Some of the important equations in this chapter are:

Equation for streamlines	$\dfrac{dy}{dx} = \dfrac{v}{u}$	**(4.1)**
Acceleration	$\mathbf{a} = \dfrac{\partial \mathbf{V}}{\partial t} + u\dfrac{\partial \mathbf{V}}{\partial x} + v\dfrac{\partial \mathbf{V}}{\partial y} + w\dfrac{\partial \mathbf{V}}{\partial z}$	**(4.3)**
Material derivative	$\dfrac{D(\ )}{Dt} = \dfrac{\partial(\ )}{\partial t} + (\mathbf{V} \cdot \nabla)(\ )$	**(4.6)**
Streamwise and normal components of acceleration	$a_s = V\dfrac{\partial V}{\partial s}, \qquad a_n = \dfrac{V^2}{\mathscr{R}}$	**(4.7)**
Reynolds transport theorem (restricted form)	$\dfrac{DB_{\text{sys}}}{Dt} = \dfrac{\partial B_{\text{cv}}}{\partial t} + \rho_2 A_2 V_2 b_2 - \rho_1 A_1 V_1 b_1$	**(4.15)**
Reynolds transport theorem (general form)	$\dfrac{DB_{\text{sys}}}{Dt} = \dfrac{\partial}{\partial t}\displaystyle\int_{\text{cv}} \rho b \, d\mathcal{V} + \int_{\text{cs}} \rho b \, \mathbf{V} \cdot \hat{\mathbf{n}} \, dA$	**(4.19)**
Relative and absolute velocities	$\mathbf{V} = \mathbf{W} + \mathbf{V}_{\text{cv}}$	**(4.22)**

References

1. Streeter, V. L., and Wylie, E. B., *Fluid Mechanics*, 8th Ed., McGraw-Hill, New York, 1985.
2. Goldstein, R. J., *Fluid Mechanics Measurements*, Hemisphere, New York, 1983.
3. Homsy, G. M., et al., *Multimedia Fluid Mechanics* CD-ROM, 2nd Ed., Cambridge University Press, New York, 2007.
4. Magarvey, R. H., and MacLatchy, C. S., The Formation and Structure of Vortex Rings, *Canadian Journal of Physics*, Vol. 42, 1964.

Problem available in *WileyPLUS* at instructor's discretion.

Tutoring problem available in *WileyPLUS* at instructor's discretion.

Problem is related to a chapter video available in *WileyPLUS*.

* Problem to be solved with aid of programmable calculator or computer.

† Open-ended problem that requires critical thinking. These problems require various assumptions to provide the necessary input data. There are not unique answers to these problems.

Review Problems

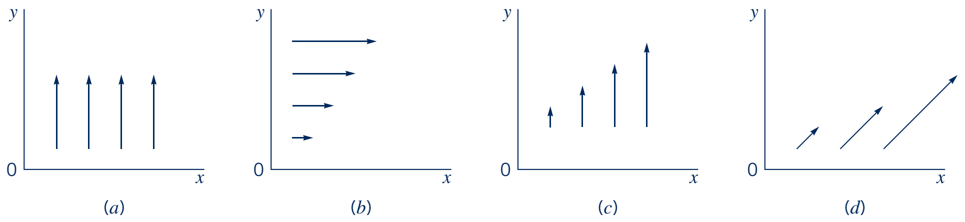
Go to Appendix G (*WileyPLUS* or the book's website, www.wiley.com/college/munson) for a set of review problems with answers. Detailed solutions can be found in the *Student Solution Manual and Study Guide for Fundamentals of Fluid Mechanics*, by Munson et al. (© 2013 John Wiley and Sons, Inc.).

Conceptual Questions

4.1C A velocity field is given by:

$$\mathbf{V} = 6x\hat{j} \text{ m/s}.$$

Velocity fields are plotted below, where the arrows indicate the magnitude and direction of the velocity vectors. The picture that best describes the field is:



4.2C Consider the path of a football thrown by Brett Favre. Suppose that you are interested in determining how far the ball travels. Then you are interested in:

a) neither Lagrangian nor Eulerian views.

b) the Eulerian view of the field.

c) the Lagrangian or particle view of the football.

4.3C The following is true of the system (versus control volume) form of the basic equations (mass, momentum, angular momentum, and energy):

a) The equations apply to a fixed quantity of mass.

b) The equations are formulated in terms of extensive properties.

c) The equations apply to a fixed volume.

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

Problems

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

Section 4.1 The Velocity Field

4.1 Obtain a photograph/image of a situation in which a fluid is flowing. Print this photo and draw in some lines to represent how you think some streamlines may look. Write a brief paragraph to describe the acceleration of a fluid particle as it flows along one of these streamlines.

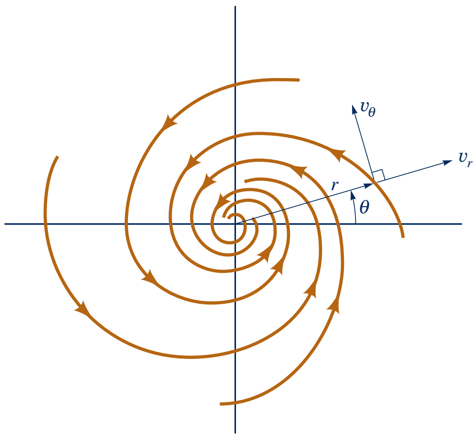
4.2 The velocity field of a flow is given by $\mathbf{V} = (3y + 2)\hat{\mathbf{i}} + (x - 8)\hat{\mathbf{j}} + 5z\hat{\mathbf{k}}$ m/s, where x, y, and z are in meters. Determine the fluid speed at the origin ($x = y = z = 0$) and on the y axis ($x = z = 0$).

4.3 The velocity field of a flow is given by $\mathbf{V} = 2x^2t\hat{\mathbf{i}} + [4y(t - 1) + 2x^2t]\hat{\mathbf{j}}$ m/s, where x and y are in meters and t is in seconds. For fluid particles on the x axis, determine the speed and direction of flow.

