Chapter 2
Fundamentals of Fluid Mechanics

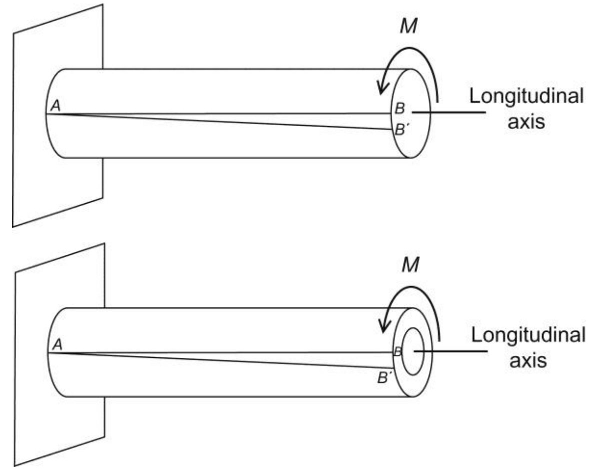

Figure 2.1 A depiction of a method to model torsion throughout a solid material. Through the application of a moment at a location on the bar, a line *AB* would deform to the arc *AB*'. With removal of the moment, point *B*' would move back to *B*, assuming the induced stress did not exceed the materials yield stress. The second figure depicts a cylinder, which may be used for torsion analysis in bones.

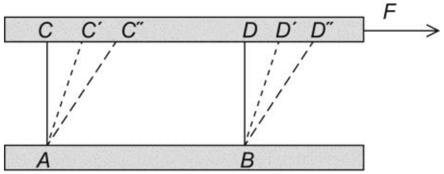

Figure 2.2 Under a constant shearing force (*F*), a fluid will continually deform. Immediately after the application of a constant force to the top plate, a fluid element *ABCD*, deforms to *ABC'D'*. At a later time, the element will have deformed to *ABC"D"* even though the force *F* is held constant and no additional force has been added to the system.

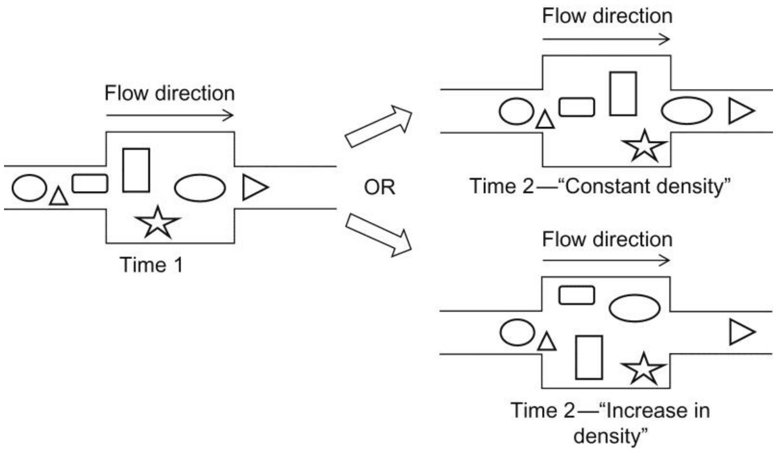

Figure 2.3 Pictorial representation of the conservation of mass principle. At time 1, the density of the fluid within the square chamber is represented with approximately three shape elements within the square chamber. At some time later, the density of the fluid can either remain the same (“constant density”•case) because the same quantity of elements is present or increase because one of the shape elements did not leave the volume of interest (“increase in density”•case).

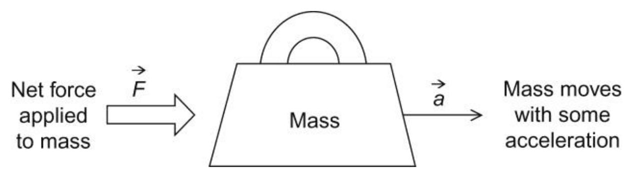

Figure 2.4 When a force is applied to a mass, the mass will move with a velocity that is proportional to the applied force and in the same direction as the net force. In this simple representation, we are not depicting all of the forces (such as friction or drag), just the net force that is acting on the mass.

