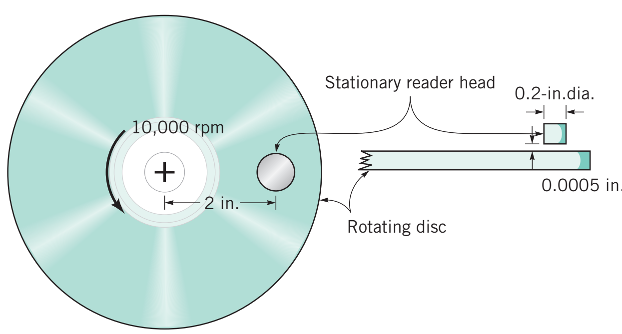
■ **FIGURE P1.47**

1.49 A layer of water flows down an inclined fixed surface with the velocity profile shown in Fig. P1.49. Determine the magnitude and direction of the shearing stress that the water exerts on the fixed surface for $U = 3$ m/s and $h = 0.1$ m.



■ **FIGURE P1.49**

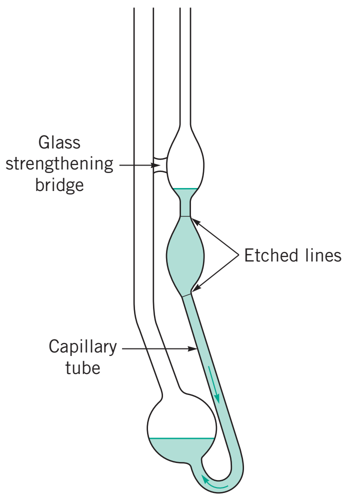
1.51 A new computer drive is proposed to have a disc, as shown in Fig. P1.51. The disc is to rotate at 10,000 rpm, and the reader head is to be positioned 0.0005 in. above the surface of the disc. Estimate the shearing force on the reader head as result of the air between the disc and the head.



■ **FIGURE P1.51**

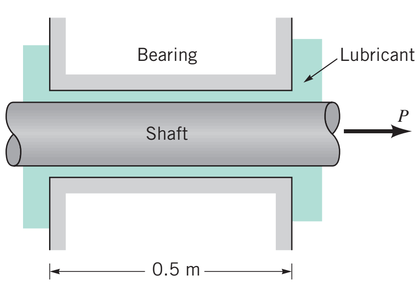
1.53 The viscosity of a soft drink was determined by using a capillary tube viscometer similar to that shown in Fig. P1.53 and **Video V1.5.** For this device the kinematic viscosity, ν, is directly proportional to the time, t, that it takes for a given amount of liquid to flow through a small capillary tube. That is, $\nu = Kt$. The following data were obtained from regular pop and diet pop. The corresponding measured specific gravities are also given. Based on these data, by what percent is the absolute viscosity, μ, of regular pop greater than that of diet pop?

	Regular pop	Diet pop
$t(s)$	377.8	300.3
SG	1.044	1.003



■ FIGURE P1.53

1.55 A 25-mm-diameter shaft is pulled through a cylindrical bearing as shown in Fig. P1.55. The lubricant that fills the 0.3-mm gap between the shaft and bearing is an oil having a kinematic viscosity of 8.0×10^{-4} m^2/s and a specific gravity of 0.91. Determine the force P required to pull the shaft at a velocity of 3 m/s. Assume the velocity distribution in the gap is linear.



■ FIGURE P1.55

1.57 There are many fluids that exhibit non-Newtonian behavior (see, for example, **Video V1.6**). For a given fluid the distinction between Newtonian and non-Newtonian behavior is usually based on measurements of shear stress and rate of shearing strain. Assume that the viscosity of blood is to be determined by measurements of shear stress, τ, and rate of shearing strain, du/dy, obtained from a small blood sample tested in a suitable viscometer. Based on the data given, determine if the blood is a Newtonian or non-Newtonian fluid. Explain how you arrived at your answer.

τ (N/m^2)	0.04	0.06	0.12	0.18	0.30	0.52	1.12	2.10
du/dy (s^{-1})	2.25	4.50	11.25	22.5	45.0	90.0	225	450

Section 1.7 Compressibility of Fluids

1.59 A sound wave is observed to travel through a liquid with a speed of 1500 m/s. The specific gravity of the liquid is 1.5. Determine the bulk modulus for this fluid.

1.61 Often the assumption is made that the flow of a certain fluid can be considered as incompressible flow if the density of the fluid changes by less than 2%. If air is flowing through a tube such that the air gage pressure at one section is 9.0 psi and at a downstream section it is 8.6 psi at the same temperature, do you think that this flow could be considered an incompressible flow? Support your answer with the necessary calculations. Assume standard atmospheric pressure.

1.63 (See Fluids in the News article titled "This water jet is a blast," Section 1.7.1.) By what percent is the volume of water decreased if its pressure is increased to an equivalent to 3000 atmospheres (44,100 psi)?

Section 1.8 Vapor Pressure

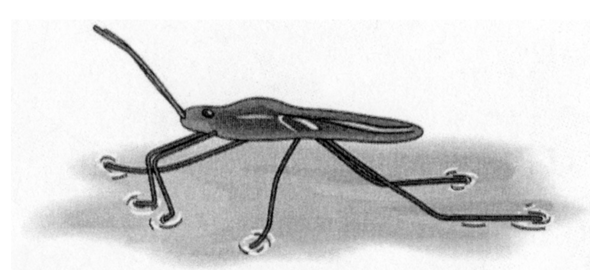
1.65 During a mountain climbing trip it is observed that the water used to cook a meal boils at 90 °C rather than the standard 100 °C at sea level. At what altitude are the climbers preparing their meal? (See Tables B.2 and C.2 for data needed to solve this problem.)

1.67 When water at 70 °C flows through a converging section of pipe, the pressure is reduced in the direction of flow. Estimate the minimum absolute pressure that can develop without causing cavitation. Express your answer in both BG and SI units.

Section 1.9 Surface Tension

1.69 Obtain a photograph/image of a situation in which the surface tension of a fluid is important. Print this photo and write a brief paragraph that describes the situation involved.

1.71 (See Fluids in the News article titled "Walking on water," Section 1.9.) **(a)** The water strider bug shown in Fig. P1.71 is supported on the surface of a pond by surface tension acting along the interface between the water and the bug's legs. Determine the minimum length of this interface needed to support the bug. Assume the bug weighs 10^{-4} N and the surface tension force acts vertically upward. **(b)** Repeat part (a) if surface tension were to support a person weighing 750 N.



■ FIGURE P1.71

1.73 Under the right conditions, it is possible, due to surface tension, to have metal objects float on water. (See **Video V1.9.**) Consider placing a short length of a small-diameter steel (sp. wt. = 490 lb/ft^3) rod on a surface of water. What is the maximum diameter that the rod can have before it will sink? Assume that the surface tension forces act vertically upward. *Note:* A standard paper clip has a diameter of 0.036 in. Partially unfold a paper clip and see if you can get it to float on water. Do the results of this experiment support your analysis?

■ Lab Problems

1.75 This problem involves the use of a capillary tube viscometer to determine the kinematic viscosity of water as a function of temperature. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

1.77 For years, lubricating oils and greases obtained by refining crude oil have been used to lubricate moving parts in a wide variety of machines, motors, and engines. With the increasing cost of crude oil and the potential for the reduced availability of it, the need for non-petroleum-based lubricants has increased considerably. Obtain information about non-petroleum-based lubricants. Summarize your findings in a brief report.

Chapter 2

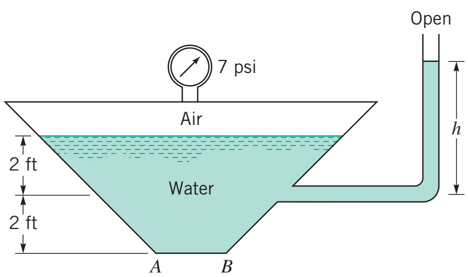
Section 2.3 Pressure Variation in a Fluid at Rest

2.1 Obtain a photograph/image of a situation in which the fact that in a static fluid the pressure increases with depth is important. Print this photo and write a brief paragraph that describes the situation involved.

2.3 Bathyscaphes are capable of submerging to great depths in the ocean. What is the pressure at a depth of 5 km, assuming that seawater has a constant specific weight of 10.1 kN/m^3? Express your answer in pascals and psi.

2.5 In a certain chemical plant, a closed tank contains ethyl alcohol to a depth of 50 ft. Air at a pressure of 25 psi fills the gap at the top of the tank. Determine the pressure at a closed valve attached to the tank 10 ft above its bottom.

2.7 The closed tank of Fig. P2.7 is filled with water and is 5 ft long. The pressure gage on the tank reads 7 psi. Determine **(a)** the height, h, in the open water column, **(b)** the gage pressure acting on the bottom tank surface *AB,* and **(c)** the absolute pressure of the air in the top of the tank if the local atmospheric pressure is 14.7 psia.



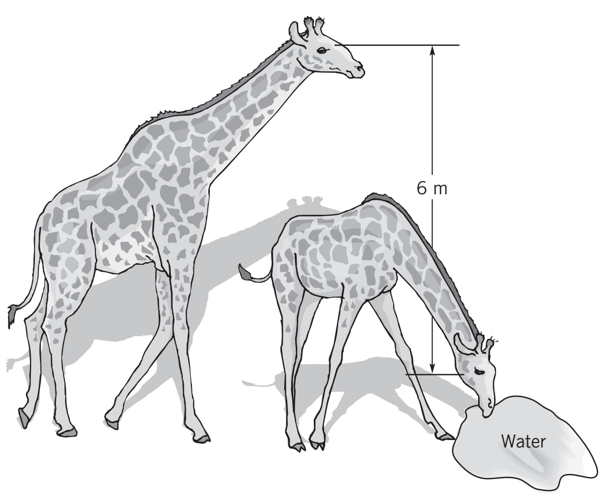
■ **FIGURE P2.7**

***2.9** In a certain liquid at rest, measurements of the specific weight at various depths show the following variation:

h (ft)	γ(lb/ft^3)
0	70
10	76
20	84
30	91
40	97
50	102
60	107
70	110
80	112
90	114
100	115

The depth $h = 0$ corresponds to a free surface at atmospheric pressure. Determine, through numerical integration of Eq. 2.4, the corresponding variation in pressure and show the results on a plot of pressure (in psf) versus depth (in feet).

2.11 (See Fluids in the News article titled "Giraffe's blood pressure," Section 2.3.1.) **(a)** Determine the change in hydrostatic pressure in a giraffe's head as it lowers its head from eating leaves 6 m above the ground to getting a drink of water at ground level as shown in Fig. P2.11. Assume the specific gravity of blood is $SG = 1$. **(b)** Compare the pressure change calculated in part **(a)** to the normal 120 mm of mercury pressure in a human's heart.



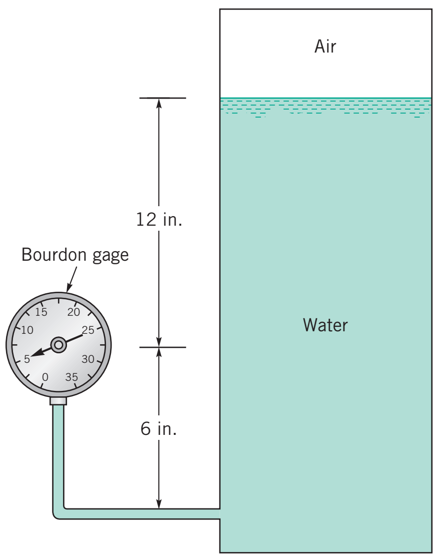
■ **FIGURE P2.11**

Section 2.5 Measurement of Pressure

2.13 On a given day, a barometer at the base of the Washington Monument reads 29.97 in. of mercury. What would the barometer reading be when you carry it up to the observation deck 500 ft above the base of the monument?

2.15 (See Fluids in the News article titled "Weather, barometers, and bars," Section 2.5.) The record low sea-level barometric pressure ever recorded is 25.8 in. of mercury. At what altitude in the standard atmosphere is the pressure equal to this value?

2.17 Bourdon gages (see **Video V2.3** and Fig. P2.17) are commonly used to measure pressure. When such a gage is attached to the closed water tank of Fig. P2.17 the gage reads 5 psi. What is the absolute air pressure in the tank? Assume standard atmospheric pressure of 14.7 psi.



■ **FIGURE P2.17**

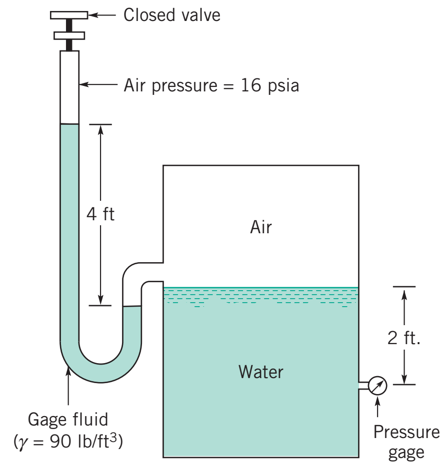
2.19 On the suction side of a pump a Bourdon pressure gage reads 40-kPa vacuum. What is the corresponding absolute pressure if the local atmospheric pressure is 100 kPa (abs)?

2.21 A flowrate measuring device is installed in a horizontal pipe through which water is flowing. A U-tube manometer is connected to the pipe through pressure taps located 3 in. on either side of the device. The gage fluid in the manometer has a specific weight of 112 lb/ft^3. Determine the differential reading of the manometer corresponding to a pressure drop between the taps of 0.5 $lb/in.^2$

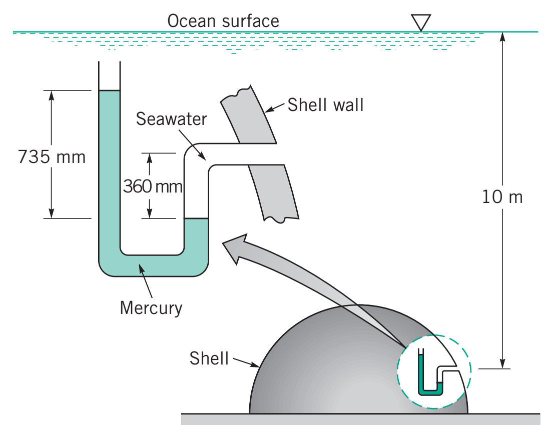
2.23 A U-tube manometer is connected to a closed tank containing air and water as shown in Fig. P2.23. At the closed end of the manometer the air pressure is 16 psia. Determine the reading on the pressure gage for a differential reading of 4 ft on the manometer. Express your answer in psi (gage). Assume standard atmospheric pressure and neglect the weight of the air columns in the manometer.

2.25 An air-filled, hemispherical shell is attached to the ocean floor at a depth of 10 m as shown in Fig. P2.25. A mercury barometer located inside the shell reads 765 mm Hg, and a mercury U-tube manometer designed to give the outside water pressure indicates a differential reading of 735 mm Hg as illustrated. Based on these data what is the atmospheric pressure at the ocean surface?

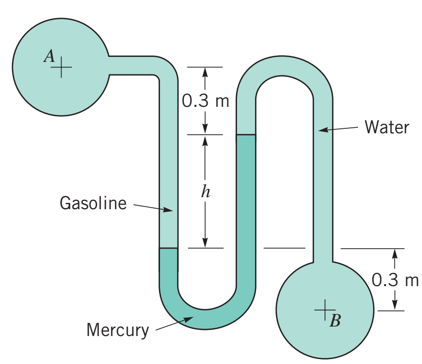
2.27 The differential mercury manometer of Fig. P2.27 is connected to pipe A containing gasoline ($SG = 0.65$) and to pipe B containing water. Determine the differential reading, h, corresponding to a pressure in A of 20 kPa and a vacuum of 150 mm Hg in B.



■ **FIGURE P2.23**

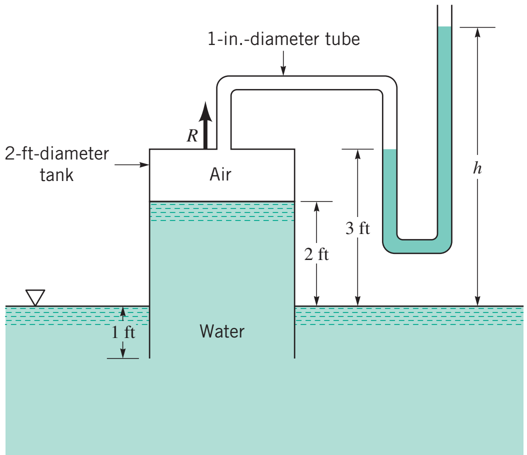


■ **FIGURE P2.25**



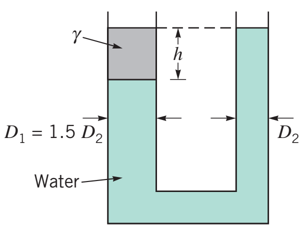
■ **FIGURE P2.27**

2.29 An inverted open tank is held in place by a force R as shown in Fig. P2.29. If the specific gravity of the manometer fluid is 2.5, determine the value of h.



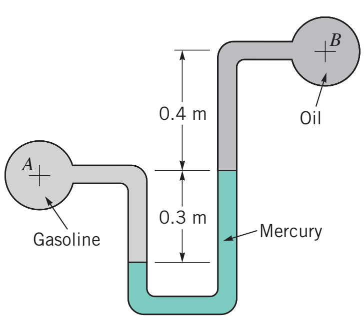
■ FIGURE P2.29

2.31 The U-shaped tube shown in Fig. P2.31 initially contains water only. A second liquid with specific weight, γ, less than water is placed on top of the water with no mixing occurring. Can the height, h, of the second liquid be adjusted so that the left and right levels are at the same height? Provide proof of your answer.



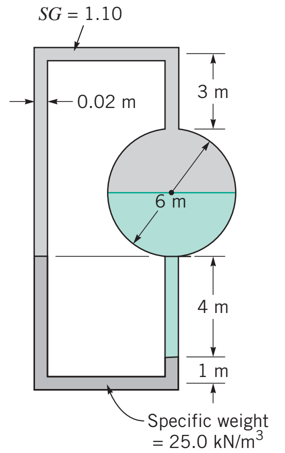
■ FIGURE P2.31

2.33 In Fig. P2.33 pipe A contains gasoline ($SG = 0.7$), pipe B contains oil ($SG = 0.9$), and the manometer fluid is mercury. Determine the new differential reading if the pressure in pipe A is decreased 25 kPa, and the pressure in pipe B remains constant. The initial differential reading is 0.30 m as shown.



■ FIGURE P2.33

2.35 A 0.02-m-diameter manometer tube is connected to a 6-m-diameter full tank as shown in Fig. P2.35. Determine the density of the unknown liquid in the tank.



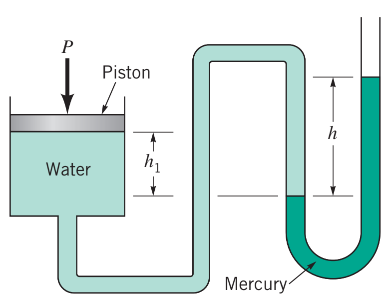
■ FIGURE P2.35

Section 2.8 Hydrostatic Force on a Plane Surface (also see Lab Problems 2.85, 2.86, 2.87, and 2.88)

2.37 Obtain a photograph/image of a situation in which the hydrostatic force on a plane surface is important. Print this photo and write a brief paragraph that describes the situation involved.

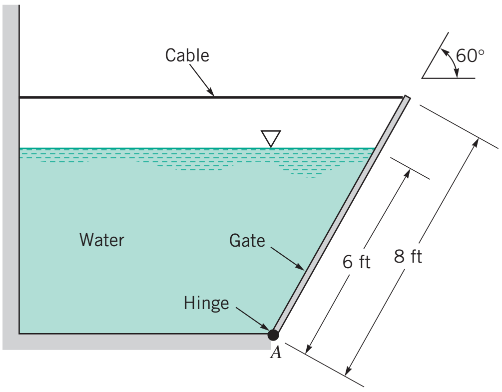
2.39 (See Fluids in the News article titled "The Three Gorges Dam," Section 2.8.) **(a)** Determine the horizontal hydrostatic force on the 2309-m-long Three Gorges Dam when the average depth of the water against it is 175 m. **(b)** If all of the 6.4 billion people on Earth were to push horizontally against the Three Gorges Dam, could they generate enough force to hold it in place? Support your answer with appropriate calculations.

2.41 A piston having a cross-sectional area of 0.07 m^2 is located in a cylinder containing water as shown in Fig. P2.41. An open U-tube manometer is connected to the cylinder as shown. For $h_1 = 60$ mm and $h = 100$ mm, what is the value of the applied force, P, acting on the piston? The weight of the piston is negligible.



■ FIGURE P2.41

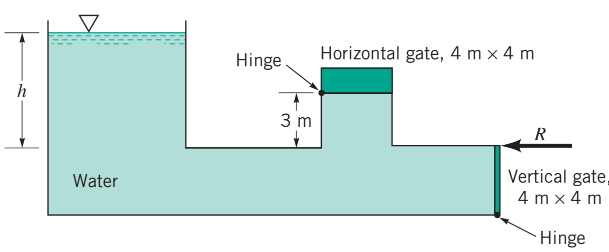
2.43 A homogeneous, 4-ft-wide, 8-ft-long rectangular gate weighing 800 lb is held in place by a horizontal flexible cable as shown in Fig. P2.43. Water acts against the gate, which is hinged at point A. Friction in the hinge is negligible. Determine the tension in the cable.



■ FIGURE P2.43

2.45 An area in the form of an isosceles triangle with a base width of 6 ft and an altitude of 8 ft lies in the plane forming one side of a tank that contains a liquid having a specific weight of 79.8 lb/ft^3. The side slopes upward, making an angle of 60° with the horizontal. The base of the triangle is horizontal and the vertex is above the base. Determine the resultant force the fluid exerts on the area when the fluid depth is 20 ft above the base of the triangular area. Show, with the aid of a sketch, where the center of pressure is located.

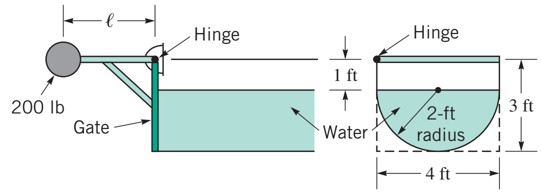
2.47 Two square gates close two openings in a conduit connected to an open tank of water as shown in Fig. P2.47. When the water depth, h, reaches 5 m, it is desired that both gates open at the same time. Determine the weight of the homogeneous horizontal gate and the horizontal force, R, acting on the vertical gate that is required to keep the gates closed until this depth is reached. The weight of the vertical gate is negligible, and both gates are hinged at one end as shown. Friction in the hinges is negligible.



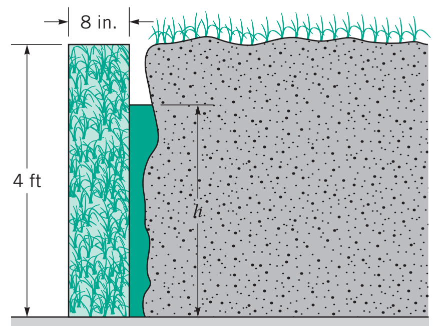
■ FIGURE P2.47

2.49 A 4-ft by 3-ft massless rectangular gate is used to close the end of the water tank shown in Fig. P2.49. A 200-lb weight attached to the arm of the gate at a distance ℓ from the frictionless hinge is just sufficient to keep the gate closed when the water depth is 2 ft, that is, when the water fills the semicircular lower portion of the tank. If the water were deeper the gate would open. Determine the distance ℓ.

2.51 A 4-ft-tall, 8-in.-wide concrete (150 lb/ft^3) retaining wall is built as shown in Fig. P2.51. During a heavy rain, water fills the space between the wall and the earth behind it to a depth h. Determine the maximum depth of water possible without the wall tipping over. The wall simply rests on the ground without being anchored to it.

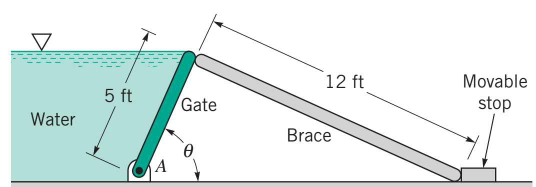


■ FIGURE P2.49



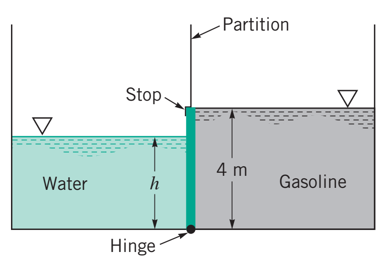
■ FIGURE P2.51

***2.53** A 200-lb homogeneous gate 10 ft wide and 5 ft long is hinged at point A and held in place by a 12-ft-long brace as shown in Fig. P2.53. As the bottom of the brace is moved to the right, the water level remains at the top of the gate. The line of action of the force that the brace exerts on the gate is along the brace. **(a)** Plot the magnitude of the force exerted on the gate by the brace as a function of the angle of the gate, θ, for $0 \leq \theta \leq 90°$. **(b)** Repeat the calculations for the case in which the weight of the gate is negligible. Comment on the results as $\theta \rightarrow 0$.



■ FIGURE P2.53

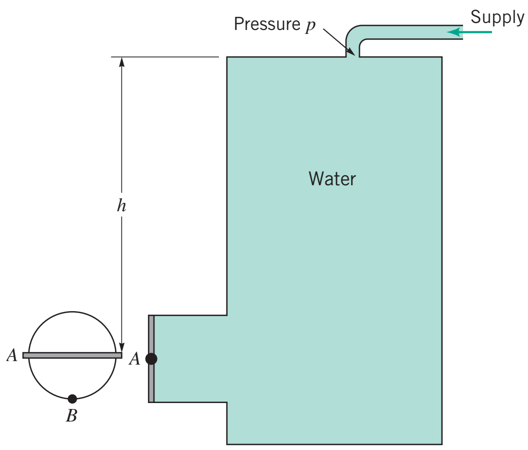
2.55 An open tank has a vertical partition and on one side contains gasoline with a density $\rho = 700$ kg/m^3 at a depth of 4 m, as shown in Fig. P2.55. A rectangular gate that is 4 m high and 2 m wide and hinged at one end is located in the partition. Water is



■ FIGURE P2.55

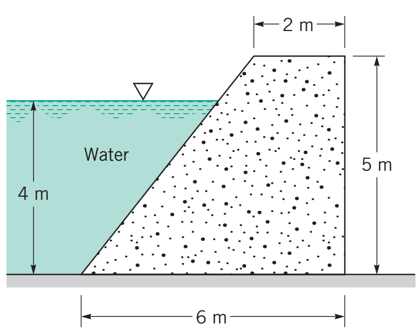
slowly added to the empty side of the tank. At what depth, h, will the gate start to open?

2.57 A pump supplies water under pressure to a large tank as shown in Fig. P2.57. The circular-plate valve fitted in the short discharge pipe on the tank pivots about its diameter A–A and is held shut against the water pressure by a latch at B. Show that the force on the latch is independent of the supply pressure, p, and the height of the tank, h.



■ **FIGURE P2.57**

2.59 The concrete dam of Fig. P2.59 weighs 23.6 kN/m^3 and rests on a solid foundation. Determine the minimum coefficient of friction between the dam and the foundation required to keep the dam from sliding at the water depth shown. Assume no fluid uplift pressure along the base. Base your analysis on a unit length of the dam.

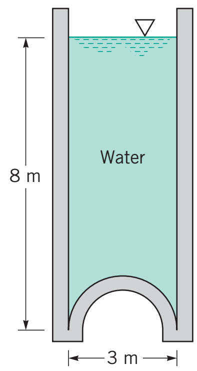


■ **FIGURE P2.59**

Section 2.10 Hydrostatic Force on a Curved Surface

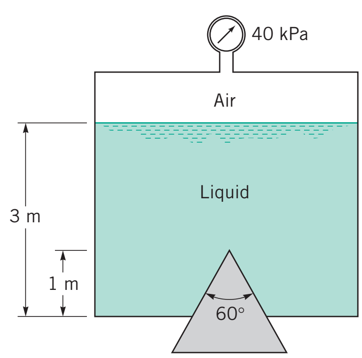
2.61 Obtain a photograph/image of a situation in which the hydrostatic force on a curved surface is important. Print this photo and write a brief paragraph that describes the situation involved.

2.63 A 3-m-diameter open cylindrical tank contains water and has a hemispherical bottom as shown in Fig. P2.63. Determine the magnitude, line of action, and direction of the force of the water on the curved bottom.



■ **FIGURE P2.63**

2.65 A plug in the bottom of a pressurized tank is conical in shape, as shown in Fig. P2.65. The air pressure is 40 kPa and the liquid in the tank has a specific weight of 27 kN/m^3. Determine the magnitude, direction and line of action of the force exerted on the curved surface of the cone within the tank due to the 40-kPa pressure and the liquid.



