

G Review Problems

This section contains a set of Review Problems for each chapter. The problems for any chapter can be obtained by clicking on the desired chapter number below. In the problem statements, the phrases within parentheses refer to the main topics to be used in solving the problems. The answer to each problem accompanies the problem statement. Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© John Wiley and Sons, Inc.).

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Review Problems for Chapter 1

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

1.1R (Dimensions) During a study of a certain flow system the following equation relating the pressures p_1 and p_2 at two points was developed:

$$p_2 = p_1 + \frac{f\ell V}{Dg}$$

In this equation V is a velocity, ℓ the distance between the two points, D a diameter, g the acceleration of gravity, and f a dimensionless coefficient. Is the equation dimensionally consistent?

(ANS: No)

1.2R (Dimensions) If V is a velocity, ℓ a length, W a weight, and μ a fluid property having dimensions of $FL^{-2}T$, determine the dimensions of: (a) $V\ell W/\mu$, (b) $W\mu\ell$, (c) $V\mu/\ell$, and (d) $V\ell^2\mu/W$.

(ANS: L^4T^{-2} ; $F^2L^{-1}T$; FL^{-2} ; L)

1.3R (Units) Make use of Table 1.4 to express the following quantities in BG units: (a) 465 W, (b) 92.1 J, (c) 536 N/m², (d) 85.9 mm³, (e) 386 kg/m².

(ANS: $3.43 \times 10^2 \text{ ft} \cdot \text{lb/s}$; $67.9 \text{ ft} \cdot \text{lb}$; 11.2 lb/ft^2 ; $3.03 \times 10^{-6} \text{ ft}^3$; 2.46 slugs/ft^2)

1.4R (Units) A person weighs 165 lb at the earth's surface. Determine the person's mass in slugs, kilograms, and pounds mass.

(ANS: 5.12 slugs; 74.8 kg; 165 lbm)

1.5R (Specific gravity) Make use of Fig. 1.1 to determine the specific gravity of water at 22 and 89 °C. What is the specific volume of water at these two temperatures?

(ANS: 0.998; 0.966; $1.002 \times 10^{-3} \text{ m}^3/\text{kg}$; $1.035 \times 10^{-3} \text{ m}^3/\text{kg}$)

1.6R (Specific weight) A 1-ft-diameter cylindrical tank that is 5 ft long weighs 125 lb and is filled with a liquid having a specific weight of 69.6 lb/ft³. Determine the vertical force required to give the tank an upward acceleration of 9 ft/s².

(ANS: 509 lb up)

1.7R (Ideal gas law) Calculate the density and specific weight of air at a gage pressure of 100 psi and a temperature of 100 °F. Assume standard atmospheric pressure.

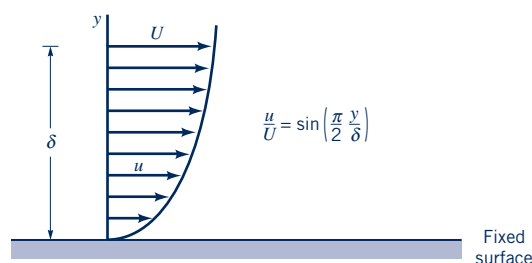
(ANS: $1.72 \times 10^{-2} \text{ slugs/ft}^3$; 0.554 lb/ft^3)

1.8R (Ideal gas law) A large dirigible having a volume of $90,000 \text{ m}^3$ contains helium under standard atmospheric conditions [pressure = 101 kPa (abs) and temperature = 15°C]. Determine the density and total weight of the helium.

(ANS: 0.169 kg/m^3 ; $1.49 \times 10^5 \text{ N}$)

1.9R (Viscosity) A Newtonian fluid having a specific gravity of 0.92 and a kinematic viscosity of $4 \times 10^{-4} \text{ m}^2/\text{s}$ flows past a fixed surface. The velocity profile near the surface is shown in Fig. P1.9R. Determine the magnitude and direction of the shearing stress developed on the plate. Express your answer in terms of U and δ , with U and δ expressed in units of meters per second and meters, respectively.

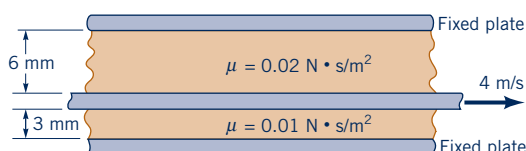
(ANS: $0.578 U/\delta \text{ N/m}^2$ acting to right on plate)



■ Figure P1.9R

1.10R (Viscosity) A large movable plate is located between two large fixed plates as shown in Fig. P1.10R. Two Newtonian fluids having the viscosities indicated are contained between the plates. Determine the magnitude and direction of the shearing stresses that act on the fixed walls when the moving plate has a velocity of 4 m/s as shown. Assume that the velocity distribution between the plates is linear.

(ANS: 13.3 N/m^2 in direction of moving plate)



■ Figure P1.10R

1.11R (Viscosity) Determine the torque required to rotate a 50-mm -diameter vertical cylinder at a constant angular velocity of 30 rad/s inside a fixed outer cylinder that has a diameter of 50.2 mm . The gap between the cylinders is filled with SAE 10 oil at 20°C . The length of the inner cylinder is 200 mm . Neglect bottom effects and assume the velocity distribution in the gap is linear. If the temperature of the oil increases to 80°C , what will be the percentage change in the torque?

(ANS: $0.589 \text{ N} \cdot \text{m}$; 92.0 percent)

1.12R (Bulk modulus) Estimate the increase in pressure (in psi) required to decrease a unit volume of mercury by 0.1% .

(ANS: $4.14 \times 10^3 \text{ psi}$)

1.13R (Bulk modulus) What is the isothermal bulk modulus of nitrogen at a temperature of 90°F and an absolute pressure of 5600 lb/ft^2 ?

(ANS: 5600 lb/ft^2)

1.14R (Speed of sound) Compare the speed of sound in mercury and oxygen at 20°C .

(ANS: $c_{\text{Hg}}/c_{\text{O}_2} = 4.45$)

1.15R (Vapor pressure) At a certain altitude it was found that water boils at 90°C . What is the atmospheric pressure at this altitude?

(ANS: 70.1 kPa (abs))

Review Problems for Chapter 2

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

2.1R (Pressure head) Compare the column heights of water, carbon tetrachloride, and mercury corresponding to a pressure of 50 kPa . Express your answer in meters.

(ANS: 5.10 m ; 3.21 m ; 0.376 m)

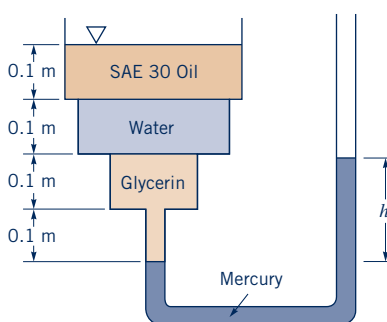
2.2R (Pressure–depth relationship) A closed tank is partially filled with glycerin. If the air pressure in the tank is 6 lb/in^2 and the depth of glycerin is 10 ft , what is the pressure in lb/ft^2 at the bottom of the tank?

(ANS: 1650 lb/ft^2)

2.3R (Gage–absolute pressure) On the inlet side of a pump a Bourdon pressure gage reads 600 lb/ft^2 vacuum. What is the corresponding absolute pressure if the local atmospheric pressure is 14.7 psia ?

(ANS: 10.5 psia)

2.4R (Manometer) A tank is constructed of a series of cylinders having diameters of 0.30 , 0.25 , and 0.15 m as shown in

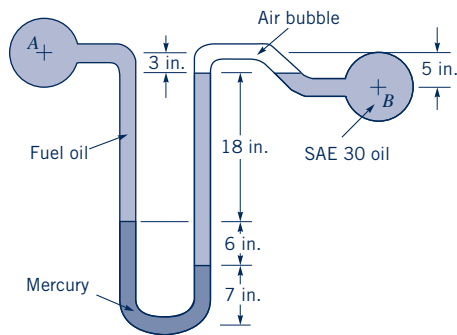


■ Figure P2.4R

Fig. P2.4R. The tank contains oil, water, and glycerin and a mercury manometer is attached to the bottom as illustrated. Calculate the manometer reading, h .

(ANS: 0.0327 m)

2.5R (Manometer) A mercury manometer is used to measure the pressure difference in the two pipelines of Fig. P2.5R. Fuel oil (specific weight = 53.0 lb/ft^3) is flowing in A and SAE

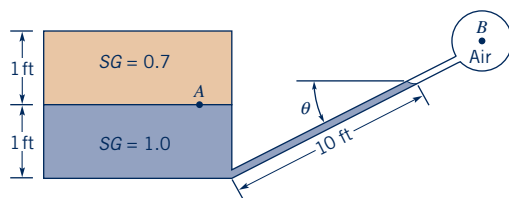
**Figure P2.5R**

30 lube oil (specific weight = 57.0 lb/ft^3) is flowing in B . An air pocket has become entrapped in the lube oil as indicated. Determine the pressure in pipe B if the pressure in A is 15.3 psi .

(ANS: 18.2 psi)

2.6R (Manometer) Determine the angle θ of the inclined tube shown in Fig. P2.6R if the pressure at A is 1 psi greater than that at B .

(ANS: 19.3 deg)

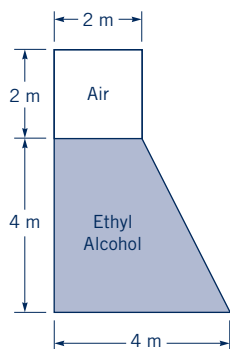
**Figure P2.6R**

2.7R (Force on plane surface) A swimming pool is 18 m long and 7 m wide. Determine the magnitude and location of the resultant force of the water on the vertical end of the pool where the depth is 2.5 m .

(ANS: 214 kN on centerline, 1.67 m below surface)

2.8R (Force on plane surface) The vertical cross section of a 7-m -long closed storage tank is shown in Fig. P2.8R. The tank contains ethyl alcohol and the air pressure is 40 kPa . Determine the magnitude of the resultant fluid force acting on one end of the tank.

(ANS: 847 kN)

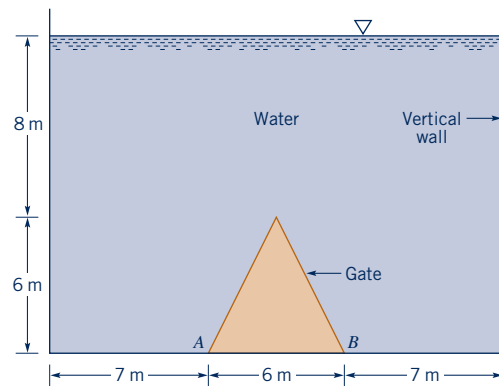
**Figure P2.8R**

2.9R (Center of pressure) A 3-ft -diameter circular plate is located in the vertical side of an open tank containing gasoline. The resultant force that the gasoline exerts on the plate acts 3.1 in. below the centroid of the plate. What is the depth of the liquid above the centroid?

(ANS: 2.18 ft)

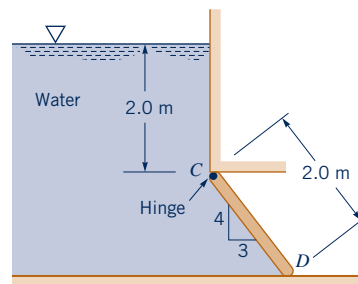
2.10R (Force on plane surface) A gate having the triangular shape shown in Fig. P2.10R is located in the vertical side of an open tank. The gate is hinged about the horizontal axis AB . The force of the water on the gate creates a moment with respect to the axis AB . Determine the magnitude of this moment.

(ANS: $3890 \text{ kN} \cdot \text{m}$)

**Figure P2.10R**

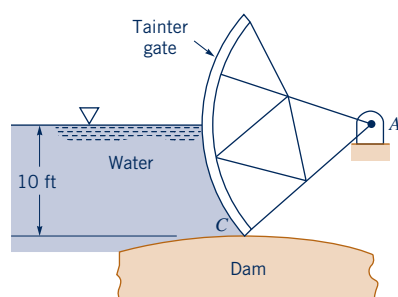
2.11R (Force on plane surface) The rectangular gate CD of Fig. P2.11R is 1.8 m wide and 2.0 m long. Assuming the material of the gate to be homogeneous and neglecting friction at the hinge C , determine the weight of the gate necessary to keep it shut until the water level rises to 2.0 m above the hinge.

(ANS: 180 kN)

**Figure P2.11R**

2.12R (Force on curved surface) A gate in the form of a partial cylindrical surface (called a *Tainter gate*) holds back water on top of a dam as shown in Fig. P2.12R. The radius of the surface is 22 ft , and its length is 36 ft . The gate can pivot about point A , and the pivot point is 10 ft above the seat, C . Determine the magnitude of the resultant water force on the gate. Will the resultant pass through the pivot? Explain.

