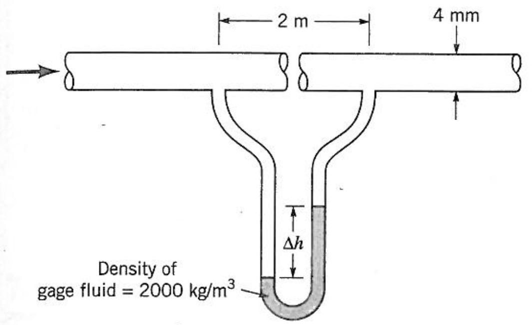
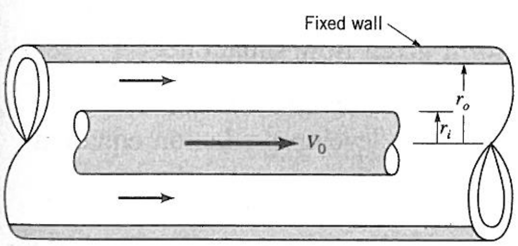
6.107 (WILEY GO) A liquid (viscosity = 0.002 N · s/m^2; density = 1000 kg/m^3) is forced through the circular tube shown in Fig. P6.107. A differential manometer is connected to the tube as shown to measure the pressure drop along the tube. When the differential reading, Δh, is 9 mm, what is the mean velocity in the tube?



■ **Figure P6.107**

Section 6.9.4 Steady, Axial, Laminar Flow in an Annulus

6.108 (WILEY) An incompressible Newtonian fluid flows steadily between two infinitely long, concentric cylinders as shown in Fig. P6.108. The outer cylinder is fixed, but the inner cylinder moves with a longitudinal velocity V_0 as shown. The pressure gradient in the axial direction is $-\Delta p/\ell$. For what value of V_0 will the drag on the inner cylinder be zero? Assume that the flow is laminar, axisymmetric, and fully developed.



■ **Figure P6.108**

6.109 (WILEY) A viscous fluid is contained between two infinitely long, vertical, concentric cylinders. The outer cylinder has a radius r_o and rotates with an angular velocity ω. The inner cylinder is fixed and has a radius r_i. Make use of the Navier–Stokes equations to obtain an exact solution for the velocity distribution in the gap. Assume that the flow in the gap is axisymmetric (neither velocity nor pressure are functions of angular position θ within the gap) and that there are no velocity components other than the tangential component. The only body force is the weight.

6.110 For flow between concentric cylinders, with the outer cylinder rotating at an angular velocity ω and the inner cylinder fixed, it is commonly assumed that the tangential velocity (v_θ) distribution in the gap between the cylinders is linear. Based on the exact solution to this problem (see Problem 6.109) the velocity distribution in the gap is not linear. For an outer cylinder with radius r_o = 2.00 in. and an inner cylinder with radius r_i = 1.80 in., show, with the aid of a plot, how the dimensionless velocity distribution, $v_\theta/r_o\omega$, varies with the dimensionless radial position, r/r_o, for the exact and approximate solutions.

6.111 (WILEY) A viscous liquid (μ = 0.012 lb · s/ft^2, ρ = 1.79 slugs/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 pressure drop along the axis of the annulus per foot when the volume flowrate is 0.14 ft^3/s?

6.112 (WILEY) Show how Eq. 6.155 is obtained.

6.113 (WILEY) A wire of diameter d is stretched along the centerline of a pipe of diameter D. For a given pressure drop per unit length of pipe, by how much does the presence of the wire reduce the flowrate if **(a)** d/D = 0.1; **(b)** d/D = 0.01?

Section 6.10 Other Aspects of Differential Analysis

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

■ Lifelong Learning Problems

6.1LL What sometimes appear at first glance to be simple fluid flows can contain subtle, complex fluid mechanics. One such example is the stirring of tea leaves in a teacup. Obtain information about "Einstein's tea leaves" and investigate some of the complex fluid motions interacting with the leaves. Summarize your findings in a brief report.

6.2LL Computational fluid dynamics (CFD) has moved from a research tool to a design tool for engineering. Initially, much of the work in CFD was focused in the aerospace industry, but now has expanded into other areas. Obtain information on what other industries (e.g., automotive) make use of CFD in their engineering design. Summarize your findings in a brief report.

■ FE Exam Problems

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

Conceptual Questions

7.1C For flow in a pipe, the Reynolds number is defined as

$$\text{Re} = \frac{V\rho D}{\mu}$$

where V is velocity, ρ is density, μ is viscosity, and D is diameter. Expressed this way, the Reynolds number can be interpreted as

a) the ratio of viscous to inertial forces.
b) the ratio of inertial to viscous forces.
c) the ratio of momentum flux to viscous forces.
d) the ratio of kinetic energy to viscous forces.