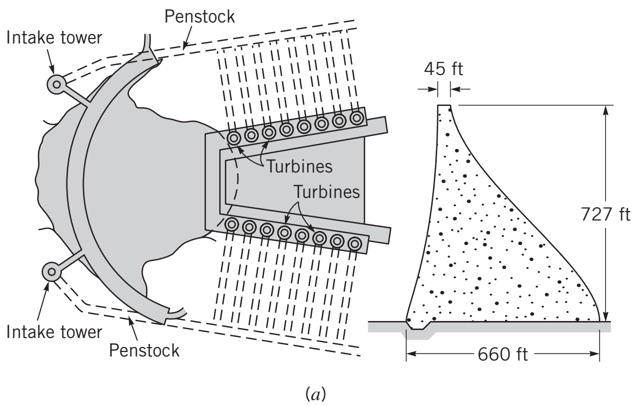
■ **FIGURE P2.65**

2.67 Hoover Dam (see **Video 2.4**) is the highest arch-gravity type of dam in the United States. A plan view and cross section of the dam are shown in Fig. P2.67*a*. The walls of the canyon in which the dam is located are sloped, and just upstream of the dam the vertical plane shown in Fig. P2.67*b* approximately represents the cross section of the water acting on the dam. Use this vertical cross section to estimate the resultant horizontal force of the water on the dam, and show where this force acts.

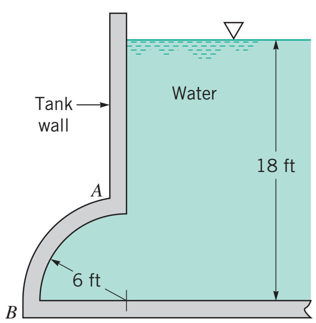
2.69 A tank wall has the shape shown in Fig. P2.69. Determine the horizontal and vertical components of the force of the water on a 1-ft width (normal to the figure) of the curved section AB.

Section 2.11 Buoyancy, Flotation, and Stability

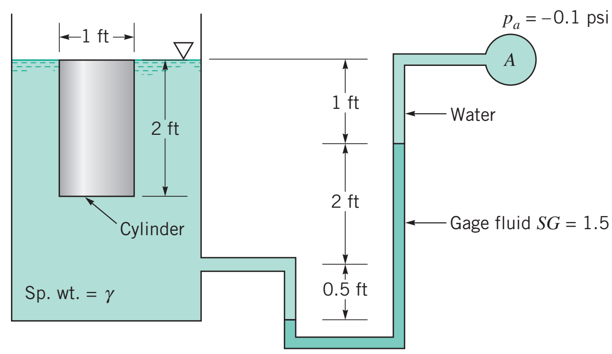
2.71 Obtain a photograph/image of a situation in which Archimedes' principle is important. Print this photo and write a brief paragraph that describes the situation involved.



■ FIGURE P2.67

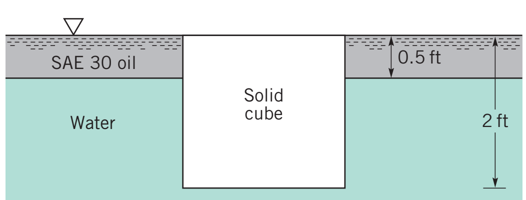


■ FIGURE P2.69



■ FIGURE P2.79

2.73 A solid cube floats in water with a 0.5-ft-thick oil layer on top as shown in Fig. P2.73. Determine the weight of the cube.



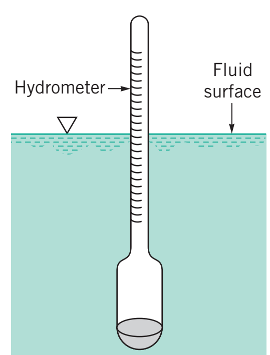
■ FIGURE P2.73

2.75 (See Fluids in the News article titled "Concrete canoes," Section 2.11.1.) How much extra water does a 175-lb concrete canoe displace compared to an ultra-lightweight 38-lb Kevlar canoe of the same size carrying the same load?

†**2.77** Estimate the minimum water depth needed to float a canoe carrying two people and their camping gear. List all assumptions and show all calculations.

2.79 A 1-ft-diameter, 2-ft-long cylinder floats in an open tank containing a liquid having a specific weight γ. A U-tube manometer is connected to the tank as shown in Fig. P2.79. When the pressure in pipe A is 0.1 psi below atmospheric pressure, the various fluid levels are as shown. Determine the weight of the cylinder. Note that the top of the cylinder is flush with the fluid surface.

2.81 The hydrometer shown in **Video V2.8** and Fig. P2.81 has a mass of 0.045 kg, and the cross-sectional area of its stem is 290 mm^2. Determine the distance between graduations (on the stem) for specific gravities of 1.00 and 0.90.



■ FIGURE P2.81

Section 2.12 Pressure Variation in a Fluid with Rigid-Body Motion

2.83 A closed cylindrical tank that is 8 ft in diameter and 24 ft long is completely filled with gasoline. The tank, with its long axis horizontal, is pulled by a truck along a horizontal surface. Determine the pressure difference between the ends (along the long axis of the tank) when the truck undergoes an acceleration of 5 ft/s^2.

■ Lab Problems

2.85 This problem involves the force needed to open a gate that covers an opening in the side of a water-filled tank. To proceed with this problem go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

2.87 This problem involves determining the weight needed to hold down an open-bottom box that has slanted sides when the box is filled with water. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

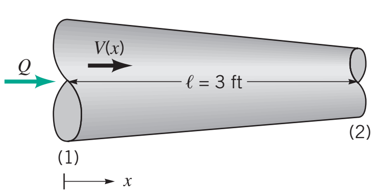
2.89 Although it is relatively easy to calculate the net hydrostatic pressure force on a dam, it is not necessarily easy to design and construct an appropriate, long-lasting, inexpensive dam. In fact, inspection of older dams has revealed that many of them are in peril of collapse unless corrective action is soon taken. Obtain information about the severity of the poor conditions of older dams throughout the country. Summarize your findings in a brief report.

2.91 Liquid-filled manometers and Bourdon tube pressure gages have been the mainstay for measuring pressure for many years. However, for many modern applications, these tried-and-true devices are not sufficient. For example, various new uses need small, accurate, inexpensive pressure transducers with digital outputs. Obtain information about some of the new concepts used for pressure measurement. Summarize your findings in a brief report.

Chapter 3

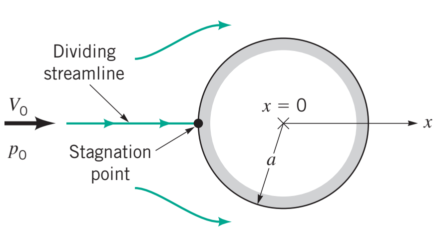
Section 3.2 F = *m*a Along a Streamline

3.1 Water flows steadily through the variable area horizontal pipe shown in Fig. P3.1. The centerline velocity is given by $\mathbf{V} = 10(1+x)\hat{\mathbf{i}}$ ft/s, where x is in feet. Viscous effects are neglected. **(a)** Determine the pressure gradient, $\partial p/\partial x$ (as a function of x), needed to produce this flow. **(b)** If the pressure at section (1) is 50 psi, determine the pressure at (2) by (i) integration of the pressure gradient obtained in **(a)** and (ii) application of the Bernoulli equation.



■ FIGURE P3.1

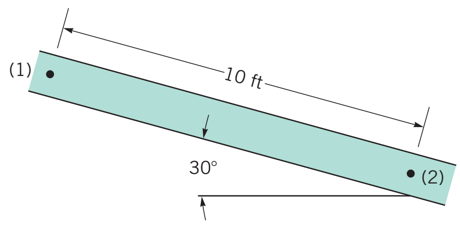
3.3 An incompressible fluid flows steadily past a circular cylinder as shown in Fig. P3.3 (see **Video V3.7** also). The fluid velocity along the dividing streamline ($-\infty \leq x \leq -a$) is found to be $V = V_0(1 - a^2/x^2)$, where a is the radius of the cylinder and V_0 is the upstream velocity. **(a)** Determine the pressure gradient along this streamline. **(b)** If the upstream pressure is p_0, integrate the pressure gradient to obtain the pressure $p(x)$ for $-\infty \leq x \leq -a$. **(c)** Show from the result of part **(b)** that the pressure at the stagnation point ($x = -a$) is $p_0 + \rho V_0^2/2$, as expected from the Bernoulli equation.



■ FIGURE P3.3

3.5 What pressure gradient along the streamline, dp/ds, is required to accelerate water upward in a vertical pipe at a rate of 30 ft/s^2? What is the answer if the flow is downward?

3.7 A fluid with a specific weight of 100 lb/ft^3 and negligible viscous effects flows in the pipe shown in Fig. P3.7. The pressures at points (1) and (2) are 400 lb/ft^2 and 900 lb/ft^2, respectively. The velocities at points (1) and (2) are equal. Is the fluid accelerating uphill, downhill, or not accelerating? Explain.

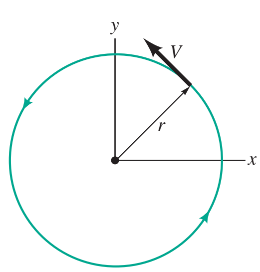


■ FIGURE P3.7

Section 3.3 F = *m*a Normal to a Streamline

3.9 Obtain a photograph/image of a situation in which Newton's second law applied across the streamlines (as given by Eq. 3.10) is important. Print this photo and write a brief paragrph that describes the situation involved.

3.11 Water in a container and air in a tornado flow in horizontal circular streamlines of radius r and speed V as shown in **Video V3.6** and Fig. P3.6. Determine the radial pressure gradient, $\partial p/\partial r$, needed for the following situations: **(a)** The fluid is water with $r = 3$ in. and $V = 0.8$ ft/s and **(b)** the fluid is air with $r = 300$ ft and $V = 200$ mph.



■ FIGURE P3.11

†3.13 Air flows smoothly past your face as you ride your bike, but bugs and particles or dust pelt your face and get into your eyes. Explain why this is so.

Section 3.5 Static, Stagnation, Dynamic, and Total Pressure

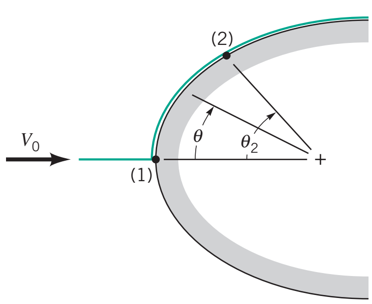
3.15 At a given point on a horizontal streamline in flowing air, the static pressure is -2.0 psi (i.e., a vacuum) and the velocity is 150 ft/s. Determine the pressure at a stagnation point on that streamline.

3.17 (See Fluids in the News article titled "Pressurized eyes," Section 3.5.) Determine the air velocity needed to produce a stagnation pressure equal to 10 mm of mercury.

3.19 Carbon tetrachloride flows in a pipe of variable diameter with negligible viscous effects. At point *A* in the pipe the pressure and velocity are 20 psi and 30 ft/s, respectively. At location *B* the pressure and velocity are 23 psi and 14 ft/s. Which point is at the higher elevation and by how much?

3.21 A loon is a diving bird equally at home "flying" in the air or water. What swimming velocity under water will produce a dynamic pressure equal to that when it flies in the air at 40 mph?

3.23 An inviscid fluid flows steadily along the stagnation streamline shown in Fig. P3.23 and **Video V3.7,** starting with speed V_0 far upstream of the object. Upon leaving the stagnation point, point (1), the fluid speed along the surface of the object is assumed to be given by $V = 2V_0 \sin\theta$, where θ is the angle indicated. At what angular position, θ_2, should a hole be drilled to give a pressure difference of $p_1 - p_2 = \rho V_0^2/2$? Gravity is negligible.

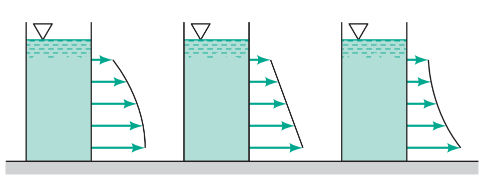


■ **FIGURE P3.23**

Section 3.6.1 Free Jets

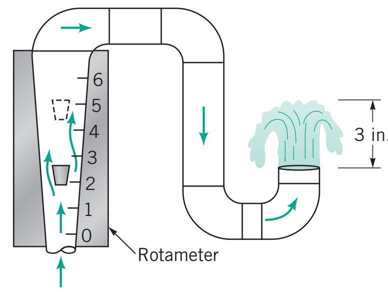
3.25 Obtain a photograph/image of a situation in which the concept of a free jet is important. Print this photo and write a brief paragraph that describes the situation involved.

3.27 Several holes are punched into a tin can as shown in Fig. P3.27. (See **Video V3.9**). Which of the figures represents the variation of the water velocity as it leaves the holes? Justify your choice.



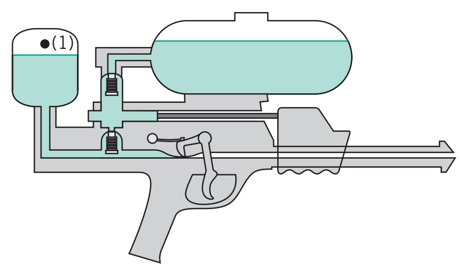
■ **FIGURE P3.27**

3.29 A rotameter is a volumetric flowmeter that consists of a tapered glass tube that contains a float as indicated in Fig. P3.29 and **Video V8.13.** The scale reading on the rotameter shown is directly proportional to the volumetric flowrate. With a scale reading of 2.6 the water bubbles up approximately 3 in. How far will it bubble up if the scale reading is 5.0?



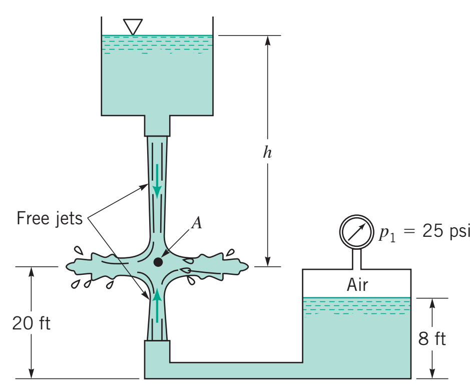
■ **FIGURE P3.29**

†3.31 The "supersoaker" water gun shown in Fig. P3.31 can shoot more than 30 ft in the horizontal direction. Estimate the minimum pressure, p_1, needed in the chamber in order to accomplish this. List all assumptions and show all calculations.



■ **FIGURE P3.31**

3.33 Streams of water from two tanks impinge upon each other as shown in Fig. P3.33. If viscous effects are negligible and point *A* is a stagnation point, determine the height *h*.

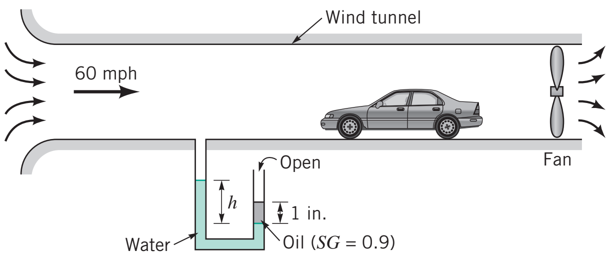


■ **FIGURE P3.33**

Section 3.6.2 Confined Flows (also see Lab Problems 3.84 and 3.86)

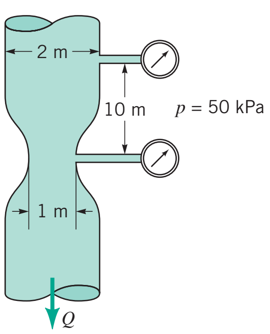
3.35 A fire hose nozzle has a diameter of $1\frac{1}{8}$ in. According to some fire codes, the nozzle must be capable of delivering at least 300 gal/min. If the nozzle is attached to a 3-in.-diameter hose, what pressure must be maintained just upstream of the nozzle to deliver this flowrate?

3.37 Air is drawn into a wind tunnel used for testing automobiles as shown in Fig. P3.37. **(a)** Determine the manometer reading, h, when the velocity in the test section is 60 mph. Note that there is a 1-in. column of oil on the water in the manometer. **(b)** Determine the difference between the stagnation pressure on the front of the automobile and the pressure in the test section.



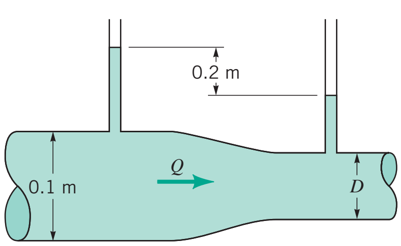
■ FIGURE P3.37

3.39 Water (assumed inviscid and incompressible) flows steadily in the vertical variable-area pipe shown in Fig. P3.39. Determine the flowrate if the pressure in each of the gages reads 50 kPa.



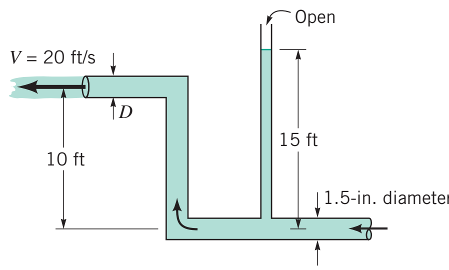
■ FIGURE P3.39

3.41 Water flows through the pipe contraction shown in Fig. P3.41. For the given 0.2-m difference in the manometer level, determine the flowrate as a function of the diameter of the small pipe, D.



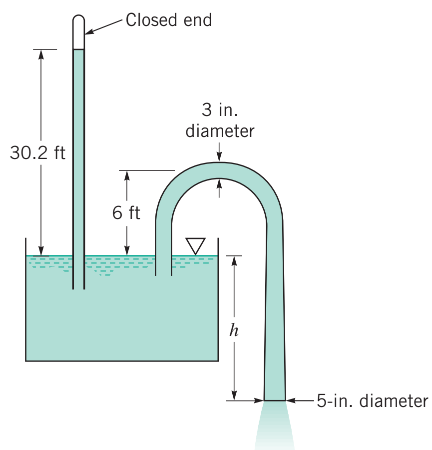
■ FIGURE P3.41

3.43 Water flows steadily with negligible viscous effects through the pipe shown in Fig. P3.43. Determine the diameter, D, of the pipe at the outlet (a free jet) if the velocity there is 20 ft/s.



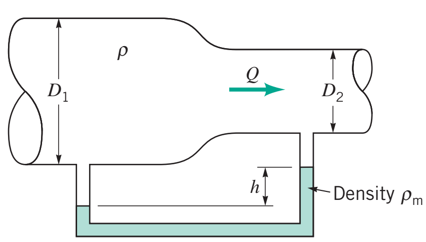
■ FIGURE P3.43

3.45 Water is siphoned from the tank shown in Fig. P3.45. The water barometer indicates a reading of 30.2 ft. Determine the maximum value of h allowed without cavitation occurring. Note that the pressure of the vapor in the closed end of the barometer equals the vapor pressure.



■ FIGURE P3.45

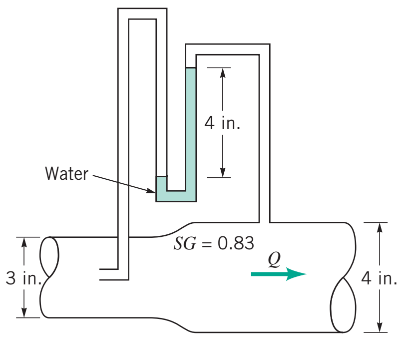
3.47 An inviscid fluid flows steadily through the contraction shown in Fig. P3.47. Derive an expression for the fluid velocity at (2) in terms of D_1, D_2, ρ, ρ_m, and h if the flow is assumed incompressible.



■ FIGURE P3.47

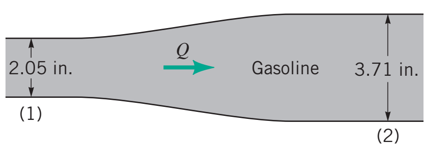
3.49 Carbon dioxide flows at a rate of 1.5 ft^3/s from a 3-in. pipe in which the pressure and temperature are 20 psi (gage) and 120 °F, respectively, into a 1.5-in. pipe. If viscous effects are neglected and incompressible conditions are assumed, determine the pressure in the smaller pipe.

3.51 Oil of specific gravity 0.83 flows in the pipe shown in Fig. P3.51. If viscous effects are neglected, what is the flowrate?



■ **FIGURE P3.51**

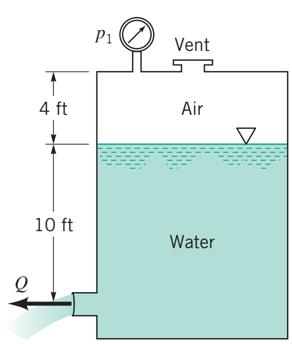
3.53 For the pipe enlargement shown in Fig. P3.53, the pressures at sections (1) and (2) are 56.3 and 58.2 psi, respectively. Determine the weight flowrate (lb/s) of the gasoline in the pipe. Assume steady, inviscid, incompressible flow.



■ **FIGURE P3.53**

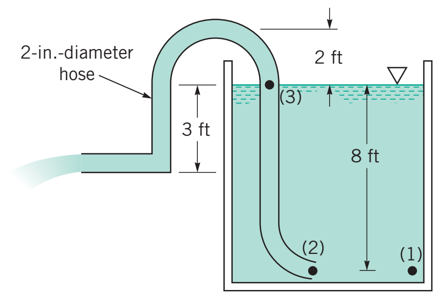
3.55 Water is pumped from a lake through an 8-in. pipe at a rate of 10 ft^3/s. If viscous effects are negligible, what is the pressure in the suction pipe (the pipe between the lake and the pump) at an elevation 6 ft above the lake?

3.57 The vent on the tank shown in Fig. P3.57 is closed and the tank pressurized to increase the flowrate. What pressure, p_1, is needed to produce twice the flowrate of that when the vent is open?



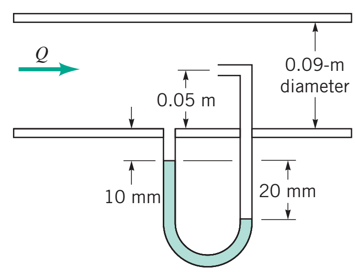
■ **FIGURE P3.57**

3.59 Water is siphoned from the tank shown in Fig. P3.59. Determine the flowrate from the tank and the pressure at points (1), (2), and (3) if viscous effects are negligible.



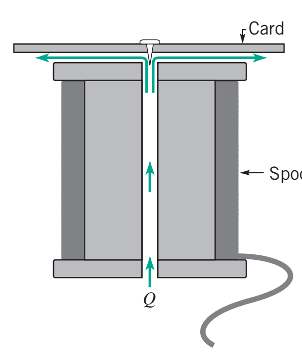
■ **FIGURE P3.59**

3.61 The specific gravity of the manometer fluid shown in Fig. P3.61 is 1.07. Determine the volume flowrate, Q, if the flow is inviscid and incompressible and the flowing fluid is **(a)** water, **(b)** gasoline, or **(c)** air at standard conditions.



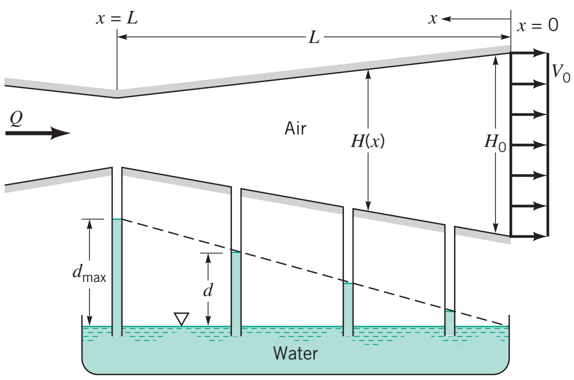
■ **FIGURE P3.61**

3.63 A small card is placed on top of a spool as shown in Fig. P3.63. It is not possible to blow the card off the spool by blowing air through the hole in the center of the spool. The harder one blows, the harder the card "sticks" to the spool. In fact, by blowing hard enough it is possible to keep the card against the spool with the spool turned upside down. (*Note:* It may be necessary to use a thumb tack to prevent the card from sliding from the spool.) Explain this phenomenon.



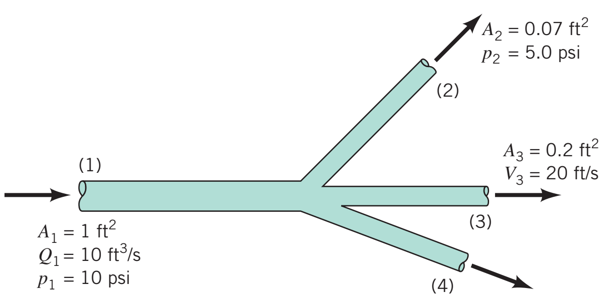
■ **FIGURE P3.63**

3.65 Air flows steadily through a converging–diverging rectangular channel of constant width as shown in Fig. P3.65 and **Video V3.10.** The height of the channel at the exit and the exit velocity are H_0 and V_0, respectively. The channel is to be shaped so that the distance, d, that water is drawn up into tubes attached to static pressure taps along the channel wall is linear with distance along the channel. That is, $d = (d_{max}/L)x$, where L is the channel length and d_{max} is the maximum water depth (at the minimum channel height; $x = L$). Determine the height, $H(x)$, as a function of x and the other important parameters.



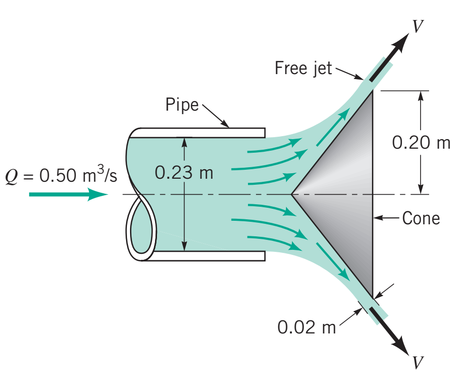
■ **FIGURE P3.65**

3.67 Water flows through the hrizontal branching pipe shown in Fig. P3.67. at a rate of 10ft^3/s. If viscous effects are negligible, determine the water speed at section (2), the pressure at section (3), and the flowrate at section (4).



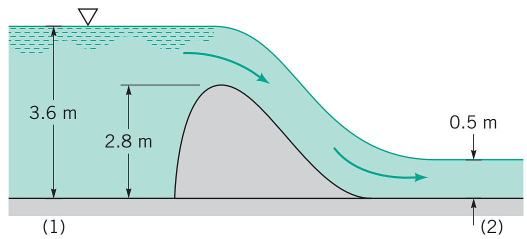
■ **FIGURE P3.67**

3.69 A conical plug is used to regulate the airflow from the pipe shown in Fig. P3.69. The air leaves the edge of the cone with a uniform thickness of 0.02 m. If viscous effects are negligible and the flowrate is 0.50 m^3/s, determine the pressure within the pipe.



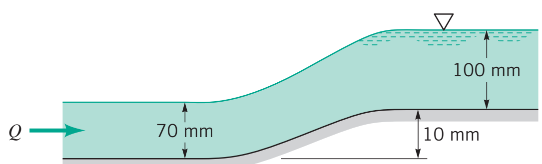
■ **FIGURE P3.69**

3.71 Water flows over the spillway shown in Fig. P3.71. If the velocity is uniform at sections (1) and (2) and viscous effects are negligible, determine the flowrate per unit width of the spillway.



■ **FIGURE P3.71**

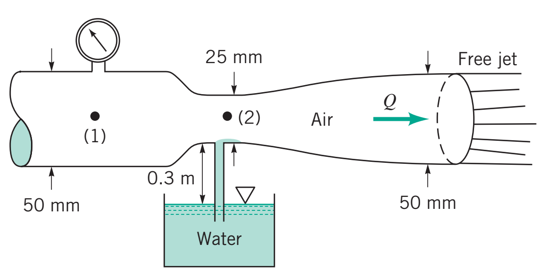
3.73 Water flows in a rectangular channel that is 0.5 m wide as shown in Fig. P3.73. The upstream depth is 70 mm. The water surface rises 40 mm as it passes over a portion where the channel bottom rises 10 mm. If viscous effects are negligible, what is the flowrate?



■ **FIGURE P3.73**

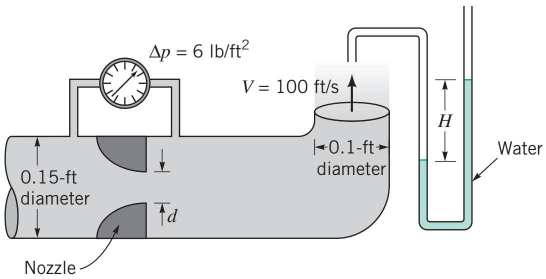
Section 3.6.3 Flowrate Measurement (also see Lab Problems 3.85 and 3.87)

3.75 Air flows through the device shown in Fig. P3.75 and **Video V3.10.** If the flowrate is large enough, the pressure within the constriction will be low enough to draw the water up into the tube. Determine the flowrate, Q, and the pressure needed at section (1) to draw the water into section (2). Neglect compressibility and viscous effects.



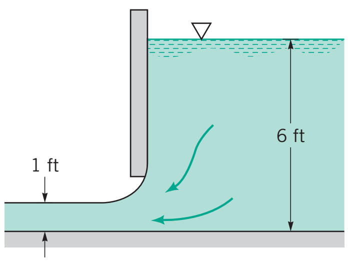
■ **FIGURE P3.75**

3.77 Air (assumed frictionless and incompressible) flows steadily through the device shown in Fig. P3.77. The exit velocity is 100 ft/s, and the differential pressure across the nozzle is 6 lb/ft^2. **(a)** Determine the reading, H, for the water-filled manometer attached to the Pitot tube. **(b)** Determine the diameter, d, of the nozzle.