4.4 A two-dimensional velocity field is given by $u = 1 + y$ and $v = 1$. Determine the equation of the streamline that passes through the origin. On a graph, plot this streamline.

4.5 The velocity field of a flow is given by $\mathbf{V} = (5z - 3)\hat{\mathbf{i}} + (x + 4)\hat{\mathbf{j}} + 4y\hat{\mathbf{k}}$ m/s, where x, y, and z are in meters. Determine the fluid speed at the origin ($x = y = z = 0$) and on the x axis ($y = z = 0$).

4.6 A flow can be visualized by plotting the velocity field as velocity vectors at representative locations in the flow as shown in **Video V4.2** and Fig. E4.1. Consider the velocity field given in polar coordinates by $v_r = -10/r$, and $v_\theta = 10/r$. This flow approximates a fluid swirling into a sink as shown in Fig. P4.6. Plot the velocity field at locations given by $r = 1$, 2, and 3 with $\theta = 0$, 30, 60, and 90°.



■ **Figure P4.6**

4.7 The velocity field of a flow is given by $\mathbf{V} = 20y/(x^2 + y^2)^{1/2}\hat{\mathbf{i}} - 20x/(x^2 + y^2)^{1/2}\hat{\mathbf{j}}$ m/s, where x and y are in meters. Determine the fluid speed at points along the x axis; 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 $(0, 5)$?

4.8 The components of a velocity field are given by $u = x + y$, $v = xy^3 + 16$, and $w = 0$. Determine the location of any stagnation points ($\mathbf{V} = 0$) in the flow field.

4.9 The x and y components of velocity for a two-dimensional flow are $u = 2y$ m/s and $v = 0.9$ m/s, where y is in meters. Determine the equation for the streamlines and sketch representative streamlines in the upper half plane.

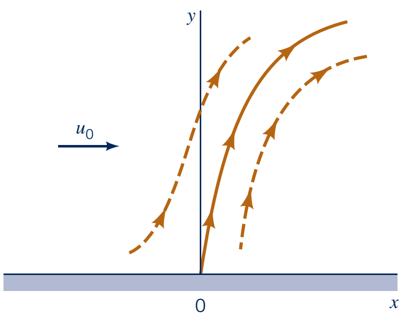
4.10 The velocity field of a flow is given by $u = -V_0y/(x^2 + y^2)^{1/2}$ and $v = V_0x/(x^2 + y^2)^{1/2}$, where V_0 is a constant. Where in the flow field is the speed equal to V_0? Determine the equation of the streamlines and discuss the various characteristics of this flow.

4.11 A velocity field is given by $\mathbf{V} = x\hat{\mathbf{i}} + x(x - 1)(y + 1)\hat{\mathbf{j}}$, where u and v are in m/s and x and y are in meters. Plot the streamline that passes through $x = 0$ and $y = 0$. Compare this streamline with the streakline through the origin.

4.12 From time $t = 0$ to $t = 5$ hr radioactive steam is released from a nuclear power plant accident located at $x = -1.6$ km and $y = 4.8$ km. The following wind conditions are expected: $\mathbf{V} = 16\hat{\mathbf{i}} - 8\hat{\mathbf{j}}$ km/h for $0 < t < 3$ h, $\mathbf{V} = 24\hat{\mathbf{i}} + 13\hat{\mathbf{j}}$ for $3 < t < 10$ h, and $\mathbf{V} = 8\hat{\mathbf{i}}$ km/h for $t > 10$ h. Draw to scale the expected streakline of the steam for $t = 3$, 10, and 15 h.

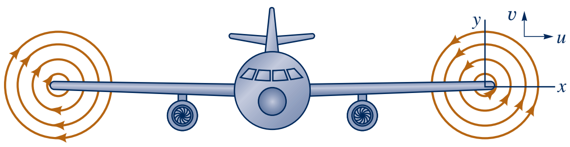
4.13 The x and y components of a velocity field are given by $u = x^2y$ and $v = -xy^2$. Determine the equation for the streamlines of this flow and compare it with those in Example 4.2. Is the flow in this problem the same as that in Example 4.2? Explain.

4.14 In addition to the customary horizontal velocity components of the air in the atmosphere (the "wind"), there often are vertical air currents (thermals) caused by buoyant effects due to uneven heating of the air as indicated in Fig. P4.14. Assume that the velocity field in a certain region is approximated by $u = u_0$, $v = v_0(1 - y/h)$ for $0 < y < h$, and $u = u_0$, $v = 0$ for $y > h$. Plot the shape of the streamline that passes through the origin for values of $u_0/v_0 = 0.5$, 1, and 2.



■ **Figure P4.14**

4.15 As shown in **Video V4.6** and Fig. P4.15, a flying airplane produces swirling flow near the end of its wings. In certain circumstances this flow can be approximated by the velocity field $u = -Ky/(x^2 + y^2)$ and $v = Kx/(x^2 + y^2)$, where K is a constant depending on various parameters associated with the airplane (i.e., its weight, speed) and x and y are measured from the center of the swirl. **(a)** Show that for this flow the velocity is inversely proportional to the distance from the origin. That is, $V = K/(x^2 + y^2)^{1/2}$. **(b)** Show that the streamlines are circles.



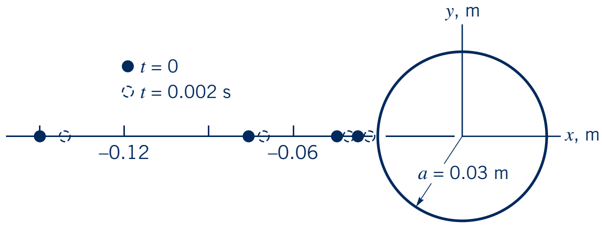
■ **Figure P4.15**

†4.16 For any steady flow the streamlines and streaklines are the same. For most unsteady flows this is not true. However, there are unsteady flows for which the streamlines and streaklines are the same. Describe a flow field for which this is true.

