The stress $\tilde{\tau}_{21}$ also is a function of x_1, x_2, x_3, as well as only one of several stresses associated with a complex flow. In the tensor discussion in Chapter 1, we learned that there are nine components of stress.

$$\underline{\underline{\tilde{\tau}}} = \begin{pmatrix} \tilde{\tau}_{11} & \tilde{\tau}_{12} & \tilde{\tau}_{13} \\ \tilde{\tau}_{21} & \tilde{\tau}_{22} & \tilde{\tau}_{23} \\ \tilde{\tau}_{31} & \tilde{\tau}_{32} & \tilde{\tau}_{33} \end{pmatrix}_{123} \tag{2.93}$$

Although Equation 2.91 gives an important local relationship between one particular stress $\tilde{\tau}_{21}$ and the local distribution of velocity, it alone does not contain sufficient information about the flow to allow us to calculate the velocity field $\underline{v}$ or the stress field $\underline{\underline{\tilde{\tau}}}$ for the entire flow. As discussed in subsequent chapters, we need mass and momentum balances, properly applied for a given situation, and we must incorporate force-deformation information such as Newton's law of viscosity to solve for velocity and stress fields. The momentum balance for fluids is introduced in Chapter 3, the stress tensor in Chapter 4, the complete stress-velocity relationship in Chapter 5, and the techniques for solving the modeling equations in Chapters 6–10.

This is the beginning of our study of fluid mechanics. After completing the course, readers will be able to calculate fluid velocity and stress fields for many flows. Therefore, the solution of this problem is postponed until more is known about how fluids work.

In this text, we present fluid-mechanics modeling in a step-by-step manner. We introduce fluid physics by tying together the familiar physics of rigid bodies (e.g., blocks sliding down a hill) with the physics of deforming systems—that is, fluids. In the next chapter, we choose our model for quantifying fluid behavior, which is called the continuum model.

2.12 Problems

1. When you have the oil changed in your car, the service attendant asks, "Would you like 10W40 or 10W30?" How should you decide?
2. What is the density of acetone? What is the viscosity of acetone? Compared to water, does acetone generate more or less stress in flow? Be quantitative in your answer.
3. What is the density of blood? What is the viscosity of blood? When doctors give a "blood thinner," is it the viscosity, the density, or something else that they are changing?
4. When medical technicians draw blood for laboratory tests, they first insert a needle attached to a tubeholder into a vein. The second step is to push a tube onto the needle, causing blood to flow into the tube (i.e., the needle penetrates a septum covering the top of the tube). Why does the blood flow into the tube? It may be necessary to search the device on the Internet to determine the answer.
5. In addition to solid, liquid, and gas, another common state of matter is foam. Foams occur in food processing (e.g., whipped cream and frothed milk), consumer products (e.g., hair mousse and shaving cream), and industrial

applications (e.g., wall insulation and fire-extinguishing fluid). Describe the structure of foam from a scientific perspective. Do the foams flow and deform like Newtonian liquids (e.g., water and oil), Bingham plastics (e.g., mayonnaise and paint), or do they comprise their own class of materials? Describe the flow behavior of foams.

6. Honey is trapped between two long wide plates (plate area = 9.0 cm^2) and the top plate is moved at 1.0 cm/s. The gap between the plates is 0.50 mm. What is the velocity gradient $\partial v_1/\partial x_2$, where 1 indicates the flow direction and 2 indicates the direction perpendicular to the plates?
7. If water is trapped between two long wide plates and subjected to a velocity gradient of 10.0 s^{-1} in the 2-direction, what is the magnitude of the shear stress τ_{21} that is generated? If the area of the top plate in contact with the water is 25 cm^2, what is the force needed to maintain the motion of the plate?
8. If water is trapped between two long wide plates and subjected to a velocity gradient of 5.0 s^{-1} in the 2-direction, what is the magnitude of the shear stress τ_{21} that is generated? If the fluid between the plates is changed from water to honey, how much shear stress is generated?
9. Olive oil is placed between two long wide plates (plate area = 97.5 in^2) and the top plate is moved at 0.25 in/s. The gap between the plates is 0.0126 in. What is the force that it takes to maintain the motion?
10. Two fluids are examined with a parallel-plate apparatus like Newton used to study fluids. The two plates have the same area A; and with the test fluid in the gap, a constant gap of H is maintained as the top plate is dragged in a uniform direction, causing the fluid to deform. When the two fluids are tested, it takes twice as much force to move the plate at a fixed velocity V with Fluid 2 as with Fluid 1. What is the ratio of the viscosities of the two fluids?
11. A tree in the wind is an object subjected to a uniform flow (a flow that everywhere has the same speed and direction). How much drag is a tree subjected to by modest winds and by hurricane-force winds? Search the literature for air speeds and drag coefficients to answer this question.
12. A bicycle racer in a racing crouch is traveling at 50 mph. How much faster will she go if her teammate drafts her by riding immediately in front of her?
13. How much wind force is a flag subjected to on a typical day? Search the literature for air speeds and drag coefficients to answer this question.
14. A disk (i.e., radius is R and thickness is H) is dropped from a great height. How much faster does the disk fall when dropped edge first versus dropped with the large circular surface perpendicular to the fall direction? Search the literature for drag coefficients for the disk in these two orientations.
15. When you stir water (or coffee or tea) in a cup, how does the shape and position of the fluid surface change compared to the fluid at rest? Sketch the quiescent and steady-state fluid interfaces. Note: The sketch should be consistent with the principle of conservation of mass.
16. The viscosity of water is about 1 cp. Showing the unit conversions, what does 1 cp translate into in American engineering units (involving lb_f, ft, s)? What does this quantity translate into in SI units (Système international d'unités, the metric system, involving kg, m, s)?