■ **FIGURE P3.77**

3.79 Water flows under the sluice gate shown in Fig. P3.79. Determine the flowrate if the gate is 8 ft wide.



■ **FIGURE P3.79**

Section 3.7 The Energy Line and the Hydraulic Grade Line

3.81 Draw the energy line and the hydraulic grade line for the flow of Problem 3.56.

3.83 Draw the energy line and hydraulic grade line for the flow shown in Problem 3.60.

Lab Problems

3.85 This problem involves calibration of a nozzle-type flowmeter. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

3.87 This problem involves determination of the flowrate under a sluice gate as a function of the water depth. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

Lifelong Learning Problems

3.89 In recent years damage due to hurricanes has been significant, particularly in the southeastern United States. The low barometric pressure, high winds, and high tides generated by hurricanes can combine to cause considerable damage. According to some experts, in the coming years hurricane frequency may increase because of global warming. Obtain information about the fluid mechanics of hurricanes. Summarize your findings in a brief report.

3.91 Ultra-high-pressure, thin jets of liquids can be used to cut various materials ranging from leather to steel and beyond. Obtain information about new methods and techniques proposed for liquid jet cutting and investigate how they may alter various manufacturing processes. Summarize your findings in a brief report.

Chapter 4

Section 4.1 The Velocity Field

4.1 Obtain a photograph/image that shows a flowing fluid. Print this photo and write a brief paragraph that describes the flow in terms of an Eulerian description and a Lagrangian description.

4.3 The velocity field of a flow is given by $\mathbf{V} = 10y/(x^2 + y^2)^{1/2}\hat{\mathbf{i}} - 10x/(x^2 + y^2)^{1/2}\hat{\mathbf{j}}$ ft/s, where x and y are in feet. Determine the fluid speed at points along the x axis and along the y axis. What is the angle between the velocity vector and the x axis at points $(x, y) = (5, 0)$, $(5, 5)$ and $(0, 5)$?

4.5 The x and y components of velocity for a two-dimensional flow are $u = 6y$ ft/s and $v = 4$ ft/s, where y is in feet. Determine the equation for the streamlines and sketch representative streamlines in the upper half plane.

4.7 (See Fluids in the News article titled "Winds on Earth and Mars," Section 4.1.4.) A 20-ft-diameter dust devil that rotates one revolution per second travels across the Martian surface (in the x direction) with a speed of 5 ft/s. Plot the pathline etched on the surface by a fluid particle 10 ft from the center of the dust devil for time $0 \leq t \leq 3$ s. The particle position is given by the sum of that for a stationary swirl $[x = 10\cos(2\pi t), y = 10 \sin(2\pi t)]$ and that for a uniform velocity ($x = 5t$, $y =$ constant), where x and y are in feet and t is in seconds.

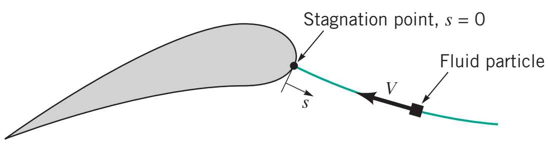
***4.9** Repeat Problem 4.8 using the same information except that $u = u_0 y/h$ for $0 \leq y \leq h$ rather than $u = u_0$. Use values of $u_0/v_0 = 0, 0.1, 0.2, 0.4, 0.6, 0.8$, and 1.0.

Section 4.2 The Acceleration Field

4.11 A three-dimensional velocity field is given by $u = x^2$, $v = -2xy$, and $w = x + y$. Determine the acceleration vector.

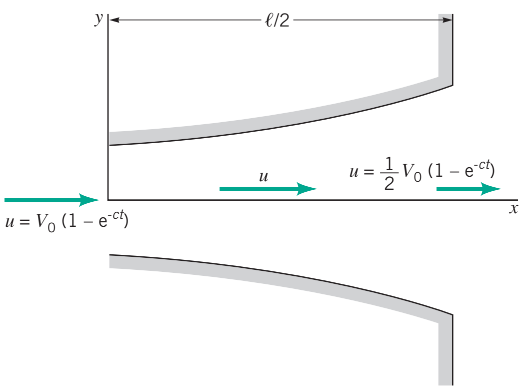
†4.13 Estimate the deceleration of a water particle in a raindrop as it strikes the sidewalk. List all assumptions and show all calculations.

4.15 A fluid particle flowing along a stagnation streamline, as shown in **Video V4.9** and Fig. P4.15, slows down as it approaches the stagnation point. Measurements of the dye flow in the video indicate that the location of a particle starting on the stagnation streamline a distance $s = 0.6$ ft upstream of the stagnation point at $t = 0$ is given approximately by $s = 0.6\, e^{-0.5t}$, where t is in seconds and s is in ft. **(a)** Determine the speed of a fluid particle as a function of time, $V_{\text{particle}}(t)$, as it flows along the streamline. **(b)** Determine the speed of the fluid as a function of position along the streamline, $V = V(s)$. **(c)** Determine the fluid acceleration along the streamline as a function of position, $a_s = a_s(s)$.



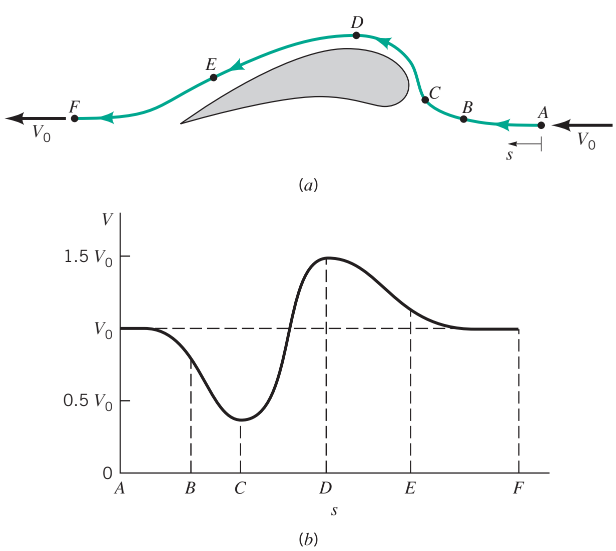
■ FIGURE P4.15

4.17 As a valve is opened, water flows through the diffuser shown in Fig. P4.17 at an increasing flowrate so that the velocity along the centerline is given by $\mathbf{V} = u\hat{\mathbf{i}} = V_0(1 - e^{-ct})(1 - x/\ell)\hat{\mathbf{i}}$, where u_0, c, and ℓ are constants. Determine the acceleration as a function of x and t. If $V_0 = 10$ ft/s and $\ell = 5$ ft, what value of c (other than $c = 0$) is needed to make the acceleration zero for any x at $t = 2$ s? Explain how the acceleration can be zero if the flowrate is increasing with time.



■ FIGURE P4.17

4.19 An incompressible fluid flows past a turbine blade as shown in Fig. P4.19*a* and **Video V4.9.** Far upstream and downstream of the blade the velocity is V_0. Measurements show that the velocity of the fluid along streamline A–F near the blade is as indicated in Fig. P4.19*b*. Sketch the streamwise component of acceleration, a_s, as a function of distance, s, along the streamline. Discuss the important characteristics of your result.



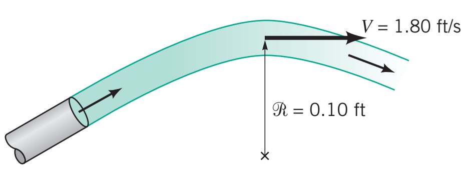
■ FIGURE P4.19

†**4.21** Estimate the average acceleration of water as it travels through the nozzle on your garden hose. List all assumptions and show all calculations.

4.23 A nozzle is designed to accelerate the fluid from V_1 to V_2 in a linear fashion. That is, $V = ax + b$, where a and b are constants. If the flow is constant with $V_1 = 10$ m/s at $x_1 = 0$ and $V_2 = 25$ m/s at $x_2 = 1$ m, determine local acceleration, convective acceleration, and acceleration of the fluid at points (1) and (2).

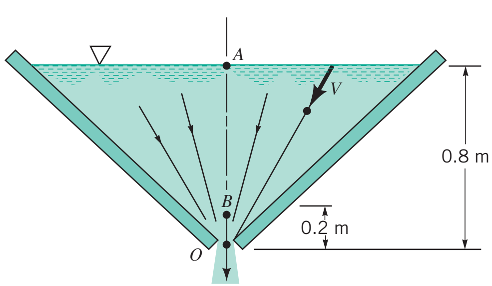
4.25 The temperature distribution in a fluid is given by $T = 10x + 5y$, where x and y are the horizontal and vertical coordinates in meters and T is in degrees centigrade. Determine the time rate of change of temperature of a fluid particle traveling **(a)** horizontally with $u = 20$ m/s, $v = 0$ or **(b)** vertically with $u = 0$, $v = 20$ m/s.

4.27 At the top of its trajectory, the stream of water shown in Fig. P4.27 and **Video V4.7** flows with a horizontal velocity of 1.80 ft/s. The radius of curvature of its streamline at that point is approximately 0.10 ft. Determine the normal component of acceleration at that location.



■ FIGURE P4.27

4.29 Water flows through the slit at the bottom of a two-dimensional water trough as shown in Fig. P4.29. Throughout most of the trough the flow is approximately radial (along rays from O) with a velocity of $V = c/r$, where r is the radial coordinate and c is a constant. If the velocity is 0.04 m/s when $r = 0.1$ m, determine the acceleration at points A and B.

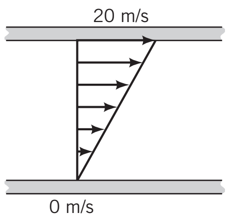


■ FIGURE P4.29

Sections 4.3 and 4.4 Control Volume and System Representations and the Reynolds Transport Theorem

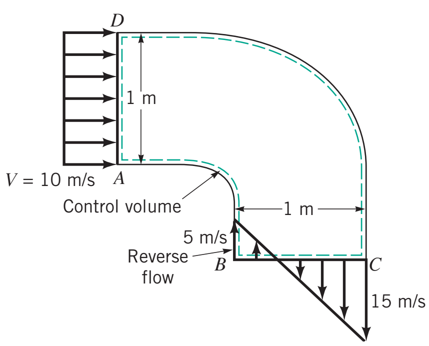
4.31 Obtain a photograph/image of a situation in which a fluid is flowing. Print this photo and draw a control volume through which the fluid flows. Write a brief paragraph that describes how the fluid flows into and out of this control volume.

4.33 Repeat Problem 4.32 if the velocity profile is linear from 0 to 20 m/s across the duct as shown in Fig. P4.33.



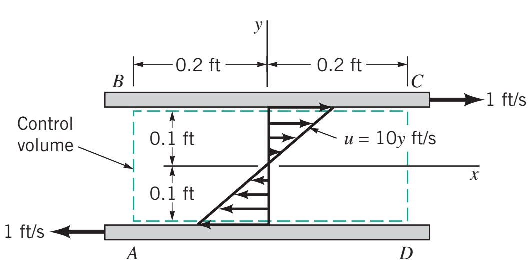
■ **FIGURE P4.33**

4.35 Air enters an elbow with a uniform speed of 10 m/s as shown in Fig. P4.35. At the exit of the elbow the velocity profile is not uniform. In fact, there is a region of separation or reverse flow. The fixed control volume *ABCD* coincides with the system at time $t = 0$. Make a sketch to indicate **(a)** the system at time $t = 0.01$ s and **(b)** the fluid that has entered and exited the control volume in that time period.



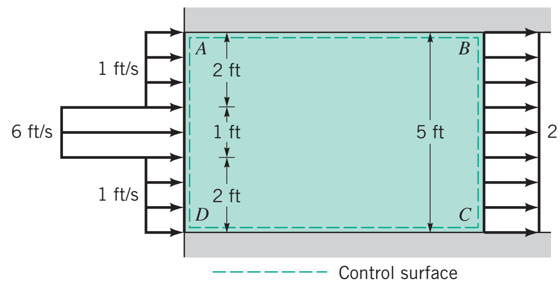
■ **FIGURE P4.35**

4.37 Two plates are pulled in opposite directions with speeds of 1.0 ft/s as shown in Fig. P4.37. The oil between the plates moves with a velocity given by $\mathbf{V} = 10y\hat{\mathbf{i}}$ ft/s, where y is in feet. The fixed control volume *ABCD* coincides with the system at time $t = 0$. Make a sketch to indicate **(a)** the system at time $t = 0.2$ s and **(b)** the fluid that has entered and exited the control volume in that time period.



■ **FIGURE P4.37**

4.39 Water enters a 5-ft-wide, 1-ft-deep channel as shown in Fig. P4.39. Across the inlet the water velocity is 6 ft/s in the center portion of the channel and 1 ft/s in the remainder of it. Farther downstream the water flows at a uniform 2-ft/s velocity across the entire channel. The fixed control volume *ABCD* coincides with the system at time $t = 0$. Make a sketch to indicate **(a)** the system at time $t = 0.5$ s and **(b)** the fluid that has entered and exited the control volume in that time period.



■ **FIGURE P4.39**

■ Lifelong Learning Problems

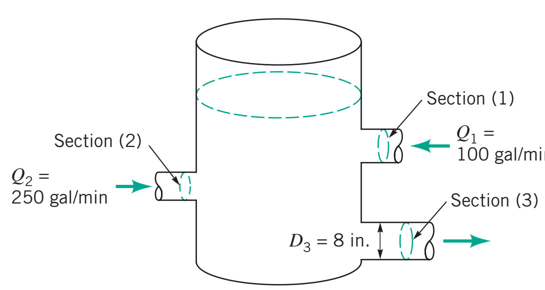
4.41 For centuries people have obtained qualitative and quantitative information about various flow fields by observing the motion of objects or particles in a flow. For example, the speed of the current in a river can be approximated by timing how long it takes a stick to travel a certain distance. The swirling motion of a tornado can be observed by following debris moving within the tornado funnel. Recently various high-tech methods using lasers and minute particles seeded within the flow have been developed to measure velocity fields. Such techniques include the laser doppler anemometer (LDA), the particle image velocimeter (PIV), and others. Obtain information about new laser-based techniques for measuring velocity fields. Summarize your findings in a brief report.

Chapter 5

Section 5.1 Conservation of Mass—Uniform Flow

5.1 Obtain a photograph/image of a situation for which the conservation of mass law is important. Briefly describe the situation and its relevance.

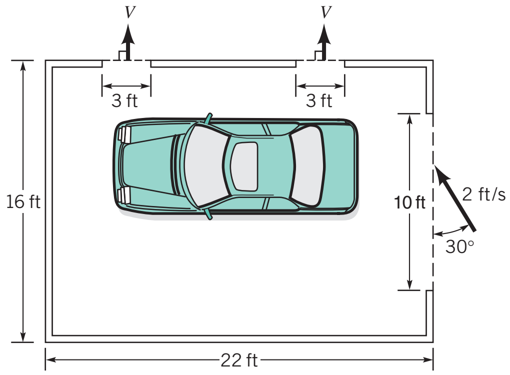
5.3 Water enters a cylindrical tank through two pipes at rates of 250 and 100 gal/min (see Fig. P5.3). If the level of the water in the tank remains constant, calculate the average velocity of the flow leaving the tank through an 8-in. inside-diameter pipe.



■ **FIGURE P5.3**

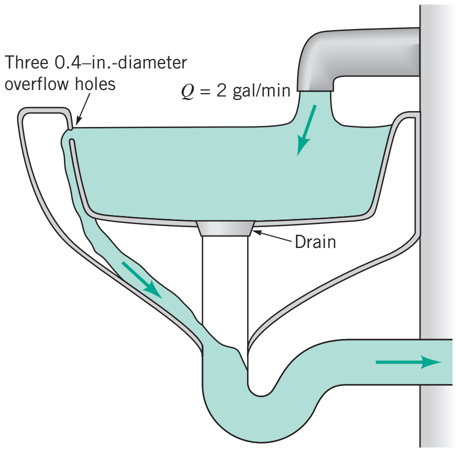
5.5 A hydroelectric turbine passes 2 million gal/min through its blades. If the average velocity of the flow in the circular cross-sectional conduit leading to the turbine is not to exceed 30 ft/s, determine the minimum allowable diameter of the conduit.

5.7 The wind blows through a 7 × 10-ft garage door with a speed of 2 ft/s as shown in Fig. P5.7. Determine the average speed, V, of the air through the two 3 × 4-ft windows.



■ **FIGURE P5.7**

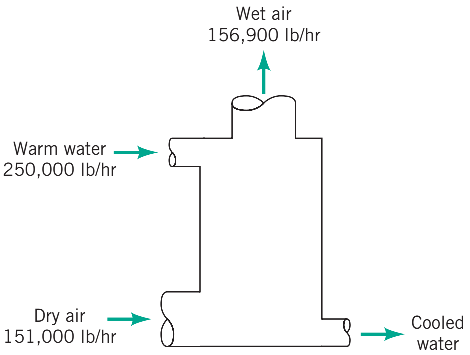
5.9 Water flows into a sink as shown in **Video V5.1** and Fig. P5.9 at a rate of 2 gallons per minute. Determine the average velocity through each of the three 0.4-in.-diameter overflow holes if the drain is closed and the water level in the sink remains constant.



■ **FIGURE P5.9**

5.11 An evaporative cooling tower (see Fig. P5.11) is used to cool water from 110 to 80 °F. Water enters the tower at a rate of 250,000 lb/hr. Dry air (no water vapor) flows into the tower at a rate of 151,000 lb/hr. If the rate of wet air flow out of the tower is 156,900 lb/hr, determine the rate of water evaporation in lb/hr and the rate of cooled water flow in lb/hr.

5.13 It takes you 1 min to fill your car's fuel tank with 8.8 gal of gasoline. What is the average velocity of the gasoline leaving the 0.60-in.-diameter nozzle at this pump?



■ **FIGURE P5.11**

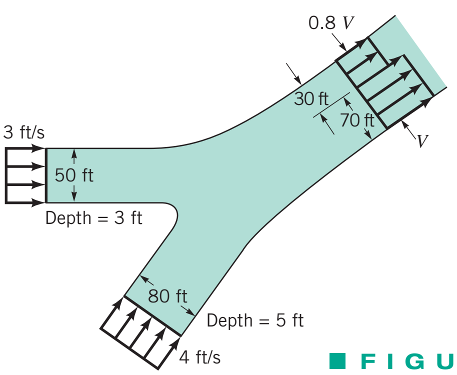
Section 5.1 Conservation of Mass—Nonuniform Flow

5.15 An appropriate turbulent pipe flow velocity profile is

$$\mathbf{V} = u_c\left(\frac{R - r}{R}\right)^{1/n}\hat{\mathbf{i}}$$

where u_c = centerline velocity, r = local radius, R = pipe radius, and $\hat{\mathbf{i}}$ = unit vector along pipe centerline. Determine the ratio of average velocity, $\bar{u}$, to centerline velocity, u_c, for **(a)** $n = 5$, **(b)** $n = 6$, **(c)** $n = 7$, **(d)** $n = 8$, **(e)** $n = 9$, **(f)** $n = 10$.

5.17 Two rivers merge to form a larger river as shown in Fig. P5.17. At a location downstream from the junction (before the two streams completely merge), the nonuniform velocity profile is as shown and the depth is 6 ft. Determine the value of V.



■ **FIGURE P5.17**

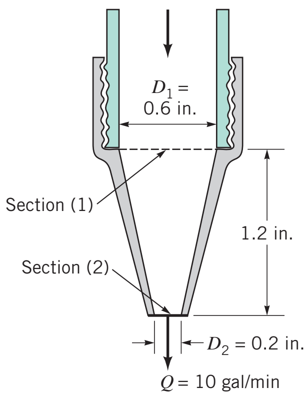
Section 5.1 Conservation of Mass—Unsteady Flow

5.19 The Hoover Dam (see **Video V2.4**) backs up the Colorado River and creates Lake Meade, which is approximately 115 miles long and has a surface area of approximately 225 square miles. If during flood conditions the Colorado River flows into the lake at a rate of 45,000 cfs and the outflow from the dam is 8000 cfs, how many feet per 24-hr day will the lake level rise?

Section 5.2.1 Linear Momentum—Uniform Flow (also see Lab Problems 5.98, 5.99, 5.100, and 5.101)

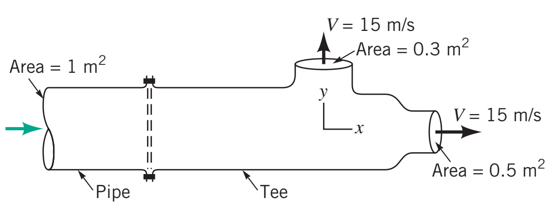
5.21 Obtain a photograph/image of a situation for which the linear momentum equation is important. Print this photo and write a brief paragraph that describes the situation involved.

5.23 Determine the anchoring force required to hold in place the conical nozzle attached to the end of the laboratory sink faucet shown in Fig. P5.23 when the water flowrate is 10 gal/min. The nozzle weight is 0.2 lb. The nozzle inlet and exit inside diameters are 0.6 and 0.2 in., respectively. The nozzle axis is vertical and the axial distance between sections (1) and (2) is 1.2 in. The pressure at section (1) is 68 psi.



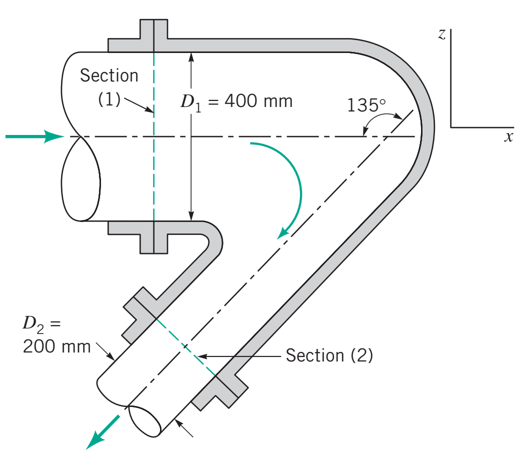
■ **FIGURE P5.23**

5.25 Water flows as two free jets from the tee attached to the pipe shown in Fig. P5.25. The exit speed is 15 m/s. If viscous effects and gravity are negligible, determine the x and y components of the force that the pipe exerts on the tee.



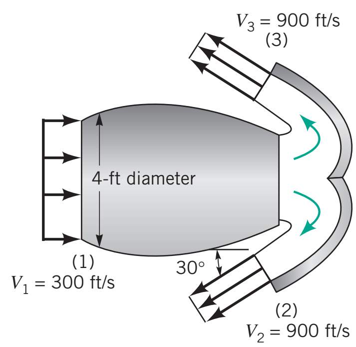
■ **FIGURE P5.25**

5.27 A converging elbow (see Fig. P5.27) turns water through an angle of 135° in a vertical plane. The flow cross-sectional diameter is 400 mm at the elbow inlet, section (1), and 200 mm at the elbow outlet, section (2). The elbow flow passage volume is 0.2 m^3 between sections (1) and (2). The water volume flowrate is 0.4 m^3/s, and the elbow inlet and outlet pressures are 150 and 90 kPa. The elbow mass is 12 kg. Calculate the horizontal (x direction) and vertical (z direction) anchoring forces required to hold the elbow in place.



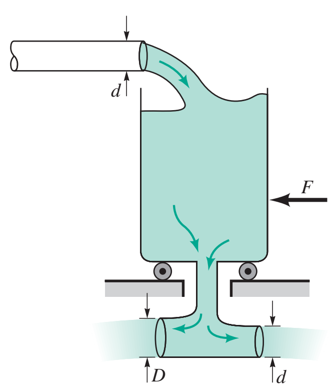
■ **FIGURE P5.27**

5.29 (See Fluids in the News article titled "Where the plume goes," Section 5.2.2.) Air flows into the jet engine shown in Fig. P5.29 at a rate of 9 slugs/s and a speed of 300 ft/s. Upon landing, the engine exhaust exits through the reverse thrust mechanism with a speed of 900 ft/s in the direction indicated. Determine the reverse thrust applied by the engine to the airplane. Assume that the inlet and exit pressures are atmospheric and that the mass flowrate of fuel is negligible compared to the air flowrate through the engine.



■ **FIGURE P5.29**

5.31 Water flows steadily into and out of a tank that sits on frictionless wheels as shown in Fig. P5.31. Determine the diameter D so that the tank remains motionless if $F = 0$.

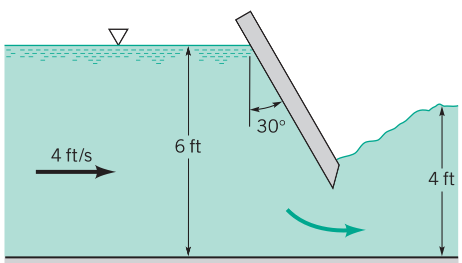


■ **FIGURE P5.31**

5.33 (See Fluids in the News article titled "Motorized surfboard," Section 5.2.2.) The thrust to propel the powered surfboard shown in Fig. P5.33 (or a jet ski; see **Video V 9.12**) is a result of water pumped through the board that exits as a high-speed, 2.75-in.-diameter jet. Determine the flowrate and the velocity of the exiting jet if the thrust is to be 300 lb. Neglect the momentum of the water entering the pump.

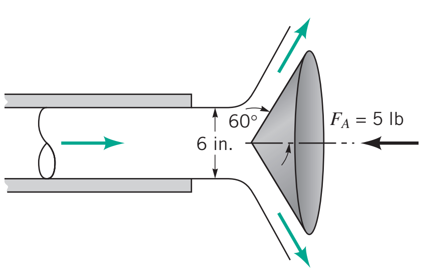
■ FIGURE P5.33

5.35 Determine the magnitude of the horizontal component of the anchoring force per unit width required to hold in place the sluice gate shown in Fig. P5.35. Compare this result with the size of the horizontal component of the anchoring force required to hold in place the sluice gate when it is closed and the depth of water upstream is 6 ft.



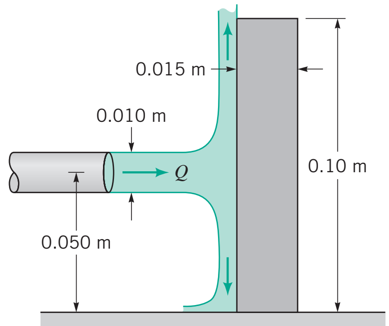
■ FIGURE P5.35

5.37 A horizontal, circular cross-sectional jet of air having a diameter of 6 in. strikes a conical deflector as shown in Fig. P5.37. A horizontal anchoring force of 5 lb is required to hold the cone in place. Estimate the nozzle flowrate in ft^3/s. The magnitude of the velocity of the air remains constant.



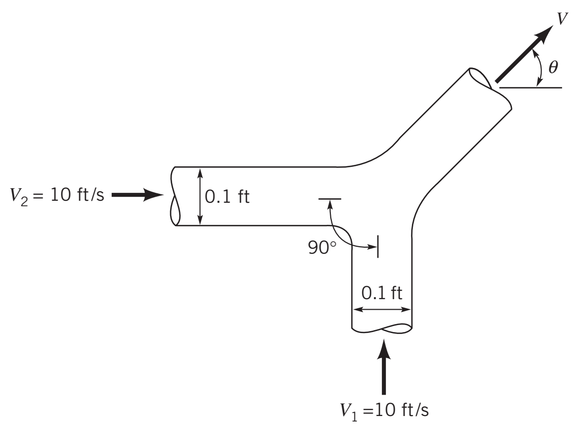
■ FIGURE P5.37

5.39 A 10-mm-diameter jet of water is deflected by a homogeneous rectangular block (15 × 200 × 100 mm) that weighs 6 N as shown in **Video V5.6** and Fig. P5.39. Determine the minimum volume flowrate needed to tip the block.



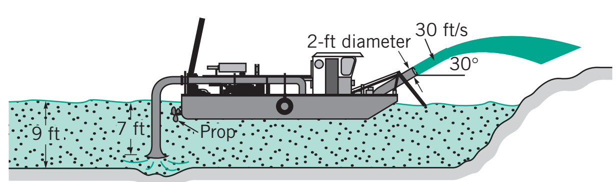
■ FIGURE P5.39

5.41 Two water jets of equal size and speed strike each other as shown in Fig. P5.41. Determine the speed, V, and direction, θ, of the resulting combined jet. Gravity is negligible.



■ FIGURE P5.41

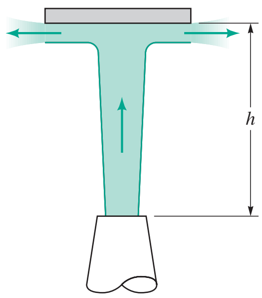
5.43 The hydraulic dredge shown in Fig. P5.43 is used to dredge sand from a river bottom. Estimate the thrust needed from the propeller to hold the boat stationary. Assume the specific gravity of the sand/water mixture is $SG = 1.2$.