4.17 A 3 m diameter dust devil that rotates one revolution per second travels across the Martian surface (in the x-direction) with a speed of 1.5 m/s. Plot the pathline etched on the surface by a fluid particle 3 m from the center of the dust devil for time $0 \le t \le 3$ 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 meter and t is in seconds.

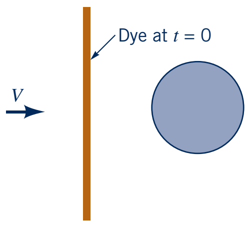
4.18 (See Fluids in the News article titled **"Follow those particles,"** Section 4.1.) Two photographs of four particles in a flow past a sphere are superposed as shown in Fig. P4.18. The time interval between the photos is $\Delta t = 0.002$ s. The locations of the particles, as determined from the photos, are shown in the table. **(a)** Determine the fluid velocity for these particles. **(b)** Plot a graph to compare the results of part **(a)** with the theoretical velocity which is given by $V = V_0(1 + a^3/x^3)$, where a is the sphere radius and V_0 is the fluid speed far from the sphere.

Particle	x at $t = 0$ s (m)	x at $t = 0.002$ s (m)
1	-0.15	-0.140
2	-0.075	-0.070
3	-0.042	-0.038
4	-0.036	-0.034



■ **Figure P4.18**

†4.19 Pathlines and streaklines provide ways to visualize flows. Another technique would be to instantly inject a line of dye across streamlines and observe how this line moves as time increases. For example, consider the initially straight dye line injected in front of the circular cylinder shown in Fig. P4.19. Discuss how this dye line would appear at later times. How would you calculate the location of this line as a function of time?



■ **Figure P4.19**

Section 4.2 The Acceleration Field

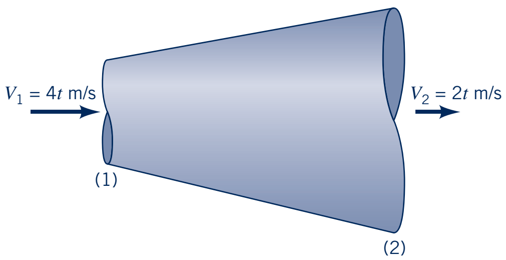
4.20 A velocity field is given by $u = cx^2$ and $v = cy^2$, where c is a constant. Determine the x and y components of the acceleration. At what point (points) in the flow field is the acceleration zero?

4.21 Determine the acceleration field for a three-dimensional flow with velocity components $u = -x$, $v = 4x^2y^2$, and $w = x - y$.

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

4.23 Water flows through a constant diameter pipe with a uniform velocity given by $\mathbf{V} = (8/t + 5)\hat{\mathbf{j}}$ m/s, where t is in seconds. Determine the acceleration at time $t = 1$, 2, and 10 s.

4.24 WILEY The velocity of air in the diverging pipe shown in Fig. P4.24 is given by $V_1 = 4t$ m/s and $V_2 = 2t$ m/s, where t is in seconds. **(a)** Determine the local acceleration at points (1) and (2). **(b)** Is the average convective acceleration between these two points negative, zero, or positive? Explain.

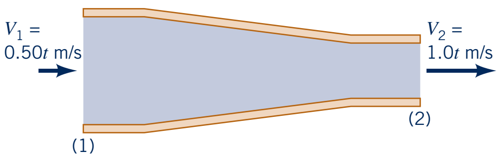


■ **Figure P4.24**

4.25 WILEY Water flows in a pipe so that its velocity triples every 20 s. At $t = 0$ it has $u = 1.5$ m/s. That is, $\mathbf{V} = u(t)\hat{\mathbf{i}} = 5\,(3^{t/20})\hat{\mathbf{i}}$ m/s. Determine the acceleration when $t = 0$, 10, and 20 s.

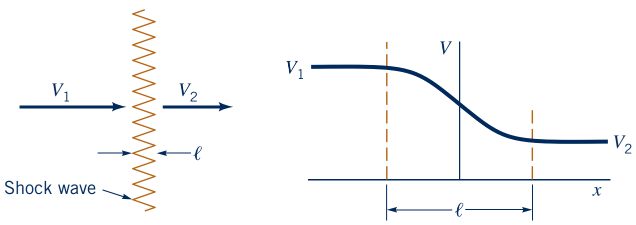
4.26 WILEY When a valve is opened, the velocity of water in a certain pipe is given by $u = 10(1 - e^{-t})$, $v = 0$, and $w = 0$, where u is in m/s and t is in seconds. Determine the maximum velocity and maximum acceleration of the water.

4.27 WILEY The velocity of the water in the pipe shown in Fig. P4.27 is given by $V_1 = 0.50t$ m/s and $V_2 = 1.0t$ m/s, where t is in seconds. Determine the local acceleration at points (1) and (2). Is the average convective acceleration between these two points negative, zero, or positive? Explain.



■ **Figure P4.27**

4.28 WILEY A shock wave is a very thin layer (thickness $= \ell$) 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. P4.28. If $V_1 = 549$ m/s, $V_2 = 213$ m/s, and $\ell = 2.5 \times 10^{-4}$ cm, estimate the average deceleration of the gas as it flows across the shock wave. How many g's deceleration does this represent?