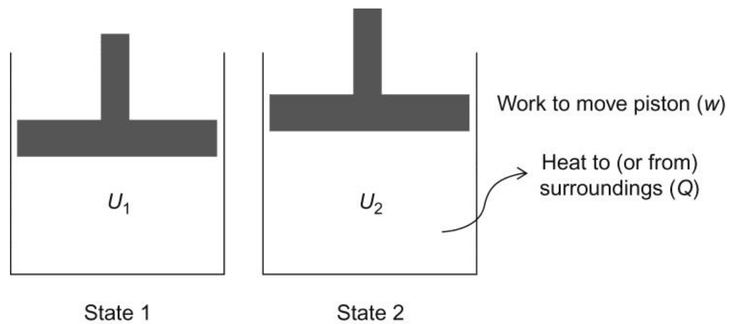

Figure 2.5 Representation of the first law of thermodynamics where the internal energy of a system is equal to the heat added to the system from the surroundings minus the work that the system conducts on its surroundings. In this example, a piston is moved up by the material within the system as heat is being lost to the surroundings.

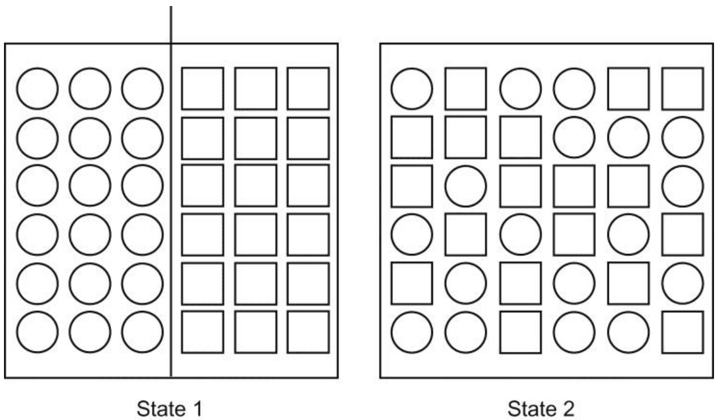

Figure 2.6 The second law of thermodynamics states that the disorder of a system will increase with time. In this case, there is a boundary between circular and square objects. Once this boundary has been removed, the system will tend to move from an orderly system to a disorderly system.

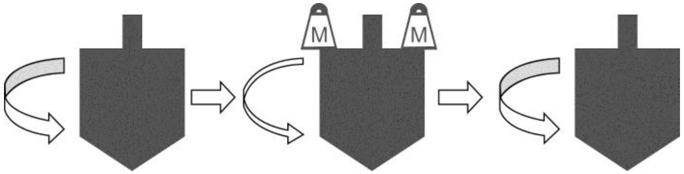

Figure 2.7 The conservation of angular momentum states that a spinning body will have a particular angular velocity. As more mass is added to the body at a larger radius from the axis of rotation, the angular velocity will decrease. If the added mass is removed, the angular velocity will return to the original angular velocity (the magnitude of angular velocity is represented by the width of the curved arrow).

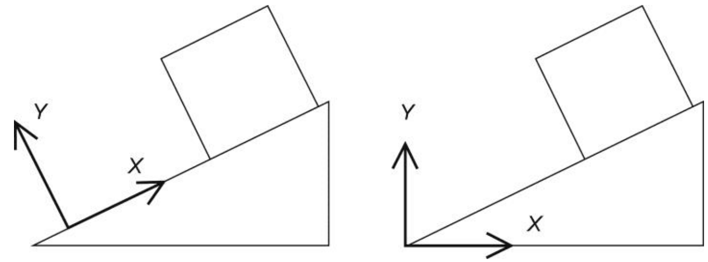

Figure 2.8 Two common ways to set up the coordinate axes in a solid mechanics problem. Either convention can produce a solution but the solution using the coordinate axis shown on the left would generally work out easier than the right coordinate axis because many variables are aligned with that axis system.