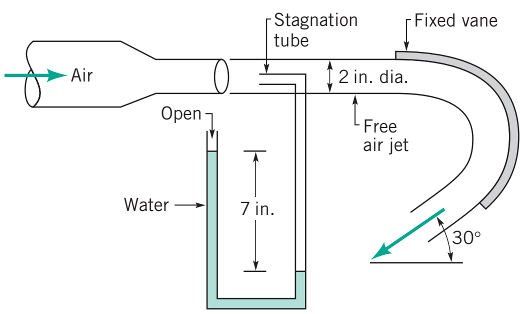
■ FIGURE P5.43

5.45 A vertical jet of water leaves a nozzle at a speed of 10 m/s and a diameter of 20 mm. It suspends a plate having a mass of 1.5 kg as indicated in Fig. P5.45. What is the vertical distance h?

5.47 Air discharges from a 2-in.-diameter nozzle and strikes a curved vane, which is in a vertical plane as shown in Fig. P5.47. A stagnation tube connected to a water U-tube manometer is located in the free air jet. Determine the horizontal component of the force that the air jet exerts on the vane. Neglect the weight of the air and all friction.



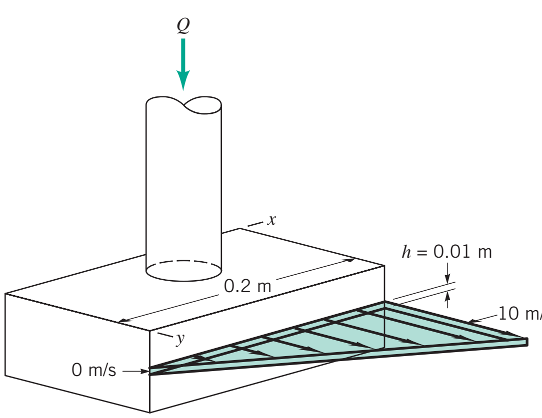
■ FIGURE P5.45



■ FIGURE P5.47

Section 5.2.1 Linear Momentum—Nonuniform Flow

5.49 A sheet of water of uniform thickness ($h = 0.01$ m) flows from the device shown in Fig. P5.49. The water enters vertically through the inlet pipe and exits horizontally with a speed that varies linearly from 0 to 10 m/s along the 0.2-m length of the slit. Determine the y component of the anchoring force necessary to hold this device stationary.

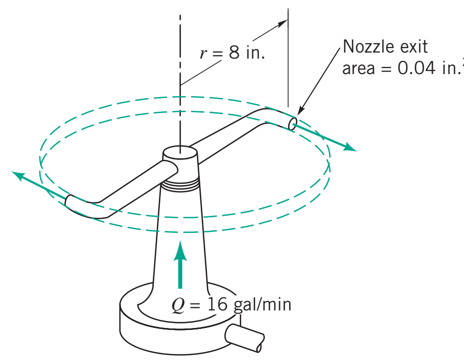


■ FIGURE P5.49

Section 5.2.4 Application of the Moment-of-Momentum Equation

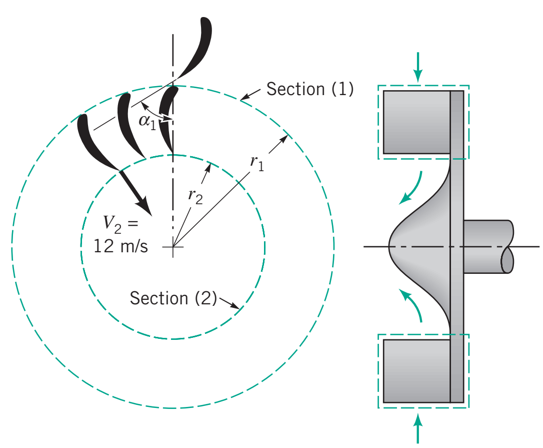
5.51 Obtain a photograph of a situation for which the moment-of-momentum equation is important. Print this photo and write a brief paragraph that describes the situation involved.

5.53 Water enters a rotating lawn sprinkler through its base at the steady rate of 16 gal/min as shown in Fig. P5.53. The exit cross-sectional area of each of the two nozzles is 0.04 in.^{2}, and the flow leaving each nozzle is tangential. The radius from the axis of rotation to the centerline of each nozzle is 8 in. **(a)** Determine the resisting torque required to hold the sprinkler head stationary. **(b)** Determine the resisting torque associated with the sprinkler rotating with a constant speed of 500 rev/min. **(c)** Determine the angular velocity of the sprinkler if no resisting torque is applied.



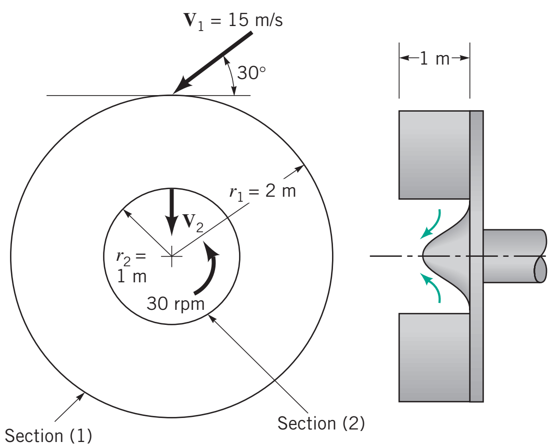
■ FIGURE P5.53

5.55 An inward flow radial turbine (see Fig. P5.55) involves a nozzle angle, α_1, of 60° and an inlet rotor tip speed, U_1, of 6 m/s. The ratio of rotor inlet to outlet diameters is 2.0. The absolute velocity leaving the rotor at section (2) is radial with a magnitude of 12 m/s. Determine the energy transfer per unit of mass of fluid flowing through this turbine if the fluid is **(a)** air or **(b)** water.



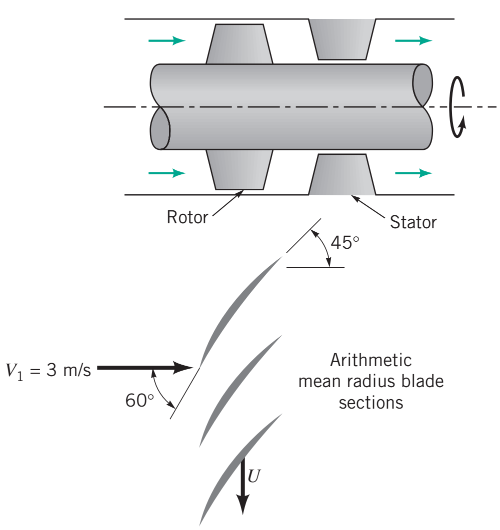
■ FIGURE P5.55

5.57 A water turbine with radial flow has the dimensions shown in Fig. P5.57. The absolute entering velocity is 15 m/s, and it makes an angle of 30° with the tangent to the rotor. The absolute exit velocity is directed radically inward. The angular speed of the rotor is 30 rpm. Find the power delivered to the shaft of the turbine.



■ FIGURE P5.57

5.59 An axial-flow gasoline pump (see Fig. P5.59) consists of a rotating row of blades (rotor) followed downstream by a stationary row of blades (stator). The gasoline enters the rotor axially (without any angular momentum) with an absolute velocity of 3 m/s. The rotor blade inlet and exit angles are 60° and 45° from axial directions. The pump annulus passage cross-sectional area is constant. Consider the flow as being tangent to the blades involved. Sketch velocity triangles for flow just upstream and downstream of the rotor and just downstream of the stator where the flow is axial. How much energy is added to each kilogram of gasoline?



■ FIGURE P5.59

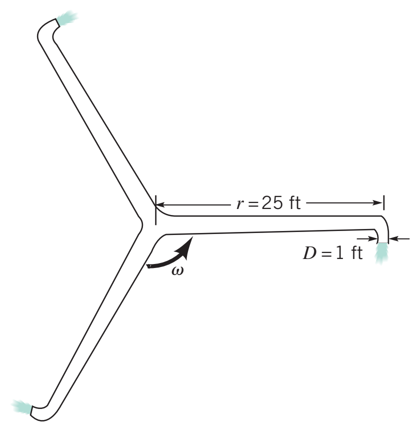
5.61 By using velocity triangles for flow upstream (1) and downstream (2) of a turbomachine rotor, prove that the shaft work in per unit mass flowing through the rotor is

$$w_{\substack{\text{shaft}\\ \text{net in}}} = \frac{V_2^2 - V_1^2 + U_2^2 - U_1^2 + W_1^2 - W_2^2}{2}$$

where V is absolute flow velocity magnitude, W is relative flow velocity magnitude, and U is blade speed.

5.63 Water enters an axial-flow turbine rotor with an absolute velocity tangential component, V_θ, of 15 ft/s. The corresponding blade velocity, U, is 50 ft/s. The water leaves the rotor blade row with no angular momentum. If the stagnation pressure drop across the turbine is 12 psi, determine the hydraulic efficiency of the turbine.

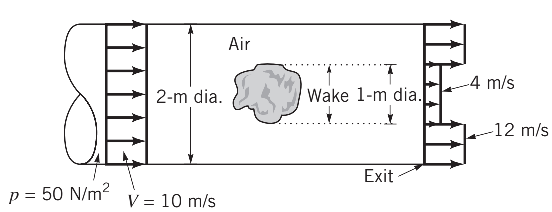
5.65 (See Fluids in the News article titled "Tailless helicopters," Section 5.2.4.) Exhaust gas from a tailless helicopter turbojet engine flows through the three 1-ft-diameter rotor blade nozzles shown in Fig. P5.65 at a rate of 500 ft^3/s. Determine the angular velocity of the rotor if the torque on the rotor is negligible.



■ FIGURE P5.65

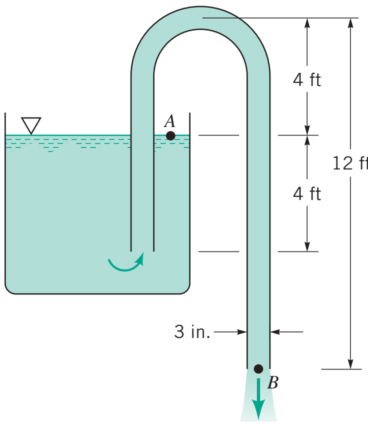
Section 5.3 First Law of Thermodynamics—The Energy Equation

5.67 Air flows past an object in a 2-m-diameter pipe and exits as a free jet as shown in Fig. P5.67. The velocity and pressure upstream are uniform at 10 m/s and 50 N/m^2, respectively. At the pipe exit the velocity is nonuniform as indicated. The shear stress along the pipe wall is negligible. **(a)** Determine the head loss associated with a particle as it flows from the uniform velocity upstream of the object to a location in the wake at the exit plane of the pipe. **(b)** Determine the force that the air puts on the object.



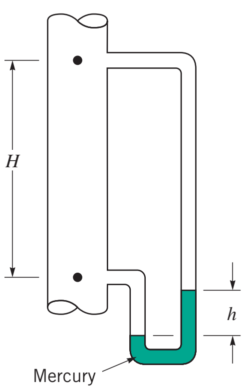
■ FIGURE P5.67

5.69 A water siphon having a constant inside diameter of 3 in. is arranged as shown in Fig. P5.69. If the friction loss between A and B is $0.6V^2/2$, where V is the velocity of flow in the siphon, determine the flowrate involved.



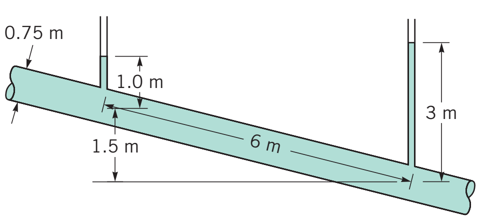
■ **FIGURE P5.69**

5.71 Water flows through a vertical pipe, as is indicated in Fig. P5.71. Is the flow up or down in the pipe? Explain.



■ **FIGURE P5.71**

5.73 An incompressible liquid flows steadily along the pipe shown in Fig. P5.73. Determine the direction of flow and the head loss over the 6-m length of pipe.



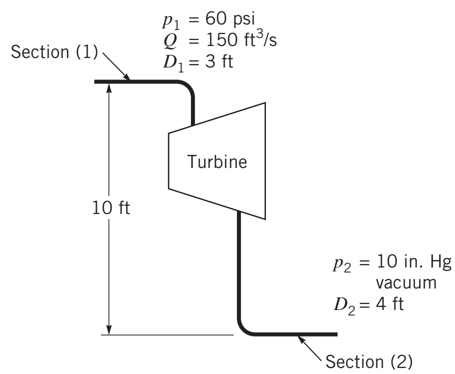
■ **FIGURE P5.73**

Section 5.3 The Energy Equation Involving a Pump or Turbine

5.75 Obtain a photograph/image of a flow involving a pump or turbine. Print this photo and write a brief paragraph that describes the situation involved.

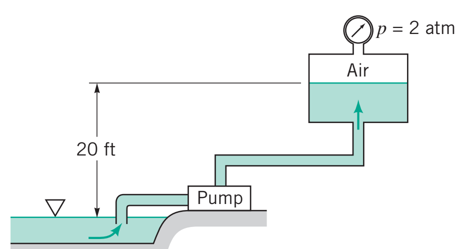
5.77 A hydroelectric turbine passes 4 million gal/min across a head of 100 ft of water. What is the maximum amount of power output possible? Why will the actual amount be less?

5.79 Water is supplied at 150 ft^3/s and 60 psi to a hydraulic turbine through a 3-ft inside-diameter inlet pipe as indicated in Fig. P5.79. The turbine discharge pipe has a 4-ft inside diameter. The static pressure at section (2), 10 ft below the turbine inlet, is 10 in. Hg vacuum. If the turbine develops 2500 hp, determine the rate of loss of available energy between sections (1) and (2).



■ **FIGURE P5.79**

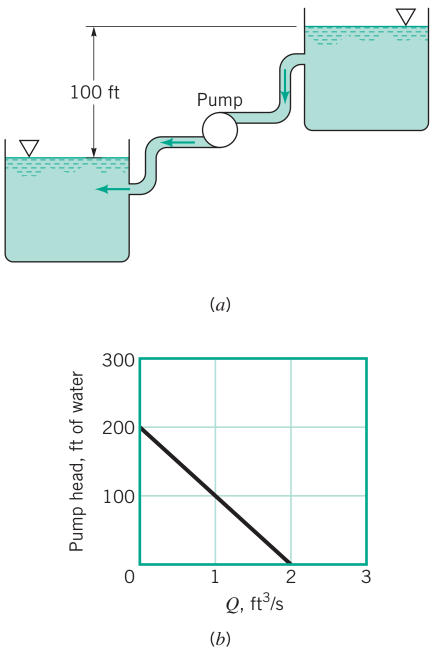
5.81 A pump is to move water from a lake into a large pressurized tank as shown in Fig. P5.81 at a rate of 1000 gal in 10 min or less. Will a pump that adds 3 hp to the water work for this purpose? Support your answer with appropriate calculations. Repeat the problem if the tank were pressurized to 3, rather than 2, atmospheres.



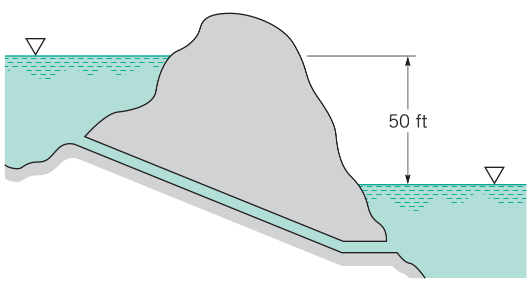
■ **FIGURE P5.81**

5.83 A pump transfers water from the upper reservoir to the lower one as shown in Fig. P5.83*a*. The difference in elevation between the two reservoirs is 100 ft. The friction head loss in the piping is given by $K_L \overline{V}^2/2g$, where $\overline{V}$ is the average fluid velocity in the pipe and K_L is the loss coefficient, which is considered constant. The relation between the head added to the water by the pump and the flowrate, Q, through the pump is given in Fig. P5.83*b*. If $K_L = 20$, and the pipe diameter is 4 in., what is the flowrate through the pump?

5.85 Water flows by gravity from one lake to another as sketched in Fig. P5.85 at the steady rate of 100 gpm. What is the loss in available energy associated with this flow? If this same amount of loss is associated with pumping the fluid from the lower lake to the higher one at the same flowrate, estimate the amount of pumping power required.

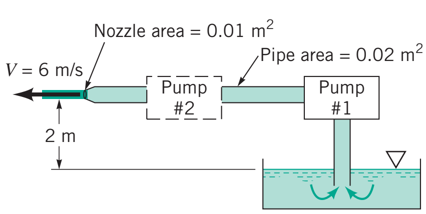


■ FIGURE P5.83



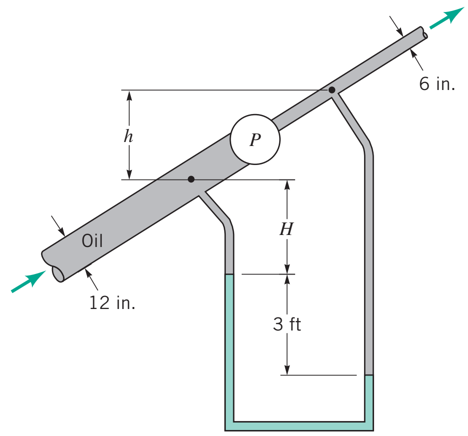
■ FIGURE P5.85

5.87 Water is to be pumped from the large tank shown in Fig. P5.87 with an exit velocity of 6 m/s. It was determined that the original pump (pump 1) that supplies 1 kW of power to the water did not produce the desired velocity. Hence, it is proposed that an additional pump (pump 2) be installed as indicated to increase the flowrate to the desired value. How much power must pump 2 add to the water? The head loss for this flow is $h_L = 250\,Q^2$, where h_L is in m when Q is in m^3/s.



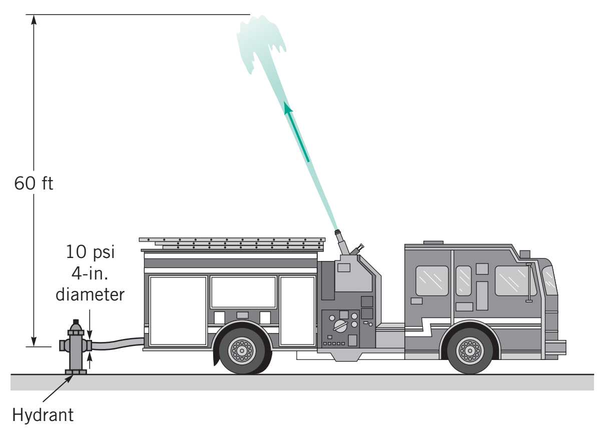
■ FIGURE P5.87

5.89 Oil ($SG = 0.88$) flows in an inclined pipe at a rate of 5 ft^3/s as shown in Fig. P5.89. If the differential reading in the mercury manometer is 3 ft, calculate the power that the pump supplies to the oil if head losses are negligible.



■ FIGURE P5.89

5.91 The pumper truck shown in Fig. P5.91 is to deliver 1.5 ft^3/s to a maximum elevation of 60 ft above the hydrant. The pressure at the 4-in.-diameter outlet of the hydrant is 10 psi. If head losses are negligibly small, determine the power that the pump must add to the water.

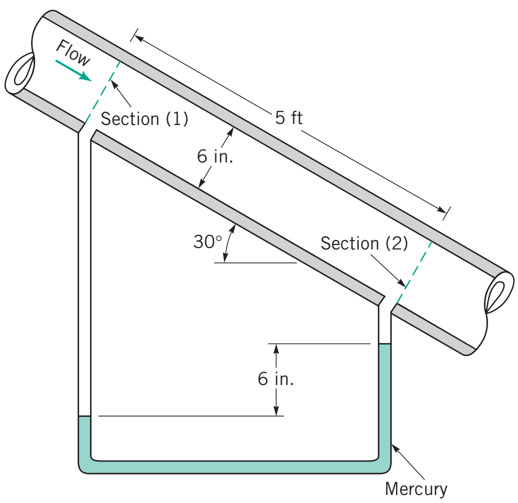


■ FIGURE P5.91

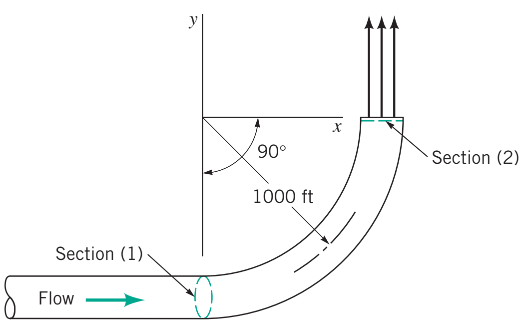
Section 5.3 The Energy and Linear Momentum Equations

5.93 Water flows steadily down the inclined pipe as indicated in Fig. P5.93. Determine the following: **(a)** the difference in pressure $p_1 - p_2$, **(b)** the loss between sections (1) and (2), and **(c)** the net axial force exerted by the pipe wall on the flowing water between sections (1) and (2).

5.95 Water flows through a 2-ft-diameter pipe arranged horizontally in a circular arc as shown in Fig. P5.95. If the pipe discharges to the atmosphere ($p = 14.7$ psia), determine the x and y components of the resultant force needed to hold the piping between sections (1) and (2) stationary. The steady flowrate is 3000 ft^3/min. The loss in pressure due to fluid friction between sections (1) and (2) is 25 psi.



■ **FIGURE P5.93**

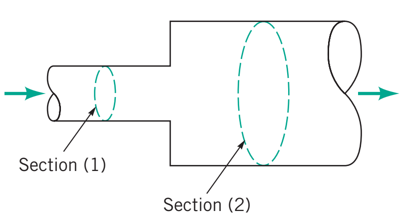


■ **FIGURE P5.95**

5.97 When fluid flows through an abrupt expansion as indicated in Fig. P5.97, the loss in available energy across the expansion, loss_{ex}, is often expressed as

$$\text{loss}_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{V_1^2}{2}$$

where A_1 is the cross-sectional area upstream of expansion, A_2 is the cross-sectional area downstream of expansion, and V_1 is the velocity of flow upstream of expansion. Derive this relationship.



■ **FIGURE P5.97**

■ Lab Problems

5.99 This problem involves the pressure distribution produced on a flat plate that deflects a jet of air. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

5.101 This problem involves the force needed to hold a pipe elbow stationary. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

5.103 Explain how local ionization of flowing air can accelerate it. How can this be useful?

5.105 Discuss the main causes of loss of available energy in a turbine and how they can be minimized. What are typical turbine efficiencies?

Chapter 6

Section 6.1 Fluid Element Kinematics

6.1 Obtain a photograph/image of a situation in which a fluid is undergoing angular deformation. Print this photo and write a brief paragraph that describes the situation involved.

6.3 The velocity in a certain flow field is given by the equation

$$\mathbf{V} = (3x^2 + 1)\hat{\mathbf{i}} - 6xy\hat{\mathbf{j}}$$

Determine the expressions for the two rectangular components of acceleration.

6.5 A one-dimensional flow is described by the velocity field

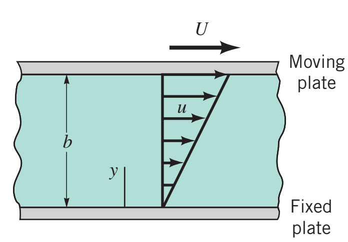
$$u = ay + by^2$$
$$v = w = 0$$

where a and b are constants. Is the flow irrotational? For what combination of constants (if any) will the rate of angular deformation as given by Eq. 6.18 be zero?

6.7 An incompressible viscous fluid is placed between two large parallel plates as shown in Fig. P6.7. The bottom plate is fixed and the upper plate moves with a constant velocity, U. For these conditions the velocity distribution between the plates is linear and can be expressed as

$$u = U\frac{y}{b}$$

Determine **(a)** the volumetric dilatation rate, **(b)** the rotation vector, **(c)** the vorticity, and **(d)** the rate of angular deformation.



■ **FIGURE P6.7**

Section 6.2 Conservation of Mass

6.9 Obtain a photograph/image of a situation in which streamlines indicate a feature of the flow field. Print this photo and write a brief paragraph that describes the situation involved.

6.11 The radial velocity component in an incompressible, two-dimensional flow field ($v_z = 0$) is

$$v_r = 2r + 3r^2 \sin \theta$$

Determine the corresponding tangential velocity component, v_θ, required to satisfy conservation of mass.

6.13 The velocity components of an incompressible, two-dimensional velocity field are given by the equations

$$u = y^2 - x(1 + x)$$
$$v = y(2x + 1)$$

Show that the flow is irrotational and satisfies conservation of mass.

6.15 For each of the following stream functions, with units of m^2/s, determine the magnitude and the angle the velocity vector makes with the x axis at $x = 1$ m, $y = 2$ m. Locate any stagnation points in the flow field.

(a) $\psi = xy$
(b) $\psi = -2x^2 + y$

6.17 For a certain incompressible flow field it is suggested that the velocity components are given by the equations

$$u = 2xy \quad v = -x^2y \quad w = 0$$

Is this a physically possible flow field? Explain.

6.19 The streamlines in a certain incompressible, two-dimensional flow field are all concentric circles so that $v_r = 0$. Determine the stream function for **(a)** $v_\theta = Ar$ and for **(b)** $v_\theta = Ar^{-1}$, where A is a constant.

6.21 The velocity components in an incompressible, two-dimensional flow field are given by the equations.

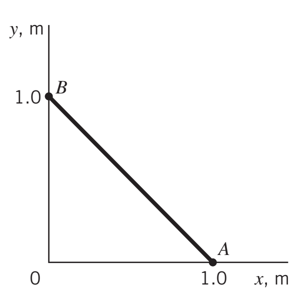
$$u = x^2$$
$$v = -2xy + x$$

Determine, if possible, the corresponding stream function.

6.23 The stream function for an incompressible flow field is given by the equation

$$\psi = 3x^2y - y^3$$

where the stream function has the units of m^2/s with x and y in meters. **(a)** Sketch the streamline(s) passing through the origin. **(b)** Determine the rate of flow across the straight path AB shown in Fig. P6.23.



■ FIGURE P6.23

Section 6.4 Inviscid Flow

6.25 The stream function for a given two-dimensional flow field is

$$\psi = 5x^2y - (5/3)y^3$$

Determine the corresponding velocity potential.

6.27 The streamlines for an incompressible, inviscid, two-dimensional flow field are all concentric circles, and the velocity varies directly with the distance from the common center of the streamlines; that is

$$v_\theta = Kr$$

where K is a constant. **(a)** For this *rotational* flow, determine, if possible, the stream function. **(b)** Can the pressure difference between the origin and any other point be determined from the Bernoulli equation? Explain.

6.29 A certain flow field is described by the stream function

$$\psi = A\,\theta + B\,r \sin \theta$$

where A and B are positive constants. Determine the corresponding velocity potential and locate any stagnation points in this flow field.

6.31 The velocity potential for a certain inviscid, incompressible flow field is given by the equation

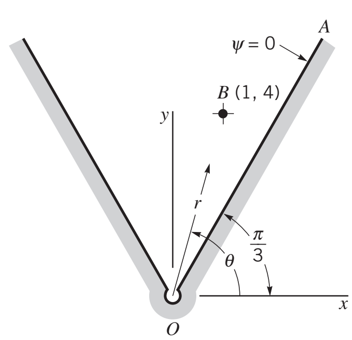
$$\phi = 2x^2y - (\tfrac{2}{3})y^3$$

where ϕ has the units of m^2/s when x and y are in meters. Determine the pressure at the point $x = 2$ m, $y = 2$ m if the pressure at $x = 1$ m, $y = 1$ m is 200 kPa. Elevation changes can be neglected and the fluid is water.

6.33 An ideal fluid flows between the inclined walls of a two-dimensional channel into a sink located at the origin (Fig. P6.33). The velocity potential for this flow field is

$$\phi = \frac{m}{2\pi} \ln r$$

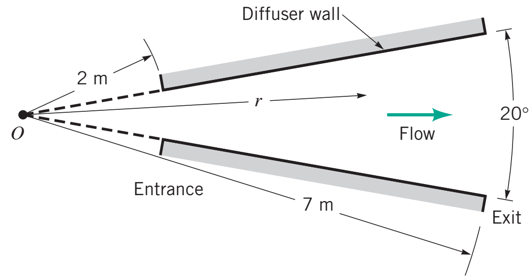
where m is a constant. **(a)** Determine the corresponding stream function. Note that the value of the stream function along the wall OA is zero. **(b)** Determine the equation of the streamline passing through the point B, located at $x = 1$, $y = 4$.



■ FIGURE P6.33

Section 6.5 Some Basic, Plane Potential Flows

6.35 Water flows through a two-dimensional diffuser having a 20° expansion angle as shown in Fig. P6.35. Assume that the flow in the diffuser can be treated as a radial flow emanating from a source at



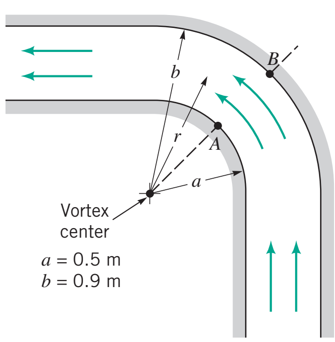
■ FIGURE P6.35

the origin O. **(a)** If the velocity at the entrance is 20 m/s, determine an expression for the pressure gradient along the diffuser walls. **(b)** What is the pressure rise between the entrance and exit?

