Solutions Manual for

Fluid Mechanics: Fundamentals and Applications

CHAPTER 1

INTRODUCTION AND BASIC CONCEPTS

Introduction, Classification, and System

1-1C

Solution We are to define a fluid and how it differs between a solid and a gas.

Analysis **A substance in the liquid or gas phase is referred to as a fluid**. A fluid differs from a solid in that a solid can resist an applied shear stress by deforming, whereas **a fluid deforms continuously under the influence of shear stress**, no matter how small. A liquid takes the shape of the container it is in, and **a liquid forms a free surface in a larger container in a gravitational field**. A gas, on the other hand, expands until it encounters the walls of the container and fills the entire available space.

Discussion The subject of fluid mechanics deals with ball fluids, both gases and liquids.

1-2C

Solution We are to determine whether the flow of air over the wings of an aircraft and the flow of gases through a jet engine is internal or external.

Analysis The flow of air over the wings of an aircraft is **external** since this is an unbounded fluid flow over a surface. The flow of gases through a jet engine is **internal** flow since the fluid is completely bounded by the solid surfaces of the engine.

Discussion If we consider the entire airplane, the flow is both internal (through the jet engines) and external (over the body and wings).

1-3C

Solution We are to define incompressible and compressible flow, and discuss fluid compressibility.

Analysis A fluid flow during which the **density of the fluid remains nearly constant** is called *incompressible flow*. A flow in which **density varies significantly** is called *compressible flow*. A fluid whose density is practically independent of pressure (such as a liquid) is commonly referred to as an "incompressible fluid," although it is more proper to refer to incompressible *flow*. The flow of compressible fluid (such as air) does not necessarily need to be treated as compressible since the density of a compressible fluid may still remain nearly constant during flow – especially flow at low speeds.

Discussion It turns out that the Mach number is the critical parameter to determine whether the flow of a gas can be approximated as an incompressible flow. If Ma is less than about 0.3, the incompressible approximation yields results that are in error by less than a couple percent.

1-4C

Solution We are to define internal, external, and open-channel flows.

Analysis *External flow* is the **flow of an unbounded fluid over a surface** such as a plate, a wire, or a pipe. The flow in a pipe or duct is *internal flow* if the **fluid is completely bounded by solid surfaces**. The flow of liquids in a pipe is called *open-channel flow* if the pipe is **partially filled with the liquid and there is a free surface**, such as the flow of water in rivers and irrigation ditches.

Discussion As we shall see in later chapters, different approximations are used in the analysis of fluid flows based on their classification.

1-5C

Solution We are to define the Mach number of a flow and the meaning for a Mach number of 2.

Analysis The Mach number of a flow is defined as **the ratio of the speed of flow to the speed of sound** in the flowing fluid. **A Mach number of 2 indicate a flow speed that is twice the speed of sound in that fluid**.

Discussion Mach number is an example of a dimensionless (or nondimensional) parameter.

1-6C

Solution We are to discuss if the Mach number of a constant-speed airplane is constant.

Analysis No. The speed of sound, and thus the Mach number, changes with temperature which may change considerably from point to point in the atmosphere.

1-7C

Solution We are to determine if the flow of air with a Mach number of 0.12 should be approximated as incompressible.

Analysis Gas flows can often be approximated as incompressible if the density changes are under about 5 percent, which is usually the case when Ma < 0.3. Therefore, air flow with a Mach number of 0.12 **may be approximated as being incompressible**.

Discussion Air is of course a compressible fluid, but at low Mach numbers, compressibility effects are insignificant.

1-8C

Solution We are to define the no-slip condition and its cause.

Analysis A **fluid in direct contact with a solid surface sticks to the surface and there is no slip**. This is known as the *no-slip condition*, and it is due to the *viscosity* of the fluid.

Discussion There is no such thing as an inviscid fluid, since all fluids have viscosity.

1-9C

Solution We are to define forced flow and discuss the difference between forced and natural flow. We are also to discuss whether wind-driven flows are forced or natural.

Analysis In *forced flow*, the fluid is forced to flow over a surface or in a tube **by *external* means** such as a pump or a fan. In *natural flow*, any fluid motion is caused by natural means such as the buoyancy effect that manifests itself as the rise of the warmer fluid and the fall of the cooler fluid. **The flow caused by winds is natural flow for the earth, but it is forced flow for bodies subjected to the winds** since for the body it makes no difference whether the air motion is caused by a fan or by the winds.

Discussion As seen here, the classification of forced vs. natural flow may depend on your frame of reference.

1-10C

Solution We are to define a boundary layer, and discuss its cause.

Analysis The **region of flow** (usually near a wall) **in which the velocity gradients are significant and frictional effects are important** is called the *boundary layer*. When a fluid stream encounters a solid surface that is at rest, the fluid velocity assumes a value of zero at that surface. The velocity then varies from zero at the surface to some larger value sufficiently far from the surface. **The development of a boundary layer is caused by the *no-slip condition***.

Discussion As we shall see later, flow within a boundary layer is *rotational* (individual fluid particles rotate), while that outside the boundary layer is typically *irrotational* (individual fluid particles move, but do not rotate).