7.2C A 1/20th scale model of an airplane is used to determine forces on the actual airplane. The 1/20th scale refers to the

a) lengths. b) velocity. c) forces.
d) Reynolds number. e) all of the above.

7.3C A 1/4th scale model of a new automobile design is tested in a wind tunnel. The Reynolds number of the model is the same as that of the full-scale prototype. Assuming the model and prototype are exposed to the same air conditions, the velocity in the wind tunnel is then

a) 1/4th that of the full-scale vehicle.
b) The same as that of the full-scale vehicle.
c) 4 times that of the full-scale vehicle.
d) 40 times that of the full-scale vehicle.

7.4C A 1/10th scale model of a new automobile design is tested in a wind tunnel at the same Reynolds number as that of the full-scale prototype. The force coefficient $(F/A)/(\frac{1}{2}\rho V^2)$ of the model is the same as that of the prototype. Assuming the model and prototype are both tested in air, the force on the scale model, F_m, is then

a) 1/10,000th that of the full-scale vehicle.
b) 1/1000th that of the full-scale vehicle.
c) 1/100th that of the full-scale vehicle.
d) 1/10th that of the full-scale vehicle.
e) The same as that of the full-scale vehicle.

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 web site, www.wiley.com/college/munson.

Section 7.1 Dimensional Analysis

7.1 What are the dimensions of density, pressure, specific weight, surface tension, and dynamic viscosity in **(a)** the *FLT* system, and **(b)** the *MLT* system? Compare your results with those given in Table 1.1 in Chapter 1.

7.2 Verify the left-hand side of Eq. 7.2 is dimensionless using the MLT system.

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

7.4 WILEY What are the dimensions of acceleration of gravity, density, dynamic viscosity, kinematic viscosity, specific weight, and speed of sound in **(a)** the *FLT* system, and **(b)** the *MLT* system? Compare your results with those given in Table 1.1 in Chapter 1.

7.5 WILEY For the flow of a thin film of a liquid with a depth h and a free surface, two important dimensionless parameters are the Froude number, $V/\sqrt{gh}$, and the Weber number, $\rho V^2 h/\sigma$. Determine the value of these two parameters for glycerin (at 20 °C) flowing with a velocity of 0.7 m/s at a depth of 3 mm.

7.6 WILEY The Mach number for a body moving through a fluid with velocity V is defined as V/c, where c is the speed of sound in the fluid. This dimensionless parameter is usually considered to be important in fluid dynamics problems when its value exceeds 0.3. What would be the velocity of a body at a Mach number of 0.3 if the fluid is **(a)** air at standard atmospheric pressure and 20 °C, and **(b)** water at the same temperature and pressure?

Section 7.3 Determination of Pi Terms

7.7 It is desired to determine the wave height when wind blows across a lake. The wave height, H, is assumed to be a function of the wind speed, V, the water density, ρ, the air density, ρ_a, the water depth, d, the distance from the shore, ℓ, and the acceleration of gravity, g, as shown in Fig. P7.7. Use d, V, and ρ as repeating variables to determine a suitable set of pi terms that could be used to describe this problem.

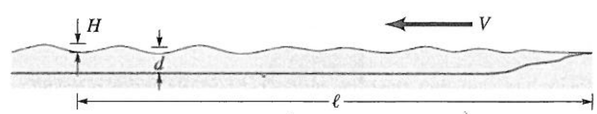


Figure P7.7

7.8 WILEY GO Water flows over a dam as illustrated in Fig. P7.8. Assume the flowrate, q, per unit length along the dam depends on the head, H, width, b, acceleration of gravity, g, fluid density, ρ, and

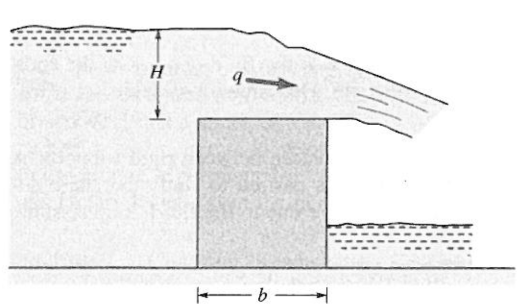


Figure P7.8

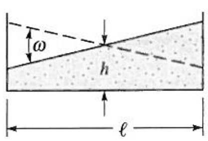
fluid viscosity, μ. Develop a suitable set of dimensionless parameters for this problem using b, g, and ρ as repeating variables.