6.37 The velocity distribution in a horizontal, two-dimensional bend through which an ideal fluid flows can be approximated with a free vortex as shown in Fig. P6.37. Show how the discharge (per unit width normal to plane of paper) through the channel can be expressed as

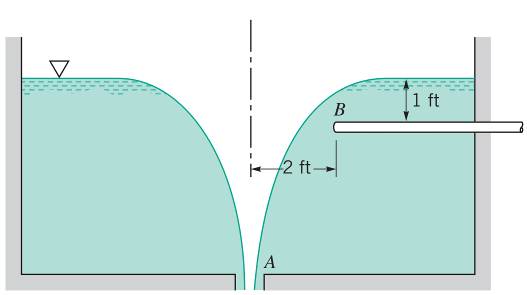
$$q = C\sqrt{\frac{\Delta p}{\rho}}$$

where $\Delta p = p_B - p_A$. Determine the value of the constant C for the bend dimensions given.



■ FIGURE P6.37

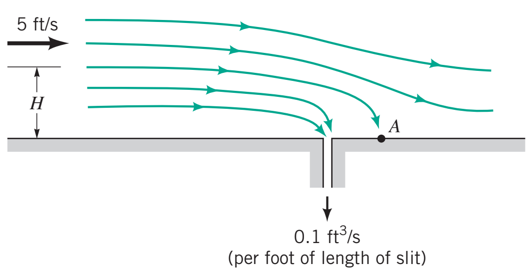
6.39 When water discharges from a tank through an opening in its bottom, a vortex may form with a curved surface profile, as shown in Fig. P6.39 and **Video V6.4.** Assume that the velocity distribution in the vortex is the same as that for a free vortex. At the same time the water is being discharged from the tank at point A, it is desired to discharge a small quantity of water through the pipe B. As the discharge through A is increased, the strength of the vortex, as indicated by its circulation, is increased. Determine the maximum strength that the vortex can have in order that no air is sucked in at B. Express your answer in terms of the circulation. Assume that the fluid level in the tank at a large distance from the opening at A remains constant and viscous effects are negligible.



■ FIGURE P6.39

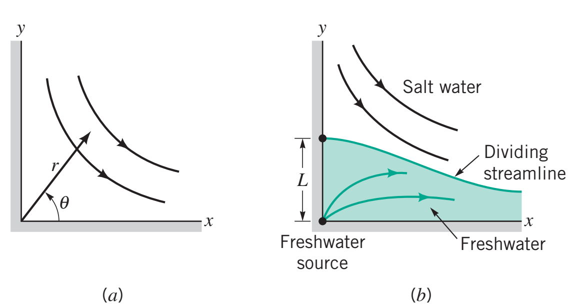
Section 6.6 Superposition of Basic, Plane Potential Flows

6.41 Water flows over a flat surface at 5 ft/s as shown in Fig. P6.41. A pump draws off water through a narrow slit at a volume rate of 0.1 ft^3/s per foot length of the slit. Assume that the fluid is incompressible and inviscid and can be represented by the combination of a uniform flow and a sink. Locate the stagnation point on the wall (point A), and determine the equation for the stagnation streamline. How far above the surface, H, must the fluid be so that it does not get sucked into the slit?



■ FIGURE P6.41

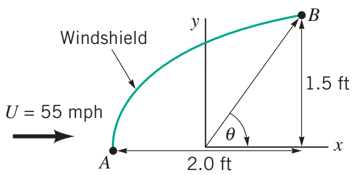
6.43 At a certain point at the beach, the coastline makes a right-angle bend, as shown in Fig. P6.43*a*. The flow of salt water in this bend can be approximated by the potential flow of an incompressible fluid in a right-angle corner. **(a)** Show that the stream function for this flow is $\psi = A\, r^2 \sin 2\theta$, where A is a positive constant. **(b)** A freshwater reservoir is located in the corner. The salt water is to be kept away from the reservoir to avoid any possible seepage of salt water into the freshwater (Fig. P6.43*b*). The freshwater source can be approximated as a line source having a strength m, where m is the volume rate of flow (per unit length) emanating from the source. Determine m if the salt water is not to get closer than a distance L to the corner. *Hint:* Find the value of m (in terms of A and L) so that a



■ FIGURE P6.43

stagnation point occurs at $y = L$. **(c)** The streamline passing through the stagnation point would represent the line dividing the freshwater from the salt water. Plot this streamline.

6.45 A vehicle windshield is to be shaped as a portion of a half-body with the dimensions shown in Fig. P6.45. **(a)** Make a scale drawing of the windshield shape. **(b)** For a free stream velocity of 55 mph, determine the velocity of the air at points A and B.



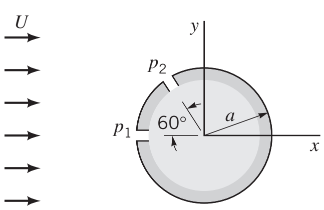
■ FIGURE P6.45

***6.47** For the half-body described in Section 6.6.1, show on a plot how the magnitude of the velocity on the surface, V_s, varies as a function of the distance, s (measured along the surface), from the stagnation point. Use the dimensionless variables V_s/U and s/b where U and b are defined in Fig. 6.23.

6.49 Assume that the flow around the long circular cylinder of Fig. P6.49 is nonviscous and incompressible. Two pressures, p_1 and p_2, are measured on the surface of the cylinder, as illustrated. It is proposed that the free-stream velocity, U, can be related to the pressure difference $\Delta p = p_1 - p_2$ by the equation

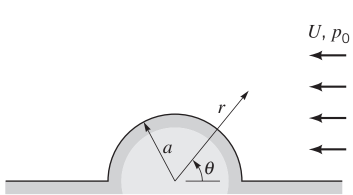
$$U = C\sqrt{\frac{\Delta p}{\rho}}$$

where ρ is the fluid density. Determine the value of the constant C. Neglect body forces.



■ FIGURE P6.49

6.51 An ideal fluid flows past an infinitely long semicircular "hump" located along a plane boundary as shown in Fig. P6.51. Far from the hump the velocity field is uniform, and the pressure is p_0. **(a)** Determine expressions for the maximum and minimum values of the pressure along the hump, and indicate where these points are located. Express your answer in terms of ρ, U, and p_0. **(b)** If the solid surface is the $\psi = 0$ streamline, determine the equation of the streamline passing through the point $\theta = \pi/2$, $r = 2a$.



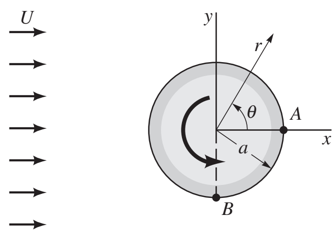
■ FIGURE P6.51

***6.53** Consider the steady potential flow around the circular cylinder shown in Fig. 6.24. Show on a plot the variation of the magnitude of the dimensionless fluid velocity, V/U, along the positive y axis. At what distance, y/a (along the y axis), is the velocity within 1% of the free-stream velocity?

6.55 The velocity potential for a cylinder (Fig. P6.55) rotating in a uniform stream of fluid is

$$\phi = Ur\left(1 + \frac{a^2}{r^2}\right)\cos\theta + \frac{\Gamma}{2\pi}\theta$$

where Γ is the circulation. For what value of the circulation will the stagnation point be located at **(a)** point A, **(b)** point B?



■ FIGURE P6.55

6.57 (See Fluids in the News article titled "A sailing ship without sails," Section 6.6.2.) Determine the magnitude of the total force developed by the two rotating cylinders on the Flettner "rotor-ship" due to the Magnus effect. Assume a wind speed relative to the ship of **(a)** 10 mph and **(b)** 30 mph. Each cylinder has a diameter of 9 ft, a length of 50 ft, and rotates at 750 rev/min. Use Eq. 6.117 and calculate the circulation by assuming the air sticks to the rotating cylinders. *Note:* This calculated force is at right angles to the direction of the wind, and it is the component of this force in the direction of motion of the ship that gives the propulsive thrust. Also, due to viscous effects, the actual propulsive thrust will be smaller than that calculated from Eq. 6.117, which is based on inviscid flow theory.

Section 6.8 Viscous Flow

6.59 The stream function for a certain incompressible, two-dimensional flow field is

$$\psi = 3r^3 \sin 2\theta + 2\theta$$

where ψ is in ft²/s when r is in feet and θ in radians. Determine the shearing stress, $\tau_{r\theta}$, at the point $r = 2$ ft, $\theta = \pi/3$ radians if the fluid is water.

6.61 For a steady, two-dimensional, incompressible flow, the velocity is given by $\mathbf{V} = (ax - cy)\hat{\mathbf{i}} + (-ay + cx)\hat{\mathbf{j}}$, where a and c are constants. Show that this flow can be considered inviscid.

6.63 For a two-dimensional incompressible flow in the $x-y$ plane show that the z component of the vorticity, ζ_z, varies in accordance with the equation

$$\frac{D\zeta_z}{Dt} = \nu\nabla^2\zeta_z$$

What is the physical interpretation of this equation for a nonviscous fluid? *Hint:* This *vorticity transport equation* can be derived from the Navier–Stokes equations by differentiating and eliminating the pressure between Eqs. 6.120a and 6.120b.

Section 6.9.1 Steady, Laminar Flow between Fixed Parallel Plates

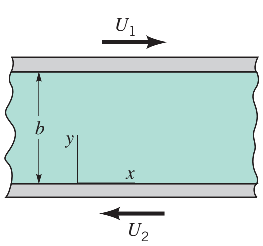
6.65 Oil ($\mu = 0.4 \text{ N} \cdot \text{s/m}^2$) flows between two fixed horizontal infinite parallel plates with a spacing of 5 mm. The flow is laminar and steady with a pressure gradient of $-900 \text{ (N/m}^2\text{)}$ per unit meter. Determine the volume flowrate per unit width and the shear stress on the upper plate.

6.67 Oil (SAE 30) at 15.6 °C flows steadily between fixed, horizontal, parallel plates. The pressure drop per unit length along the channel is 30 kPa/m, and the distance between the plates is 4 mm. The flow is laminar. Determine **(a)** the volume rate of flow (per meter of width), **(b)** the magnitude and direction of shearing stress acting on the bottom plate, and **(c)** the velocity along the centerline of the channel.

Section 6.9.2 Couette Flow

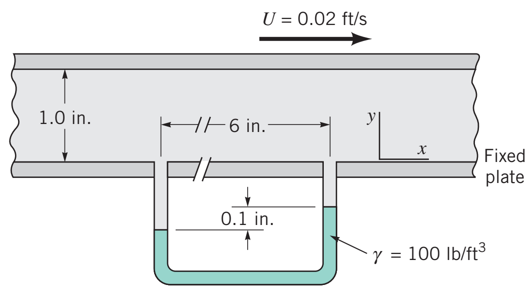
6.69 Two horizontal, infinite, parallel plates are spaced a distance b apart. A viscous liquid is contained between the plates. The bottom plate is fixed, and the upper plate moves parallel to the bottom plate with a velocity U. Because of the no-slip boundary condition (see **Video V6.11**), the liquid motion is caused by the liquid being dragged along by the moving boundary. There is no pressure gradient in the direction of flow. Note that this is a so-called simple *Couette flow* discussed in Section 6.9.2. **(a)** Start with the Navier–Stokes equations and determine the velocity distribution between the plates. **(b)** Determine an expression for the flowrate passing between the plates (for a unit width). Express your answer in terms of b and U.

6.71 An incompressible, viscous fluid is placed between horizontal, infinite, parallel plates as is shown in Fig. P6.71. The two plates move in opposite directions with constant velocities, U_1 and U_2, as shown. The pressure gradient in the x direction is zero, and the only body force is due to the fluid weight. Use the Navier–Stokes equations to derive an expression for the velocity distribution between the plates. Assume laminar flow.



■ FIGURE P6.71

6.73 A viscous fluid (specific weight = 80 lb/ft^3; viscosity = 0.03 lb · s/ft^2) is contained between two infinite, horizontal parallel plates as shown in Fig. P6.73. The fluid moves between the plates under the action of a pressure gradient, and the upper plate moves with a velocity U while the bottom plate is fixed. A U-tube manometer connected between two points along the bottom indicates a differential reading of 0.1 in. If the upper plate moves with a velocity of 0.02 ft/s, at what distance from the bottom plate does the maximum velocity in the gap between the two plates occur? Assume laminar flow.



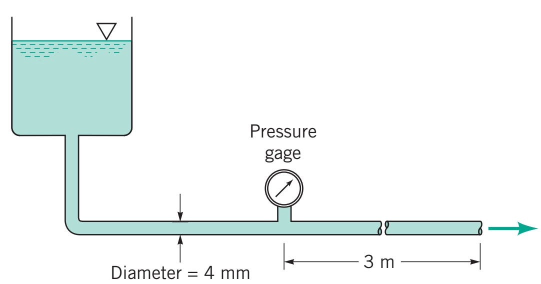
■ FIGURE P6.73

***6.75** Oil (SAE 30) flows between parallel plates spaced 5 mm apart. The bottom plate is fixed but the upper plate moves with a velocity of 0.2 m/s in the positive x direction. The pressure gradient is 60 kPa/m and is negative. Compute the velocity at various points across the channel and show the results on a plot. Assume laminar flow.

6.77 A layer of viscous liquid of constant thickness (no velocity perpendicular to plate) flows steadily down an infinite, inclined plane. Determine, by means of the Navier–Stokes equations, the relationship between the thickness of the layer and the discharge per unit width. The flow is laminar, and assume air resistance is negligible so that the shearing stress at the free surface is zero.

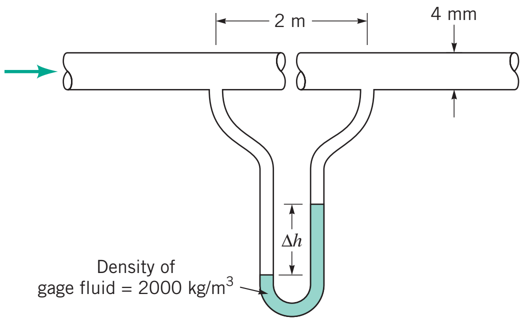
Section 6.9.3 Steady, Laminar Flow in Circular Tubes

6.79 A simple flow system to be used for steady flow tests consists of a constant head tank connected to a length of 4-mm-diameter tubing as shown in Fig. P6.79. The liquid has a viscosity of 0.015 · s/m^2 and a density of 1200 kg/m^3 and discharges into the atmosphere with a mean velocity of 1 m/s. **(a)** Verify that the flow will be laminar. **(b)** The flow is fully developed in the last 3 m of the tube. What is the pressure at the pressure gage? **(c)** What is the magnitude of the wall shearing stress, τ_{rz}, in the fully developed region?



■ FIGURE P6.79

6.81 A liquid (viscosity = 0.002 N · s/m^2; density = 1000 kg/m^3) is forced through the circular tube shown in Fig. P6.81. A differential manometer is connected to the tube as shown to measure the pressure drop along the tube. When the differential reading, Δh, is 9 mm, what is the mean velocity in the tube?



■ FIGURE P6.81

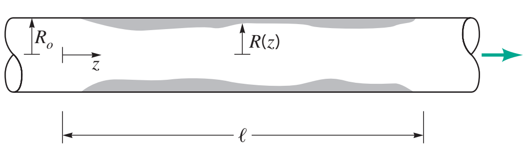
***6.83** As is shown by Eq. 6.143 the pressure gradient for laminar flow through a tube of constant radius is given by the expression

$$\frac{\partial p}{\partial z} = -\frac{8\mu Q}{\pi R^4}$$

For a tube whose radius is changing very gradually, such as the one illustrated in Fig. P6.83, it is expected that this equation can be used to approximate the pressure change along the tube if the actual radius, $R(z)$, is used at each cross section. The following measurements were obtained along a particular tube.

z/ℓ	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$R(z)/R_o$	1.00	0.73	0.67	0.65	0.67	0.80	0.80	0.71	0.73	0.77	1.00

Compare the pressure drop over the length ℓ for this nonuniform tube with one having the constant radius R_0. *Hint:* To solve this problem you will need to numerically integrate the equation for the pressure gradient given previously.



■ FIGURE P6.83

Section 6.10 Other Aspects of Differential Analysis

6.85 Obtain a photograph/image of a situation in which computational fluid dynamics (CFD) has been used to solve a fluid flow problem. Print this photo and write a brief paragraph that describes the situation involved.

■ Lifelong Learning Problems

6.87 Computational fluid dynamics has moved from a research tool to a design tool for engineering. Initially, much of the work in CFD was focused in the aerospace industry but now has expanded into other areas. Obtain information on what other industries (e.g., automotive) make use of CFD in their engineering design. Summarize your findings in a brief report.

Chapter 7

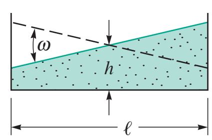
Section 7.1 Dimensional Analysis

7.1 The Reynolds number, $\rho VD/\mu$, is a very important parameter in fluid mechanics. Verify that the Reynolds number is dimensionless, using both the *FLT* system and the *MLT* system for basic dimensions, and determine its value for ethyl alcohol flowing at a velocity of 3 m/s through a 2-in.-diameter pipe.

7.3 For the flow of a thin film of a liquid with a depth h and a free surface, two important dimensionless parameters are the Froude number, $V/\sqrt{gh}$, and the Weber number, $\rho V^2 h/\sigma$. Determine the value of these two parameters for glycerin (at 20 °C) flowing with a velocity of 0.5 m/s at a depth of 2 mm.

Section 7.3 Determination of Pi Terms

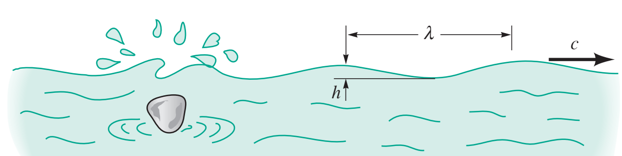
7.5 Water sloshes back and forth in a tank as shown in Fig. P7.5. The frequency of sloshing, ω, is assumed to be a function of the acceleration of gravity, g, the average depth of the water, h, and the length of the tank, ℓ. Develop a suitable set of dimensionless parameters for this problem using g and ℓ as repeating variables.



■ FIGURE P7.5

7.7 The power, $\mathcal{P}$, required to run a pump that moves fluid within a piping system is dependent upon the volume flowrate, Q, density, ρ, impeller diameter, d, angular velocity, ω, and fluid viscosity, μ. Find the number of pi terms for this relationship.

7.9 When a small pebble is dropped into a liquid, small waves travel outward as shown in Fig. P7.9. The speed of these waves, c, is assumed to be a function of the liquid density, ρ, the wavelength, λ, the wave height, h, and the surface tension of the liquid, σ. Use h, ρ, and σ as repeating variables to determine a suitable set of pi terms that could be used to describe this problem.



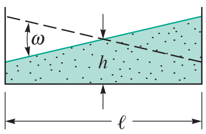
■ FIGURE P7.9

7.11 The drag, $\mathcal{D}$, on a washer-shaped plate placed normal to a stream of fluid can be expressed as

$$\mathcal{D} = f(d_1, d_2, V, \mu, \rho)$$

where d_1 is the outer diameter, d_2 the inner diameter, V the fluid velocity, μ the fluid viscosity, and ρ the fluid density. Some experiments are to be performed in a wind tunnel to determine the drag. What dimensionless parameters would you use to organize these data?

7.13 Water sloshes back and forth in a tank as shown in Fig. P7.13. The frequency of sloshing, ω, is assumed to be a function of the acceleration of gravity, g, the average depth of the water, h, the length of the tank, ℓ, and the viscosity, μ. Explain why it is not possible to form a suitable set of dimensionless parameters for this problem using g and ℓ as repeating variables.



■ **FIGURE P7.13**

Section 7.5 Determination of Pi Terms by Inspection

7.15 The velocity, c, at which pressure pulses travel through arteries (pulse-wave velocity) is a function of the artery diameter, D, and wall thickness, h, the density of blood, ρ, and the modulus of elasticity, E, of the arterial wall. Determine a set of nondimensional parameters that can be used to study experimentally the relationship between the pulse-wave velocity and the variables listed. Form the nondimensional parameters by inspection.

7.17 A liquid spray nozzle is designed to produce a specific size droplet with diameter, d. The droplet size depends on the nozzle diameter, D, nozzle velocity, V, and the liquid properties ρ, μ, and σ. Using the common dimensionless terms found in Table 7.1, determine the functional relationship for the dependent diameter ratio of d/D.

7.19 Assume that the drag, $\mathscr{D}$, on an aircraft flying at supersonic speeds is a function of its velocity, V, fluid density, ρ, speed of sound, c, and a series of lengths, $\ell_1, \ldots, \ell_i$, which describe the geometry of the aircraft. Develop a set of pi terms that could be used to investigate experimentally how the drag is affected by the various factors listed. Form the pi terms by inspection.

Section 7.7 Correlation of Experimental Data (also see Lab Problems 7.58, 7.59, 7.60, and 7.61)

***7.21** Describe some everyday situations involving fluid flow and estimate the Reynolds numbers for them. Based on your results, do you think fluid inertia is important in most typical flow situations? Explain.

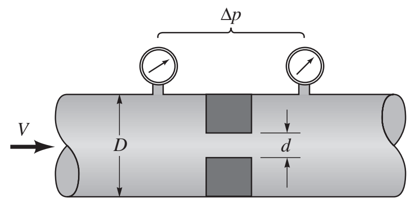
***7.23** The pressure drop across a short hollowed plug placed in a circular tube through which a liquid is flowing (see Fig. P7.23) can be expressed as

$$\Delta p = f(\rho, V, D, d)$$

where ρ is the fluid density and V is the mean velocity in the tube. Some experimental data obtained with $D = 0.2$ ft, $\rho = 2.0$ slugs/ft^3, and $V = 2$ ft/s are given in the following table:

d (ft)	0.06	0.08	0.10	0.15
Δp (lb/ft^2)	493.8	156.2	64.0	12.6

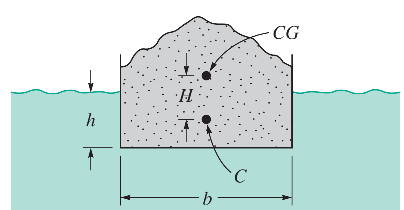
Plot the results of these tests, using suitable dimensionless parameters, on log–log graph paper. Use a standard curve-fitting technique to determine a general equation for Δp. What are the limits of applicability of the equation?



■ **FIGURE P7.23**

***7.25** As shown in Fig. 2.16, Fig. P7.25, and **Video V2.10,** a rectangular barge floats in a stable configuration provided the distance between the center of gravity, CG, of the object (boat and load) and the center of buoyancy, C, is less than a certain amount, H. If this distance is greater than H, the boat will tip over. Assume H is a function of the boat's width, b, length, ℓ, and draft, h. **(a)** Put this relationship into dimensionless form. **(b)** The results of a set of experiments with a model barge with a width of 1.0 m are shown in the table. Plot these data in dimensionless form and determine a power-law equation relating the dimensionless parameters.

ℓ, m	h, m	H, m
2.0	0.10	0.833
4.0	0.10	0.833
2.0	0.20	0.417
4.0	0.20	0.417
2.0	0.35	0.238
4.0	0.35	0.238



■ **FIGURE P7.25**

7.27 In order to maintain uniform flight, smaller birds must beat their wings faster than larger birds. It is suggested that the relationship between the wingbeat frequency, ω, beats per second, and the bird's wingspan, ℓ, is given by a power law relationship, $\omega \sim \ell^n$. **(a)** Use dimensional analysis with the assumption that the wingbeat frequency is a function of the wingspan, the specific weight of the bird, γ, the acceleration of gravity, g, and the density of the air, ρ_a, to determine the value of the exponent n. **(b)** Some typical data for various birds are given in the following table. Do these data support your result obtained in part (a)? Provide appropriate analysis to show how you arrived at your conclusion.

Bird	Wingspan, m	Wingbeat frequency, beats/s
Purple martin	0.28	5.3
Robin	0.36	4.3
Mourning dove	0.46	3.2
Crow	1.00	2.2
Canada goose	1.50	2.6
Great blue heron	1.80	2.0

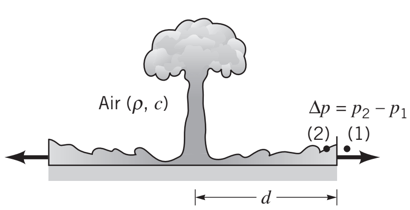
Section 7.8 Modeling and Similitude

7.29 Air at 80 °F is to flow through a 2-ft pipe at an average velocity of 6 ft/s. What size pipe should be used to move water at 60 °F and average velocity of 3 ft/s if Reynolds number similarity is enforced?

7.31 SAE 30 oil at 60 °F is pumped through a 3-ft-diameter pipeline at a rate of 5700 gal/min. A model of this pipeline is to be designed using a 2-in.-diameter pipe and water at 60 °F as the working fluid. To maintain Reynolds number similarity between these two systems, what fluid velocity will be required in the model?

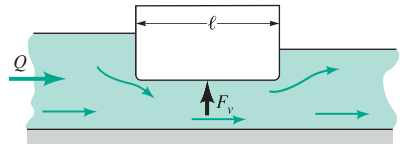
7.33 The design of a river model is to be based on Froude number similarity, and a river depth of 3 m is to correspond to a model depth of 100 mm. Under these conditions what is the prototype velocity corresponding to a model velocity of 2 m/s?

7.35 The pressure rise, Δp, across a blast wave, as shown in Fig. P7.35 is assumed to be a function of the amount of energy released in the explosion, E, the air density, ρ, the speed of sound, c, and the distance from the blast, d. **(a)** Put this relationship in dimensionless form. **(b)** Consider two blasts: the prototype blast with energy release E and a model blast with 1/1000th the energy release ($E_m = 0.001\,E$). At what distance from the model blast will the pressure rise be the same as that at a distance of 1 mile from the prototype blast?



■ FIGURE P7.35

7.37 Water flowing under the obstacle shown in Fig. P7.37 puts a vertical force, F_v, on the obstacle. This force is assumed to be a function of the flowrate, Q, the density of the water, ρ, the acceleration of gravity, g, and a length, ℓ, that characterizes the size of the obstacle. A 1/20-scale model is to be used to predict the vertical force on the prototype. **(a)** Perform a dimensional analysis for this problem. **(b)** If the prototype flowrate is 1000 ft^3/s, determine the water flowrate for the model if the flows are to be similar. **(c)** If the model force is measured as $(F_v)_m = 20$ lb, predict the corresponding force on the prototype.

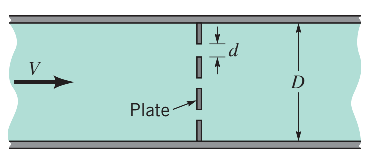


■ FIGURE P7.37

7.39 (See Fluids in the News article titled "Modeling parachutes in a water tunnel," Section 7.8.1.) Flow characteristics for a 30-ft-diameter prototype parachute are to be determined by tests of a 1-ft-diameter model parachute in a water tunnel. Some data collected with the model parachute indicate a drag of 17 lb when the water velocity is 4 ft/s. Use the model data to predict the drag on the prototype parachute falling through air at 10 ft/s. Assume the drag to be a function of the velocity, V, the fluid density, ρ, and the parachute diameter, D.

7.41 As shown in Fig. P7.41, a thin, flat plate containing a series of holes is to be placed in a pipe to filter out any particles in the liquid flowing through the pipe. There is some concern about the large pressure drop that may develop across the plate, and it is proposed to study this problem with a geometrically similar model. The following data apply.

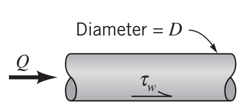
Prototype	Model
d—hole diameter = 1.0 mm	d = ?
D—pipe diameter = 50 mm	D = 10 mm
μ—viscosity = 0.002 N · s/m^2	μ = 0.002 N · s/m^2
ρ—density = 1000 kg/m^3	ρ = 1000 kg/m^3
V—velocity = 0.1 m/s to 2 m/s	V = ?



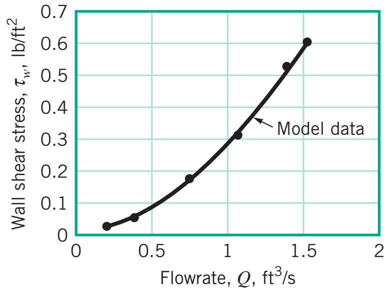
■ FIGURE P7.41

(a) Assuming that the pressure drop, Δp, depends on the variables listed, use dimensional analysis to develop a suitable set of dimensionless parameters for this problem. **(b)** Determine values for the model indicated in the list with a question mark. What will be the pressure drop scale, $\Delta p_m/\Delta p$?

7.43 Assume that the wall shear stress, τ_w, created when a fluid flows through a pipe (see Fig. P7.43*a*) depends on the pipe diameter, D, the flowrate, Q, the fluid density, ρ, and the kinematic viscosity, ν. Some model tests run in a laboratory using water in a 0.2-ft-diameter pipe yield the τ_w vs. Q data shown in Fig. P7.43*b*. Perform a dimensional analysis and use model data to predict the wall shear stress in a 0.3-ft-diameter pipe through which water flows at the rate of 1.5 ft^3/s.