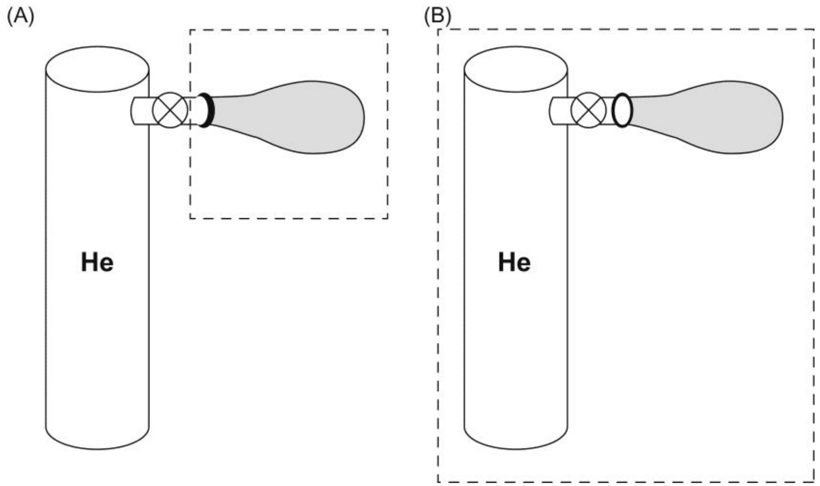

Figure 2.9 Two choices for the system of interest (dashed line). With the first choice (A) the balloon will remain uninflated for the entire problem because no mass can transfer through the system boundary. For the second choice (B) the balloon can be inflated and the boundary would follow the balloons wall in time.

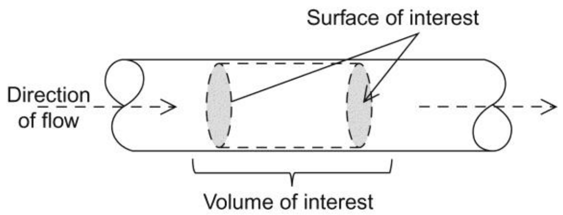

Figure 2.10 Examples of a volume of interest and a surface of interest within a blood vessel. The two highlighted surfaces of interest are imaginary. The boundary of the dashed cylinder and the tube wall is a real surface. By choosing the surfaces in this manner the solution of fluid mechanics problem would be easier, compared with other choices for the surfaces/volumes of interest.

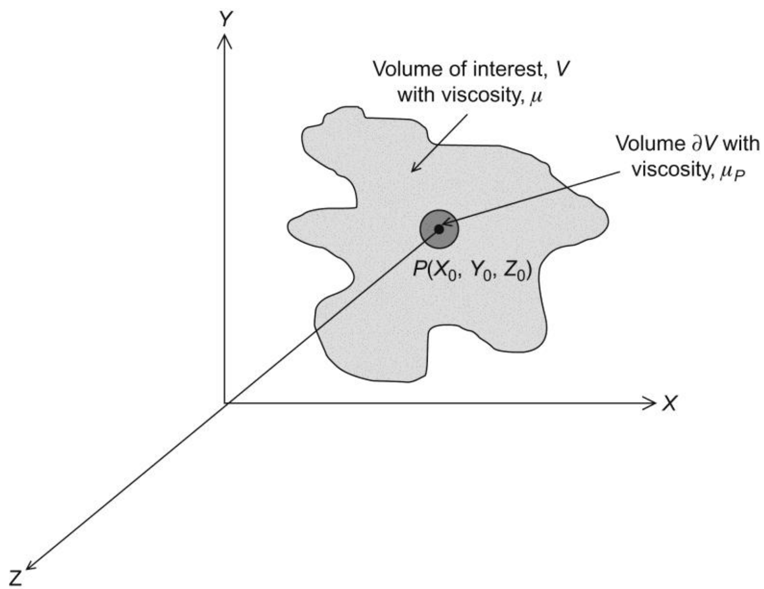

Figure 2.11 The bulk viscosity (μ) of a fluid element can be described by the weighted average of the individual viscosities (μ_P) of differential elements (∂V). The viscosity within each differential element can be greater or lower than the bulk viscosity, but if we ignore these changes, we would assume that the fluid is a continuum.