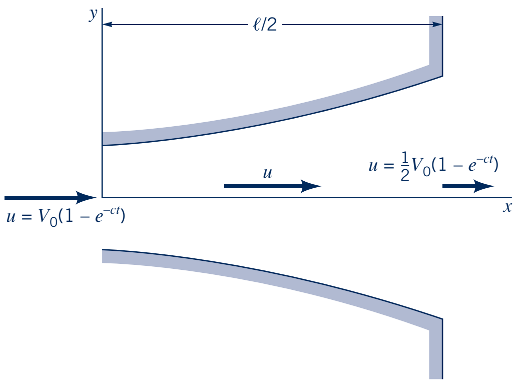


■ **Figure P4.28**

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

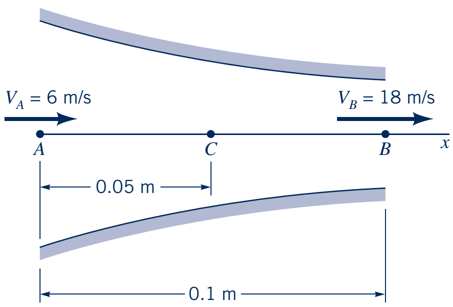
†4.30 A stream of water from the faucet strikes the bottom of the sink. Estimate the maximum acceleration experienced by the water particles. List all assumptions and show calculations.

4.31 WILEY As a valve is opened, water flows through the diffuser shown in Fig. P4.31 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 $V_0 = 3.0$ m/s and $\ell = 1.5$ m, what value of c (other than $c = 0$) is needed to make the acceleration zero for any x at $t = 1$ s? Explain how the acceleration can be zero if the flowrate is increasing with time.



■ **Figure P4.31**

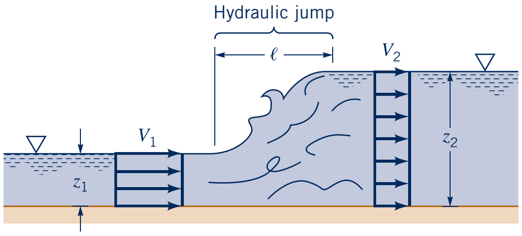
4.32 The fluid velocity along the x axis shown in Fig. P4.32 changes from 6 m/s at point A to 18 m/s at point B. It is also known that the velocity is a linear function of distance along the streamline. Determine the acceleration at points A, B, and C. Assume steady flow.



■ **Figure P4.32**

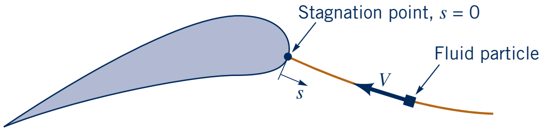
4.33 WILEY A fluid flows along the x axis with a velocity given by $\mathbf{V} = (x/t)\,\hat{\mathbf{i}}$, where x is in meters and t in seconds. **(a)** Plot the speed for $0 \le x \le 10$ m and $t = 3$ s. **(b)** Plot the speed for $x = 7$ m and $2 \le t \le 4$ s. **(c)** Determine the local and convective acceleration. **(d)** Show that the acceleration of any fluid particle in the flow is zero. **(e)** Explain physically how the velocity of a particle in this unsteady flow remains constant throughout its motion.

4.34 WILEY A hydraulic jump is a rather sudden change in depth of a liquid layer as it flows in an open channel as shown in Fig. P4.34 and **Video V10.12**. In a relatively short distance (thickness = ℓ) the liquid depth changes from z_1 to z_2, with a corresponding change in velocity from V_1 to V_2. If V_1 = 0.37 m/s, V_2 = 0.09 m/s, and ℓ = 0.006 m, estimate the average deceleration of the liquid as it flows across the hydraulic jump. How many g's deceleration does this represent?



■ **Figure P4.34**

4.35 A fluid particle flowing along a stagnation streamline, as shown in **Video V4.9** and Fig. P4.35, 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 = 0.2 m upstream of the stagnation point at t = 0 is given approximately by $s = 0.2e^{-0.5t}$, where t is in seconds and s is in meter. **(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, $a_s = a_s(s)$.

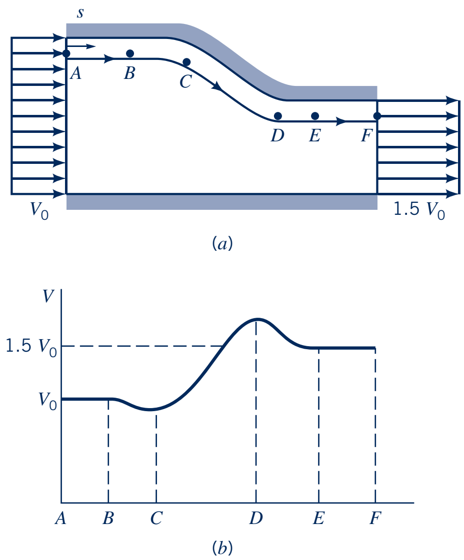


■ **Figure P4.35**

4.36 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 the local acceleration, the convective acceleration, and the acceleration of the fluid at points (1) and (2).

4.37 Repeat Problem 4.36 with the assumption that the flow is not steady, but at the time when V_1 = 10 m/s and V_2 = 25 m/s, it is known that $\partial V_1/\partial t$ = 20 m/s^2 and $\partial V_2/\partial t$ = 60 m/s^2.

4.38 An incompressible fluid flows through the converging duct shown in Fig. P4.38a with velocity V_0 at the entrance. Measurements indicate that the actual velocity of the fluid near the wall of the duct along streamline A–F is as shown in Fig. P4.38b. Sketch the component of acceleration along this streamline, a, as a function of s. Discuss the important characteristics of your result.

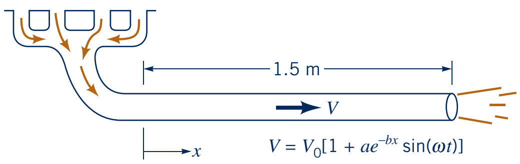


■ **Figure P4.38**

***4.39** Air flows steadily through a variable area pipe with a velocity of $\mathbf{V} = u(x)\hat{\mathbf{i}}$ m/s, where the approximate measured values of $u(x)$ are given in the table. Plot the acceleration as a function of x for $0 \leq x \leq 30$ cm. Plot the acceleration if the flowrate is increased by a factor of N (i.e., the values of u are increased by a factor of N) for N = 2, 4, 10.