(*a*)



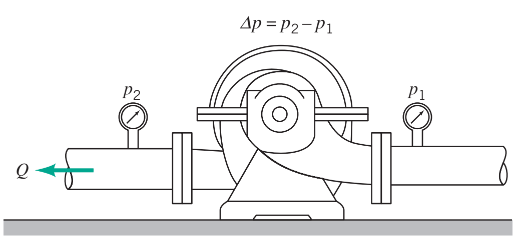
(*b*)

■ **FIGURE P7.43**

7.45 The pressure rise, Δp, across a centrifugal pump of a given shape (see Fig. P7.45*a*) can be expressed as

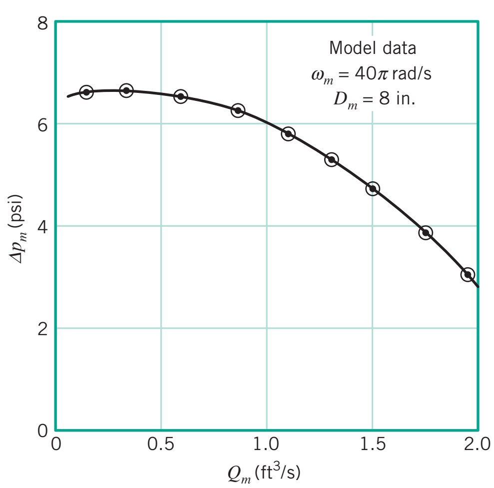
$$\Delta p = f(D, \omega, \rho, Q)$$

where D is the impeller diameter, ω the angular velocity of the impeller, ρ the fluid density, and Q the volume rate of flow through the pump. A model pump having a diameter of 8 in. is tested in the laboratory using water. When operated at an angular velocity of 40 π rad/s, the model pressure rises as a function of Q as shown in Fig. P7.45*b*. Use this curve to predict the pressure rise across a geometrically similar pump (prototype) for a prototype flowrate of 6 ft^3/s. The prototype has a diameter of 12 in. and operates at an angular velocity of 60 π rad/s. The prototype fluid is also water.



Centrifugal pump

(*a*)



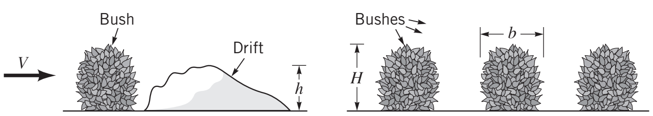
(*b*)

■ **FIGURE P7.45**

Section 7.9 Some Typical Model Studies

7.47 Drag measurements were taken for a sphere, with a diameter of 5 cm, moving at 4 m/s in water at 20 °C. The resulting drag on the sphere was 10 N. For a balloon with 1-m diameter rising in air with standard temperature and pressure, determine **(a)** the velocity if Reynolds number similarity is enforced and **(b)** the drag force if the drag coefficient (Eq. 7.16) is the dependent pi term.

7.49 During a storm, a snow drift is formed behind some bushes as shown in Fig. P7.49 and **Video V9.6.** Assume that the height of the drift, h, is a function of the number of inches of snow deposited by the storm, d, the height of the bush, H, the width of the bush, b, the wind speed, V, the acceleration of gravity, g, the air density, ρ, the specific weight of the snow, γ_s, and the porosity of the bush, η. Note that porosity is defined as the percentage of open area of the bush. **(a)** Determine a suitable set of dimensionless variables for this problem. **(b)** A storm with 30-mph winds deposits 16 in. of snow having a specific weight of 5.0 lb/ft^3. A half-sized-scale model bush is to be used to investigate the drifting behind the bush. If the air density is the same for the model and the storm, determine the required specific weight of the model snow, the required wind speed for the model, and the number of inches of model snow to be deposited.



■ **FIGURE P7.49**

7.51 Flow patterns that develop as winds blow past a vehicle, such as a train, are often studied in low-speed environmental (meteorological) wind tunnels. (See **Video V7.16**.) Typically, the air velocities in these tunnels are in the range of 0.1 m/s to 30 m/s. Consider a cross wind blowing past a train locomotive. Assume that the local wind velocity, V, is a function of the approaching wind velocity (at some distance from the locomotive), U, the locomotive length, ℓ, height, h, and width, b, the air density, ρ, and the air viscosity, μ. **(a)** Establish the similarity requirements and prediction equation for a model to be used in the wind tunnel to study the air velocity, V, around the locomotive. **(b)** If the model is to be used for cross winds gusting to $U = 25$ m/s, explain why it is not practical to maintain Reynolds number similarity for a typical length scale 1:50.

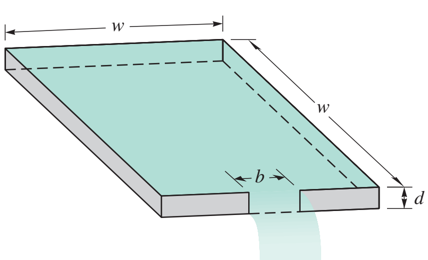
7.53 As illustrated in **Video V7.9,** models are commonly used to study the dispersion of a gaseous pollutant from an exhaust stack located near a building complex. Similarity requirements for the pollutant source involve the following independent variables: the stack gas speed, V, the wind speed, U, the density of the atmospheric air, ρ, the difference in densities between the air and the stack gas, $\rho - \rho_s$, the acceleration of gravity, g, the kinematic viscosity of the stack gas, ν_s, and the stack diameter, D. **(a)** Based on these variables, determine a suitable set of similarity requirements for modeling the pollutant source. **(b)** For this type of model a typical length scale might be 1:200. If the same fluids were used in model and prototype, would the similarity requirements be satisfied? Explain and support your answer with the necessary calculations.

7.55 A 1/50-scale model is to be used in a towing tank to study the water motion near the bottom of a shallow channel as a large barge passes over. (See **Video V7.18.**) Assume that the model is operated in accordance with the Froude number criteria for dynamic similitude. The prototype barge moves at a typical speed of 15 knots. **(a)** At what speed (in ft/s) should the model be towed? **(b)** Near the bottom of the model channel a small particle is found to move 0.15 ft in 1 s so that the fluid velocity at that point is approximately 0.15 ft/s. Determine the velocity at the corresponding point in the prototype channel.

7.57 A square parking lot of width w is bounded on all sides by a curb of height d with only one opening of width b as shown in Fig. P7.57. During a heavy rain the lot fills with water and it is of interest to determine the time, t, it takes for the water to completely drain from the lot after the rain stops. A scale model is to be used to study this problem, and it is assumed that

$$t = f(w, b, d, g, \mu, \rho)$$

where g is the acceleration of gravity, μ is the fluid viscosity, and ρ is the fluid density. **(a)** A dimensional analysis indicates that two important dimensionless parameters are b/w and d/w. What additional dimensionless parameters are required? **(b)** For a geometrically similar model having a length scale of 1/10, what is the relationship between the drain time for the model and the corresponding drain time for the actual parking lot? Assume all similarity requirements are satisfied. Can water be used as the model fluid? Explain and justify your answer.



■ **FIGURE P7.57**

■ Lab Problems

7.59 This problem involves determining the frequency of vortex shedding from a circular cylinder as water flows past it. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

7.61 This problem involves the calibration of a rotameter. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

7.63 For some types of aerodynamic wind tunnel testing, it is difficult to simultaneously match both the Reynolds number and Mach number between model and prototype. Engineers have developed several potential solutions to the problem including pressurized wind tunnels and lowering the temperature of the flow. Obtain information about cryogenic wind tunnels and explain the advantages and disadvantages. Summarize your findings in a brief report.

Chapter 8

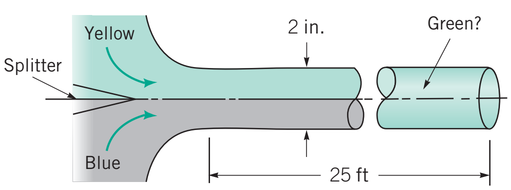
Section 8.1 General Characteristics of Pipe Flow (also see Lab Problem 8.105)

8.1 Rainwater runoff from a parking lot flows through a 3-ft-diameter pipe, completely filling it. Whether flow in a pipe is laminar or turbulent depends on the value of the Reynolds number. (See **Video V8.2.**) Would you expect the flow to be laminar or turbulent? Support your answer with appropriate calculations.

8.3 Air at 200 °F flows at standard atmospheric pressure in a pipe at a rate of 0.08 lb/s. Determine the minimum diameter allowed if the flow is to be laminar.

8.5 A long small-diameter tube is to be used as a viscometer by measuring the flowrate through the tube as a function of the pressure drop along the tube. The calibration constant, $K = Q/\Delta p$, is calculated by assuming the flow is laminar. For tubes of diameter 0.5, 1.0, and 2.0 mm, determine the maximum flowrate allowed (in cm^3/s) if the fluid is **(a)** 20 °C water, or **(b)** standard air.

8.7 Blue and yellow streams of paint at 60 °F (each with a density of 1.6 $slugs/ft^3$ and a viscosity 1000 times greater than water) enter a pipe with an average velocity of 4 ft/s as shown in Fig. P8.7. Would you expect the paint to exit the pipe as green paint or separate streams of blue and yellow paint? Explain. Repeat the problem if the paint were "thinned" so that it is only 10 times more viscous than water. Assume the density remains the same.



■ **FIGURE P8.7**

8.9 To sufficiently vent a vault in which a maintenance crew is doing repairs it is necessary to supply 3.5 ft^3/s of air through a 6-in.-diameter pipe. Approximately how long is the entrance length in this pipe?

Section 8.2 Fully Developed Laminar Flow

8.11 The pressure drop needed to force water through a horizontal 1-in.-diameter pipe is 0.60 psi for every 12-ft length of pipe. Determine the shear stress on the pipe wall. Determine the shear stress at distances 0.3 and 0.5 in. away from the pipe wall.

8.13 A fluid of specific gravity 0.96 flows steadily in a long, vertical 1-in.-diameter pipe with an average velocity of 0.50 ft/s. If the pressure is constant throughout the fluid, what is the viscosity of the fluid? Determine the shear stress on the pipe wall.

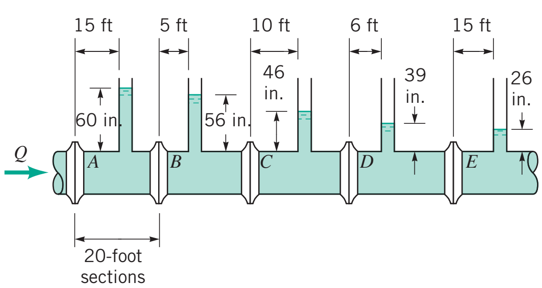
8.15 Glycerin at 20 °C flows upward in a vertical 75-mm-diameter pipe with a centerline velocity of 1.0 m/s. Determine the head loss and pressure drop in a 10-m length of the pipe.

8.17 The wall shear stress in a fully developed flow portion of a 12-in.-diameter pipe carrying water is 1.85 lb/ft^2. Determine the pressure gradient, $\partial p/\partial x$, where x is in the flow direction, if the pipe is **(a)** horizontal, **(b)** vertical with flow up, or **(c)** vertical with flow down.

8.19 A large artery in a person's body can be approximated by a tube of diameter 9 mm and length 0.35 m. Also assume that blood has a viscosity of approximately $4 \times 10^{-3}\ \text{N} \cdot \text{s/m}^2$, a specific gravity of 1.0, and that the pressure at the beginning of the artery is equivalent to 120 mm Hg. If the flow were steady (it is not) with $V = 0.2$ m/s, determine the pressure at the end of the artery if it is oriented **(a)** vertically up (flow up) or **(b)** horizontal.

8.21 A fluid flows through a horizontal 0.1-in.-diameter pipe with an average velocity of 2 ft/s and a Reynolds number of 1500. Determine the head loss over a 20-ft length of pipe.

8.23 Oil flows through the horizontal pipe shown in Fig. P8.23 under laminar conditions. All sections are the same diameter except one. Which section of the pipe (A, B, C, D, or E) is slightly smaller in diameter than the others? Explain.

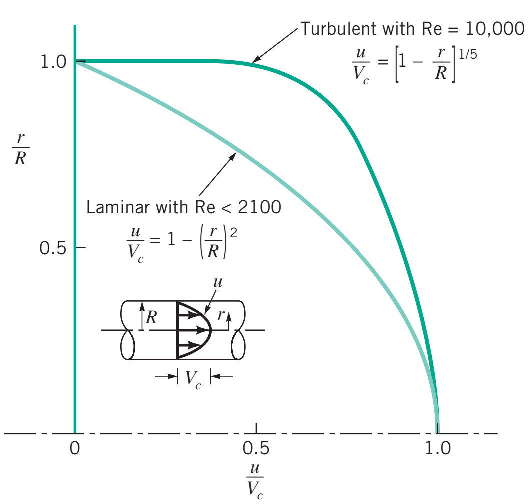


■ **FIGURE P8.23**

Section 8.3 Fully Developed Turbulent Flow

8.25 For oil ($SG = 0.86$, $\mu = 0.025\ \text{Ns/m}^2$) flow of $0.3\ \text{m}^3/\text{s}$ through a round pipe with diameter of 500 mm, determine the Reynolds number. Is the flow laminar or turbulent?

8.27 As shown in **Video V8.9** and Fig. P8.27, the velocity profile for laminar flow in a pipe is quite different from that for turbulent flow. With laminar flow the velocity profile is parabolic; with turbulent flow at Re = 10,000 the velocity profile can be approximated by the power-law profile shown in Fig. P8.27. **(a)** For laminar flow, determine at what radial location you would place a Pitot tube if it is to measure the average velocity in the pipe. **(b)** Repeat part **(a)** for turbulent flow with Re = 10,000.



■ **FIGURE P8.27**

Section 8.4.1 Major Losses (also see Lab Problem 8.101)

8.29 During a heavy rainstorm, water from a parking lot completely fills an 18-in.-diameter, smooth, concrete storm sewer. If the flowrate is $10\ \text{ft}^3/\text{s}$, determine the pressure drop in a 100-ft horizontal section of the pipe. Repeat the problem if there is a 2-ft change in elevation of the pipe per 100 ft of its length.

8.31 A person with no experience in fluid mechanics wants to estimate the friction factor for 1-in.-diameter galvanized iron pipe at a Reynolds number of 8000. The person stumbles across the simple equation of $f = 64/\text{Re}$ and uses this to calculate the friction factor. Explain the problem with this approach and estimate the error.

8.33 Water flows in a cast-iron pipe of 200-mm diameter at a rate of $0.10\ \text{m}^3/\text{s}$. Determine the friction factor for this flow.

8.35 Gasoline flows in a smooth pipe of 40-mm diameter at a rate of $0.001\ \text{m}^3/\text{s}$. If it were possible to prevent turbulence from occurring, what would be the ratio of the head loss for the actual turbulent flow compared to that if it were laminar flow?

8.37 Repeat Problem 8.20 if the pipe diameter is changed to 0.1 ft rather than 0.1 in. *Note:* The flow may not be laminar for this case.

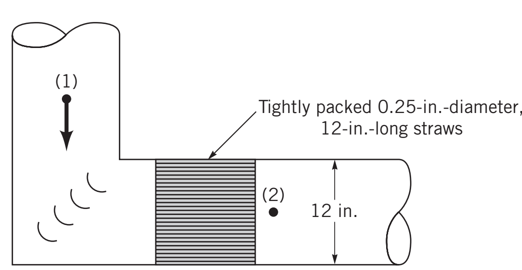
8.39 Water flows at a rate of 10 gallons per minute in a new horizontal 0.75-in.-diameter galvanized iron pipe. Determine the pressure gradient, $\Delta p/\ell$, along the pipe.

Section 8.4.2 Minor Losses (also see Lab Problem 8.106)

8.41 Air at standard temperature and pressure flows through a 1-in.-diameter galvanized iron pipe with an average velocity of 10 ft/s. What length of pipe produces a head loss equivalent to **(a)** a flanged 90° elbow, **(b)** a wide-open angle valve, or **(c)** a sharp-edged entrance?

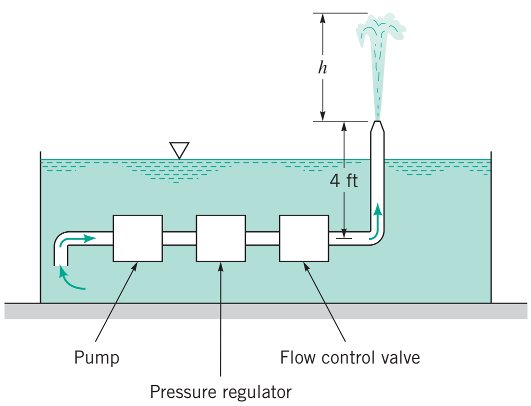
8.43 Given 90° threaded elbows used in conjunction with copper pipe (drawn tubing) of 0.75-in. diameter, convert the loss for a single elbow to equivalent length of copper pipe for wholly turbulent flow.

8.45 Air flows through the mitered bend shown in Fig. P8.45 at a rate of 5.0 cfs. To help straighten the flow after the bend, a set of 0.25-in.-diameter drinking straws is placed in the pipe as shown. Estimate the extra pressure drop between points (1) and (2) caused by these straws.



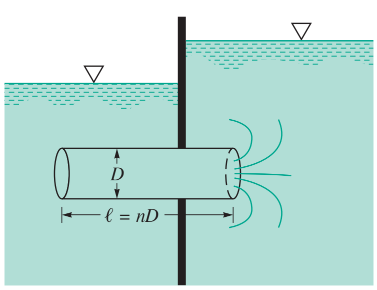
■ **FIGURE P8.45**

8.47 (See Fluids in the News article titled "New hi-tech fountains," Section 8.5.) The fountain shown in Fig. P8.47 is designed to provide a stream of water that rises $h = 10$ ft to $h = 20$ ft above the nozzle exit in a periodic fashion. To do this the water from the pool enters a pump, passes through a pressure regulator that maintains a constant pressure ahead of the flow control valve. The valve is electronically adjusted to provide the desired water height. With $h = 10$ ft the loss coefficient for the valve is $K_L = 50$. Determine the valve loss coefficient needed for $h = 20$ ft. All losses except for the flow control valve are negligible. The area of the pipe is 5 times the area of the exit nozzle.



■ FIGURE P8.47

8.49 As shown in Fig. P8.49, water flows from one tank to another through a short pipe whose length is n times the pipe diameter. Head losses occur in the pipe and at the entrance and exit. (See **Video V8.10.**) Determine the maximum value of n if the major loss is to be no more than 10% of the minor loss and the friction factor is 0.02.

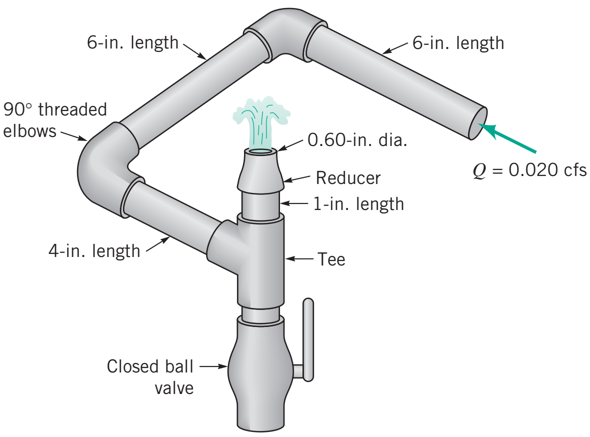


■ FIGURE P8.49

8.51 Water flows steadily through the 0.75-in.-diameter galvanized iron pipe system shown in **Video V8.13** and Fig. P8.51 at a rate of 0.020 cfs. Your boss suggests that friction losses in the straight pipe sections are negligible compared to losses in the threaded elbows and fittings of the system. Do you agree or disagree with your boss? Support your answer with appropriate calculations.

Section 8.4.3 Noncircular Conduits

8.53 Air flows through a rectangular galvanized iron duct of size 0.30 m by 0.15 m at a rate of 0.068 m^3/s. Determine the head loss in 12 m of this duct.



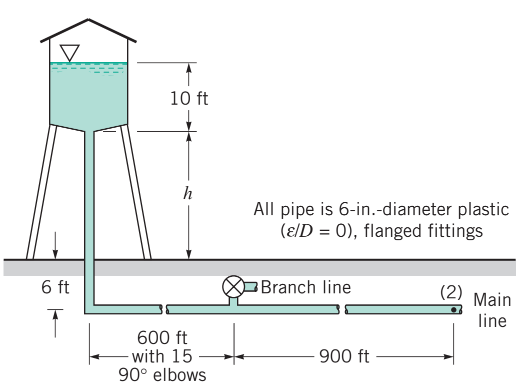
■ FIGURE P8.51

Section 8.5.1 Single Pipes—Determine Pressure Drop

8.55 A 70-ft-long, 0.5-in.-diameter hose with a roughness of $\varepsilon = 0.0009$ ft is fastened to a water faucet where the pressure is p_1. Determine p_1 if there is no nozzle attached and the average velocity in the hose is 6 ft/s. Neglect minor losses and elevation changes.

8.57 Determine the pressure drop per 100-m length of horizontal new 0.20-m-diameter cast-iron water pipe when the average velocity is 1.7 m/s.

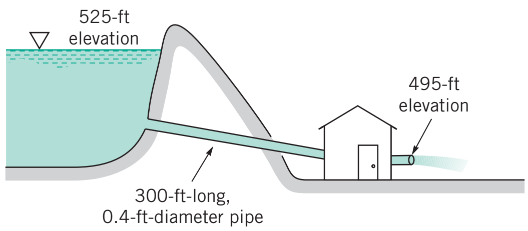
8.59 The pressure at section (2) shown in Fig. P8.59 is not to fall below 60 psi when the flowrate from the tank varies from 0 to 1.0 cfs and the branch line is shut off. Determine the minimum height, h, of the water tank under the assumption that **(a)** minor losses are negligible, **(b)** minor losses are not negligible.



■ FIGURE P8.59

8.61 Gasoline flows in a smooth pipe of 40-mm diameter at a rate of 0.001 m^3/s. If it were possible to prevent turbulence from occurring, what would be the ratio of the head loss for the actual turbulent flow compared to that if it were laminar flow?

8.63 Water flows from a lake as is shown in Fig. P8.63 at a rate of 4.0 cfs. Is the device inside the building a pump or a turbine? Explain and determine the horsepower of the device. Neglect all minor losses and assume the friction factor is 0.025.

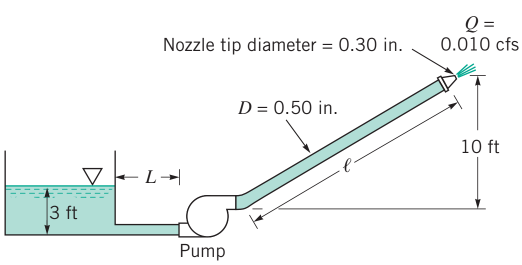


■ **FIGURE P8.63**

8.65 At a ski resort water at 40 °F is pumped through a 3-in.-diameter, 2000-ft-long steel pipe from a pond at an elevation of 4286 ft to a snow-making machine at an elevation of 4623 ft at a rate of 0.26 ft^3/s. If it is necessary to maintain a pressure of 180 psi at the snow-making machine, determine the horsepower added to the water by the pump. Neglect minor losses.

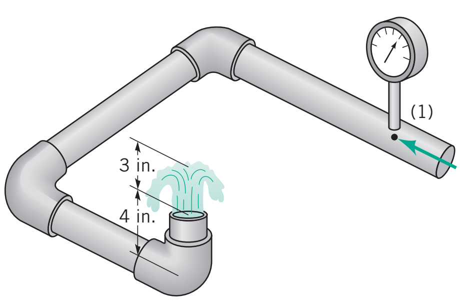
8.67 Water is pumped through a 60-m-long, 0.3-m-diameter pipe from a lower reservoir to a higher reservoir whose surface is 10 m above the lower one. The sum of the minor loss coefficients for the system is $K_L = 14.5$. When the pump adds 40 kW to the water, the flowrate is 0.20 m^3/s. Determine the pipe roughness.

8.69 The $\frac{1}{2}$-in.-diameter hose shown in Fig. P8.69 can withstand a maximum pressure of 200 psi without rupturing. Determine the maximum length, ℓ, allowed if the friction factor is 0.022 and the flowrate is 0.010 cfs. Neglect minor losses. The fluid is water.



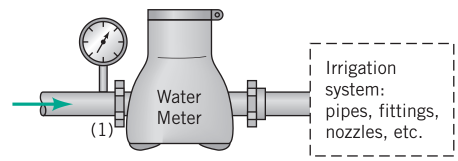
■ **FIGURE P8.69**

8.71 As shown in **Video V8.13** and Fig. P8.71, water "bubbles up" 3 in. above the exit of the vertical pipe attached to three horizontal pipe segments. The total length of the 0.75-in.-diameter galvanized iron pipe between point (1) and the exit is 21 in. Determine the pressure needed at point (1) to produce this flow.



■ **FIGURE P8.71**

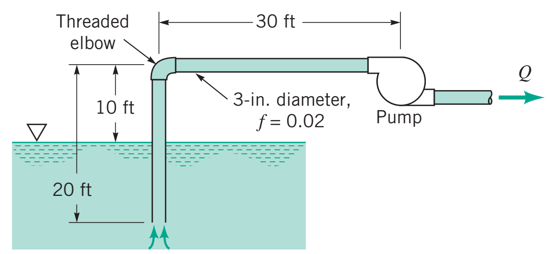
8.73 As shown in Fig. P8.73, a standard household water meter is incorporated into a lawn irrigation system to measure the volume of water applied to the lawn. Note that these meters measure volume, not volume flowrate. (See **Video V8.14.**) With an upstream pressure of $p_1 = 50$ psi the meter registered that 120 ft^3 of water was delivered to the lawn during an "on" cycle. Estimate the upstream pressure, p_1, needed if it is desired to have 150 ft^3 delivered during an "on" cycle. List any assumptions needed to arrive at your answer.



■ **FIGURE P8.73**

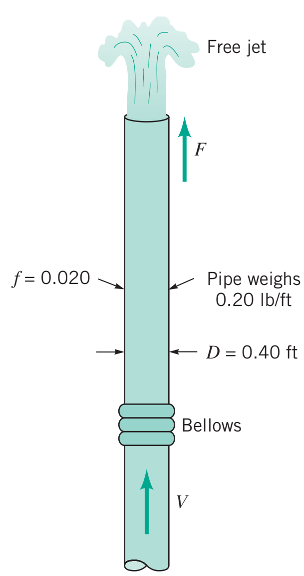
Section 8.5.1 Single Pipes—Determine Flowrate (also see Lab Problems 8.103 and 8.104)

8.75 Water at 40 °F is pumped from a lake as shown in Fig. P8.75. What is the maximum flowrate possible without cavitation occurring in the pipe?



■ **FIGURE P8.75**

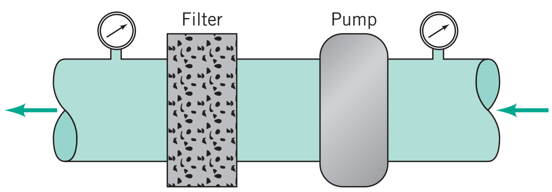
8.77 Water flows through two sections of the vertical pipe shown in Fig. P8.77. The bellows connection cannot support any force in the vertical direction. The 0.4-ft-diameter pipe weighs 0.2 lb/ft, and the friction factor is assumed to be 0.02. At what velocity will the force, F, required to hold the pipe be zero?



■ **FIGURE P8.77**

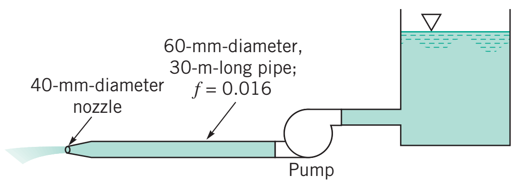
8.79 When the pump shown in Fig. P8.79 adds 0.2 horsepower to the flowing water, the pressures indicated by the two gages are equal. Determine the flowrate.

Length of pipe between gages = 60 ft
Pipe diameter = 0.1 ft
Pipe friction factor = 0.03
Filter loss coefficient = 12



■ FIGURE P8.79

8.81 The pump shown in Fig. P8.81 adds 25 kW to the water and causes a flowrate of 0.04 m^3/s. Determine the flowrate expected if the pump is removed from the system. Assume $f = 0.016$ for either case and neglect minor losses.



■ FIGURE P8.81

Section 8.5.1 Single Pipes—Determine Diameter

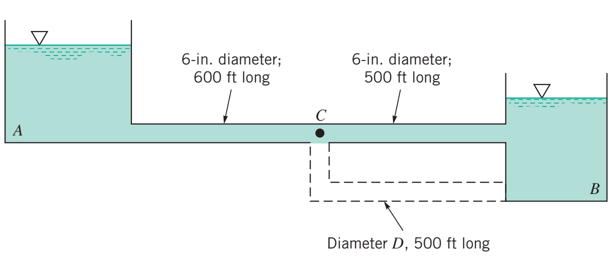
8.83 According to fire regulations in a town, the pressure drop in a commercial steel, horizontal pipe must not exceed 1.0 psi per 150-ft pipe for flowrates up to 500 gal/min. If the water temperature is never below 50 °F, what diameter pipe is needed?