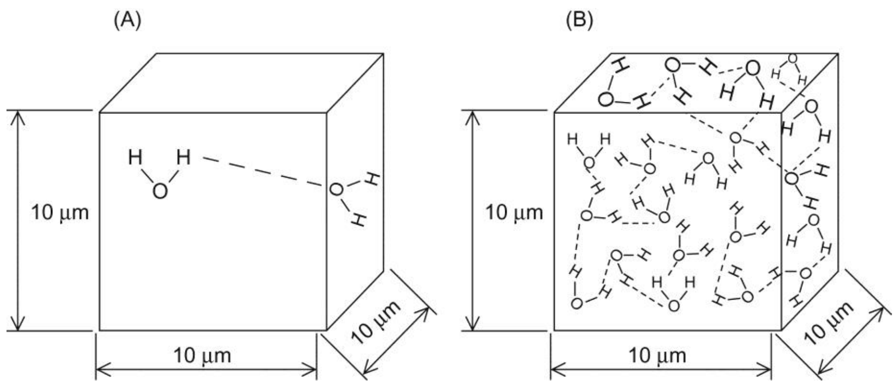

Figure 2.12 If a noncontinuum fluid is divided into small volumes (e.g., 1 pL), the properties of the fluid may be different than the bulk property. In this figure, panel A shows a volume with a smaller viscosity compared with panel B because there are less intermolecular interactions (dashed lines) between the molecules in panel A than in B.

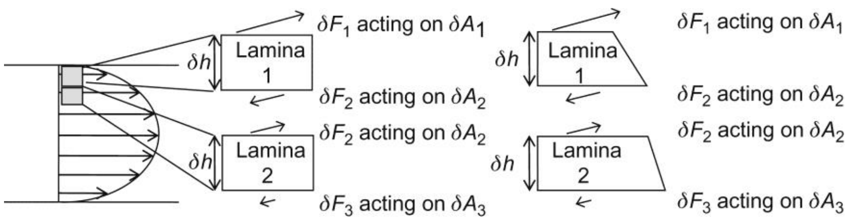

Figure 2.13 Internal laminae of fluid exert forces on neighboring laminae. These forces must be balanced within the fluid. Areas in contact of the individual laminae are the same and are represented as δA_2 as in the text.

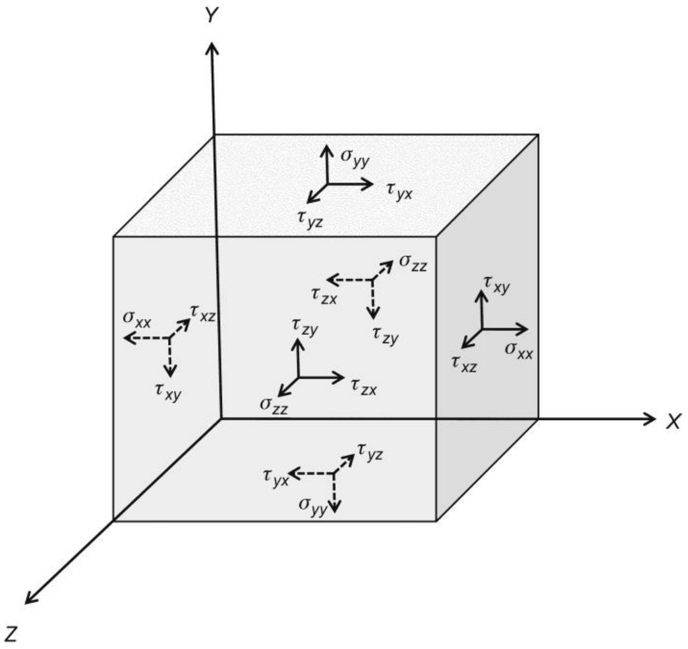

Figure 2.14 The nine components of the stress tensor on a differential fluid volume. For momentum balance, only six of these values are independent.