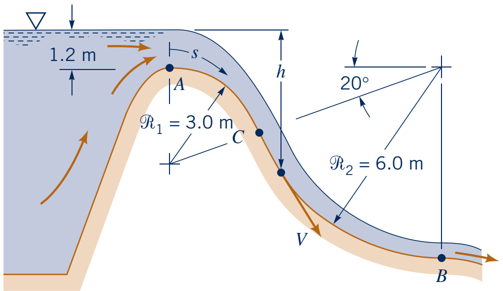
x (cm)	u (m/s)	x (cm)	u (m/s)
0	3.0	17.5	6.1
2.5	3.1	20.0	5.3
5.0	4.0	22.5	4.1
7.5	6.1	25.0	3.6
10.0	8.6	27.5	3.1
12.5	8.7	30.5	3.6
15.0	7.9	33.0	3.6

***4.40** As is indicated in Fig. P4.40, the speed of exhaust in a car's exhaust pipe varies in time and distance because of the periodic nature of the engine's operation and the damping effect with distance from the engine. Assume that the speed is given by $V = V_0[1 + ae^{-bx}\sin(\omega t)]$, where V_0 = 2.4 m/s, a = 0.05, b = 0.66 m^{-1}, and ω = 50 rad/s. Calculate and plot the fluid acceleration at x = 0, 0.3, 0.6, 0.9, 1.2, and 1.5 m for $0 \leq t \leq \pi/25$ s.



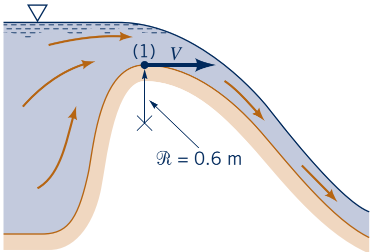
■ **Figure P4.40**

4.41 Water flows down the face of the dam shown in Fig. P4.41. The face of the dam consists of two circular arcs with radii of 3.0 and 6.0 m as shown. If the speed of the water along streamline A–B is approximately $V = (2gh)^{1/2}$, where the distance h is as indicated, plot the normal acceleration as a function of distance along the streamline, $a_n = a_n(s)$.



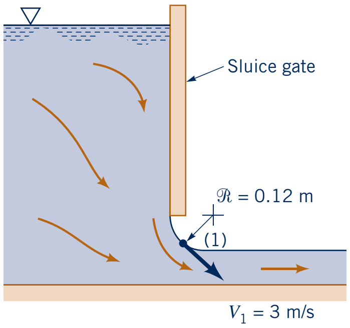
■ **Figure P4.41**

4.42 WILEY Water flows over the crest of a dam with speed V as shown in Fig. P4.42. Determine the speed if the magnitude of the normal acceleration at point (1) is to equal the acceleration of gravity, g.



■ **Figure P4.42**

4.43 Water flows under the sluice gate shown in Fig. P4.43. If $V_1 = 3$ m/s, what is the normal acceleration at point (1)?

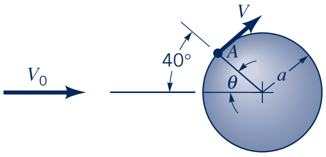


■ **Figure P4.43**

4.44 For the flow given in Problem 4.41, plot the streamwise acceleration, a_s, as a function of distance, s, along the surface of the dam from A to C.

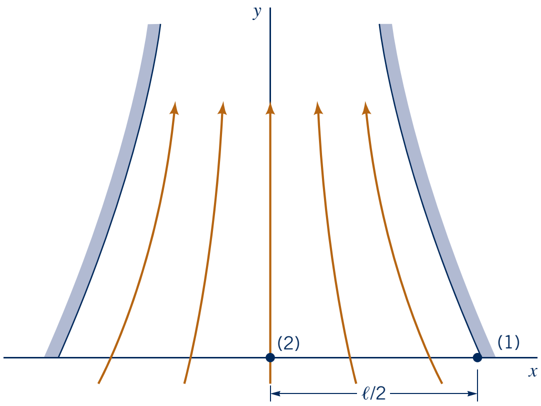
4.45 WILEY Assume that the streamlines for the wingtip vortices from an airplane (see Fig. P4.15 and **Video V4.6**) can be approximated by circles of radius r and that the speed is $V = K/r$, where K is a constant. Determine the streamline acceleration, a_s, and the normal acceleration, a_n, for this flow.

4.46 WILEY A fluid flows past a sphere with an upstream velocity of $V_0 = 40$ m/s as shown in Fig. P4.46. From a more advanced theory it is found that the speed of the fluid along the front part of the sphere is $V = \frac{3}{2}V_0 \sin\theta$. Determine the streamwise and normal components of acceleration at point A if the radius of the sphere is $a = 0.20$ m.



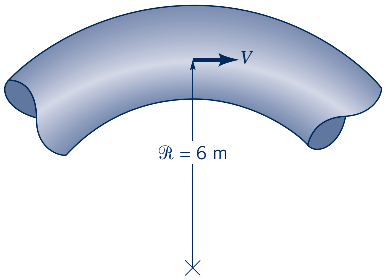
■ **Figure P4.46**

4.47 WILEY The velocity components for steady flow through the nozzle shown in Fig. P4.47 are $u = -V_0 x/\ell$ and $v = V_0[1 + (y/\ell)]$, where V_0 and ℓ are constants. Determine the ratio of the magnitude of the acceleration at point (1) to that at point (2).



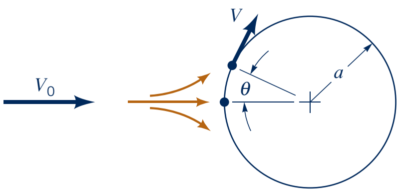
■ **Figure P4.47**

4.48 Water flows through the curved hose shown in Fig. P4.48 with an increasing speed of $V = 3t$ m/s, where t is in seconds. For $t = 2$ s determine **(a)** the component of acceleration along the streamline, **(b)** the component of acceleration normal to the streamline, and **(c)** the net acceleration (magnitude and direction).