7.9 The excess pressure inside a bubble (discussed in Chapter 1) is known to be dependent on bubble radius and surface tension. After finding the pi terms, determine the variation in excess pressure if we **(a)** double the radius and **(b)** double the surface tension.

7.10 The flowrate, Q, of water in an open channel is assumed to be a function of the cross-sectional area of the channel, A, the height of the roughness of the channel surface, ε, the acceleration of gravity, g, and the slope, S_o, of the hill on which the channel sits. Put this relationship into dimensionless form.

7.11 At a sudden contraction in a pipe the diameter changes from D_1 to D_2. The pressure drop, Δp, which develops across the contraction is a function of D_1 and D_2, as well as the velocity, V, in the larger pipe, and the fluid density, ρ, and viscosity, μ. Use D_1, V, and μ as repeating variables to determine a suitable set of dimensionless parameters. Why would it be incorrect to include the velocity in the smaller pipe as an additional variable?

7.12 Water sloshes back and forth in a tank as shown in Fig. P7.12. The frequency of sloshing, ω, is assumed to be a function of the acceleration of gravity, g, the average depth of the water, h, and the length of the tank, ℓ. Develop a suitable set of dimensionless parameters for this problem using g and ℓ as repeating variables.



■ **Figure P7.12**

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

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

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

7.14 Assume that the flowrate, Q, of a gas from a smokestack is a function of the density of the ambient air, ρ_a, the density of the gas, ρ_g, within the stack, the acceleration of gravity, g, and the height and diameter of the stack, h and d, respectively. Use ρ_a, d, and g as repeating variables to develop a set of pi terms that could be used to describe this problem.

7.15 The pressure rise, Δp, across a pump can be expressed as

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

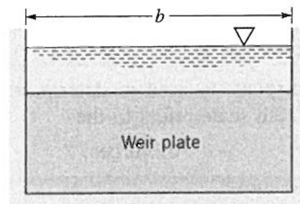
where D is the impeller diameter, ρ the fluid density, ω the rotational speed, and Q the flowrate. Determine a suitable set of dimensionless parameters.

7.16 A thin elastic wire is placed between rigid supports. A fluid flows past the wire, and it is desired to study the static deflection, δ, at the center of the wire due to the fluid drag. Assume that

$$\delta = f(\ell, d, \rho, \mu, V, E)$$

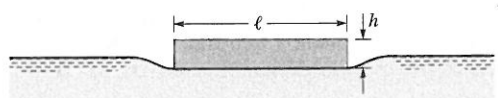
where ℓ is the wire length, d the wire diameter, ρ the fluid density, μ the fluid viscosity, V the fluid velocity, and E the modulus of elasticity of the wire material. Develop a suitable set of pi terms for this problem.

7.17 The water flowrate, Q, in an open rectangular channel can be measured by placing a plate across the channel as shown in Fig. P7.17. This type of a device is called a *weir*. The height of the water, H, above the weir crest is referred to as the head and can be used to determine the flowrate through the channel. Assume that Q is a function of the head, H, the channel width, b, and the acceleration of gravity, g. Determine a suitable set of dimensionless variables for this problem.



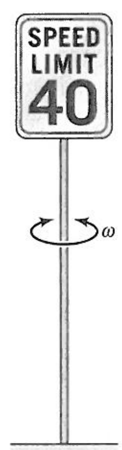
■ **Figure P7.17**

7.18 Because of surface tension, it is possible, with care, to support an object heavier than water on the water surface as shown in Fig. P7.18. (See **Video V1.9.**) The maximum thickness, h, of a square of material that can be supported is assumed to be a function of the length of the side of the square, ℓ, the density of the material, ρ, the acceleration of gravity, g, and the surface tension of the liquid, σ. Develop a suitable set of dimensionless parameters for this problem.



■ **Figure P7.18**

7.19 Under certain conditions, wind blowing past a rectangular speed limit sign can cause the sign to oscillate with a frequency ω. (See Fig. P7.19 and **Video V9.9.**) Assume that ω is a function of the sign width, b, sign height, h, wind velocity, V, air density, ρ, and an elastic constant, k, for the supporting pole. The constant, k, has dimensions of FL. Develop a suitable set of pi terms for this problem.

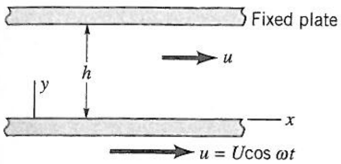


■ **Figure P7.19**

7.91 A viscous fluid is contained between wide, parallel plates spaced a distance h apart as shown in Fig. P7.91. The upper plate is fixed, and the bottom plate oscillates harmonically with a velocity amplitude U and frequency ω. The differential equation for the velocity distribution between the plates is

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

where u is the velocity, t is time, and ρ and μ are fluid density and viscosity, respectively. Rewrite this equation in a suitable nondimensional form using h, U, and ω as reference parameters.