1-11C

Solution We are to discuss the differences between classical and statistical approaches.

Analysis The *classical approach* is **a *macroscopic* approach**, based on experiments or analysis of the gross behavior of a fluid, without knowledge of individual molecules, whereas the *statistical approach* is a ***microscopic* approach** based on the average behavior of large groups of individual molecules.

Discussion The classical approach is easier and much more common in fluid flow analysis.

1-12C

Solution We are to define a steady-flow process.

Analysis A process is said to be *steady* if it involves **no changes with time** anywhere within the system or at the system boundaries.

Discussion The opposite of steady flow is *unsteady flow*, which involves changes with time.

1-13C

Solution We are to define stress, normal stress, shear stress, and pressure.

Analysis *Stress* is defined as **force per unit area**, and is determined by dividing the force by the area upon which it acts. The **normal component of a force acting on a surface per unit area** is called the *normal stress*, and the **tangential component of a force acting on a surface per unit area** is called *shear stress*. In a fluid at rest, the normal stress is called *pressure*.

Discussion Fluids in motion may have both shear stresses and additional normal stresses besides pressure, but when a fluid is at rest, the only normal stress is the pressure, and there are no shear stresses.

1-14C

Solution We are to discuss how to select system when analyzing the acceleration of gases as they flow through a nozzle.

Analysis When analyzing the acceleration of gases as they flow through a nozzle, a wise choice for the system is **the volume within the nozzle**, bounded by the entire inner surface of the nozzle and the inlet and outlet cross-sections. This is a **control volume (or open system)** since mass crosses the boundary.

Discussion It would be much more difficult to follow a chunk of air as a closed system as it flows through the nozzle.

1-15C

Solution We are to discuss when a system is considered closed or open.

Analysis Systems may be considered to be *closed* or *open*, depending on whether a fixed mass or a volume in space is chosen for study. A *closed system* (also known as a *control mass* or simply a *system*) consists of a **fixed amount of mass, and no mass can cross its boundary**. An *open system*, or a *control volume*, is a **selected region in space**. Mass may cross the boundary of a control volume or open system

Discussion In thermodynamics, it is more common to use the terms *open system* and *closed system*, but in fluid mechanics, it is more common to use the terms *system* and *control volume* to mean the same things, respectively.

1-16C

Solution We are to discuss how to select system for the operation of a reciprocating air compressor.

Analysis We would most likely take the system as **the air contained in the piston-cylinder device**. This system is a **closed or fixed mass system when it is compressing and no mass enters or leaves it**. However, it is an **open system during intake or exhaust**.

Discussion In this example, the system boundary is the same for either case – closed or open system.

1-17C

Solution We are to define system, surroundings, and boundary.

Analysis A *system* is defined as a **quantity of matter or a region in space chosen for study**. The mass or **region outside the system** is called the *surroundings***.** The real or imaginary **surface that separates the system from its surroundings** is called the *boundary*.

Discussion Some authors like to define *closed systems* and *open systems*, while others use the notation "system" to mean a closed system and "control volume" to mean an open system. This has been a source of confusion for students for many years. [See the next question for further discussion about this.]

Mass, Force, and Units

1-18C

Solution We are to explain why the light-year has the dimension of length.

Analysis In this unit, the word *light* refers to the speed of light. The light-year unit is then the product of a velocity and time. Hence, this product forms a distance dimension and unit.

1-19C

Solution We are to discuss the difference between kg-mass and kg-force.

Analysis The unit *kilogram* (kg) is the **mass unit in the SI system**, and it is sometimes called *kg-mass*, whereas *kg-force* (kgf) is a **force unit**. One kg-force is the force required to accelerate a 1-kg mass by 9.807 m/s^2. In other words, the weight of 1-kg mass at sea level on earth is 1 kg-force.

Discussion It is *not* proper to say that one kg-mass is equal to one kg-force since the two units have different dimensions.

1-20C

Solution We are to discuss the difference between pound-mass and pound-force.

Analysis *Pound-mass* lbm is the **mass unit in English system** whereas *pound-force* lbf is the **force unit in the English system**. One pound-force is the force required to accelerate a mass of 32.174 lbm by 1 ft/s^2. In other words, the weight of a 1-lbm mass at sea level on earth is 1 lbf.

Discussion It is *not* proper to say that one lbm is equal to one lbf since the two units have different dimensions.

1-21C

Solution We are to discuss the difference between pound-mass (lbm) and pound-force (lbf).

Analysis The "pound" mentioned here must be "**lbf**" since thrust is a force, and the lbf is the force unit in the English system.

Discussion You should get into the habit of *never* writing the unit "lb", but always use either "lbm" or "lbf" as appropriate since the two units have different dimensions.

1-22C

Solution We are to calculate the net force on a car cruising at constant velocity.

Analysis There is no acceleration (car moving at constant velocity), thus **the net force is zero in both cases**.

Discussion By Newton's second law, the force on an object is directly proportional to its acceleration. If there is zero acceleration, there must be zero net force.