■ **Figure P4.48**

***4.49** WILEY A fluid flows past a circular cylinder of radius a with an upstream speed of V_0 as shown in Fig. P4.49. A more advanced theory indicates that if viscous effects are negligible, the velocity of the fluid along the surface of the cylinder is given by $V = 2V_0 \sin\theta$. Determine the streamline and normal components of acceleration on the surface of the cylinder as a function of V_0, a, and θ and plot graphs of a_s and a_n for $0 \le \theta \le 90°$ with $V_0 = 10$ m/s and $a = 0.01, 0.10, 1.0,$ and 10.0 m.



■ **Figure P4.49**

4.50 Determine the x and y components of acceleration for the flow $u = c(x^2 - y^2)$ and $v = -2cxy$, where c is a constant. If $c > 0$, is the particle at point $x = x_0 > 0$ and $y = 0$ accelerating or decelerating? Explain. Repeat if $x_0 < 0$.

4.51 WILEY When the floodgates in a channel are opened, water flows along the channel downstream of the gates with an increasing speed given by $V = 1.2(1 + 0.1t)$ m/s, for $0 \le t \le 20$ s, where t is in seconds. For $t > 20$ s the speed is a constant $V = 3.6$ m/s. Consider a location in the curved channel where the radius of curvature of the streamlines is 15 m. For $t = 10$ s, determine **(a)** the component of acceleration along the streamline, **(b)** the component of acceleration normal to the streamline, and **(c)** the net acceleration (magnitude and direction). Repeat for $t = 30$ s.

4.52 WILEY Water flows steadily through the funnel shown in Fig. P4.52. Throughout most of the funnel the flow is approximately radial (along rays from O) with a velocity of $V = c/r^2$, where r is the radial coordinate and c is a constant. If the velocity is 0.4 m/s when $r = 0.1$ m, determine the acceleration at points A and B.

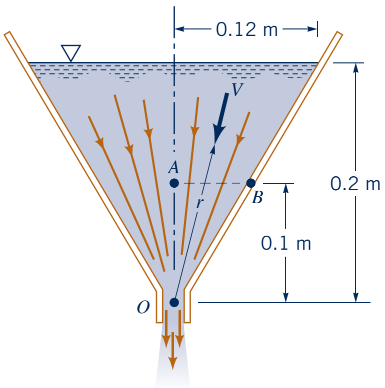


Figure P4.52

4.53 WILEY Water flows though the slit at the bottom of a two-dimensional water trough as shown in Fig. P4.53. 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.

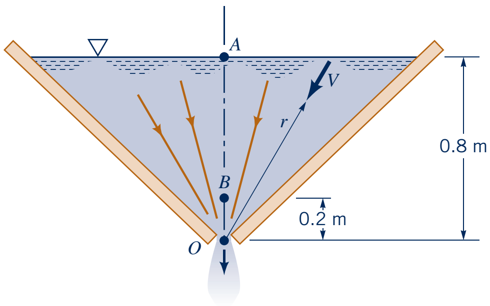


Figure P4.53

4.54 WILEY Air flows from a pipe into the region between two parallel circular disks as shown in Fig. P4.54. The fluid velocity in the gap between the disks is closely approximated by $V = V_0R/r$, where R is the radius of the disk, r is the radial coordinate, and V_0 is the fluid velocity at the edge of the disk. Determine the acceleration for $r = 0.3$, 0.6, or 0.9 m if $V_0 = 1.5$ m/s and $R = 0.9$ m.

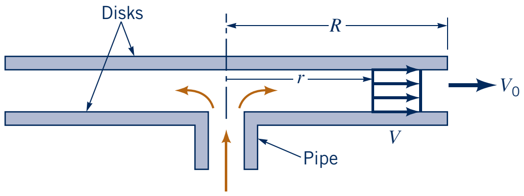


Figure P4.54

4.55 WILEY Air flows into a pipe from the region between a circular disk and a cone as shown in Fig. P4.55. The fluid velocity in the gap between the disk and the cone is closely approximated by $V = V_0R^2/r^2$, where R is the radius of the disk, r is the radial coordinate, and V_0 is the fluid velocity at the edge of the disk. Determine the acceleration for $r = 0.15$ m and 0.6 m if $V_0 = 1.5$ m/s and $R = 0.6$ m.

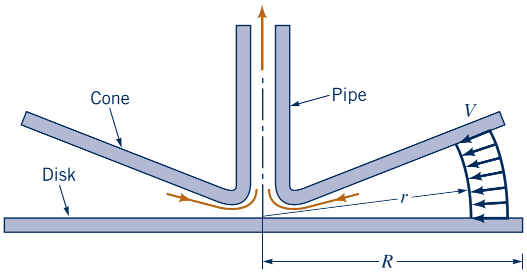


Figure P4.55

Section 4.2.1 The Material Derivative

4.56 WILEY Air flows steadily through a long pipe with a speed of $u = 15 + 0.5x$, where x is the distance along the pipe in meter, and u is in m/s. Due to heat transfer into the pipe, the air temperature, T, within the pipe is $T = 300 + 10x$ °C. Determine the rate of change of the temperature of air particles as they flow past the section at $x = 1.5$ m.

4.57 A gas flows along the x axis with a speed of $V = 5x$ m/s and a pressure of $p = 10x^2$ N/m^2, where x is in meters. **(a)** Determine the time rate of change of pressure at the fixed location $x = 1$. **(b)** Determine the time rate of change of pressure for a fluid particle flowing past $x = 1$. **(c)** Explain without using any equations why the answers to parts (a) and (b) are different.

4.58 WILEY Assume the temperature of the exhaust in an exhaust pipe can be approximated by $T = T_0(1 + ae^{-bx})\,[1 + c\cos(\omega t)]$, where $T_0 =$ 100 °C, $a = 3$, $b = 0.03$ m^{-1}, $c = 0.05$, and $\omega = 100$ rad/s. If the exhaust speed is a constant 3 m/s, determine the time rate of change of temperature of the fluid particles at $x = 0$ and $x = 4$ m when $t = 0$.