17. In this chapter, we discuss the force it takes to push fluid through a needle attached to a syringe. If the fluid ejected from the needle is glycerin rather than water, how much force would it take? Use all of the same assumptions as in the text example.
18. The rate of blood circulation in the body is 5.0 lpm (liters per minute) [145]. How much blood passes through the heart in a day?
19. Laminar flow in a tube is described by the Hagen-Poiseuille equation, introduced in this chapter. (a) For water (25°C) flowing through a 10-foot section of 1/2-inch pipe (Schedule 40) in laminar flow, what is the maximum flow rate (in gpm) through the pipe before the flow becomes transitional? (b) What is the pressure drop (in psi) across the pipe at this maximum flow rate?
20. Water (25°C) is pushed through a pipe (ID 4.0 mm and length 1.5 m) and laminar flow is produced at a Reynolds number of 800. For the same fluid subjected to the same pressure drop in a pipe of the same length, at what pipe diameter will it no longer be possible to produce laminar flow?
21. Blood travels through the large arteries of a human body (internal radius 12 mm) at an average velocity of about 50 cm/s. What is the flow rate of blood through these arteries? Is the flow laminar or turbulent? The viscosity of blood is 3.0 cp and the density of blood is 1,060 kg/m^3 [145].
22. Blood travels through the human heart's ascending aorta (diameter = 3.2 cm) at an average velocity of about 63 cm/s [145]. What is the flow rate of blood through this vessel? See the previous problem for viscosity and density of blood.
23. A carbon-dioxide bubble rises in a glass of soda. From the perspective of an observer sitting on the bubble, sketch the flow lines as the liquid parts and flows around the rising bubble. Is there a flow (i.e., motion) in the carbon dioxide inside the bubble? Discuss why or why not.
24. How does drinking from a straw work? In your answer, use scientific terms such as pressure, continuum, and flow.
25. An open container of fluid has a hole in the side and the fluid leaks out under the force of gravity. If a tight-fitting but movable piston is placed on top of the fluid and a 10-kg weight is placed on top of the piston, how would the flow out the hole change? Sketch your answer. Why is there a change?
26. Many teapots dribble. Why? Which forces mentioned in this chapter influence teapot dribble?
27. Consider the following (admittedly improbable) two ways to make an open-faced peanut-butter-and-jelly sandwich: (1) Spread a layer of peanut butter on a slice of bread; then top this layer with a layer of jelly. (2) First spread a layer of jelly on a slice of bread; then spread peanut butter over the jelly layer. Discuss the pros and cons of the two methods. If forced to choose one of these two methods, which would you choose? Give a fluid-mechanics explanation of your choice.
28. Why do ice cubes float in water? Why do olives sink in water? Which physical property is important to the answer: viscosity, density, surface tension, or something else?
29. You are standing facing a strong wind and you are cold. Will any of the following actions reduce how cold you feel? Explain your reasoning using

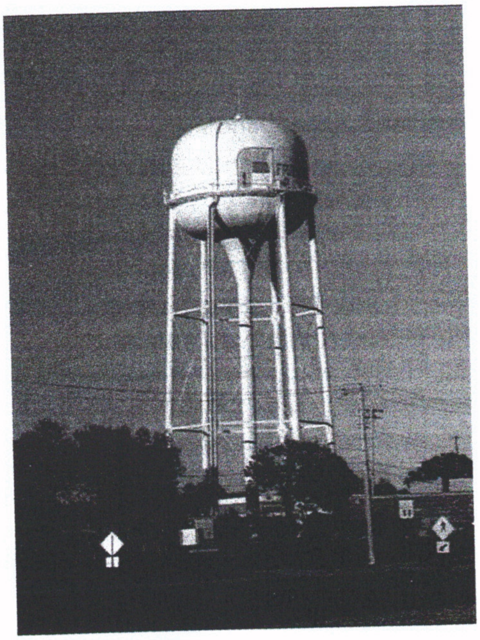

Figure 2.51 Water towers are visible in many towns in the United States and Europe, and they serve an important role in daily life (Problem 32).

fluid mechanics: (a) turning sidewise to the wind; (b) laying flat on the ground; and (c) crouching down on the ground.