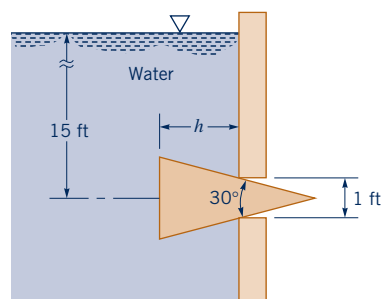
(ANS: $118,000 \text{ lb}$)



■ Figure P2.12R

2.13R (Force on curved surface) A conical plug is located in the side of a tank as shown in Fig. 2.13R. (a) Show that the horizontal component of the force of the water on the plug does not depend on h . (b) For the depth indicated, what is the magnitude of this component?

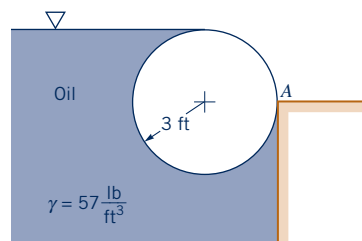
(ANS: 735 lb)



■ Figure P2.13R

2.14R (Force on curved surface) The 9-ft-long cylinder of Fig. P2.14R floats in oil and rests against a wall. Determine the horizontal force the cylinder exerts on the wall at the point of contact, A.

(ANS: 2300 lb)



■ Figure P2.14R

2.15R (Buoyancy) A hot-air balloon weighs 500 lb, including the weight of the balloon, the basket, and one person. The air outside the balloon has a temperature of 80 °F, and the heated air inside the balloon has a temperature of 150 °F. Assume the inside and outside air to be at standard atmospheric pressure of 14.7 psia. Determine the required volume of the balloon to support the weight. If the balloon had a spherical shape, what would be the required diameter?

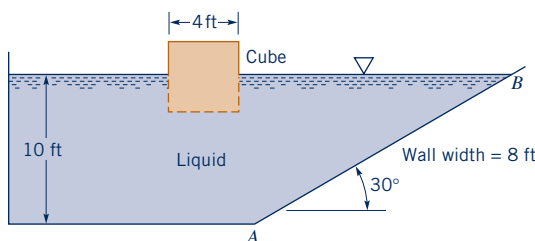
(ANS: 59,200 ft³; 48.3 ft)

2.16R (Buoyancy) An irregularly shaped piece of a solid material weighs 8.05 lb in air and 5.26 lb when completely submerged in water. Determine the density of the material.

(ANS: 5.60 slugs/ft³)

2.17R (Buoyancy, force on plane surface) A cube, 4 ft on a side, weighs 3000 lb and floats half-submerged in an open tank as shown in Fig. P2.17R. For a liquid depth of 10 ft, determine the force of the liquid on the inclined section AB of the tank wall. The width of the wall is 8 ft. Show the magnitude, direction, and location of the force on a sketch.

(ANS: 75,000 lb on centerline, 13.33 ft along wall from free surface)



■ Figure P2.17R

2.18R (Rigid-body motion) A container that is partially filled with water is pulled with a constant acceleration along a plane horizontal surface. With this acceleration the water surface slopes downward at an angle of 40° with respect to the horizontal. Determine the acceleration. Express your answer in m/s².

(ANS: 8.23 m/s²)

2.19R (Rigid-body motion) An open, 2-ft-diameter tank contains water to a depth of 3 ft when at rest. If the tank is rotated about its vertical axis with an angular velocity of 160 rev/min, what is the minimum height of the tank walls to prevent water from spilling over the sides?

(ANS: 5.18 ft)

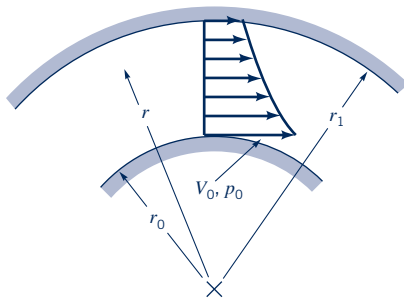
Review Problems for Chapter 3

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

3.1R ($F = ma$ along streamline) What pressure gradient along the streamline, dp/ds , is required to accelerate air at standard temperature and pressure in a horizontal pipe at a rate of 300 ft/s²?

(ANS: -0.714 lb/ft³)

3.2R ($F = ma$ normal to streamline) An incompressible, inviscid fluid flows steadily with circular streamlines around a horizontal bend as shown in Fig. P3.2R. The radial variation of the velocity profile is given by $rV = r_0V_0$, where V_0 is the velocity at the inside of the bend which has radius $r = r_0$. Determine the pressure variation across the bend in terms of V_0 , r_0 , ρ , r , and p_0 , where p_0 is the pressure at $r = r_0$. Plot the pressure distribution, $p = p(r)$,



■ Figure P3.2R

if $r_0 = 1.2$ m, $r_1 = 1.8$ m, $V_0 = 12$ m/s, $p_0 = 20$ kN/m², and the fluid is water. Neglect gravity.

(ANS: $p_0 + 0.5\rho V_0^2[1 - (r_0/r)^2]$)

3.3R (Stagnation pressure) A hang glider soars through standard sea-level air with an airspeed of 10 m/s. What is the gage pressure at a stagnation point on the structure?

(ANS: 61.5 Pa)

3.4R (Bernoulli equation) The pressure in domestic water pipes is typically 60 psi above atmospheric. If viscous effects are neglected, determine the height reached by a jet of water through a small hole in the top of the pipe.

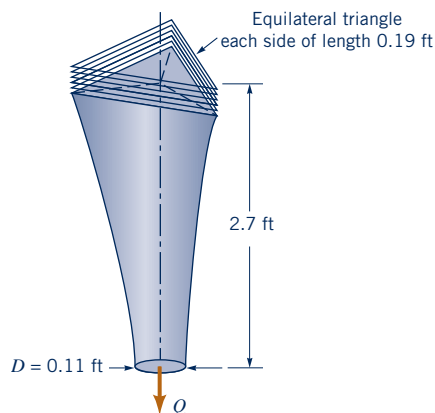
(ANS: 138 ft)

3.5R (Heads) A 4-in.-diameter pipe carries 300 gal/min of water at a pressure of 30 psi. Determine (a) the pressure head in feet of water, (b) the velocity head, and (c) the total head with reference to a datum plane 20 ft below the pipe.

(ANS: 69.2 ft; 0.909 ft; 90.1 ft)

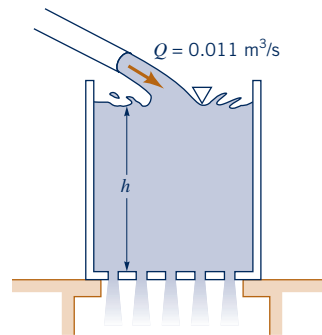
3.6R (Free jet) Water flows from a nozzle of triangular cross section as shown in Fig. P3.6R. After it has fallen a distance of 2.7 ft, its cross section is circular (because of surface tension effects) with a diameter $D = 0.11$ ft. Determine the flowrate, Q .

(ANS: 0.158 ft³/s)



■ Figure P3.6R

3.7R (Bernoulli/continuity) Water flows into a large tank at a rate of 0.011 m³/s as shown in Fig. P3.7R. The water leaves the tank through 20 holes in the bottom of the tank, each of



■ Figure P3.7R

which produces a stream of 10-mm diameter. Determine the equilibrium height, h , for steady-state operation.

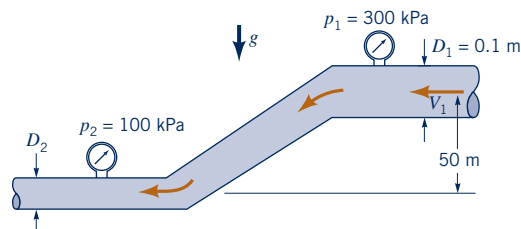
(ANS: 2.50 m)

3.8R (Bernoulli/continuity) Gasoline flows from a 0.3-m-diameter pipe in which the pressure is 300 kPa into a 0.15-m-diameter pipe in which the pressure is 120 kPa. If the pipes are horizontal and viscous effects are negligible, determine the flowrate.

(ANS: 0.420 m³/s)

3.9R (Bernoulli/continuity) Water flows steadily through the pipe shown in Fig. P3.9R such that the pressures at sections (1) and (2) are 300 kPa and 100 kPa, respectively. Determine the diameter of the pipe at section (2), D_2 , if the velocity at section 1 is 20 m/s and viscous effects are negligible.

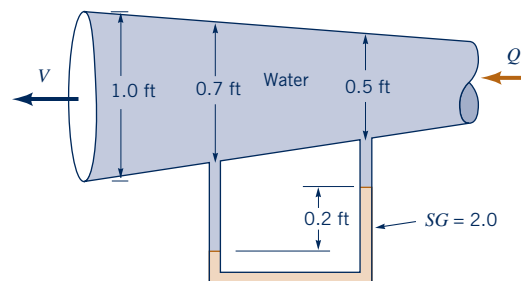
(ANS: 0.0688 m)



■ Figure P3.9R

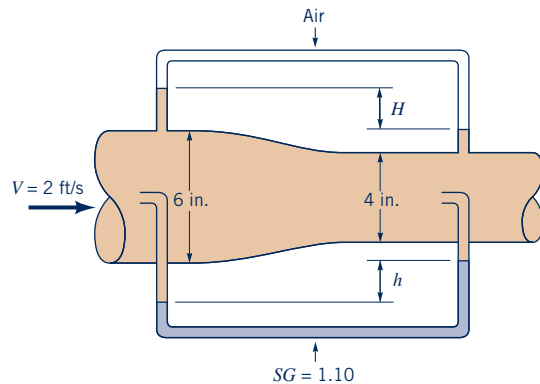
3.10R (Bernoulli/continuity) Water flows steadily through a diverging tube as shown in Fig. P3.10R. Determine the velocity, V , at the exit of the tube if frictional effects are negligible.

(ANS: 1.04 ft/s)



■ Figure P3.10R

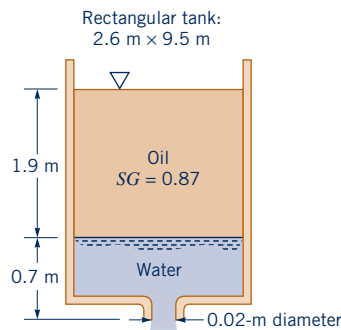
3.11R (Bernoulli/continuity/Pitot tube) Two Pitot tubes and two static pressure taps are placed in the pipe contraction shown in Fig. P3.11R. The flowing fluid is water, and viscous effects are negligible. Determine the two manometer readings, h and H . (ANS: 0; 0.252 ft)



■ Figure P3.11R

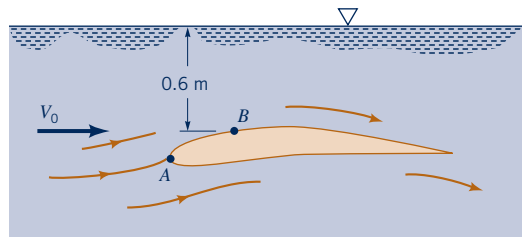
3.12R (Bernoulli/continuity) Water collects in the bottom of a rectangular oil tank as shown in Fig. P3.12R. How long will it take for the water to drain from the tank through a 0.02-m-diameter drain hole in the bottom of the tank? Assume quasi-steady flow.

(ANS: 2.45 hr)



■ Figure P3.12R

3.13R (Cavitation) Water flows past the hydrofoil shown in Fig. P3.13R with an upstream velocity of V_0 . A more advanced



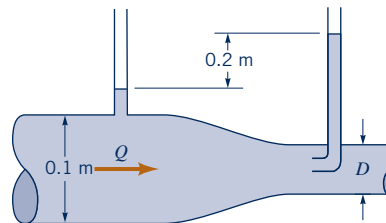
■ Figure P3.13R

analysis indicates that the maximum velocity of the water in the entire flow field occurs at point B and is equal to $1.1 V_0$. Calculate the velocity, V_0 , at which cavitation will begin if the atmospheric pressure is 101 kPa (abs) and the vapor pressure of the water is 3.2 kPa (abs).

(ANS: 31.4 m/s)

3.14R (Flowrate) Water flows through the pipe contraction shown in Fig. P3.14R. For the given 0.2-m difference in manometer level, determine the flowrate as a function of the diameter of the small pipe, D .

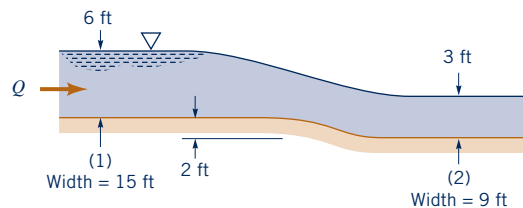
(ANS: $0.0156 \text{ m}^3/\text{s}$)



■ Figure P3.14R

3.15R (Channel flow) Water flows down the ramp shown in the channel of Fig. P3.15R. The channel width decreases from 15 ft at section (1) to 9 ft at section (2). For the conditions shown, determine the flowrate.