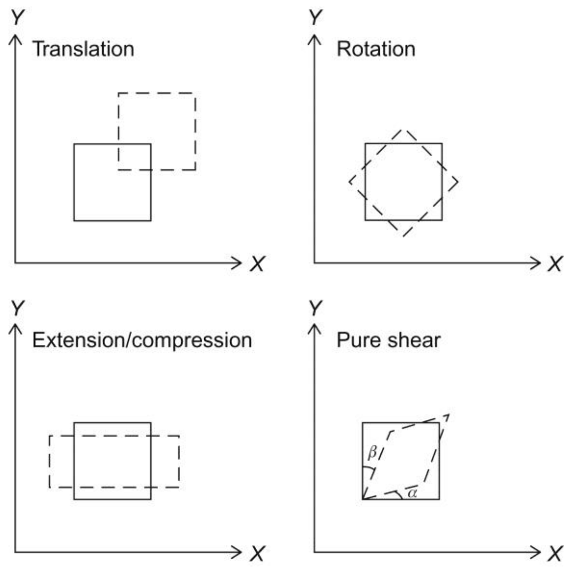

Figure 2.15 Different motions that a fluid element can undergo. These include translation, rotation, extension/compression, and pure shear. In general, these motions can occur all at the same time, which would be described as a general planar rotation/deformation.

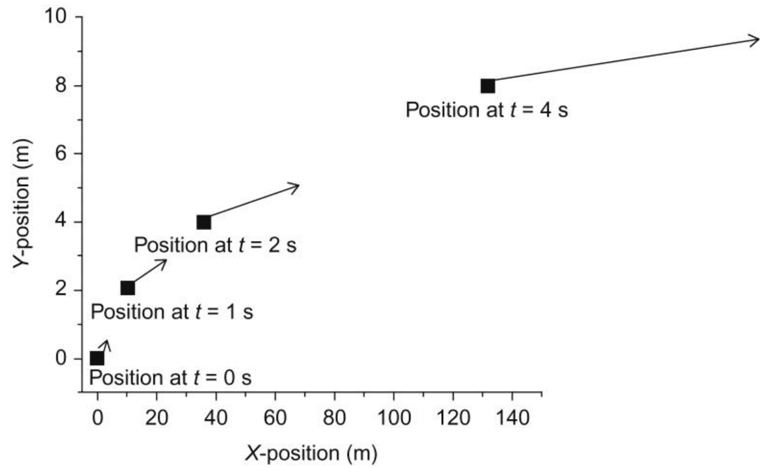

Figure 2.16 The fluid particles position as a function of time. The arrows represent the magnitude of velocity at each time. Please note that the *x* and *y* axes are not on the same scale.

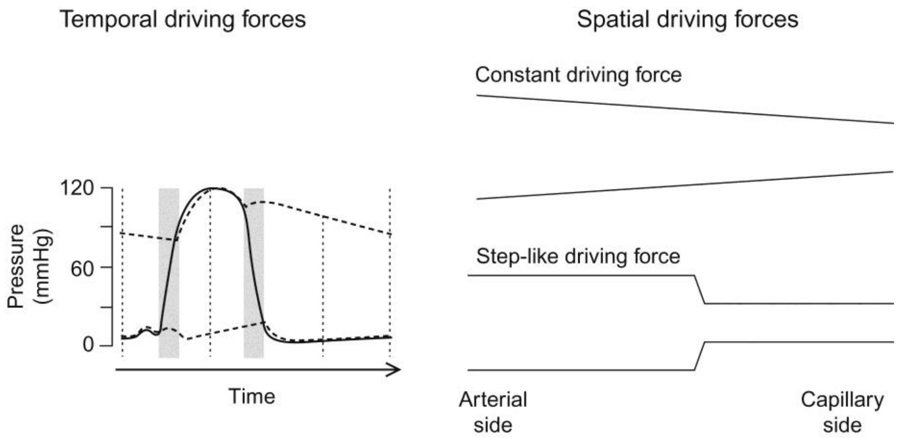

Figure 2.17 Examples of temporal and spatial driving forces that may arise in the vascular system. In general, temporal and spatial driving forces can be coupled within the same problem.