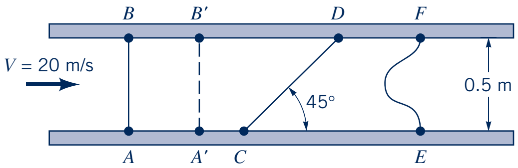
4.59 WILEY GO A bicyclist leaves from her home at 9 A.M. and rides to a beach 64 km away. Because of a breeze off the ocean, the temperature at the beach remains 15 °C throughout the day. At the cyclist's home the temperature increases linearly with time, going from 15 °C at 9 A.M. to 27 °C by 1 P.M. The temperature is assumed to vary linearly as a function of position between the cyclist's home and the beach. Determine the rate of change of temperature observed by the cyclist for the following conditions: **(a)** as she pedals 16 km/h through a town 16 km from her home at 10 A.M.; **(b)** as she eats lunch at a rest stop 48 km from her home at noon; **(c)** as she arrives enthusiastically at the beach at 1 P.M., pedaling 32 km/h.

4.60 WILEY 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.

Section 4.4 The Reynolds Transport Theorem

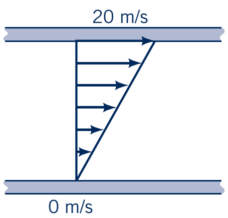
4.61 Obtain a photograph/image of a situation in which a fluid is flowing. Print this photo and draw a control volume through which the fluid flows. Write a brief paragraph that describes how the fluid flows into and out of this control volume.

4.62 Water flows through a duct of square cross section as shown in Fig. P4.62 with a constant, uniform velocity of $V = 20$ m/s. Consider fluid particles that lie along line A–B at time $t = 0$. Determine the position of these particles, denoted by line A'–B', when $t = 0.20$ s. Use the volume of fluid in the region between lines A–B and A'–B' to determine the flowrate in the duct. Repeat the problem for fluid particles originally along line C–D; along line E–F. Compare your three answers.



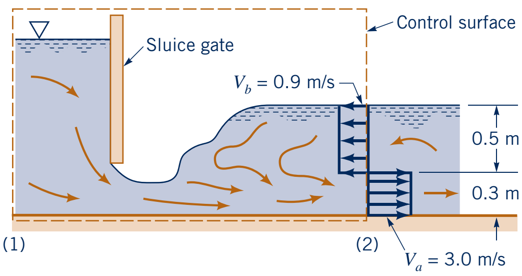
■ **Figure P4.62**

4.63 Repeat Problem 4.62 if the velocity profile is linear from 0 to 20 m/s across the duct as shown in Fig. P4.63.



■ **Figure P4.63**

4.64 In the region just downstream of a sluice gate, the water may develop a reverse flow region as is indicated in Fig. P4.64 and **Video V10.9**. The velocity profile is assumed to consist of two uniform regions, one with velocity $V_a = 3.0$ m/s and the other with $V_b = 0.9$ m/s. Determine the net flowrate of water across the portion of the control surface at section (2) if the channel is 6.0 m wide.



■ **Figure P4.64**

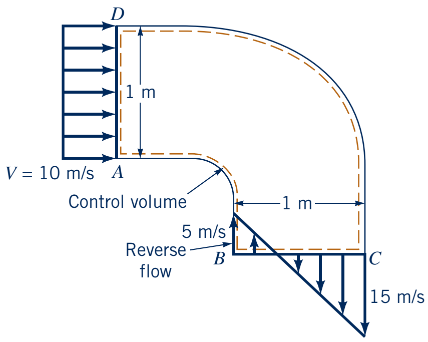
4.65 At time $t = 0$ the valve on an initially empty (perfect vacuum, $\rho = 0$) tank is opened and air rushes in. If the tank has a volume of $\mathcal{V}_0$ and the density of air within the tank increases as $\rho = \rho_\infty(1 - e^{-bt})$, where b is a constant, determine the time rate of change of mass within the tank.

†4.66 From calculus, one obtains the following formula (Leibnitz rule) for the time derivative of an integral that contains time in both the integrand and the limits of the integration:

$$\frac{d}{dt}\int_{x_1(t)}^{x_2(t)} f(x, t)dx = \int_{x_1}^{x_2} \frac{\partial f}{\partial t} dx + f(x_2, t)\frac{dx_2}{dt} - f(x_1, t)\frac{dx_1}{dt}$$

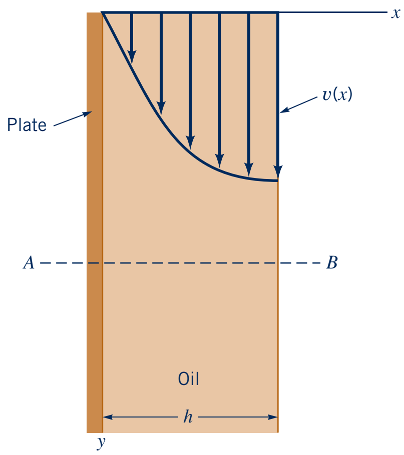
Discuss how this formula is related to the time derivative of the total amount of a property in a system and to the Reynolds transport theorem.

4.67 Air enters an elbow with a uniform speed of 10 m/s as shown in Fig. P4.67. 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.



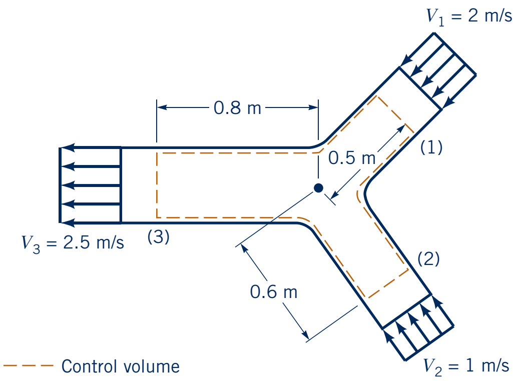
■ **Figure P4.67**

4.68 A layer of oil flows down a vertical plate as shown in Fig. P4.68 with a velocity of $\mathbf{V} = (V_0/h^2)(2hx - x^2)\hat{\mathbf{j}}$ where V_0 and h are constants. **(a)** Show that the fluid sticks to the plate and that the shear stress at the edge of the layer $(x = h)$ is zero. **(b)** Determine the flowrate across surface AB. Assume the width of the plate is b. (*Note:* The velocity profile for laminar flow in a pipe has a similar shape. See **Video V6.13**.)