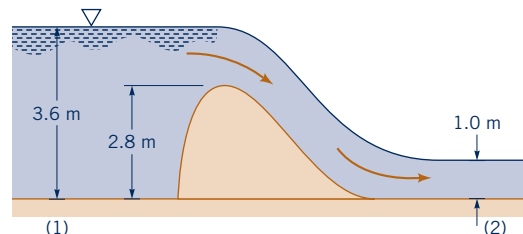
(ANS: $509 \text{ ft}^3/\text{s}$)



■ Figure P3.15R

3.16R (Channel flow) Water flows over the spillway shown in Fig. P3.16R. If the velocity is uniform at sections (1) and (2) and viscous effects are negligible, determine the flowrate per unit width of the spillway.

(ANS: $7.44 \text{ m}^2/\text{s}$)



■ Figure P3.16R

3.17R (Energy line/hydraulic grade line) Draw the energy line and hydraulic grade line for the flow shown in Problem 3.43.

3.18R (Restrictions on Bernoulli equation) A 0.3-m-diameter soccer ball, pressurized to 20 kPa, develops a small leak with an area equivalent to 0.006 mm². If viscous effects are neglected and the air is assumed to be incompressible, determine the flowrate through the hole. Would the ball become noticeably softer during a 1-hr soccer game? Explain. Is it reasonable to assume incompressible flow for this situation? Explain.

(ANS: $9.96 \times 10^{-7} \text{ m}^3/\text{s}$; yes; no, $Ma > 0.3$)

3.19R (Restrictions on Bernoulli equation) Niagara Falls is approximately 167 ft high. If the water flows over the crest of the falls with a velocity of 8 ft/s and viscous effects are neglected, with what velocity does the water strike the rocks at the bottom of the falls? What is the maximum pressure of the water on the rocks? Repeat the calculations for the 1430-ft-high Upper Yosemite Falls in Yosemite National Park. Is it reasonable to neglect viscous effects for these falls? Explain.

(ANS: 104 ft/s, 72.8 psi; 304 ft/s, 620 psi; no)

Review Problems for Chapter 4

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

4.1R (Streamlines) The velocity field in a flow is given by $\mathbf{V} = x^2y\mathbf{i} + x^2y\mathbf{j}$. (a) Plot the streamline through the origin at times $t = 0$, $t = 1$, and $t = 2$. (b) Do the streamlines plotted in part (a) coincide with the path of particles through the origin? Explain.

(ANS: $y^2/2 = tx + C$; no)

4.2R (Streamlines) A velocity field is given by $u = y - 1$ and $v = y - 2$, where u and v are in m/s and x and y are in meters. Plot the streamline that passes through the point $(x, y) = (4, 3)$. Compare this streamline with the streakline through the point $(x, y) = (4, 3)$.

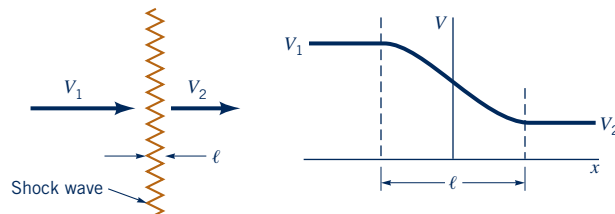
(ANS: $x = y + \ln(y - 2) + 1$)

4.3R (Material derivative) The pressure in the pipe near the discharge of a reciprocating pump fluctuates according to $p = [200 + 40 \sin(8t)] \text{ kPa}$, where t is in seconds. If the fluid speed in the pipe is 5 m/s, determine the maximum rate of change of pressure experienced by a fluid particle.

(ANS: 320 kPa/s)

4.4R (Acceleration) A shock wave is a very thin layer (thickness = ℓ) in a high-speed (supersonic) gas flow across which the flow properties (velocity, density, pressure, etc.) change from state (1) to state (2) as shown in Fig. P4.4R. If $V_1 = 1800 \text{ fps}$, $V_2 = 700 \text{ fps}$, and $\ell = 10^{-4} \text{ in.}$, estimate the average deceleration of the gas as it flows across the shock wave. How many g 's deceleration does this represent?

(ANS: $-1.65 \times 10^{11} \text{ ft/s}^2$; -5.12×10^9)



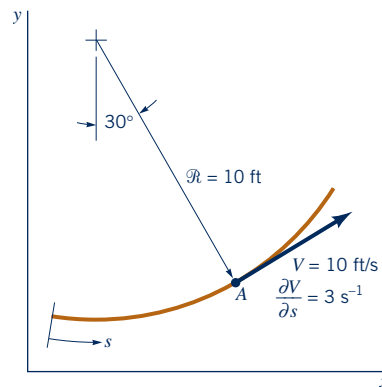
■ Figure P4.4R

4.5R (Acceleration) Air flows through a pipe with a uniform velocity of $\mathbf{V} = 5t^2\mathbf{i} \text{ ft/s}$, where t is in seconds. Determine the acceleration at time $t = -1, 0$, and 1 s .

(ANS: $-10\mathbf{i} \text{ ft/s}^2$; 0 ; $10\mathbf{i} \text{ ft/s}^2$)

4.6R (Acceleration) A fluid flows steadily along the streamline as shown in Fig. P4.6R. Determine the acceleration at point A. At point A what is the angle between the acceleration and the x axis? At point A what is the angle between the acceleration and the streamline?

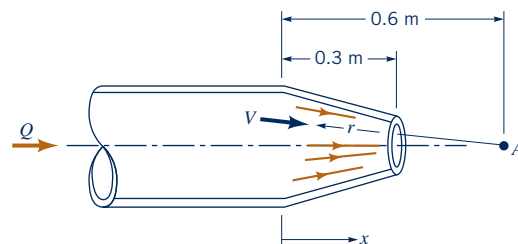
(ANS: $10\mathbf{n} + 30\mathbf{s} \text{ ft/s}^2$; 48.5 deg ; 18.5 deg)



■ Figure P4.6R

4.7R (Acceleration) In the conical nozzle shown in Fig. P4.7R the streamlines are essentially radial lines emanating from point A and the fluid velocity is given approximately by $V = C/r^2$, where C is a constant. The fluid velocity is 2 m/s along the centerline at the beginning of the nozzle ($x = 0$). Determine the acceleration along the nozzle centerline as a function of x . What is the value of the acceleration at $x = 0$ and $x = 0.3 \text{ m}$?

(ANS: $1.037/(0.6 - x)^5 \text{ m/s}^2$; 13.3 m/s^2 ; 427 m/s^2)



■ Figure P4.7R

4.8R (Reynolds transport theorem) A sanding operation injects 10^5 particles/s into the air in a room as shown in

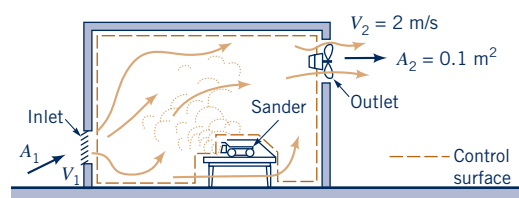
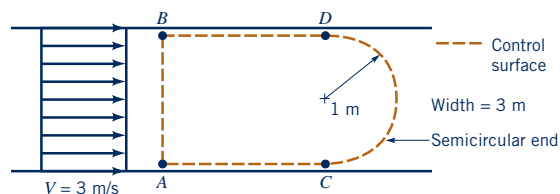

Figure P4.8R

Fig. P4.8R. The amount of dust in the room is maintained at a constant level by a ventilating fan that draws clean air into the room at section (1) and expels dusty air at section (2). Consider a control volume whose surface is the interior surface of the room (excluding the sander) and a system consisting of the material within the control volume at time $t = 0$. (a) If N is the number of particles, discuss the physical meaning of and evaluate the terms DN_{sys}/Dt and $\partial N_{\text{cv}}/\partial t$. (b) Use the Reynolds transport theorem to determine the concentration of particles (particles/m³) in the exhaust air for steady-state conditions.

(ANS: 5×10^5 particles/m³)

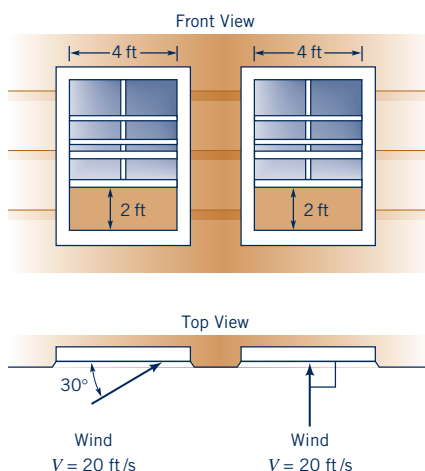
4.9R (Flowrate) Water flows through the rectangular channel shown in Fig. P4.9R with a uniform velocity. Directly integrate Eqs. 4.16 and 4.17 with $b = 1$ to determine the mass flow rate (kg/s) across $A-B$ of the control volume. Repeat for $C-D$.

(ANS: 18,000 kg/s; 18,000 kg/s)

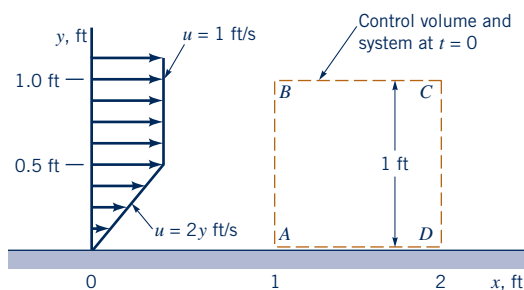

Figure P4.9R

4.10R (Flowrate) Air blows through two windows as indicated in Fig. P4.10R. Use Eq. 4.16 with $b = 1/\rho$ to determine the volume flowrate (ft³/s) through each window. Explain the relationship between the two results you obtained.

(ANS: 80 ft³/s; 160 ft³/s)


Figure P4.10R

4.11R (Control volume/system) Air flows over a flat plate with a velocity profile given by $\mathbf{V} = u(y)\mathbf{i}$, where $u = 2y$ ft/s for $0 \leq y \leq 0.5$ ft and $u = 1$ ft/s for $y > 0.5$ ft as shown in Fig. P4.11R. The fixed rectangular control volume $ABCD$ coincides with the system at time $t = 0$. Make a sketch to indicate (a) the boundary of the system at time $t = 0.1$ s, (b) the fluid that moved out of the control volume in the interval $0 \leq t \leq 0.1$ s, and (c) the fluid that moved into the control volume during that time interval.


Figure P4.11R

Review Problems for Chapter 5

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

5.1R (Continuity equation) Water flows steadily through a 2-in.-inside-diameter pipe at the rate of 200 gal/min. The 2-in. pipe branches into two 1-in.-inside-diameter pipes. If the average velocity in one of the 1-in. pipes is 30 ft/s, what is the average velocity in the other 1-in. pipe?

(ANS: 51.7 ft/s)

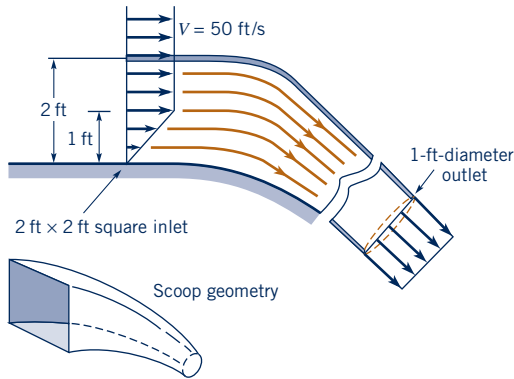
5.2R (Continuity equation) Air (assumed incompressible) flows steadily into the square inlet of an air scoop with the

nonuniform velocity profile indicated in Fig. P5.2R. The air exits as a uniform flow through a round pipe 1 ft in diameter. (a) Determine the average velocity at the exit plane. (b) In one minute, how many pounds of air pass through the scoop?

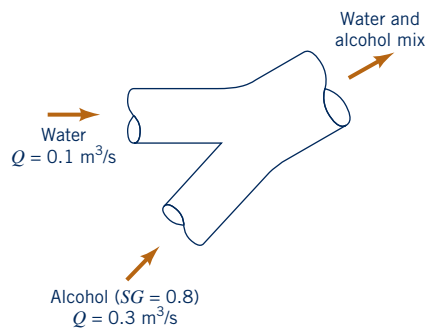
(ANS: 191 ft/s; 688 lb/min)

5.3R (Continuity equation) Water at 0.1 m³/s and alcohol ($SG = 0.8$) at 0.3 m³/s are mixed in a y-duct as shown in Fig. P5.3R. What is the average density of the mixture of alcohol and water?