30. What is a boundary layer? Give an example of a boundary-layer effect that you have experienced.
31. Players at the 2010 Football World Cup in South Africa complained that the ball had an erratic flight path. Discuss possible fluid-mechanics reasons for problems with the ball.
32. What is the purpose of water towers built in many towns (Figure 2.51)? What determines how high the water tank should be?
33. Fill a straw by placing it in a liquid. If we place a finger over the top and remove the straw from the liquid, the straw remains full. Why does the water not flow out of the straw (Figure 2.52)?

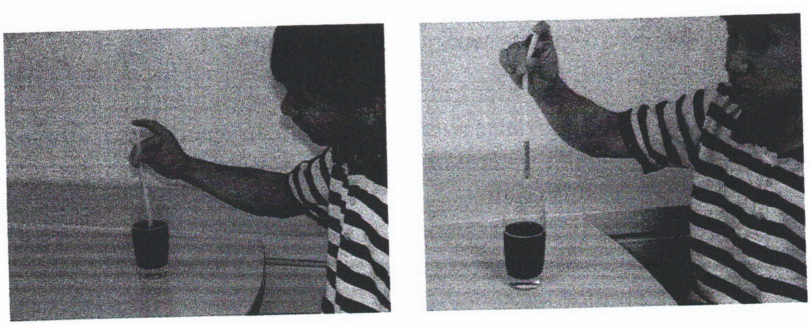

Figure 2.52 Liquid can be captured by submerging a straw in liquid and then plugging the top of the straw with a finger before withdrawing the straw from the liquid (Problem 33).

Figure 2.53 An important design element of an indoor plumbing system is the presence of vents (Problem 34).

34. Why do home plumbing systems have vents (Figure 2.53)?
35. In an experiment showed to schoolchildren, a colored liquid is placed in a 2-liter soda bottle that is subsequently connected at the neck to a second 2-liter bottle. When all the liquid is in one bottle and the contraption is inverted, the liquid flows slowly and haltingly from top to bottom. If the fluid is swirled, however, it drains rapidly from top to bottom. What is happening in this experiment? Use fluid-mechanics concepts in your explanation.
36. Many adventure and horror movies feature quicksand. What is quicksand? Does it really exist? How does quicksand work? Is quicksand a Newtonian fluid?
37. In some homes, residents learn that when someone is showering, no one should flush the toilet or otherwise use water lest the person in the shower receives a scalding from hot water. What is happening in this circumstance? What is wrong with the plumbing design to cause this effect?
38. Trees need water to live, and they get much of the required water from the ground through their roots. How does water flow up a tree trunk against the downward pull of gravity? Use scientific principles in your answer.
39. In the living space in a spacecraft in orbit around planet Earth, Earth's gravitational pull is not very strong. How are the following processes affected by a zero-gravity working environment?

    (a) Drinking water from the lip of an open glass.
    (b) Drinking water with a straw from an open glass.
    (c) Drinking water with a straw from a closed box.
    (d) Flushing a toilet.
    (e) Brewing coffee with an automatic-drip coffeemaker.
    (f) The human digestive system.
    (g) Swallowing food.
    (h) Blood circulating in the human body.

40. Why do helium balloons float in air?

41. What is the definition of the Fanning friction factor? What is the definition of the Darcy or Moody friction factor? How can the friction factor be measured for a given piping system?
42. Water flows through a smooth pipe at a Reynolds number of 53,000. What is the Fanning friction factor for this flow? For glycerin and acetone flowing at the same Reynolds number, what are the friction factors?
43. When a balloon inflated with air is released, it accelerates and flies around. Where does the kinetic energy of the balloon originate?
44. Can you suck foam (e.g., frothed milk from a cappuccino or whipped cream from a milkshake) up a straw? Why or why not?
45. What is a tornado? How does it form? How does it dissipate?
46. How does water-repellant fabric work?
47. When the flow rate in a water faucet is high, water emerges as an unbroken column of fluid. When the flow rate is decreased, the faucet eventually begins to drip. Why does the fluid stream break up into droplets?
48. What is vorticity? For what types of flow is vorticity important?
49. How fast is an aircraft going in km/hr if it is traveling at Mach 1.4?
50. An aircraft has a mass of 35,000 kg and a planform area of 250 m^2. How much lift must the aircraft generate to fly?
51. An aircraft (mass = 25,000 kg; planform area = 203 m^2) has a lift coefficient of $C_L = 1.8$ at stall. What is the stall speed of the aircraft?