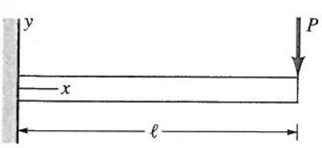


■ **Figure P7.91**

7.92 The deflection of the cantilever beam of Fig. P7.92 is governed by the differential equation.

$$EI\frac{d^2y}{dx^2} = P(x - \ell)$$

where E is the modulus of elasticity and I is the moment of inertia of the beam cross section. The boundary conditions are $y = 0$ at $x = 0$ and $dy/dx = 0$ at $x = 0$. **(a)** Rewrite the equation and boundary conditions in dimensionless form using the beam length, ℓ, as the reference length. **(b)** Based on the results of part (a), what are the similarity requirements and the prediction equation for a model to predict deflections?

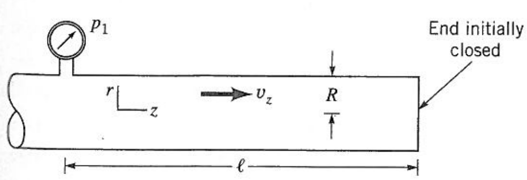


■ **Figure P7.92**

7.93 A liquid is contained in a pipe that is closed at one end as shown in Fig. P7.93. Initially the liquid is at rest, but if the end is suddenly opened the liquid starts to move. Assume the pressure p_1 remains constant. The differential equation that describes the resulting motion of the liquid is

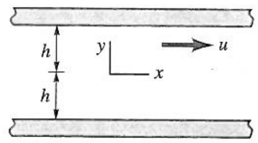
$$\rho \frac{\partial v_z}{\partial t} = \frac{p_1}{\ell} + \mu\left(\frac{\partial^2 v_z}{\partial r^2} + \frac{1}{r}\frac{\partial v_z}{\partial r}\right)$$

where v_z is the velocity at any radial location, r, and t is time. Rewrite this equation in dimensionless form using the liquid density, ρ, the viscosity, μ, and the pipe radius, R, as reference parameters.



■ **Figure P7.93**

7.94 An incompressible fluid is contained between two infinite parallel plates as illustrated in Fig. P7.94. Under the influence of a harmonically varying pressure gradient in the x direction, the fluid oscillates harmonically with a frequency ω. The differential equation describing the fluid motion is



■ **Figure P7.94**

$$\rho \frac{\partial u}{\partial t} = X \cos \omega t + \mu \frac{\partial^2 u}{\partial y^2}$$

where X is the amplitude of the pressure gradient. Express this equation in nondimensional form using h and ω as reference parameters.

■ Lab Problems

7.1LP This problem involves the time that it takes water to drain from two geometrically similar tanks. To proceed with this problem, go to *WileyPLUS* or the book's web site, www.wiley.com/college/munson.

7.2LP This problem involves determining the frequency of vortex shedding from a circular cylinder as water flows past it. To proceed with this problem, go to *WileyPLUS* or the book's web site, www.wiley.com/college/munson.

7.3LP This problem involves the determination of the head loss for flow through a valve. To proceed with this problem, go to *WileyPLUS* or the book's web site, www.wiley.com/college/munson.

7.4LP This problem involves the calibration of a rotameter. To proceed with this problem, go to *WileyPLUS* or the book's web site, www.wiley.com/college/munson.

■ Lifelong Learning Problems

7.1LL Microfluidics is the study of fluid flow in fabricated devices at the micro scale. Advances in microfluidics have enhanced the ability of scientists and engineers to perform laboratory experiments using miniaturized devices known as a "lab-on-a-chip." Obtain information about a lab-on-a-chip device that is available commercially and investigate its capabilities. Summarize your findings in a brief report.

7.2LL For some types of aerodynamic wind tunnel testing, it is difficult to simultaneously match both the Reynolds number and Mach number between model and prototype. Engineers have developed several potential solutions to the problem including pressurized wind tunnels and lowering the temperature of the flow. Obtain information about cryogenic wind tunnels and explain the advantages and disadvantages. Summarize your findings in a brief report.

■ FE Exam Problems

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

■ Computational Fluid Dynamics (CFD)

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

7.1CFD This CFD problem involves investigation of the Reynolds number significance in fluid dynamics through the simulation of flow past a cylinder. To proceed with this problem, go to *WileyPLUS* or the book's web site, www.wiley.com/college/munson.

There are additional CFD problems located in *WileyPLUS*.