(ANS: 849 kg/m³)



■ Figure P5.2R



■ Figure P5.3R

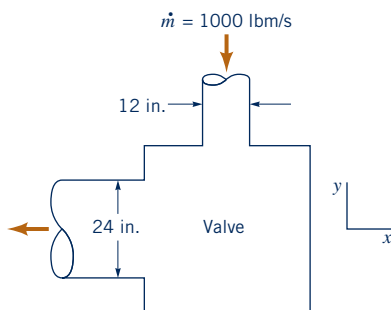
5.4R (Average velocity) The flow in an open channel has a velocity distribution

$$\mathbf{V} = U(y/h)^{1/5} \hat{\mathbf{i}} \text{ ft/s}$$

where U = free-surface velocity, y = perpendicular distance from the channel bottom in feet, and h = depth of the channel in feet. Determine the average velocity of the channel stream as a fraction of U .

(ANS: 0.833)

5.5R (Linear momentum) Water flows through a right-angle valve at the rate of 1000 lbm/s, as is shown in Fig. P5.5R. The pressure just upstream of the valve is 90 psi, and the pressure drop across the valve is 50 psi. The inside diameters of the valve inlet and exit pipes are 12 and 24 in. If the flow through



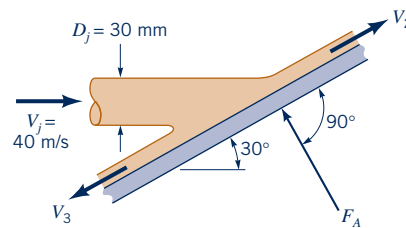
■ Figure P5.5R

the valve occurs in a horizontal plane, determine the x and y components of the force exerted by the valve on the water.

(ANS: 18,200 lb; 10,800 lb)

5.6R (Linear momentum) A horizontal circular jet of air strikes a stationary flat plate as indicated in Fig. P5.6R. The jet velocity is 40 m/s and the jet diameter is 30 mm. If the air velocity magnitude remains constant as the air flows over the plate surface in the directions shown, determine: (a) the magnitude of F_A , the anchoring force required to hold the plate stationary, (b) the fraction of mass flow along the plate surface in each of the two directions shown, (c) the magnitude of F_A , the anchoring force required to allow the plate to move to the right at a constant speed of 10 m/s.

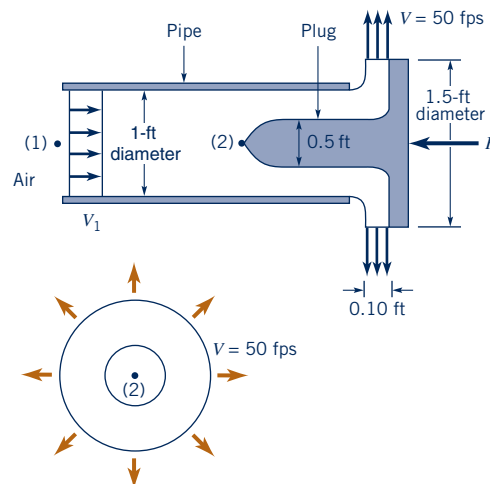
(ANS: 0.696 N; 0.933 and 0.0670; 0.391 N)



■ Figure P5.6R

5.7R (Linear momentum) An axisymmetric device is used to partially “plug” the end of the round pipe shown in Fig. P5.7R. The air leaves in a radial direction with a speed of 50 ft/s as indicated. Gravity and viscous forces are negligible. Determine the (a) flowrate through the pipe, (b) gage pressure at point (1), (c) gage pressure at the tip of the plug, point (2), (d) force, F , needed to hold the plug in place.

(ANS: 23.6 ft³/s; 1.90 lb/ft²; 2.97 lb/ft²; 3.18 lb)



■ Figure P5.7R

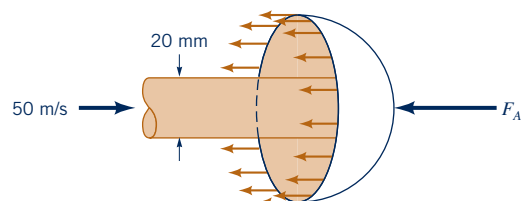
5.8R (Linear momentum) A nozzle is attached to an 80-mm inside-diameter flexible hose. The nozzle area is 500 mm². If the delivery pressure of water at the nozzle inlet is

700 kPa, could you hold the hose and nozzle stationary? Explain.

(ANS: yes, 707 N or 159 lb)

5.9R (Linear momentum) A horizontal air jet having a velocity of 50 m/s and a diameter of 20 mm strikes the inside surface of a hollow hemisphere as indicated in Fig. P5.9R. How large is the horizontal anchoring force needed to hold the hemisphere in place? The magnitude of velocity of the air remains constant.

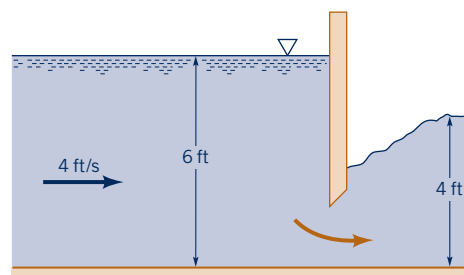
(ANS: 1.93 N)



■ Figure P5.9R

5.10R (Linear momentum) Determine the magnitude of the horizontal component of the anchoring force required to hold in place the 10-foot-wide sluice gate shown in Fig. P5.10R. 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.

(ANS: 5310 lb; 11,200 lb)



■ Figure P5.10R

5.11R (Linear momentum) Two jets of liquid, one with specific gravity 1.0 and the other with specific gravity 1.3, collide and form one homogeneous jet as shown in Fig. P5.11R. Determine the speed, V , and the direction, θ , of the combined jet. Gravity is negligible.

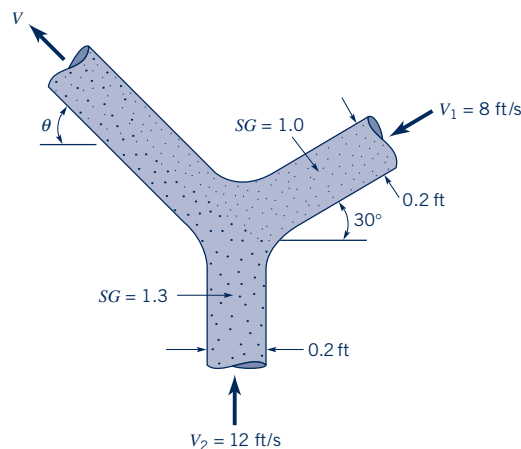
(ANS: 6.97 ft/s; 70.3 deg)

5.12R (Linear momentum) Water flows vertically upward in a circular cross-sectional pipe as shown in Fig. P5.12R. At section (1), the velocity profile over the cross-sectional area is uniform. At section (2), the velocity profile is

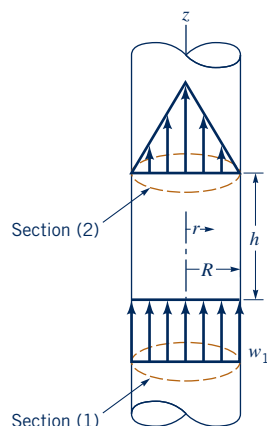
$$\mathbf{V} = w_c \left(\frac{R-r}{R} \right) \hat{\mathbf{k}}$$

where $\mathbf{V}$ = local velocity vector, w_c = centerline velocity in the axial direction, R = pipe radius, and r = radius from pipe axis. Develop an expression for the fluid pressure drop that occurs between sections (1) and (2).

(ANS: $p_1 - p_2 = R_z / \pi R^2 + 0.50 \rho w_1^2 + g \rho h$, where R_z = friction force)

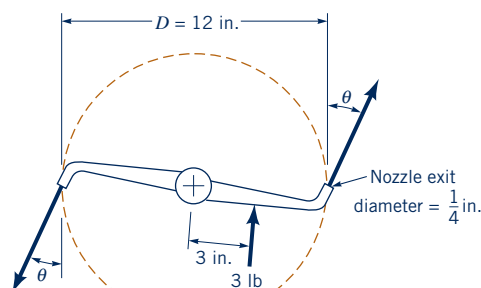


■ Figure P5.11R



■ Figure P5.12R

5.13R (Moment-of-momentum) A lawn sprinkler is constructed from pipe with $\frac{1}{4}$ -in. inside diameter as indicated in Fig. P5.13R. Each arm is 6 in. in length. Water flows through the sprinkler at the rate of 1.5 lb/s. A force of 3 lb positioned halfway along one arm holds the sprinkler stationary. Compute the angle,



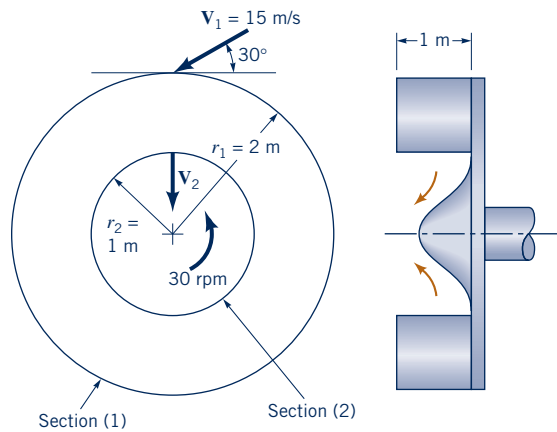
■ Figure P5.13R

θ , which the exiting water stream makes with the tangential direction. The flow leaves the nozzles in the horizontal plane.

(ANS: 23.9 deg)

5.14R (Moment-of-momentum) A water turbine with radial flow has the dimensions shown in Fig. P5.14R. 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 radially inward. The angular speed of the rotor is 30 rpm. Find the power delivered to the shaft of the turbine.

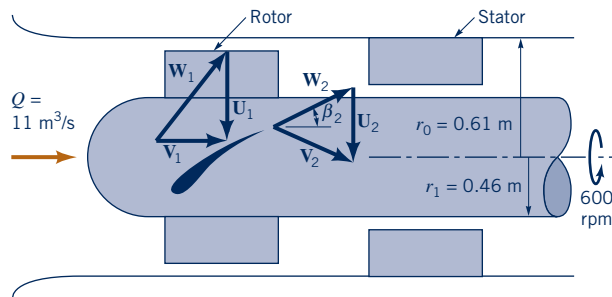
(ANS: -7.68 MW)



■ Figure 5.14R

5.15R (Moment-of-momentum) The single-stage, axial-flow turbomachine shown in Fig. P5.15R involves water flow at a volumetric flowrate of $11 \text{ m}^3/\text{s}$. 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 $\beta_2 = 30^\circ$. The flow entering the rotor row and leaving the stator row is axial viewed from the stationary casing. Is this device a turbine or a pump? Estimate the amount of power transferred to or from the fluid.

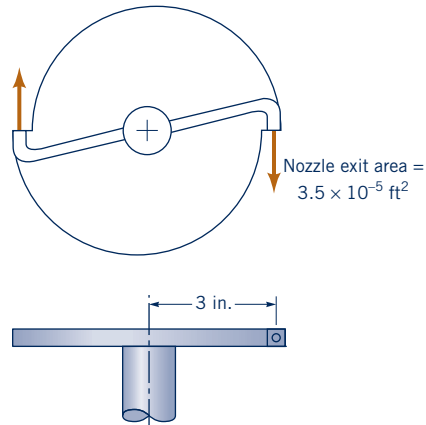
(ANS: pump; 7760 kW)



■ Figure P5.15R

5.16R (Moment-of-momentum) A small water turbine is designed as shown in Fig. P5.16R. If the flowrate through the turbine is 0.0030 slugs/s, and the rotor speed is 300 rpm, estimate the shaft torque and shaft power involved. Each nozzle exit cross-sectional area is $3.5 \times 10^{-5} \text{ ft}^2$.

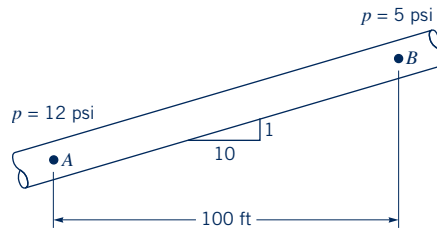
(ANS: -0.0107 ft · lb; -0.336 ft · lb/s)



■ Figure P5.16R

5.17R (Energy equation) Water flows steadily from one location to another in the inclined pipe shown in Fig. P5.17R. At one section, the static pressure is 12 psi. At the other section, the static pressure is 5 psi. Which way is the water flowing? Explain.