8.85 Determine the diameter of a steel pipe that is to carry 2000 gal/min of gasoline with a pressure drop of 5 psi per 100 ft of horizontal pipe.

8.87 Repeat Problem 8.86 if there are numerous components (valves, elbows, etc.) along the pipe so that the minor loss is equal to 40 velocity heads.

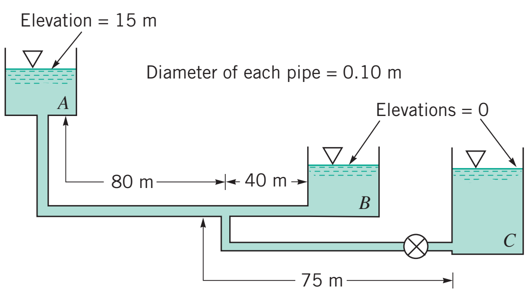
Section 8.5.2 Multiple Pipe Systems

8.89 The flowrate between tank A and tank B shown in Fig. P8.89 is to be increased by 30% (i.e., from Q to $1.30Q$) by the addition of a second pipe (indicated by the dotted lines) running from node C to tank B. If the elevation of the free surface in tank A is 25 ft above that in tank B, determine the diameter, D, of this new pipe. Neglect minor losses and assume that the friction factor for each pipe is 0.02.



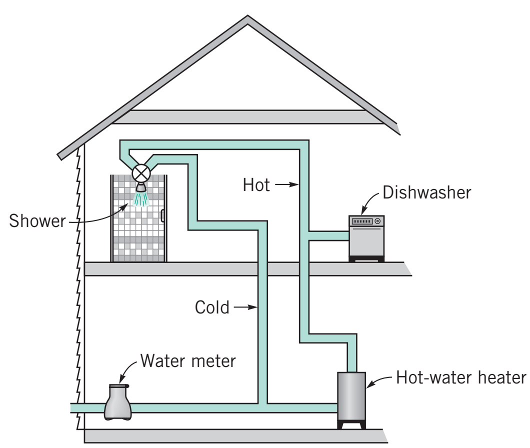
■ FIGURE P8.89

8.91 With the valve closed, water flows from tank A to tank B as shown in Fig. P8.91. What is the flowrate into tank B when the valve is opened to allow water to flow into tank C also? Neglect all minor losses and assume that the friction factor is 0.02 for all pipes.



■ FIGURE P8.91

†8.93 As shown in Fig. P8.93, cold water (T = 50 °F) flows from the water meter to either the shower or the hot-water heater. In the hot-water heater it is heated to a temperature of 150 °F. Thus, with equal amounts of hot and cold water, the shower is at a comfortable 100 °F. However, when the dishwasher is turned on, the shower water becomes too cold. Indicate how you would predict this new shower temperature (assume the shower faucet is not adjusted). State any assumptions needed in your analysis.



■ FIGURE P8.93

Section 8.6 Pipe Flowrate Measurement (also see Lab Problem 8.102)

8.95 Air to ventilate an underground mine flows through a large 2-m-diameter pipe. A crude flowrate meter is constructed by placing a sheet metal "washer" between two sections of the pipe. Estimate the flowrate if the hole in the sheet metal has a diameter of 1.6 m and the pressure difference across the sheet metal is 8.0 mm of water.

8.97 A 2.5-in.-diameter nozzle meter is installed in a 3.8-in.-diameter pipe that carries water at 160 °F. If the inverted air–water U-tube manometer used to measure the pressure difference across the meter indicates a reading of 3.1 ft, determine the flowrate.

8.99 A 2-in.-diameter orifice plate is inserted in a 3-in.-diameter pipe. If the water flowrate through the pipe is 0.70 cfs, determine the pressure difference indicated by a manometer attached to the flowmeter.

8.101 Water flows through the orifice meter shown in Fig. P8.100 at a rate of 0.10 cfs. If $h = 3.8$ ft, determine the value of d.

■ Lab Problems

8.103 This problem involves the determination of the friction factor in a pipe for laminar and transitional flow conditions. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

8.105 This problem involves the flow of water from a tank and through a pipe system. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

8.107 This problem involves the pressure distribution in the entrance region of a pipe. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

8.109 The field of bioengineering has undergone significant growth in recent years. Some universities have undergraduate and graduate programs in this field. Bioengineering applies engineering principles to help solve problems in the medical field for human health. Obtain information about bioengineering applications in blood flow. Summarize your findings in a brief report.

8.111 As discussed in Sec. 8.4.2, flow separation in pipes can lead to losses (we will also see in Chapter 9 that external flow separation is a significant problem). For external flows, there have been many mechanisms devised to help mitigate and control flow separation from the surface (e.g., from the wing of an airplane). Investigate either passive or active flow control mechanisms that can reduce or eliminate internal flow separation (e.g., flow separation in a diffuser). Summarize your findings in a brief report.

■ FlowLab Problems

***8.113** This FlowLab problem involves investigation of the centerline pressure distribution along a pipe. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

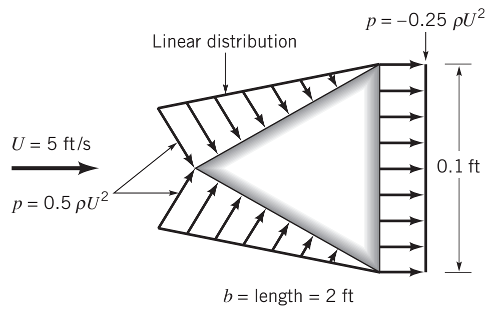
***8.115** This FlowLab problem involves investigation of pressure drop in the entrance region of a pipe as a function of Reynolds number as well as comparing simulation results to analytic values. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

***8.117** This FlowLab problem involves conducting a parametric study on the effects of a sudden pipe expansion on the overall pressure drop in a pipe. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

Chapter 9

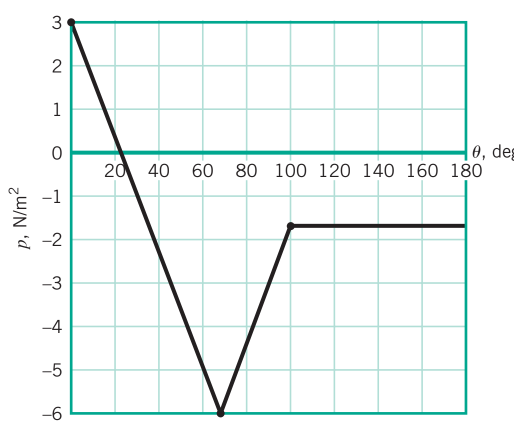
Section 9.1 General External Flow Characteristics

9.1 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

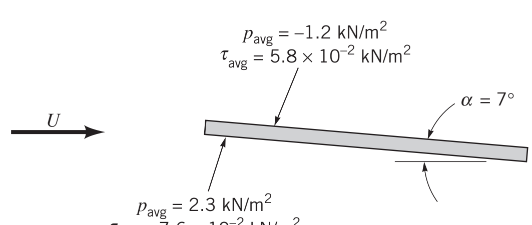
9.3 A 0.10-m-diameter circular cylinder moves through air with a speed U. The pressure distribution on the cylinder's surface is approximated by the three straight-line segments shown in Fig. P9.3. Determine the drag on the cylinder. Neglect shear forces.



■ FIGURE P9.3

†9.5 Estimate the Reynolds numbers associated with the following objects moving through air: **(a)** a snowflake settling to the ground, **(b)** a mosquito, **(c)** the Space Shuttle, **(d)** you walking.

9.7 The average pressure and shear stress acting on the surface of the 1-m-square flat plate are as indicated in Fig. P9.7.



■ FIGURE P9.7

Determine the lift and drag generated. Determine the lift and drag if the shear stress is neglected. Compare these two sets of results.

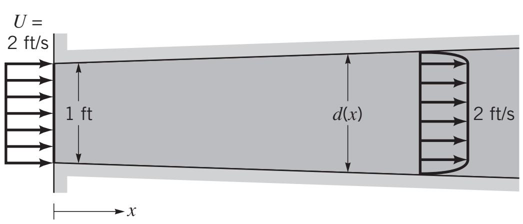
Section 9.2 Boundary Layer Characteristics (also see Lab Problems 9.89 and 9.90)

9.9 A 17-ft-long kayak moves with a speed of 5 ft/s (see **Video V9.2**). Would a boundary layer type flow be developed along the sides of the boat? Explain.

9.11 **(a)** 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. **(b)** If the upstream velocity of the flow in part (a) is $U = 1.5$ m/s, determine the kinematic viscosity of the fluid.

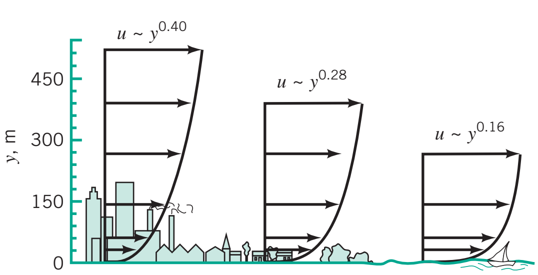
9.13 Water flows past a flat plate that is oriented parallel to the flow with an upstream velocity of 0.5 m/s. Determine the approximate location downstream from the leading edge where the boundary layer becomes turbulent. What is the boundary layer thickness at this location?

9.15 Air enters a square duct through a 1-ft opening as shown in Fig. P9.15. 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 $U = 2$ ft/s velocity is to be maintained outside the boundary layer. Plot a graph of the duct size, d, as a function of x for $0 \le x \le 10$ ft if U is to remain constant. Assume laminar flow.



■ FIGURE P9.15

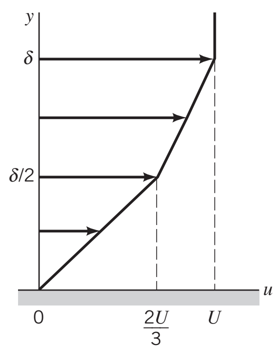
9.17 An atmospheric boundary layer is formed when the wind blows over the earth's surface. Typically, such velocity profiles can be written as a power law: $u = ay^n$, where the constants a and n depend on the roughness of the terrain. As indicated in Fig. P9.17, typical values are $n = 0.40$ for urban areas, $n = 0.28$ for woodland or suburban areas, and $n = 0.16$ for flat open country. **(a)** If the velocity is 20 ft/s at the bottom of the sail on your boat ($y = 4$ ft), what is the velocity at the top of the mast ($y = 30$ ft)? **(b)** If the average velocity is 10 mph on the 10th floor of an urban building, what is the average velocity on the 60th floor?



■ FIGURE P9.17

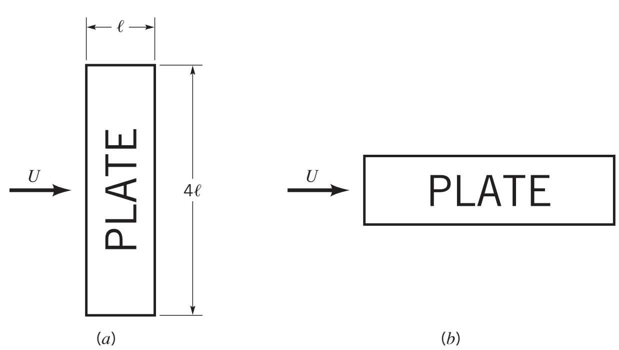
†9.19 If the boundary layer on the hood of your car behaves as one on a flat plate, estimate how far from the front edge of the hood the boundary layer becomes turbulent. How thick is the boundary layer at this location?

9.21 A laminar boundary layer velocity profile is approximated by the two straight-line segments indicated in Fig. P9.21. 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 Eqs. 9.8 and 9.11.



■ FIGURE P9.21

9.23 A plate is oriented parallel to the free stream as is indicated in Fig. 9.23. If the boundary layer flow is laminar, determine the ratio of the drag for case a to that for case b. Explain your answer physically.



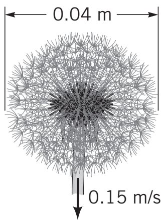
■ FIGURE P9.23

9.25 It is relatively easy to design an efficient nozzle to accelerate a fluid. Conversely, it is very difficult to build an efficient diffuser to decelerate a fluid without boundary layer separation and its subsequent inefficient flow behavior. Use the ideas of favorable and adverse pressure gradients to explain these facts.

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

Section 9.3 Drag

9.29 The 5×10^{-6} kg dandelion seed shown in Fig. P9.29 settles through the air with a constant speed of 0.15 m/s. Determine the drag coefficient for this object.



■ **FIGURE P9.29**

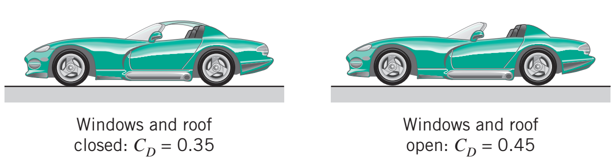
9.31 Compare the rise velocity of an $\frac{1}{8}$-in.-diameter air bubble in water to the fall velocity of an $\frac{1}{8}$-in.-diameter water drop in air. Assume each to behave as a solid sphere.

9.33 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.

9.35 Define the purpose of "streamlining" a body.

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

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 65 mph with the windows and roof closed? Assume the frontal area remains the same. Recall that power is force times velocity.



■ **FIGURE P9.39**

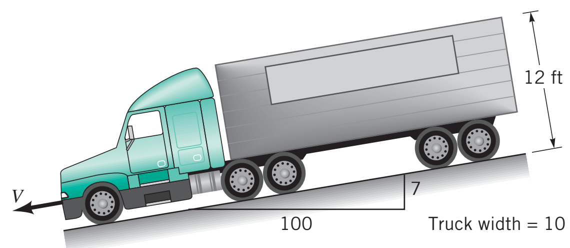
9.41 A logging boat is towing a log that is 2 m in diameter and 8 m long at 4 m/s through water. Estimate the power required if the axis of the log is parallel to the low direction.

9.43 Determine the moment needed at the base of a 30-m-tall, 0.12-m-diameter flagpole to keep it in place in a 20-m/s wind.

9.45 If for a given vehicle it takes 20 hp to overcome aerodynamic drag while being driven at 55 mph, estimate the horsepower required at 65 mph.

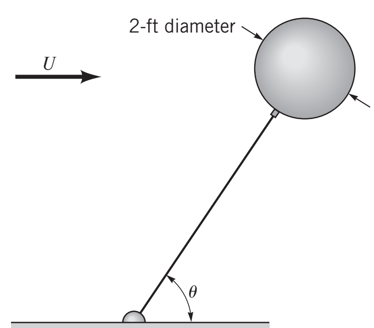
9.47 On a day without any wind, your car consumes x gallons of gasoline when you drive at a constant speed, U, from point A to point B and back to point A. Assume that you repeat the journey, driving at the same speed, on another day when there is a steady wind blowing from B to A. Would you expect your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

9.49 A 25-ton (50,000-lb) truck coasts down a steep 7% mountain grade without brakes, as shown in Fig. P9.49. The truck's ultimate steady-state speed, V, is determined by a balance among weight, rolling resistance, and aerodynamic drag. Assume that the rolling resistance for a truck on concrete is 1.2% of the weight and the drag coefficient is 0.96 for a truck without an air deflector but 0.70 if it has an air deflector (see **Video V9.13**). Determine V for these two situations.



■ **FIGURE P9.49**

***9.51** The helium-filled balloon shown in Fig. P9.51 is to be used as a wind speed indicator. The specific weight of the helium is $\gamma = 0.011$ lb/ft^3, the weight of the balloon material is 0.20 lb, and the weight of the anchoring cable is negligible. Plot a graph of θ as a funtion of U for $1 \leq U \leq 50$ mph. Would this be an effective device over the range of U indicated? Explain.



■ **FIGURE P9.51**

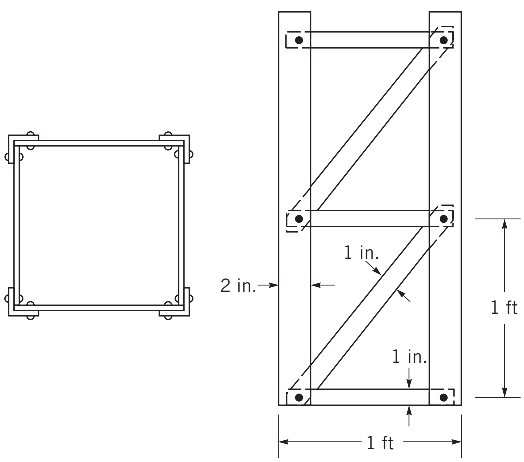
9.53 A 22 × 34-in. speed limit sign is supported on a 3-in.-wide, 5-ft-long pole. Estimate the bending moment in the pole at ground level when a 30-mph wind blows against the sign. (See **Video V9.9.**) List any assumptions used in your calculations.

9.55 A rectangular cartop carrier of 1.6-ft height, 5.0-ft length (front to back), and 4.2-fit width is attached to the top of a car. Estimate the additional power required to drive the car with the carrier at 60 mph through still air compared with the power required to drive only the car at 60 mph.

9.57 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.

9.59 How much more power is required to pedal a bicycle at 15 mph into a 20-mph headwind than at 15 mph through still air? Assume a frontal area of 3.9 ft^2 and a drag coefficient of $C_D = 0.88$.

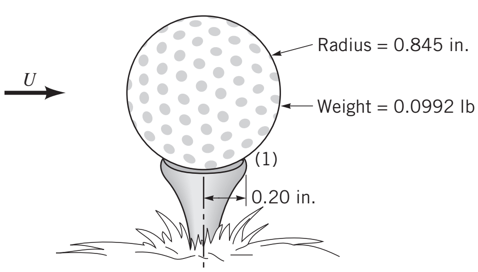
9.61 A 30-ft-tall tower is constructed of equal 1-ft segments as is indicated in Fig. P9.61. Each of the four sides is similar. Estimate the drag on the tower when a 75-mph wind blows against it.



■ **FIGURE P9.61**

9.63 A hot-air balloon roughly spherical in shape has a volume of 70,000 ft^3 and a weight of 500 lb (including passengers, basket, balloon fabric, etc.). If the outside air temperature is 80 °F and the temperature within the balloon is 165 °F, estimate the rate at which it will rise under steady-state conditions if the atmospheric pressure is 14.7 psi.

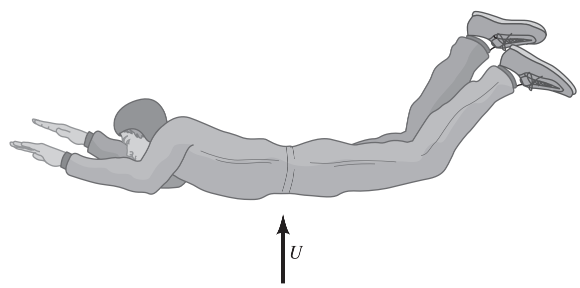
9.65 A strong wind can blow a golf ball off the tee by pivoting it about point 1 as shown in Fig. P9.65. Determine the wind speed necessary to do this.



■ **FIGURE P9.65**

9.67 (See Fluids in the News article titled "At 12,600 mpg 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 (6-ft^2 cross section), streamlined ($C_D = 0.12$) vehicle traveling 15 mph. **(b)** Compare the power calculated in part **(a)** with that for a large (36-ft^2 cross-sectional area), nonstreamlined ($C_D = 0.48$) SUV traveling 65 mph on the interstate.

9.69 As shown in **Video V9.7** and Fig. P9.69, a vertical wind tunnel can be used for skydiving practice. Estimate the vertical wind speed needed if a 150-lb 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.

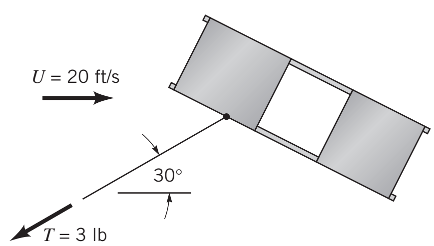


■ **FIGURE P9.69**

9.71 A fishnet consists of 0.10-in.–diameter strings tied into squares 4 in. per side. Estimate the force needed to tow a 15-ft by 30-ft section of this net through seawater at 5 ft/s.

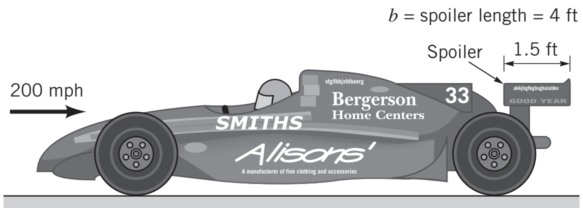
Section 9.4 Lift

9.73 When the 0.9-lb box kite shown in Fig. P9.73 is flown in a 20-ft/s wind, the tension in the string, which is at a 30° angle relative to the ground, is 3.0 lb. **(a)** Determine the lift and drag coefficients for the kite based on the frontal area of 6.0 ft^2. **(b)** If the wind speed increased to 30 ft/s, would the kite rise or fall? That is, would the 30° angle shown in the figure increase or decrease? Assume the lift and drag coefficients remain the same. Support your answer with appropriate calculations.



■ **FIGURE P9.73**

9.75 As shown in **Video V9.19** and Fig. P9.75, 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 200 mph, 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 P9.75

9.77 Explain why aircraft and birds take off and land into the wind.

9.79 Commercial airliners normally cruise at relatively high altitudes (30,000 to 35,000 ft). Discuss how flying at this high altitude (rather than 10,000 ft, for example) can save fuel costs.

9.81 If the takeoff speed of a particular airplane is 120 mi/hr at sea level, what will it be at Denver (elevation 5000 ft)? Use properties of the U.S. Standard Atmosphere.

9.83 **(a)** Show that for unpowered flight (for which the lift, drag, and weight forces are in equilibrium) the glide slope angle, θ, is given by $\tan\theta = C_D/C_L$. **(b)** If the lift coefficient for a Boeing 757 aircraft is 16 times greater than its drag coefficient, can it glide from an altitude of 30,000 ft to an airport 60 mi away if it loses power from its engines? Explain.

9.85 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 110 °F compared to a day when it is 50 °F? Assume the atmospheric pressure remains constant.

9.87 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 data given in the following table to determine the lift coefficient for each of the aircraft listed.

Aircraft	Year	$\mathcal{W}$ (lb)	U (mph)	$\mathcal{W}/A$ (lb/ft^2)	h (ft)
Wright Flyer	1903	750	35	1.5	0
Douglas DC-3	1935	25,000	180	25.0	10,000
Douglas DC-6	1947	105,000	315	72.0	15,000
Boeing 747	1970	800,000	570	150.0	30,000

■ Lab Problems

9.89 This problem involves measuring the boundary layer profile on a flat plate. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

9.91 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.

9.93 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 in 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.

■ FlowLab Problems

***9.95** This FlowLab problem involves investigation of the effects of angle of attack on lift and drag for flow past an airfoil. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

***9.97** This FlowLab problem involves comparison between inviscid and viscous flows past an airfoil. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

***9.99** This FlowLab problem involves comparing CFD predictions and theoretical values of the drag coefficient of flow past a cylinder. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

Chapter 10

Section 10.2 Surface Waves

10.1 The flowrate in a 10-ft-wide, 2-ft-deep river is Q = 190 cfs. Is the flow subcritical or supercritical?

10.3 Waves on the surface of a tank are observed to travel at a speed of 2 m/s. How fast would these waves travel if **(a)** the tank were in an elevator accelerating upward at a rate of 4 m/s^2, **(b)** the tank accelerated horizontally at a rate of 9.81 m/s^2, and **(c)** the tank were aboard the orbiting Space Shuttle. Explain.

10.5 A rectangular channel 3 m wide carries 10 m^3/s at a depth of 2 m. Is the flow subcritical or supercritical? For the same flowrate, what depth will give critical flow?

10.7 Often when an earthquake shifts a segment of the ocean floor, a relatively small-amplitude wave of very long wavelength is produced. Such waves go unnoticed as they move across the open ocean: Only when they approach the shore do they become dangerous (e.g., a tsunami or as often miscalled, a "tidal wave"). Determine the wave speed if the wavelength, λ, is 6000 ft and the ocean depth is 15,000 ft.

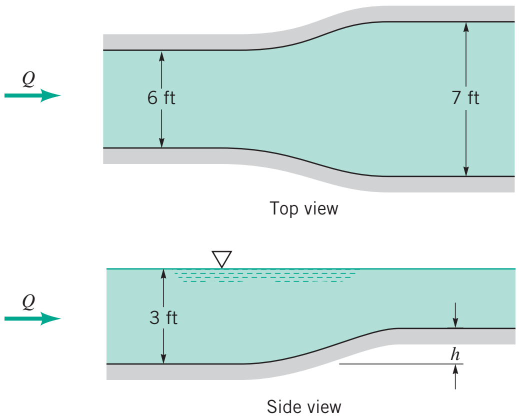
10.9 (See Fluids in the News article titled "Tsunami, the nonstorm wave," Section 10.2.1.) An earthquake causes a shift in the ocean floor that produces a tsunami with a wavelength of 100 km. How fast will this wave travel across the ocean surface if the ocean depth is 3000 m?

Section 10.3 Energy Considerations

***10.11** Water flows in a rectangular channel with a specific energy of E = 5 ft. If the flowrate per unit width is q = 30 ft^2/s, determine the two possible flow depths and the corresponding

Froude numbers. Plot the specific energy diagram for this flow. Repeat the problem for $E = 1$, 2, 3, and 4 ft.

10.13 A smooth transition section connects two rectangular channels as shown in Fig. 10.13. The channel width increases from 6.0 to 7.0 ft and the water surface elevation is the same in each channel. If the upstream depth of flow is 3.0 ft, determine h, the amount the channel bed needs to be raised across the transition section to maintain the same surface elevation.

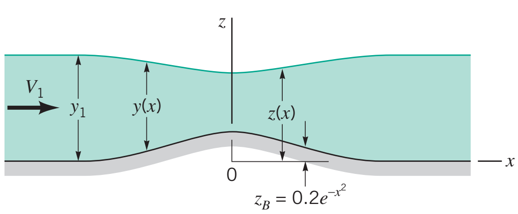


■ **FIGURE P10.13**

10.15 Repeat Problem 10.14 if the upstream depth is $y_1 = 0.5$ ft.

10.17 Repeat Problem 10.16 if the upstream depth is $y_1 = 0.5$ ft. Assume that there are no losses between sections (1) and (2).

***10.19** Water flows over the bump in the bottom of the rectangular channel shown in Fig. P10.19 with a flowrate per unit width of $q = 4\ \text{m}^2/\text{s}$. The channel bottom contour is given by $z_B = 0.2e^{-x^2}$, where z_B and x are in meters. The water depth far upstream of the bump is $y_1 = 2$ m. Plot a graph of the water depth, $y = y(x)$, and the surface elevation, $z = z(x)$, for $-4\ \text{m} \leq x \leq 4$ m. Assume one-dimensional flow.



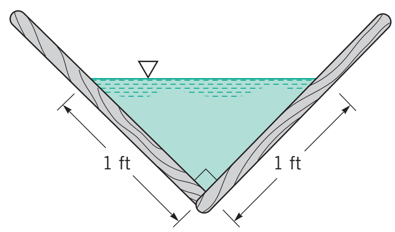
■ **FIGURE P10.19**

Section 10.4 Uniform Depth Channel Flow—Determine Flowrate

10.21 Water flows in a 10-ft-wide rectangular channel with a flowrate of 200 cfs and a depth of 3 ft. If the slope is 0.005, determine the Manning coefficient, n, and the average shear stress at the sides and bottom of the channel.

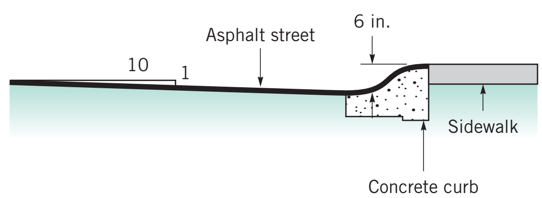
10.23 (See Fluids in the News article titled "Done without a GPS or lasers," Section 10.4.2.) Determine the number of gallons of water delivered per day by a rubble masonary, 1.2-m-wide aqueduct laid on an average slope of 14.6 m per 50 km if the water depth is 1.8 m.

10.25 The great Kings River flume in Fresno County, California, was used from 1890 to 1923 to carry logs from an elevation of 4500 ft where trees were cut to an elevation of 300 ft at the railhead. The flume was 54 miles long, constructed of wood, and had a V cross section as indicated in Fig. P10.25. It is claimed that logs would travel the length of the flume in 15 hr. Do you agree with this claim? Provide appropriate calculations to support your answer.



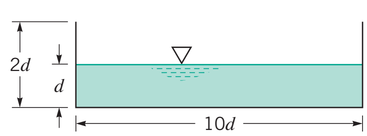
■ **FIGURE P10.25**

10.27 Rainwater flows down a street whose cross section is shown in Fig. P10.27. The street is on a hill at an angle of 2°. Determine the maximum flowrate possible if the water is not to overflow onto the sidewalk.



■ **FIGURE P10.27**

10.29 Water flows in a channel as shown in Fig. P10.29. The velocity is 4.0 ft/s when the channel is half full with depth d. Determine the velocity when the channel is completely full, depth $2d$.