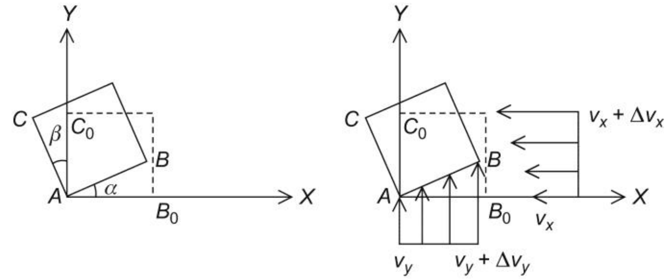

Figure 2.18 Rotation of a rigid body used to calculate angular velocity, vorticity, and shear rate. The rate of change of the displacement of point *B* is defined from the change in velocity over time across line segment *AB*. The same analysis conducted on all other line segments in three dimensions would yield the angular velocity formula. Remember that α and βdo not have to be the same.

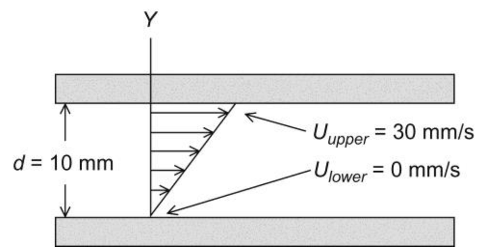

Figure 2.19 Figure for the example problem.

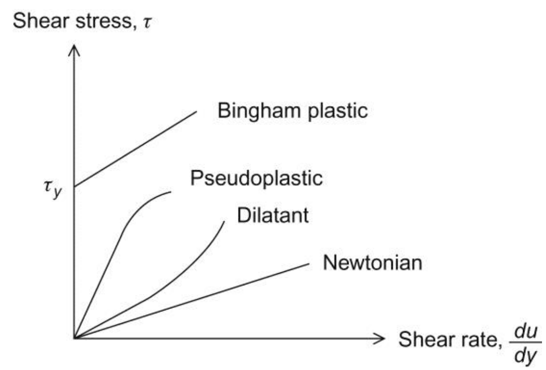

Figure 2.20 Relationship between shear stress and shear rate for Newtonian and non-Newtonian fluids. Newtonian fluids have a constant viscosity as a function of shear rate. Non-Newtonian fluids have a nonconstant viscosity.

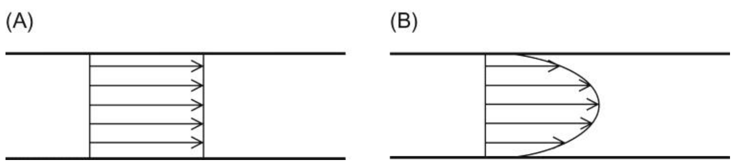

Figure 2.21 The velocity profile for blood flowing through an artery that is modeled as an inviscid fluid (A) or a viscous fluid (B). An inviscid fluid has a uniform velocity profile because there is no internal resistance to motion. A viscous fluid has a nonuniform velocity profile, which can be idealized to a parabolic velocity profile for many conditions.

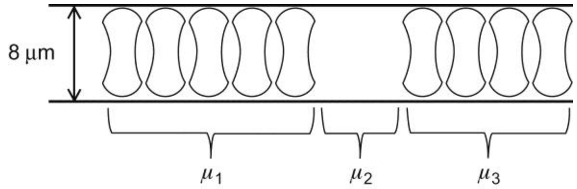

Figure 2.22 The apparent viscosity within the microcirculation would represent the viscosity of the individual fluid and cell pockets, which may have different nominal values for viscosity. The apparent viscosity could be considered a weighted average of these different viscosities but is realistically just an estimated value. Under most conditions, the apparent viscosity is not the same as the bulk viscosity.