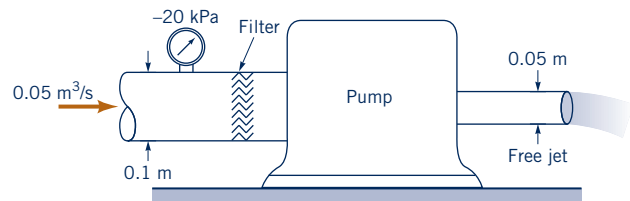
(ANS: from A to B)



■ Figure P5.17R

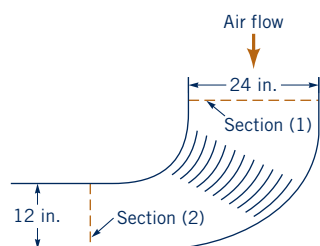
5.18R (Energy equation) The pump shown in Fig. P5.18R adds 20 kW of power to the flowing water. The only loss is that which occurs across the filter at the inlet of the pump. Determine the head loss for this filter.

(ANS: 7.69 m)



■ Figure P5.18R

5.19R (Linear momentum/energy) Eleven equally spaced turning vanes are used in the horizontal plane 90° bend as indicated in Fig. P5.19R. The depth of the rectangular cross-sectional bend remains constant at 3 in. The velocity distributions upstream and downstream of the vanes may be considered uniform. The loss in available energy across the vanes is $0.2V_1^2/2$. The required velocity and pressure downstream of the vanes, section (2), are 180 ft/s and 15 psia. What is the average magnitude of the force exerted by the air flow on each vane? Assume



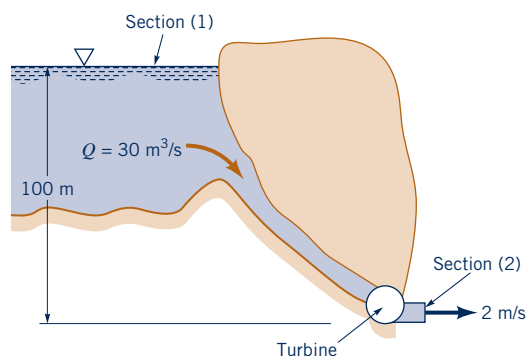
■ Figure P5.19R

that the force of the air on the duct walls is equivalent to the force of the air on one vane.

(ANS: 4.61 lb)

5.20R (Energy equation) A hydroelectric power plant operates under the conditions illustrated in Fig. P5.20R. The head loss associated with flow from the water level upstream of the dam, section (1), to the turbine discharge at atmospheric pressure, section (2), is 20 m. How much power is transferred from the water to the turbine blades?

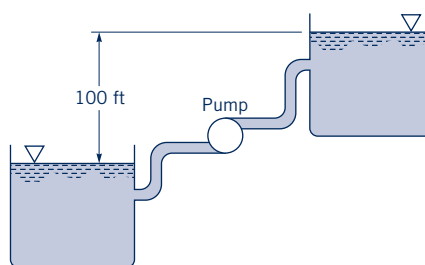
(ANS: 23.5 MW)



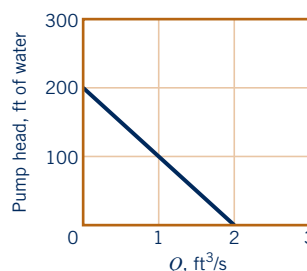
■ Figure P5.20R

5.21R (Energy equation) A pump transfers water uphill from one large reservoir to another, as shown in Fig. P5.21R a. The difference in elevation between the two reservoirs is 100 ft. The friction head loss in the piping is given by $K_L \bar{V}^2/2g$, where $\bar{V}$ is the average fluid velocity in the pipe and K_L is the loss coefficient, which is considered constant. The relation between the total head rise, H , across the pump and the flow rate, Q , through the pump is given in Fig. 5.21R b. If $K_L = 40$, and the pipe diameter is 4 in., what is the flow rate through the pump?

(ANS: 0.653 ft³/s)



(a)

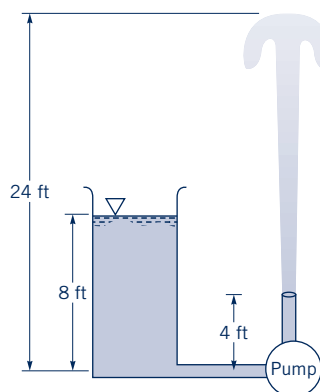


(b)

■ Figure P5.21R

5.22R (Energy equation) The pump shown in Fig. P5.22R adds 1.6 horsepower to the water when the flow rate is 0.6 ft³/s. Determine the head loss between the free surface in the large, open tank and the top of the fountain (where the velocity is zero).

(ANS: 7.50 ft)



■ Figure P5.22R

Review Problems for Chapter 6

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

6.1R (Acceleration) The velocity in a certain flow field is given by the equation.

$$\mathbf{V} = 3yz^2\hat{i} + xz\hat{j} + y\hat{k}$$

Determine the expressions for the three rectangular components of acceleration

(ANS: $3xz^3 + 6y^2z; 3yz^3 + xy; xz$)

6.2R (Vorticity) Determine an expression for the vorticity of the flow field described by

$$\mathbf{V} = x^2y\hat{i} - xy^2\hat{j}$$

Is the flow irrotational?

(ANS: $-(x^2 + y^2)\hat{k}$; no)

6.3R (Conservation of mass) For a certain incompressible, two-dimensional flow field the velocity component in the y direction is given by the equation

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

Determine the velocity component in the x direction so that the continuity equation is satisfied.

(ANS: $-x^2 + f(y)$)

6.4R (Conservation of mass) For a certain incompressible flow field it is suggested that the velocity components are given by the equations

$$u = x^2y \quad v = 4y^3z \quad w = 2z$$

Is this a physically possible flow field? Explain.

(ANS: No)

6.5R (Stream function) The velocity potential for a certain flow field is

$$\phi = 4xy$$

Determine the corresponding stream function.

(ANS: $2(y^2 - x^2) + C$)

6.6R (Velocity potential) A two-dimensional flow field is formed by adding a source at the origin of the coordinate system to the velocity potential

$$\phi = r^2 \cos 2\theta$$

Locate any stagnation points in the upper half of the coordinate plane ($0 \leq \theta \leq \pi$).

(ANS: $\theta_s = \pi/2$; $r_s = (m/4\pi)^{1/2}$)

6.7R (Potential flow) The stream function for a two-dimensional, incompressible flow field is given by the equation

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

where the stream function has the units of ft^2/s with x and y in feet. (a) Sketch the streamlines for this flow field. Indicate the direction of flow along the streamlines. (b) Is this an irrotational flow field? (c) Determine the acceleration of a fluid particle at the point $x = 1 \text{ ft}$, $y = 2 \text{ ft}$.

(ANS: yes; no acceleration)

6.8R (Inviscid flow) In a certain steady, incompressible, inviscid, two-dimensional flow field ($w = 0$, and all variables independent of z), the x component of velocity is given by the equation

$$u = x^2 - y$$

Will the corresponding pressure gradient in the horizontal x direction be a function only of x , only of y , or of both x and y ? Justify your answer.

(ANS: only of x)

6.9R (Inviscid flow) The stream function for the flow of a non-viscous, incompressible fluid in the vicinity of a corner (Fig. P6.9R) is

$$\psi = 2r^{4/3} \sin \frac{4}{3}\theta$$

Determine an expression for the pressure gradient along the boundary $\theta = 3\pi/4$.

(ANS: $-64 \rho/27 r^{1/3}$)

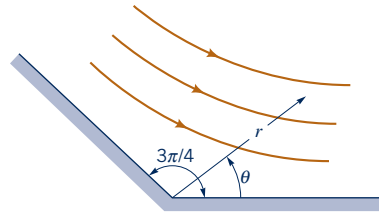


Figure P6.9R

6.10R (Potential flow) A certain body has the shape of a half-body with a thickness of 0.5 m. If this body is to be placed in an airstream moving at 20 m/s, what source strength is required to simulate flow around the body?

(ANS: $10.0 \text{ m}^2/\text{s}$)

6.11R (Potential flow) A source and a sink are located along the x axis with the source at $x = -1 \text{ ft}$ and the sink at $x = 1 \text{ ft}$. Both the source and the sink have a strength of $10 \text{ ft}^2/\text{s}$. Determine the location of the stagnation points along the x axis when this source-sink pair is combined with a uniform velocity of 20 ft/s in the positive x direction.

(ANS: $\pm 1.08 \text{ ft}$)

6.12R (Viscous flow) In a certain viscous, incompressible flow field with zero body forces the velocity components are

$$u = ay - b(cy - y^2) \\ v = w = 0$$

where a , b , and c are constant. (a) Use the Navier-Stokes equations to determine an expression for the pressure gradient in the x direction. (b) For what combination of the constants a , b , and c (if any) will the shearing stress, τ_{yx} , be zero at $y = 0$ where the velocity is zero?

(ANS: $2b\mu$; $a = bc$)

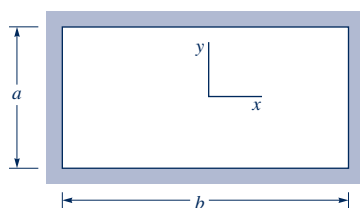
6.13R (Viscous flow) A viscous fluid is contained between two infinite, horizontal parallel plates that are spaced 0.5 in. apart. The bottom plate is fixed, and the upper plate moves with a constant velocity, U . The fluid motion is caused by the movement of the upper plate, and there is no pressure gradient in the direction of flow. The flow is laminar. If the velocity of the upper plate is 2 ft/s and the fluid has a viscosity of $0.03 \text{ lb} \cdot \text{s}/\text{ft}^2$ and a specific weight of $70 \text{ lb}/\text{ft}^3$, what is the required horizontal force per square foot on the upper plate to maintain the 2 ft/s velocity? What is the pressure differential in the fluid between the top and bottom plates?

(ANS: $1.44 \text{ lb}/\text{ft}^2$; $2.92 \text{ lb}/\text{ft}^2$)

6.14R (Viscous flow) A viscous liquid ($\mu = 0.016 \text{ lb} \cdot \text{s}/\text{ft}^2$, $\rho = 1.79 \text{ slugs}/\text{ft}^3$) flows through the annular space between two horizontal, fixed, concentric cylinders. If the radius of the inner cylinder is 1.5 in. and the radius of the outer cylinder is 2.5 in., what is the volume flowrate when the pressure drop along the axis of annulus is $100 \text{ lb}/\text{ft}^2$ per ft?

(ANS: $0.317 \text{ ft}^3/\text{s}$)

6.15R (Viscous flow) Consider the steady, laminar flow of an incompressible fluid through the horizontal rectangular channel of Fig. P6.15R. Assume that the velocity components in the x and y directions are zero and the only body force is the weight. Start with the Navier-Stokes equations. (a) Determine the appropriate set of differential equations and boundary conditions for this

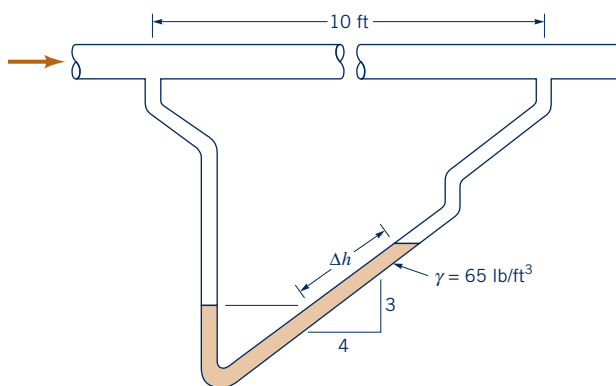


■ Figure P6.15R

problem. You need not solve the equations. (b) Show that the pressure distribution is hydrostatic at any particular cross section.

(ANS: $\partial \rho / \partial x = 0$; $\partial p / \partial y = -\rho g$; $\partial p / \partial z = \mu(\partial^2 w / \partial x^2 + \partial^2 w / \partial y^2)$ with $w = 0$ for $x = \pm b/2$ and $y = \pm a/2$)

6.16R (Viscous flow) A viscous liquid, having a viscosity of 10^{-4} lb · s/ft² and a specific weight of 50 lb/ft³, flows steadily through the 2-in.-diameter, horizontal, smooth pipe shown in Fig. P6.16R. The mean velocity in the pipe is 0.5 ft/s. Determine



■ Figure P6.16R

the differential reading, Δh , on the inclined-tube manometer. (ANS: 0.0640 ft)

Review Problems for Chapter 7

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

7.1R (Common Pi terms) Standard air with velocity V flows past an airfoil having a chord length, b , of 6 ft. (a) Determine the Reynolds number, $\rho V b / \mu$, for $V = 150$ mph. (b) If this airfoil were attached to an airplane flying at the same speed in a standard atmosphere at an altitude of 10,000 ft, what would be the value of the Reynolds number?

(ANS: 8.40×10^6 ; 6.56×10^6)

7.2R (Dimensionless variables) Some common variables in fluid mechanics include: volume flowrate, Q , acceleration of gravity, g , viscosity, μ , density, ρ , and a length, ℓ . Which of the following combinations of these variables are dimensionless? (a) $Q^2/g\ell^2$. (b) $\rho Q/\mu\ell$. (c) $g\ell^5/Q^2$. (d) $\rho Q\ell/\mu$.