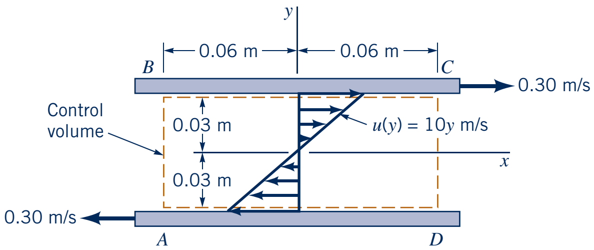
■ **Figure P4.68**

4.69 Water flows in the branching pipe shown in Fig. P4.69 with uniform velocity at each inlet and outlet. The fixed control volume coincides with the system at time $t = 20$ s. Make a sketch to indicate **(a)** the boundary of the system at time $t = 20.1$ s, **(b)** the fluid that left the control volume during that 0.1 s interval, and **(c)** the fluid that entered the control volume during that time interval.



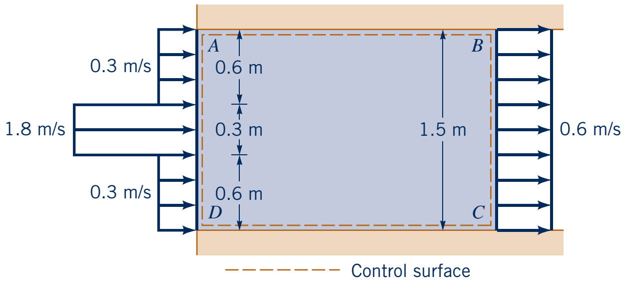
■ **Figure P4.69**

4.70 WILEY Two plates are pulled in opposite directions with speeds of 0.3 m/s as shown in Fig. P4.70. The oil between the plates moves with a velocity given by $\mathbf{V} = 10\, y\hat{\mathbf{i}}$ m/s, where y is in meters. 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.



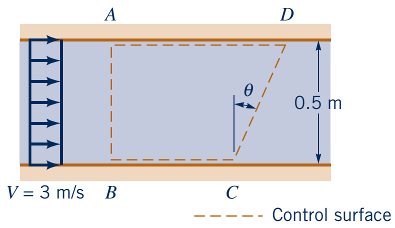
■ **Figure P4.70**

4.71 Water enters a 1.5 m wide, 0.3 m deep channel as shown in Fig. P4.71. Across the inlet the water velocity is 1.8 m/s in the center portion of the channel and 0.3 m/s in the remainder of it. Farther downstream the water flows at a uniform 0.6 m/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.



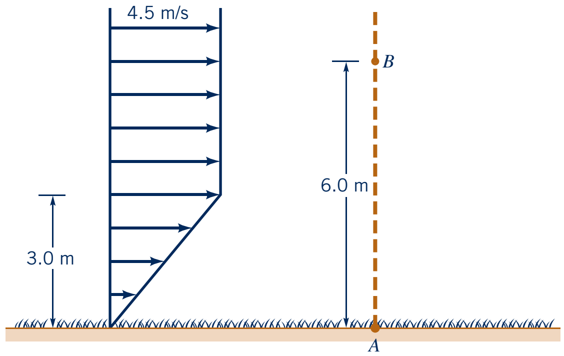
■ **Figure P4.71**

4.72 WILEY Water flows through the 2 m wide rectangular channel shown in Fig. P4.72 with a uniform velocity of 3 m/s. **(a)** Directly integrate Eq. 4.16 with $b = 1$ to determine the mass flowrate (kg/s) across section *CD* of the control volume. **(b)** Repeat part (a) with $b = 1/\rho$, where ρ is the density. Explain the physical interpretation of the answer to part **(b)**.



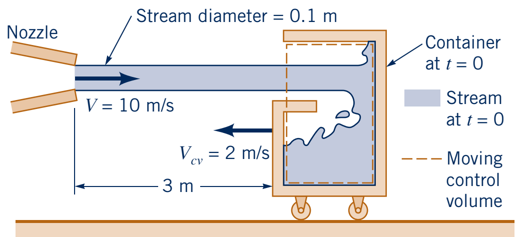
■ **Figure P4.72**

4.73 WILEY The wind blows across a field with an approximate velocity profile as shown in Fig. P4.73. Use Eq. 4.16 with the parameter b equal to the velocity to determine the momentum flowrate across the vertical surface *A–B*, which is of unit depth into the paper.



■ **Figure P4.73**

4.74 Water flows from a nozzle with a speed of $V = 10$ m/s and is collected in a container that moves toward the nozzle with a speed of $V_{cv} = 2$ m/s as shown in Fig. P4.74. The moving control surface consists of the inner surface of the container. The system consists of the water in the container at time $t = 0$ and the water between the nozzle and the tank in the constant diameter stream at $t = 0$. At time $t = 0.1$ s what volume of the system remains outside of the control volume? How much water has entered the control volume during this time period? Repeat the problem for $t = 0.3$ s.



■ **Figure P4.74**

■ Lifelong Learning Problems

4.1LL Even for the simplest flows it is often not easy to visually represent various flow field quantities such as velocity, pressure, or temperature. For more complex flows, such as those involving three-dimensional or unsteady effects, it is extremely difficult to "show the data." However, with the use of computers and appropriate software, novel methods are being devised to more effectively illustrate the structure of a given flow. Obtain information about methods used to present complex flow data. Summarize your findings in a brief report.

4.2LL 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.

■ FE Exam Problems

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