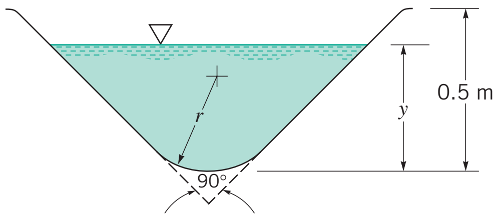


■ **FIGURE P10.29**

10.31 Water flows in a weedy earthen channel at a rate of $30\ \text{m}^3/\text{s}$. What flowrate can be expected if the weeds are removed and the depth remains constant?

10.33 Because of neglect, an irrigation canal has become weedy and the maximum flowrate possible is only 90% of the desired flowrate. Would removing the weeds, thus making the surface gravel, allow the canal to carry the desired flowrate? Support your answer with appropriate calculations.

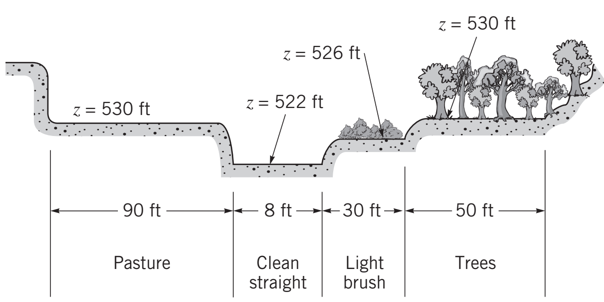
***10.35** Water flows in the fiberglass ($n = 0.014$) triangular channel with a round bottom shown in Fig. P10.35. The channel slope is 0.1 m/90 m. Plot a graph of flowrate as a function of



■ **FIGURE P10.35**

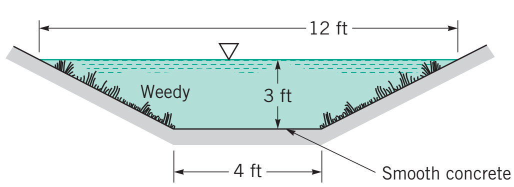
water depth for $0 \leq y \leq 0.50$ with bottom radii of $r = 0, 0.25, 0.50, 0.75$, and 1.0 m.

***10.37** The cross section of a creek valley is shown in Fig. P10.37. Plot a graph of flowrate as a function of depth, *y*, for $0 \leq y \leq 10$ ft. The slope is 5 ft/mi.



■ **FIGURE P10.37**

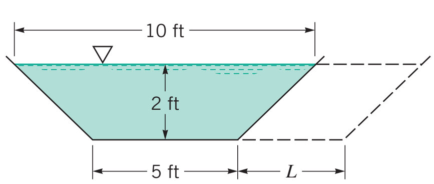
10.39 Determine the flowrate for the symmetrical channel shown in Fig. P10.39 if the bottom is smooth concrete and the sides are weedy. The bottom slope is $S_0 = 0.001$.



■ **FIGURE P10.39**

Section 10.4 Uniform Depth Channel Flow—Determine Depth or Size

10.41 (See Fluids in the News article titled "Plumbing the Everglades," Section 10.4.3.) The canal shown in Fig. P10.41 is to be widened so that it can carry twice the amount of water. Determine the additional width, *L*, required if all other parameters (i.e., flow depth, bottom slope, surface material, side slope) are to remain the same.



■ **FIGURE P10.41**

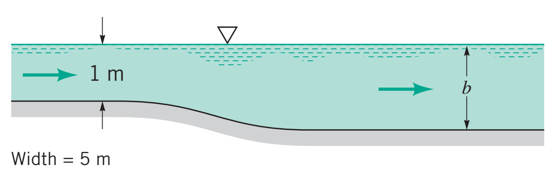
10.43 An engineer is to design a channel lined with planed wood to carry water at a flowrate of 2 m^3/s on a slope of 10 m/800 m. The channel cross section can be either a 90° triangle or a rectangle with a cross section twice as wide as its depth. Which would require less wood and by what percent?

10.45 A smooth steel water slide at an amusement park is of semicircular cross section with a diameter of 2.5 ft. The slide descends a vertical distance of 35 ft in its 420-ft length. If pumps supply water to the slide at a rate of 6 cfs, determine the depth of flow. Neglect the effects of the curves and bends of the slide.

10.47 An old, rough-surfaced, 2-m-diameter concrete pipe with a Manning coefficient of 0.025 carries water at a rate of 5.0 m^3/s when it is half full. It is to be replaced by a new pipe with a Manning coefficient of 0.012 that is also to flow half full at the same flowrate. Determine the diameter of the new pipe.

10.49 A circular finished concrete culvert is to carry a discharge of 50 ft^3/s on a slope of 0.0010. It is to flow not more than half full. The culvert pipes are available from the manufacturer with diameters that are multiples of 1 ft. Determine the smallest suitable culvert diameter.

10.51 Water flows uniformly at a depth of 1 m in a channel that is 5 m wide, as shown in Fig. P10.51. Further downstream the channel cross section changes to that of a square of width and height *b*. Determine the value of *b* if the two portions of this channel are made of the same material and are constructed with the same bottom slope.

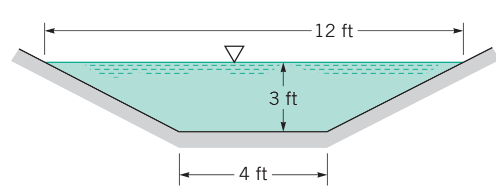


■ **FIGURE P10.51**

Section 10.4 Uniform Depth Channel Flow—Determine Slope

10.53 Water flows 1 m deep in a 2-m wide finished concrete channel. Determine the slope if the flowrate is 3 m^3/s.

10.55 To prevent weeds from growing in a clean earthen-lined canal, it is recommended that the velocity be no less than 2.5 ft/s. For the symmetrical canal shown in Fig. P10.55, determine the minimum slope needed.



■ **FIGURE P10.55**

10.57 The symmetrical channel shown in Fig. P10.55 is dug in sandy loam soil with $n = 0.020$. For such surface material it is recommended that to prevent scouring of the surface the average velocity be no more than 1.75 ft/s. Determine the maximum slope allowed.

Section 10.6.1 The Hydraulic Jump (also see Lab Problems 10.83 and 10.84)

10.59 A hydraulic jump at the base of a spillway of a dam is such that the depths upstream and downstream of the jump are 0.90 and 3.6 m, respectively (see **Video V10.11**). If the spillway is 10 m wide, what is the flowrate over the spillway?

10.61 The water depths upstream and downstream of a hydraulic jump are 0.3 and 1.2 m, respectively. Determine the upstream velocity and the power dissipated if the channel is 50 m wide.

10.63 At a given location in a 12-ft-wide rectangular channel the flowrate is 900 ft^3/s and the depth is 4 ft. Is this location upstream or downstream of the hydraulic jump that occurs in this channel? Explain.

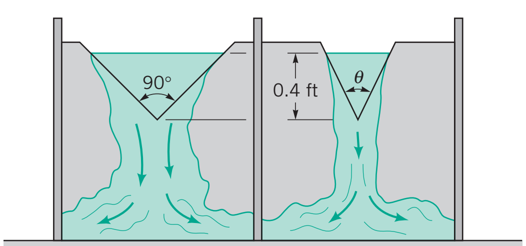
10.65 Water flows in a 2-ft-wide rectangular channel at a rate of 10 ft^3/s. If the water depth downstream of a hydraulic jump is 2.5 ft, determine **(a)** the water depth upstream of the jump, **(b)** the upstream and downstream Froude numbers, and **(c)** the head loss across the jump.

10.67 Determine the head loss and power dissipated by the hydraulic jump of Problem 10.59.

Section 10.6 Weirs (also see Lab Problems 10.81 and 10.82)

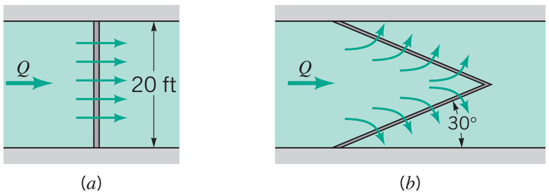
10.69 Water flows over a 5-ft-wide rectangular sharp-crested weir that is $P_w = 4.5$ ft tall. If the depth upstream is 5 ft, determine the flowrate.

10.71 Water flows from a storage tank, over two triangular weirs, and into two irrigation channels as shown in **Video V10.13** and Fig. P10.71. The head for each weir is 0.4 ft, and the flowrate in the channel fed by the 90° V-notch weir is to be twice the flowrate in the other channel. Determine the angle θ for the second weir.



■ **FIGURE P10.71**

10.73 **(a)** The rectangular sharp-crested weir shown in Fig. P10.73*a* is used to maintain a relatively constant depth in the channel upstream of the weir. How much deeper will the water be upstream of the weir during a flood when the flowrate is 45 ft^3/s compared to normal conditions when the flowrate is 30 ft^3/s? Assume the weir coefficient remains constant at $C_{wr} = 0.62$. **(b)** Repeat the calculations if the weir of part **(a)** is replaced by a rectangular sharp-crested "duck bill" weir that is oriented at an angle of 30° relative to the channel centerline as shown in Fig. P10.73*b*. The weir coefficient remains the same.



■ **FIGURE P10.73**

10.75 Determine the flowrate per unit width, *q,* over a broad-crested weir that is 2.0 m tall if the head, *H,* is 0.50 m.

10.77 Water flows in a rectangular channel of width $b = 20$ ft at a rate of 100 ft^3/s. The flowrate is to be measured by using either a rectangular weir of height $P_w = 4$ ft or a triangular ($\theta = 90°$) sharp-crested weir. Determine the head, *H*, necessary for each weir. If measurement of the head is accurate to only ± 0.04 ft, determine the accuracy of the measured flowrate expected for each of the weirs. Which weir would be more accurate? Explain.

10.79 Water flows under a sluice gate in a channel of 10-ft width. If the upstream depth remains constant at 5 ft, plot a graph of flowrate as a function of the distance between the gate and the channel bottom as the gate is slowly opened. Assume free outflow.

■ Lab Problems

10.81 This problem involves the calibration of a triangular weir. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

10.83 This problem involves the depth ratio across a hydraulic jump. To proceed with this problem, go to the book's web site, www.wiley.com/college/young, or *WileyPLUS*.

■ Lifelong Learning Problems

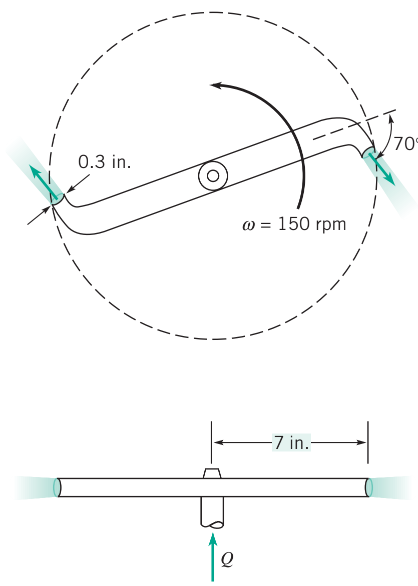
10.85 With the increased usage of low-lying coastal areas and the possible rise in ocean levels because of global warming, the potential for widespread damage from tsunamis is increasing. Obtain information about new and improved methods available to predict the occurrence of these damaging waves and how to better use coastal areas so that massive loss of life and property does not occur. Summarize your findings in a brief report.

10.87 Hydraulic jumps are normally associated with water flowing in rivers, gullies, and other such relatively high-speed open channels. However, recently, hydraulic jumps have been used in various manufacturing processes involving fluids other than water (such as liquid metal solder) in relatively small-scale flows. Obtain information about new manufacturing processes that involve hydraulic jumps as an integral part of the process. Summarize your findings in a brief report.

Chapter 11

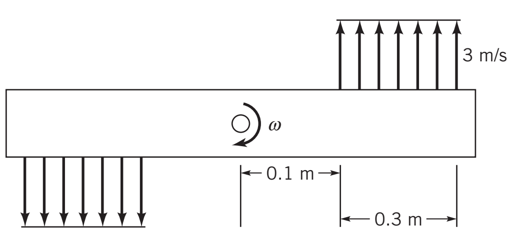
Section 11.3 Basic Angular Momentum Considerations

11.1 Water flows through a rotating sprinkler arm as shown in Fig. P11.1 and **Video V11.2.** Determine the flowrate if the angular velocity is 150 rpm. Friction is negligible. Is this a turbine or a pump? What is the maximum angular velocity for this flowrate?



■ FIGURE P11.1

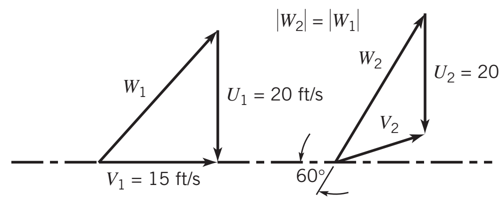
11.3 Uniform horizontal sheets of water of 3-mm thickness issue from the slits on the rotating manifold shown in Fig. P11.3. The velocity relative to the arm is a constant 3 m/s along each slit. Determine the torque needed to hold the manifold stationary. What would the angular velocity of the manifold be if the resisting torque is negligible?



■ FIGURE P11.3

11.5 At a given radial location, a 15 ft/s wind against a windmill (see **Video V11.1**) results in the upstream (1) and downstream (2) velocity triangles shown in Fig. P11.5. Sketch an appropriate blade section at that radial location and determine the energy transferred per unit mass of fluid.

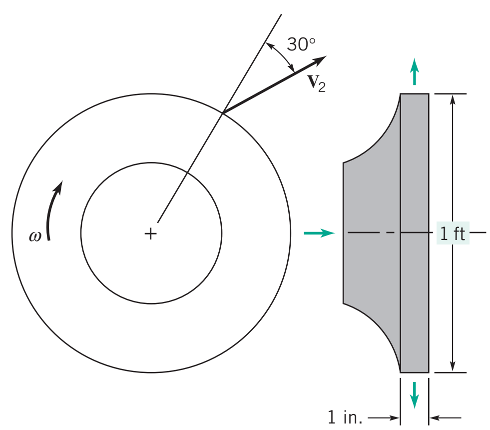
11.7 Obtain a schematic of a torque converter and briefly explain how it works.



■ FIGURE P11.5

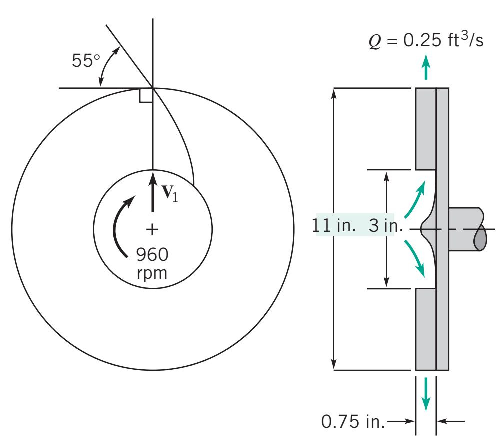
Section 11.4 The Centrifugal Pump

11.9 A centrifugal pump impeller is rotating at 1200 rpm in the direction shown in Fig. P11.9. The flow enters parallel to the axis of rotation and leaves at an angle of 30° to the radial direction. The absolute exit velocity, V_2, is 90 ft/s. **(a)** Draw the velocity triangle for the impeller exit flow. **(b)** Estimate the torque necessary to turn the impeller if the fluid density is 2.0 slugs/ft^3. What will the impeller rotation speed become if the shaft breaks?



■ FIGURE P11.9

11.11 A centrifugal radial water pump has the dimensions shown in Fig. P11.11. The volume rate of flow is 0.25 ft^3/s, and the absolute inlet velocity is directed radially outward. The angular velocity of the impeller is 960 rpm. The exit velocity as seen from a coordinate system attached to the impeller can be



■ FIGURE P11.11

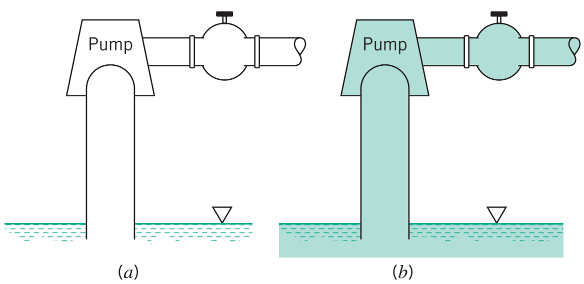
assumed to be tangent to the vane at its trailing edge. Calculate the power required to drive the pump.

11.13 The performance characteristics of a certain centrifugal pump having a 9-in.-diameter impeller and operating at 1750 rpm are determined using an experimental setup similar to that shown in Fig. 11.11. The following data were obtained during a series of tests in which $z_2 - z_1 = 0$, $V_2 = V_1$, and the fluid was water.

Q (gpm)	20	40	60	80	100	120	140
$p_2 - p_1$ (psi)	40.2	40.1	38.1	36.2	33.5	30.1	25.8
Power input (hp)	1.58	2.27	2.67	2.95	3.19	3.49	4.00

Based on these data, show or plot how the actual head rise, h_p, and the pump efficiency, η, vary with the flowrate. What is the design flowrate for this pump?

11.15 The centrifugal pump shown in Fig. P11.15 is not self-priming. That is, if the water is drained from the pump and pipe as shown in Fig. P11.15*a*, the pump will not draw the water into the pump and start pumping when the pump is turned on. However, if the pump is primed (i.e., filled with water as in Fig. P11.15*b*), the pump does start pumping water when turned on. Explain this behavior.



■ FIGURE P11.15

11.17 A centrifugal pump having a head–capacity relationship given by the equation $h_p = 180 - 6.10 \times 10^{-4} Q^2$, with h_p in feet when Q is in gpm, is to be used with a system similar to that shown in Fig. 11.10. For $z_2 - z_1 = 50$ ft, what is the expected flowrate if the total length of a constant-diameter pipe is 600 ft and the fluid is water? Assume the pipe diameter to be 4 in. and the friction factor to be equal to 0.02. Neglect all minor losses.

11.19 A centrifugal pump having the characteristics shown in Example 11.3 is used to pump water between two large open tanks through 100 ft of 8-in.-diameter pipe. The pipeline contains four regular flanged 90° elbows, a check valve, and a fully open globe valve. Other minor losses are negligible. Assume the friction factor $f = 0.02$ for the 100-ft section of pipe. If the static head (difference in height of fluid surfaces in the two tanks) is 30 ft, what is the expected flowrate? Do you think this pump is a good choice? Explain.

†11.21 Water is pumped between the two tanks described in Example 11.3 once a day, 365 days a year, with each pumping period lasting 2 hr. The water levels in the two tanks remain essentially constant. Estimate the annual cost of the electrical power needed to operate the pump if it were located in your city. You will have to make a reasonable estimate for the efficiency of the motor used to drive the pump. Due to aging, it can be expected that the overall resistance of the system will increase with time. If the operating point shown in Fig. E11.3*c* changes to a point where the flowrate has been reduced to 1000 gpm, what will be the new annual cost of operating the pump? Assume the cost of electrical power remains the same.

Section 11.5 Dimensionless Parameters and Similarity Laws

11.23 A centrifugal pump provides a flowrate of 500 gpm when operating at 1760 rpm against a 200-ft head. Determine the pump's flowrate and developed head if the pump speed is increased to 3500 rpm.

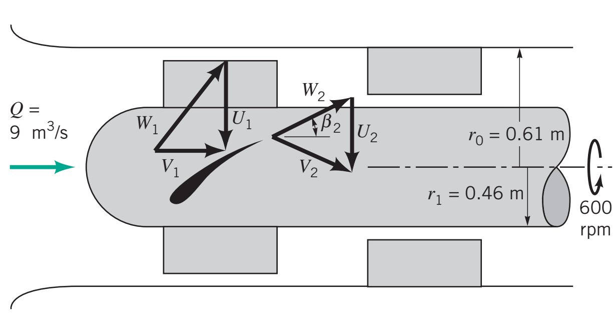
11.25 A centrifugal pump has the performance characteristics of the pump with the 6-in.-diameter impeller described in Fig. 11.9. Note that in Fig. 11.9 the pump is operating at 3500 rpm. What is the expected flowrate and head gain if the speed of this pump is reduced to 2800 rpm while operating at peak efficiency?

11.27 A certain pump is known to have a capacity of 3 m^3/s when operating at a speed of 60 rad/s against a head of 20 m. Based on the information in Fig. 11.13, would you recommend a radial-flow, mixed-flow, or axial-flow pump?

11.29 A centrifugal pump having an impeller diameter of 1 m is to be constructed so that it will supply a head rise of 200 m at a flowrate of 4.1 m^3/s of water when operating at a speed of 1200 rpm. To study the characteristics of this pump, a 1/5-scale, geometrically similar model operated at the same speed is to be tested in the laboratory. Determine the required model discharge and head rise. Assume both model and prototype operate with the same efficiency (and therefore the same flow coefficient).

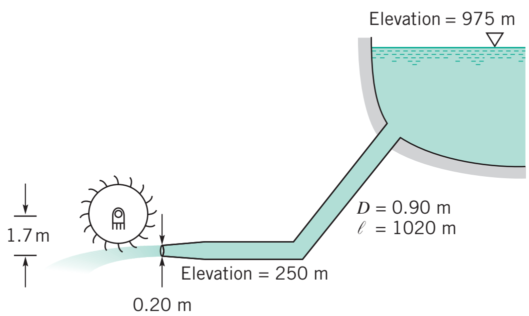
Section 11.7 Turbines

11.31 The single-stage, axial-flow turbomachine shown in Fig. P11.31 involves water flow at a volumetric flowrate of 9 m^3/s. The rotor revolves at 600 rpm. The inner and outer radii of the annular flow path through the stage are 0.46 and 0.61 m, and $\beta_2 = 60°$. The flow entering the rotor row and leaving the stator row is axial when viewed from the stationary casing. Is this device a turbine or a pump? Estimate the amount of power transferred to or from the fluid.



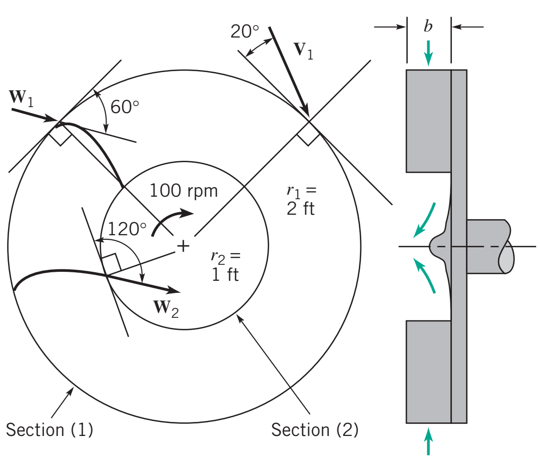
■ FIGURE P11.31

11.33 Water for a Pelton wheel turbine flows from the headwater and through the penstock as shown in Fig. P11.33. The effective friction factor for the penstock, control valves, and the like is 0.032 and the diameter of the jet is 0.20 m. Determine the maximum power output.



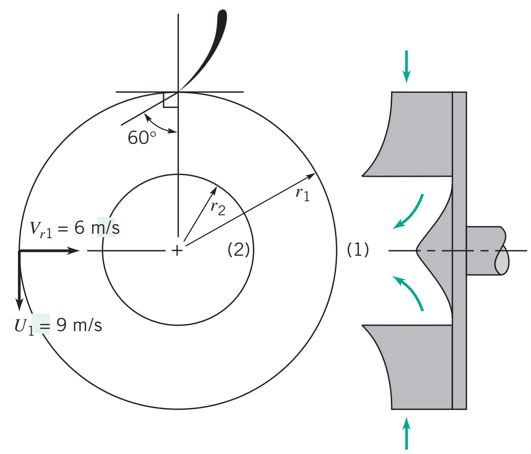
■ FIGURE P11.33

11.35 A water turbine wheel rotates at the rate of 100 rpm in the direction shown in Fig. P11.35. The inner radius, r_2, of the blade row is 1 ft, and the outer radius, r_1, is 2 ft. The absolute velocity vector at the turbine rotor entrance makes an angle of 20° with the tangential direction. The inlet blade angle is 60° relative to the tangential direction. The blade outlet angle is 120°. The flowrate is 10 ft^3/s. For the flow tangent to the rotor blade surface at inlet and outlet, determine an appropriate constant blade height, *b,* and the corresponding power available at the rotor shaft. Is the shaft power greater or less than the power lost by the fluid? Explain.



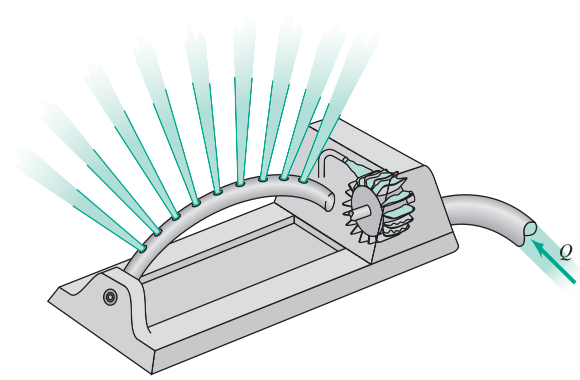
■ FIGURE P11.35

11.37 An inward flow radial turbine (see Fig. P11.37) involves a nozzle angle, α_1, of 60° and an inlet rotor tip speed, U_1, of 9 m/s. The ratio of rotor inlet to outlet diameters is 2.0. The radial component of velocity remains constant at 6 m/s through the rotor, and the flow leaving the rotor at section (2) is without angular momentum. If the flowing fluid is water and the stagnation pressure drop across the rotor is 110 kPa, determine the loss of available energy across the rotor and the efficiency involved.



■ FIGURE P11.37

11.39 A small Pelton wheel is used to power an oscillating lawn sprinkler as shown in **Video V11.4** and Fig. P11.39. The arithmetic mean radius of the turbine is 1 in., and the exit angle of the blade is 135° relative to the blade motion. Water is supplied through a single 0.20-in.-diameter nozzle at a speed of 50 ft/s. Determine the flowrate, the maximum torque developed, and the maximum power developed by this turbine.



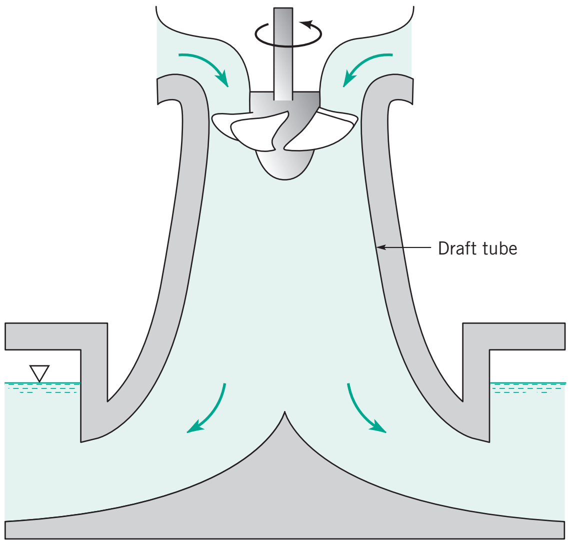
■ FIGURE P11.39

11.41 Water to run a Pelton wheel is supplied by a penstock of length ℓ and diameter D with a friction factor f. If the only losses associated with the flow in the penstock are due to pipe friction, show that the maximum power output of the turbine occurs when the nozzle diameter, D_1, is given by $D_1 = D/(2f\,\ell/D)^{1/4}$.

11.43 Draft tubes as shown in Fig. P11.43 are often installed at the exit of Kaplan and Francis turbines. Explain why such draft tubes are advantageous.

11.45 A 1-m-diameter Pelton wheel rotates at 300 rpm. Which of the following heads (in meters) would be best suited for this turbine: **(a)** 2, **(b)** 5, **(c)** 40, **(d)** 70, or **(e)** 140? Explain.

11.47 A high-speed turbine used to power a dentist's drill is shown in **Video V11.5** and Fig. E11.6. With the conditions stated in Example 11.6, for every slug of air that passes through the turbine there is 310,000 ft · lb of energy available at the shaft to drive



■ **FIGURE P11.43**

the drill. One of the assumptions made to obtain this numerical result is that the tangential component of the absolute velocity out of the rotor is zero. Suppose this assumption were not true (but all other parameter values remain the same). Discuss how and why the value of 310,000 ft · lb/slug would change for these new conditions.

†11.49 It is possible to generate power using the water from your garden hose to drive a small Pelton wheel turbine. (See **Video V11.4.**) Provide a preliminary design of such a turbine and estimate the power output expected. List all assumptions and show calculations.

■ Lifelong Learning Problems

11.51 What do you think are the major unresolved fluid dynamics problems associated with gas turbine engine compressors? For gas turbine engine high-pressure and low-pressure turbines? For gas turbine engine fans?

11.53 What are current efficiencies achieved by the following categories of turbomachines? **(a)** wind turbines; **(b)** hydraulic turbines; **(c)** power plant steam turbines; **(d)** aircraft gas turbine engines; **(e)** natural gas pipeline compressors; **(f)** home vacuum cleaner blowers; **(g)** laptop computer cooling fans; **(h)** irrigation pumps; **(i)** dentist drill air turbines. What is being done to improve these devices?