(ANS: (b); (c))

7.3R (Determination of Pi terms) A fluid flows at a velocity V through a horizontal pipe of diameter D . An orifice plate containing a hole of diameter d is placed in the pipe. It is desired to investigate the pressure drop, Δp , across the plate. Assume that

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

where ρ is the fluid density. Determine a suitable set of pi terms.

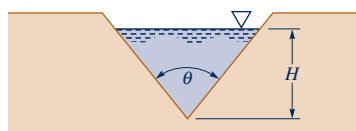
(ANS: $\Delta p/\rho V^2 = \phi(d/D)$)

7.4R (Determination of Pi terms) The flowrate, Q , in an open canal or channel can be measured by placing a plate with a V-notch across the channel as illustrated in Fig. P7.4R. This type of device is called a V-notch weir. The height, H , of the liquid above the crest can be used to determine Q . Assume that

$$Q = f(H, g, \theta)$$

where g is the acceleration of gravity. What are the significant dimensionless parameters for this problem?

(ANS: $Q/(gH^5)^{1/2} = \phi(\theta)$)



■ Figure P7.4R

7.5R (Determination of Pi terms) In a fuel injection system, small droplets are formed due to the breakup of the liquid jet. Assume the droplet diameter, d , is a function of the liquid density, ρ , viscosity, μ , and surface tension, σ , and the jet velocity, V , and diameter, D . Form an appropriate set of dimensionless parameters using μ , V , and D as repeating variables.

(ANS: $d/D = \phi(\rho V D / \mu, \sigma / \mu V)$)

7.6R (Determination of Pi terms) The thrust, $\mathcal{T}$, developed by a propeller of a given shape depends on its diameter, D , the fluid density, ρ , and viscosity, μ , the angular speed of rotation, ω , and the advance velocity, V . Develop a suitable set of pi terms, one of which should be $\rho D^2 \omega / \mu$. Form the pi terms by inspection.

(ANS: $\mathcal{T} / \rho V^2 D^2 = \phi(\rho V D / \mu, \rho D^2 \omega / \mu)$)

7.7R (Modeling/similarity) The water velocity at a certain point along a 1 : 10 scale model of a dam spillway is 5 m/s. What is the corresponding prototype velocity if the model and prototype operate in accordance with Froude number similarity?

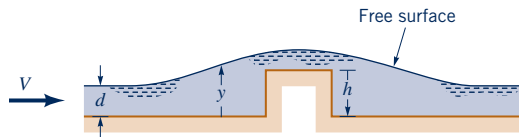
(ANS: 15.8 m/s)

7.8R (Modeling/similarity) The pressure drop per unit length in a 0.25-in.-diameter gasoline fuel line is to be determined from a laboratory test using the same tubing but with water as the fluid. The pressure drop at a gasoline velocity of 1.0 ft/s is of interest. (a) What water velocity is required? (b) At the properly scaled velocity from part (a), the pressure drop per unit length (using water) was found to be 0.45 psf/ft. What is the predicted pressure drop per unit length for the gasoline line?

(ANS: 2.45 ft/s; 0.0510 lb/ft² per ft)

7.9R (Modeling/similarity) A thin layer of an incompressible fluid flows steadily over a horizontal smooth plate as shown in Fig. P7.9R. The fluid surface is open to the atmosphere, and an obstruction having a square cross section is placed on the plate as shown. A model with a length scale of $\frac{1}{4}$ and a fluid density scale of 1.0 is to be designed to predict the depth of fluid, y , along the plate. Assume that inertial, gravitational, surface tension, and viscous effects are all important. What are the required viscosity and surface tension scales?

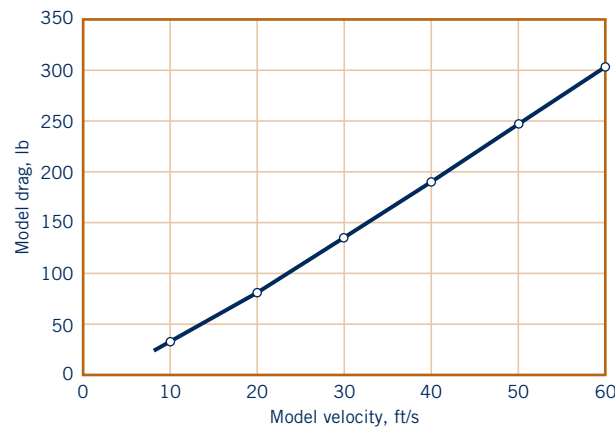
(ANS: 0.125; 0.0625)



■ Figure P7.9R

7.10R (Correlation of experimental data) The drag on a 30-ft long, vertical, 1.25-ft-diameter pole subjected to a 30-mph wind is to be determined with a model study. It is expected that the drag is a function of the pole length and diameter, the fluid density and viscosity, and the fluid velocity. Laboratory model tests were performed in a high-speed water tunnel using a model pole having a length of 2 ft and a diameter of 1 in. Some model drag data are shown in Fig. P7.10R. Based on these data, predict the drag on the full-sized pole.

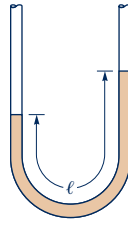
(ANS: 52.2 lb)



■ Figure 7.10R

7.11R (Correlation of experimental data) A liquid is contained in a U-tube as is shown in Fig. P7.11R. When the liquid is displaced from its equilibrium position and released, it oscillates with a period τ . Assume that τ is a function of the acceleration of gravity, g , and the column length, ℓ . Some laboratory measurements made by varying ℓ and measuring τ , with $g = 32.2 \text{ ft/s}^2$, are given in the following table.

τ (s)	0.548	0.783	0.939	1.174
ℓ (ft)	0.49	1.00	1.44	2.25



■ Figure P7.11R

Based on these data, determine a general equation for the period.

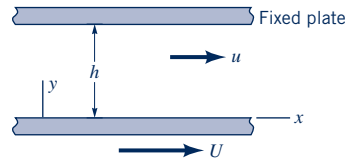
(ANS: $\tau = 4.44(\ell/g)^{1/2}$)

7.12R (Dimensionless governing equations) An incompressible fluid is contained between two large parallel plates as shown in Fig. P7.12R. The upper plate is fixed. If the fluid is initially at rest and the bottom plate suddenly starts to move with a constant velocity, U , the governing differential equation describing the fluid motion is

$$\rho \frac{\partial u}{\partial t} = \mu \frac{\partial^2 u}{\partial y^2}$$

where u is the velocity in the x direction, and ρ and μ are the fluid density and viscosity, respectively. Rewrite the equation and the initial and boundary conditions in dimensionless form using h and U as reference parameters for length and velocity, and $h^2\rho/\mu$ as a reference parameter for time.

(ANS: $\partial u^*/\partial t^* = \partial^2 u^*/\partial y^{*2}$ with $u^* = 0$ at $t^* = 0$, $u^* = 1$ at $y^* = 0$, and $u^* = 0$ at $y^* = 1$)



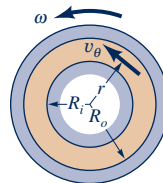
■ Figure P7.12R

7.13R (Dimensionless governing equations) The flow between two concentric cylinders (see Fig. P7.13R) is governed by the differential equation

$$\frac{d^2 v_\theta}{dr^2} + \frac{d}{dr} \left(\frac{v_\theta}{r} \right) = 0$$

where v_θ is the tangential velocity at any radial location, r . The inner cylinder is fixed and the outer cylinder rotates with an angular velocity ω . Express the equation in dimensionless form using R_o and ω as reference parameters.

(ANS: $d^2 v_\theta^*/dr^{*2} + d(v_\theta^*/r^*)/dr^* = 0$)



■ Figure P7.13R

Review Problems for Chapter 8

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

8.1R (Laminar flow) Asphalt at 120 °F, considered to be a Newtonian fluid with a viscosity 80,000 times that of water and a specific gravity of 1.09, flows through a pipe of diameter 2.0 in. If the pressure gradient is 1.6 psi/ft, determine the flowrate assuming the pipe is (a) horizontal; (b) vertical with flow up.

(ANS: $4.69 \times 10^{-3} \text{ ft}^3/\text{s}$; $3.30 \times 10^{-3} \text{ ft}^3/\text{s}$)

8.2R (Laminar flow) A fluid flows through two horizontal pipes of equal length which are connected together to form a pipe of length 2ℓ . The flow is laminar and fully developed. The pressure drop for the first pipe is 1.44 times greater than it is for the second pipe. If the diameter of the first pipe is D , determine the diameter of the second pipe.

(ANS: 1.095 D)

8.3R (Velocity profile) A fluid flows through a pipe of radius R with a Reynolds number of 100,000. At what location, r/R , does the fluid velocity equal the average velocity? Repeat if the Reynolds number is 1000.

(ANS: 0.758; 0.707)

8.4R (Turbulent velocity profile) Water at 80 °C flows through a 120-mm-diameter pipe with an average velocity of 2 m/s. If the pipe wall roughness is small enough so that it does not protrude through the laminar sublayer, the pipe can be considered as smooth. Approximately what is the largest roughness allowed to classify this pipe as smooth?

(ANS: $2.31 \times 10^{-5} \text{ m}$)

8.5R (Moody chart) Water flows in a smooth plastic pipe of 200-mm diameter at a rate of $0.10 \text{ m}^3/\text{s}$. Determine the friction factor for this flow.

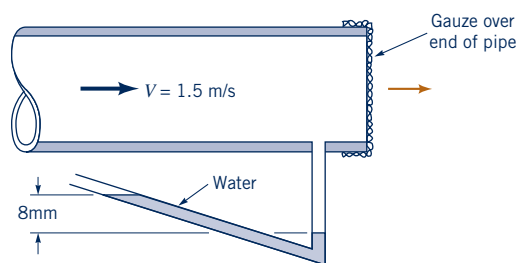
(ANS: 0.0128)

8.6R (Moody chart) After a number of years of use, it is noted that to obtain a given flowrate, the head loss is increased to 1.6 times its value for the originally smooth pipe. If the Reynolds number is 10^6 , determine the relative roughness of the old pipe.

(ANS: 0.00070)

8.7R (Minor losses) Air flows through the fine mesh gauze shown in Fig. P8.7R with an average velocity of 1.50 m/s in the pipe. Determine the loss coefficient for the gauze.

(ANS: 56.7)



■ Figure P8.7R

8.8R (Noncircular conduits) A manufacturer makes two types of drinking straws: one with a square cross-sectional shape, and the other type the typical round shape. The amount of material in each straw is to be the same. That is, the length of the perimeter of the cross section of each shape is the same. For a given pressure drop, what is the ratio of the flowrates through the straws? Assume the drink is viscous enough to ensure laminar flow and neglect gravity.

(ANS: $Q_{\text{round}} = 1.83 Q_{\text{square}}$)

8.9R (Single pipe—determine pressure drop) Determine the pressure drop per 300-m length of a new 0.20-m-diameter horizontal cast-iron water pipe when the average velocity is 1.7 m/s.

(ANS: 47.6 kN/m²)

8.10R (Single pipe—determine pressure drop) A fire protection association code requires a minimum pressure of 65 psi at the outlet end of a 250-ft-long, 4-in.-diameter hose when the flowrate is 500 gal/min. What is the minimum pressure allowed at the pumper truck that supplies water to the hose? Assume a roughness of $\epsilon = 0.03 \text{ in.}$

(ANS: 94.0 psi)

8.11R (Single pipe—determine flowrate) An aboveground swimming pool of 30 ft diameter and 5 ft depth is to be filled from a garden hose (smooth interior) of length 100 ft and diameter 5/8 in. If the pressure at the faucet to which the hose is attached remains at 55 psi, how long will it take to fill the pool? The water exits the hose as a free jet 6 ft above the faucet.

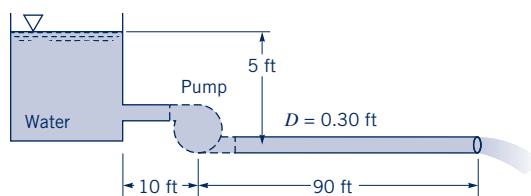
(ANS: 32.0 hr)

8.12R (Single pipe—determine pipe diameter) Water is to flow at a rate of $1.0 \text{ m}^3/\text{s}$ through a rough concrete pipe ($\epsilon = 3 \text{ mm}$) that connects two ponds. Determine the pipe diameter if the elevation difference between the two ponds is 10 m and the pipe length is 1000 m. Neglect minor losses.

(ANS: 0.748 m)

8.13R (Single pipe with pump) Without the pump shown in Fig. P8.13R it is determined that the flowrate is too small. Determine the horsepower added to the fluid if the pump causes the flowrate to be doubled. Assume that the friction factor remains at 0.020 in either case.