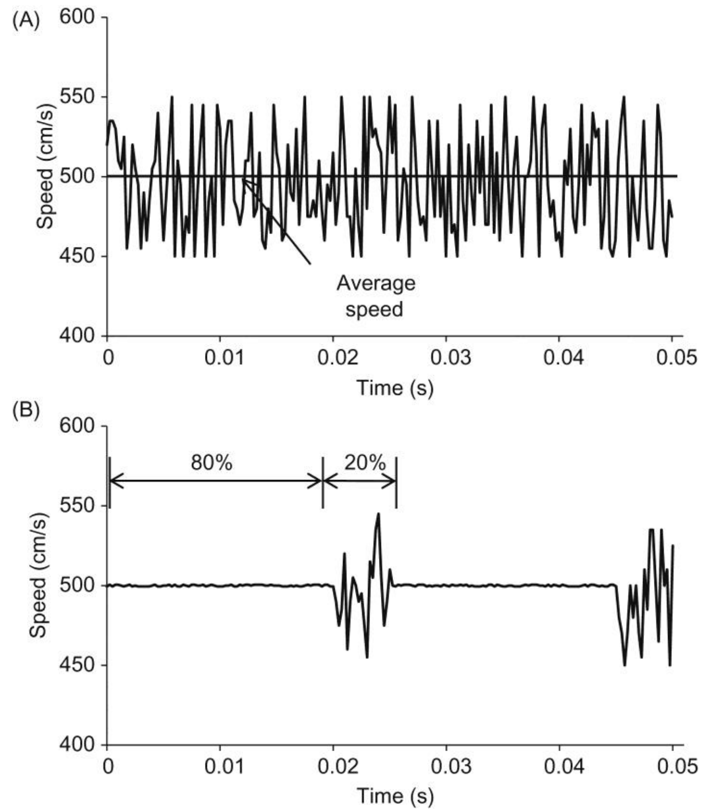

Figure 2.23 Turbulent absolute velocity fluctuations in the shear layer (A) and at the boundary (B) of an external flow. Velocity fluctuations, in both instances, have a mean speed of 500 cm/s, however, the turbulence in the shear layer is self-sustaining, whereas the turbulence at the boundary can dissipate and reform. The reformation of the turbulence at the boundary is due to the ambient fluid becoming entrained within the turbulent fluid. However, the viscous forces can overcome this entrainment for approximately 80% of the time.

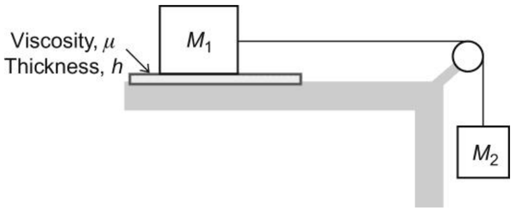

Figure 2.24 Figure for Homework Problem 2.13.

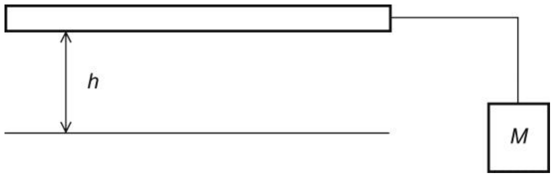

Figure 2.25 Figure for Homework Problem 2.16.

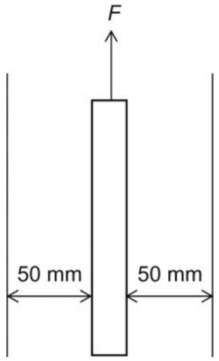

Figure 2.26 Figure for Homework Problem 2.18/2.19.

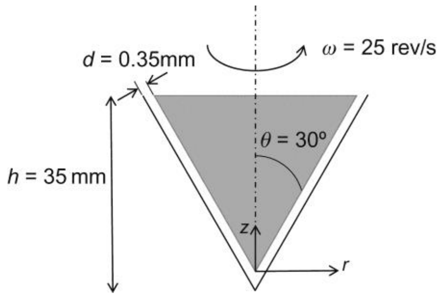

Figure 2.27 Figure for Homework Problem 2.20.