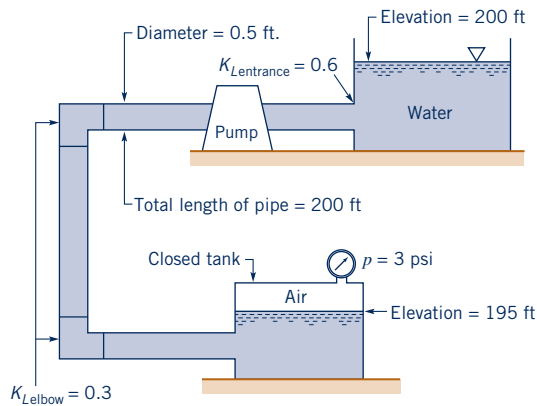
(ANS: 1.51 hp)



■ Figure P8.13R

8.14R (Single pipe with pump) The pump shown in Fig. P8.14R adds a 15-ft head to the water being pumped from the upper tank to the lower tank when the flowrate is $1.5 \text{ ft}^3/\text{s}$. Determine the friction factor for the pipe.

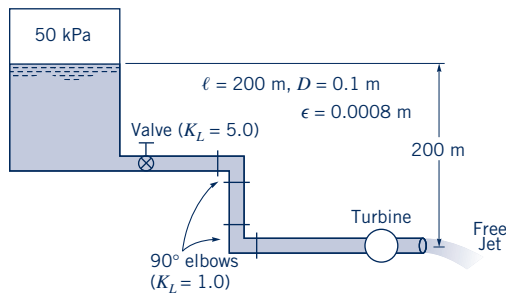
(ANS: 0.0306)



■ Figure P8.14R

8.15R (Single pipe with turbine) Water drains from a pressurized tank through a pipe system as shown in Fig. P8.15R. The head of the turbine is equal to 116 m. If entrance effects are negligible, determine the flowrate.

(ANS: $3.71 \times 10^{-2} \text{ m}^3/\text{s}$)



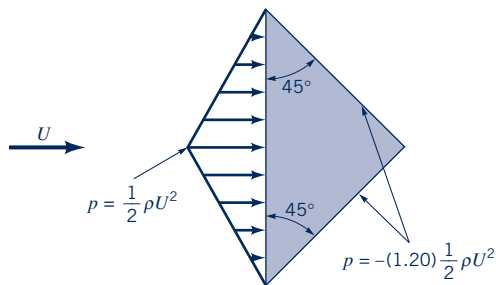
■ Figure P8.15R

Review Problems for Chapter 9

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

9.1R (Lift/drag calculation) Determine the lift and drag coefficients (based on frontal area) for the triangular two-dimensional object shown in Fig. P9.1R. Neglect shear forces.

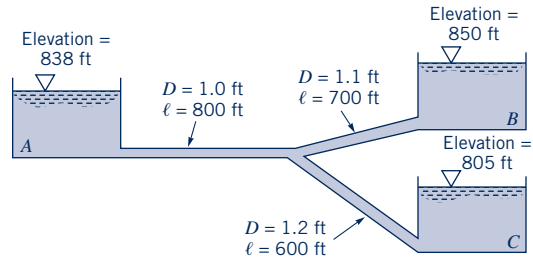
(ANS: 0; 1.70)



■ Figure P9.1R

8.16R (Multiple pipes) The three tanks shown in Fig. P8.16R are connected by pipes with friction factors of 0.03 for each pipe. Determine the water velocity in each pipe. Neglect minor losses.

(ANS: (A) 4.73 ft/s, (B) 8.35 ft/s, (C) 10.3 ft/s)



■ Figure P8.16R

8.17R (Flowmeters) Water flows in a 0.10-m-diameter pipe at a rate of $0.02 \text{ m}^3/\text{s}$. If the pressure difference across the orifice meter in the pipe is to be 28 kPa, what diameter orifice is needed?

(ANS: 0.070 m)

8.18R (Flowmeters) A 2.5-in.-diameter flow nozzle is installed in a 3.8-in.-diameter pipe that carries water at 160°F . If the flowrate is 0.78 cfs, determine the reading on the inverted air–water U-tube manometer used to measure the pressure difference across the meter.

(ANS: 6.75 ft)

9.2R (External flow character) A 0.23-m-diameter soccer ball moves through the air with a speed of 10 m/s. Would the flow around the ball be classified as low, moderate, or large Reynolds number flow? Explain.

(ANS: Large Reynolds number flow)

9.3R (External flow character) A small 15-mm-long fish swims with a speed of 20 mm/s. Would a boundary layer type flow be developed along the sides of the fish? Explain.

(ANS: No)

9.4R (Boundary layer flow) Air flows over a flat plate of length $\ell = 2 \text{ ft}$ such that the Reynolds number based on the plate length is $\text{Re} = 2 \times 10^5$. Plot the boundary layer thickness, δ , for $0 \leq x \leq \ell$.

9.5R (Boundary layer flow) At a given location along a flat plate the boundary layer thickness is $\delta = 45 \text{ mm}$. At this location, what would be the boundary layer thickness if it were

defined as the distance from the plate where the velocity is 97% of the upstream velocity rather than the standard 99%? Assume laminar flow.

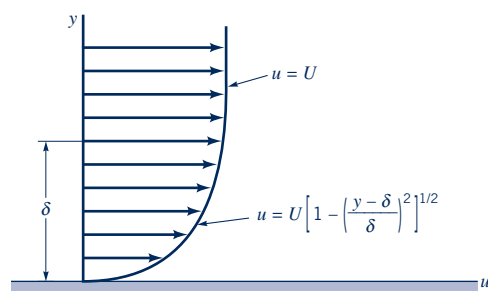
(ANS: 38.5 mm)

9.6R (Friction drag) A laminar boundary layer formed on one side of a plate of length ℓ produces a drag $\mathcal{D}$. How much must the plate be shortened if the drag on the new plate is to be $\mathcal{D}/4$? Assume the upstream velocity remains the same. Explain your answer physically.

(ANS: $\ell_{\text{new}} = \ell/16$)

9.7R (Momentum integral equation) As is indicated in Table 9.2, the laminar boundary layer results obtained from the momentum integral equation are relatively insensitive to the shape of the assumed velocity profile. Consider the profile given by $u = U$ for $y > \delta$, and $u = U\{1 - [(y - \delta)/\delta]^2\}^{1/2}$ for $y \leq \delta$ as shown in Fig. P9.7R. Note that this satisfies the conditions $u = 0$ at $y = 0$ and $u = U$ at $y = \delta$. However, show that such a profile produces meaningless results when used with the momentum integral equation. Explain.

(ANS)



■ Figure P9.7R

9.8R (Drag—low Reynolds number) How fast do small water droplets of $0.06\text{-}\mu\text{m}$ ($6 \times 10^{-8}\text{ m}$) diameter fall through the air under standard sea-level conditions? Assume the drops do not evaporate. Repeat the problem for standard conditions at 5000-m altitude.

(ANS: $1.10 \times 10^{-7}\text{ m/s}$; $1.20 \times 10^{-7}\text{ m/s}$)

9.9R (Drag) A 12-mm-diameter cable is strung between a series of poles that are 40 m apart. Determine the horizontal force this cable puts on each pole if the wind velocity is 30 m/s.

(ANS: 372 N)

9.10R (Drag) How much less power is required to pedal a racing-style bicycle at 20 mph with a 10-mph tail wind than at the same speed with a 10-mph head wind? (See Fig. 9.30.)

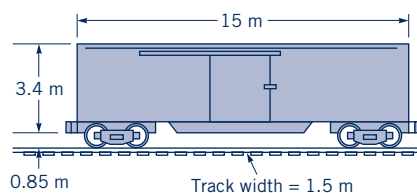
(ANS: 0.375 hp)

9.11R (Drag) A rectangular cartop carrier of 1.6-ft height, 5.0-ft length (front to back), and a 4.2-ft 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.

(ANS: 12.9 hp)

9.12R (Drag) Estimate the wind velocity necessary to blow over the 250-kN boxcar shown in Fig. P9.12R.

(ANS: approximately 32.6 m/s to 35.1 m/s)



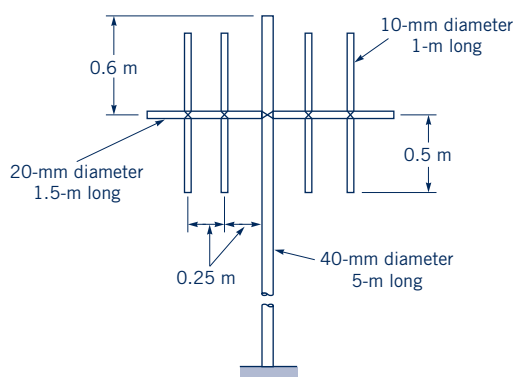
■ Figure P9.12R

9.13R (Drag) A 200-N rock (roughly spherical in shape) of specific gravity $SG = 1.93$ falls at a constant speed U . Determine U if the rock falls through (a) air; (b) water.

(ANS: 176 m/s; 5.28 m/s)

9.14R (Drag—composite body) A shortwave radio antenna is constructed from circular tubing, as is illustrated in Fig. P9.14R. Estimate the wind force on the antenna in a 100 km/hr wind.

(ANS: 180 N)



■ Figure P9.14R

9.15R (Lift) Show that for level flight the drag on a given airplane is independent of altitude if the lift and drag coefficients remain constant. Note that with C_L constant the airplane must fly faster at a higher altitude.

(ANS)

9.16R (Lift) The wing area of a small airplane weighing 6.22 kN is 10.2 m^2 . (a) If the cruising speed of the plane is 210 km/hr, determine the lift coefficient of the wing. (b) If the engine delivers 150 kW at this speed, and if 60% of this power represents propeller loss and body resistance, what is the drag coefficient of the wing?

(ANS: 0.292; 0.0483)

Review Problems for Chapter 10

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

10.1R (Surface waves) If the water depth in a pond is 15 ft, determine the speed of small amplitude, long wavelength ($\lambda \gg y$) waves on the surface.

(ANS: 22.0 ft/s)

10.2R (Surface waves) A small amplitude wave travels across a pond with a speed of 9.6 ft/s. Determine the water depth.

(ANS: $y \geq 2.86$ ft)

10.3R (Froude number) The average velocity and average depth of a river from its beginning in the mountains to its discharge into the ocean are given in the table below. Plot a graph of the Froude number as a function of distance along the river.

Distance (mi)	Average Velocity (ft/s)	Average Depth (ft)
0	13	1.5
5	10	2.0
10	9	2.3
30	5	3.7
50	4	5.4
80	4	6.0
90	3	6.2

(ANS: $Fr = 1.87$ at the beginning, 0.212 at the discharge)

10.4R (Froude number) Water flows in a rectangular channel at a depth of 4 ft and a flowrate of $Q = 200$ cfs. Determine the minimum channel width if the flow is to be subcritical.

(ANS: 4.41 ft)

10.5R (Specific energy) Plot the specific energy diagram for a wide channel carrying $q = 50$ ft²/s. Determine (a) the critical depth, (b) the minimum specific energy, (c) the alternate depth corresponding to a depth of 2.5 ft, and (d) the possible flow velocities if $E = 10$ ft.

(ANS: 4.27 ft; 6.41 ft; 8.12 ft; 5.22 ft/s or 22.3 ft/s)

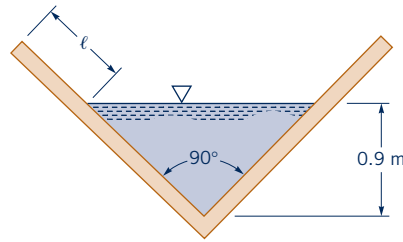
10.6R (Specific energy) Water flows at a rate of 1000 ft³/s in a horizontal rectangular channel 30 ft wide with a 2-ft depth. Determine the depth if the channel contracts to a width of 25 ft. Explain.

(ANS: 2.57 ft)

10.7R (Wall shear stress) Water flows in a 10-ft-wide rectangular channel with a flowrate of 150 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.

(ANS: 0.0320; 0.585 lb/ft²)

10.8R (Manning equation) The triangular flume shown in Fig. P10.8R is built to carry its design flowrate, Q_0 , at a depth of 0.90 m as is indicated. If the flume is to be able to carry up



■ Figure P10.8R

to twice its design flowrate, $Q = 2Q_0$, determine the freeboard, ℓ , needed.

(ANS: 0.378 m)

10.9R (Manning equation) Water flows in a rectangular channel of width b at a depth of $b/3$. Determine the diameter of a circular channel (in terms of b) that carries the same flowrate when it is half-full. Both channels have the same Manning coefficient, n , and slope.

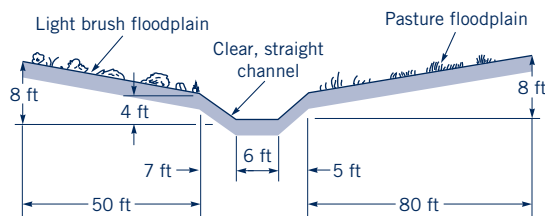
(ANS: $0.889 b$)

10.10R (Manning equation) A weedy irrigation canal of trapezoidal cross section is to carry 20 m³/s when built on a slope of 0.56 m/km. If the sides are at a 45° angle and the bottom is 8 m wide, determine the width of the waterline at the free surface.

(ANS: 12.0 m)

10.11R (Manning equation) Determine the maximum flowrate possible for the creek shown in Fig. P10.11R if it is not to overflow onto the floodplain. The creek bed drops an average of 5 ft/half-mile of length. Determine the flowrate during a flood if the depth is 8 ft.

(ANS: 182 ft³/s; 1517 ft³/s)



■ Figure P10.11R

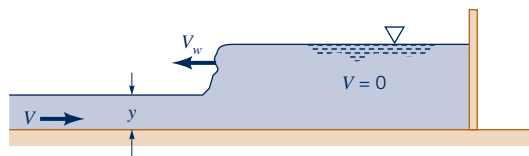
10.12R (Best hydraulic cross section) Show that the triangular channel with the best hydraulic cross section (i.e., minimum area, A , for a given flowrate) is a right triangle as is shown in Fig. E10.8b.

10.13R (Hydraulic jump) At the bottom of a water ride in an amusement park, the water in the rectangular channel has a depth of 1.2 ft and a velocity of 15.6 ft/s. Determine the height of the “standing wave” (a hydraulic jump) that the boat passes through for its final “splash.”

(ANS: 2.50 ft)

10.14R (Hydraulic jump) Water flows in a rectangular channel with velocity $V = 6$ m/s. A gate at the end of the channel is suddenly closed so that a wave (a moving hydraulic jump) travels upstream with velocity $V_w = 2$ m/s as is indicated in Fig. P10.14R. Determine the depths ahead of and behind the wave. Note that this is an unsteady problem for a stationary observer. However, for an observer moving to the left with velocity V_w , the flow appears as a steady hydraulic jump.

(ANS: 0.652 m; 2.61 m)



■ Figure P10.14R

10.15R (Sharp-crested weir) Determine the head, H , required to allow a flowrate of $600 \text{ m}^3/\text{hr}$ over a sharp-crested triangular weir with $\theta = 60^\circ$.

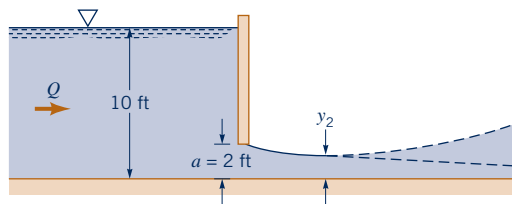
(ANS: 0.536 m)

10.16R (Broad-crested weir) The top of a broad-crested weir block is at an elevation of 724.5 ft, which is 4 ft above the channel bottom. If the weir is 20 ft wide and the flowrate is 400 cfs, determine the elevation of the reservoir upstream of the weir.

(ANS: 730.86 ft)

10.17R (Underflow gate) Water flows under a sluice gate in a 60-ft-wide finished concrete channel as is shown in Fig. P10.17R. Determine the flowrate. If the slope of the channel is 2.5 ft/100 ft, will the water depth increase or decrease downstream of the gate? Assume $C_c = y_2/a = 0.65$. Explain.

(ANS: $1670 \text{ ft}^3/\text{s}$; decrease)



■ Figure P10.17R

Review Problems for Chapter 11

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

11.1R (Speed of sound) Determine the speed of sound in air for a hot summer day when the temperature is 100°F ; for a cold winter day when the temperature is -20°F .

(ANS: 1160 ft/s; 1028 ft/s)

11.2R (Speed of sound) Compare values of the speed of sound in ft/s in the following liquids at 68°F : (a) ethyl alcohol, (b) glycerin, (c) mercury.

(ANS: 3810 ft/s; 6220 ft/s; 4760 ft/s)

11.3R (Sound waves) A stationary point source emits weak pressure pulses in a flow that moves uniformly from left to right with a Mach number of 0.5. Sketch the instantaneous outline at time = 10 s of pressure waves emitted earlier at time = 5 s and time = 8 s. Assume that the speed of sound is 1000 ft/s .

11.4R (Mach number) An airplane moves forward in air with a speed of 500 mph at an altitude of 40,000 ft. Determine the Mach number involved if the air is considered as U.S. standard atmosphere (see Table C.1).

(ANS: 0.757)

11.5R (Isentropic flow) At section (1) in the isentropic flow of carbon dioxide, $p_1 = 40 \text{ kPa(absolute)}$, $T_1 = 60^\circ\text{C}$, and $V_1 = 350 \text{ m/s}$. Determine the flow velocity, V_2 , in m/s, at another section, section (2), where the Mach number is 2.0. Also calculate the section area ratio, A_2/A_1 .

(ANS: 500 m/s; 1.71)

11.6R (Isentropic flow) An ideal gas in a large storage tank at 100 psia and 60°F flows isentropically through a converging duct to the atmosphere. The throat area of the duct is 0.1 ft^2 . Determine the pressure, temperature, velocity, and mass flowrate of the gas at the duct throat if the gas is (a) air, (b) carbon dioxide, (c) helium.

(ANS: (a) 52.8 psia; 433 °R; 1020 ft/s; 1.04 slugs/s; (b) 54.6 psia; 452 °R; 815 ft/s; 1.25 slugs/s; (c) 48.8 psia; 391 °R; 2840 ft/s; 0.411 slugs/s)

11.7R (Fanno flow) A long, smooth wall pipe ($f = 0.01$) is to deliver $8000 \text{ ft}^3/\text{min}$ of air at 60°F and 14.7 psia. The inside diameter of the pipe is 0.5 ft, and the length of the pipe is 100 ft. Determine the static temperature and pressure required at the pipe entrance if the flow through the pipe is adiabatic.

(ANS: 539 °R; 23.4 psia)

11.8R (Rayleigh flow) Air enters a constant-area duct that may be considered frictionless with $T_1 = 300 \text{ K}$ and $V_1 = 300 \text{ m/s}$. Determine the amount of heat transfer in kJ/kg required to choke the Rayleigh flow involved.

(ANS: 5020 J/kg)

11.9R (Normal shock waves) Standard atmospheric air enters subsonically and accelerates isentropically to supersonic flow in a duct. If the ratio of duct exit to throat cross-sectional areas is 3.0, determine the ratio of back pressure to inlet stagnation pressure that will result in a standing normal shock at the duct exit. Determine also the stagnation pressure loss across the normal shock in kPa.

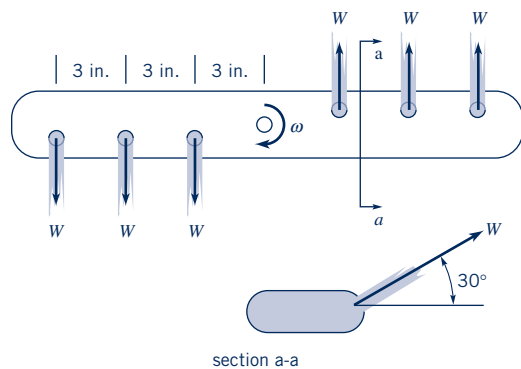
(ANS: 0.375; 56.1 kPa)

Review Problems for Chapter 12

Complete detailed solutions to the review problems can be found in *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2006 John Wiley and Sons, Inc.).

12.1R (Angular momentum) Water is supplied to a dishwasher through the manifold shown in Fig. P12.1R. Determine the rotational speed of the manifold if bearing friction and air resistance are neglected. The total flowrate of 2.3 gpm is divided evenly among the six outlets, each of which produces a 5/16-in.-diameter stream.

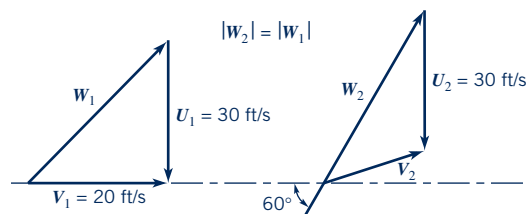
(ANS: 0.378 rev/s)



■ Figure P12.1R

12.2R (Velocity triangles) An axial-flow turbomachine rotor involves the upstream (1) and downstream (2) velocity triangles shown in Fig. P12.2R. Is this turbomachine a turbine or a fan? Sketch an appropriate blade section and determine the energy transferred per unit mass of fluid.

(ANS: turbine; $-36.9 \text{ ft}^2/\text{s}^2$)

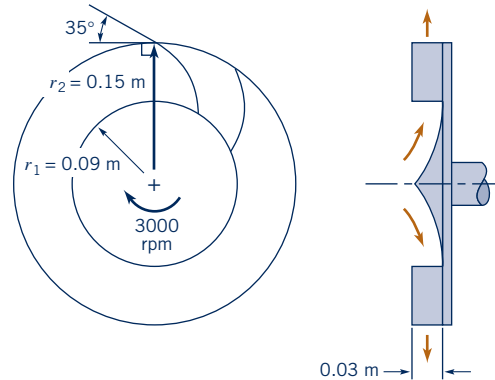


■ Figure P12.2R

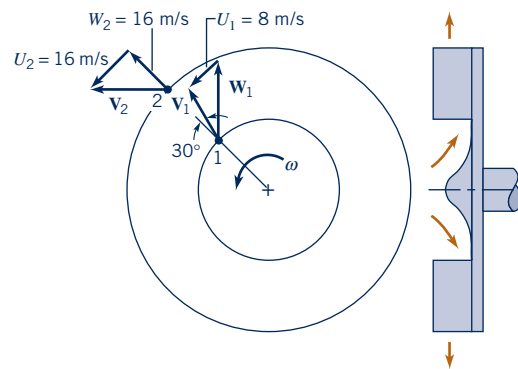
12.3R (Centrifugal pump) Shown in Fig. P12.3R are front and side views of a centrifugal pump rotor or impeller. If the pump delivers 200 liters/s of water and the blade exit angle is 35° from the tangential direction, determine the power requirement associated with flow leaving at the blade angle. The flow entering the rotor blade row is essentially radial as viewed from a stationary frame.

(ANS: 348 kW)

12.4R (Centrifugal pump) The velocity triangles for water flow through a radial pump rotor are as indicated in Fig. P12.4R. (a) Determine the energy added to each unit mass (kg) of water



■ Figure P12.3R



■ Figure P12.4R

as it flows through the rotor. (b) Sketch an appropriate blade section.

(ANS: $404 \text{ N} \cdot \text{m}/\text{kg}$)

12.5R (Similarity laws) When the shaft horsepower supplied to a certain centrifugal pump is 25 hp, the pump discharges 700 gpm of water while operating at 1800 rpm with a head rise of 90 ft. (a) If the pump speed is reduced to 1200 rpm, determine the new head rise and shaft horsepower. Assume the efficiency remains the same. (b) What is the specific speed, N_{sd} , for this pump?

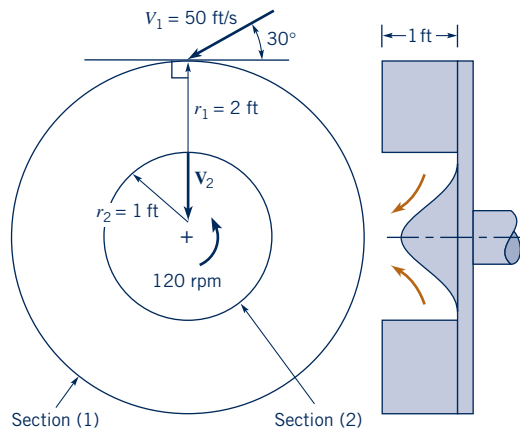
(ANS: 40 ft, 7.41 hp; 1630)

12.6R (Specific speed) An axial-flow turbine develops 10,000 hp when operating with a head of 40 ft. Determine the rotational speed if the efficiency is 88%.

(ANS: 65.4 rpm)

12.7R (Turbine) A water turbine with radial flow has the dimensions shown in Fig. P12.7R. The absolute entering velocity is 50 ft/s, and it makes an angle of 30° with the tangent to the rotor. The absolute exit velocity is directed radially inward. The angular speed of the rotor is 120 rpm. Find the power delivered to the shaft of the turbine.

(ANS: -1200 hp)



■ **Figure P12.7R**

12.8R (Turbine) Water enters an axial-flow turbine rotor with an absolute velocity tangential component, V_{θ} , of 30 ft/s . The corresponding blade velocity, U , is 100 ft/s . The water leaves the rotor blade row with no angular momentum. If the stagnation pressure drop across the turbine is 45 psi , determine the efficiency of the turbine.

(ANS: 0.898)