

Chapter 1

INTRODUCTION AND BASIC CONCEPTS

Fluid Mechanics and Classification of Fluid Flow

1-1C The flow of an unbounded fluid over a surface such as a plate, a wire, or a pipe is *external flow*. 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.

1-2C A fluid flow during which the density of the fluid remains nearly constant is called *incompressible flow*. A fluid whose density is practically independent of pressure (such as a liquid) is called an incompressible fluid. The flow of compressible fluid (such as air) is not necessarily compressible since the density of a compressible fluid may still remain constant during flow.

1-3C 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.

1-4C 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.

1-5C When a fluid stream encounters a solid surface, the fluid velocity assumes a value of zero at the surface. The velocity then varies from zero at the surface to the freestream value sufficiently far from the surface. The region of flow in which the velocity gradients are significant is called the *boundary layer*. The development of a boundary layer is caused by the *no-slip condition*.

1-6C Classical approach is based on experimental observations whereas statistical approach is based on the average behavior of large groups of particles.

1-7C A process is said to be steady-flow if it involves no changes with time anywhere within the system or at the system boundaries.

1-8C **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, the normal stress is called **pressure**.

1-9C 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**.

1-10C 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**) consists of a fixed amount of mass, and no mass can cross its boundary. An **open system**, or a **control volume**, is a properly selected region in space.

Mass, Force, and Units

1-11C Pound-mass lbm is the mass unit in English system whereas pound-force lbf is the force unit. 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 is 1 lbf.

1-12C Kg is the mass unit in the SI system whereas kg-force is a force unit. 1-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 is 1 kg-force.

1-13C There is no acceleration, thus the net force is zero in both cases.

1-14 A plastic tank is filled with water. The weight of the combined system is to be determined.

Assumptions The density of water is constant throughout.

Properties The density of water is given to be $\rho = 1000 \text{ kg/m}^3$.

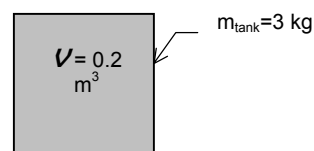
Analysis The mass of the water in the tank and the total mass are

$$m_w = \rho V = (1000 \text{ kg/m}^3)(0.2 \text{ m}^3) = 200 \text{ kg}$$

$$m_{\text{total}} = m_w + m_{\text{tank}} = 200 + 3 = 203 \text{ kg}$$

Thus,

$$W = mg = (203 \text{ kg})(9.81 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \mathbf{1991 \text{ N}}$$



1-15 The interior dimensions of a room are given. The mass and weight of the air in the room are to be determined.

Assumptions The density of air is constant throughout the room.

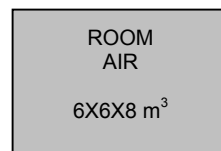
Properties The density of air is given to be $\rho = 1.16 \text{ kg/m}^3$.

Analysis The mass of the air in the room is

$$m = \rho V = (1.16 \text{ kg/m}^3)(6 \times 6 \times 8 \text{ m}^3) = \mathbf{334.1 \text{ kg}}$$

Thus,

$$W = mg = (334.1 \text{ kg})(9.81 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \mathbf{3277 \text{ N}}$$



1-16 The variation of gravitational acceleration above the sea level is given as a function of altitude. The height at which the weight of a body will decrease by 1% is to be determined.

Analysis The weight of a body at the elevation z can be expressed as

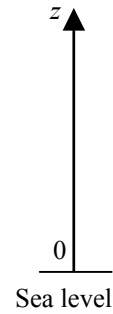
$$W = mg = m(9.807 - 3.32 \times 10^{-6} z)$$

In our case,

$$W = 0.99W_s = 0.99mg_s = 0.99(m)(9.807)$$

Substituting,

$$0.99(9.807) = (9.807 - 3.32 \times 10^{-6} z) \longrightarrow z = \mathbf{29,540 \text{ m}}$$



1-17E An astronaut took his scales with him to space. It is to be determined how much he will weigh on the spring and beam scales in space.

Analysis (a) A spring scale measures weight, which is the local gravitational force applied on a body:

$$W = mg = (150 \text{ lbm})(5.48 \text{ ft/s}^2) \left(\frac{1 \text{ lbf}}{32.2 \text{ lbm} \cdot \text{ft/s}^2} \right) = \mathbf{25.5 \text{ lbf}}$$

(b) A beam scale compares masses and thus is not affected by the variations in gravitational acceleration. The beam scale will read what it reads on earth,

$$W = \mathbf{150 \text{ lbf}}$$

1-18 The acceleration of an aircraft is given in g 's. The net upward force acting on a man in the aircraft is to be determined.

Analysis From the Newton's second law, the force applied is

$$F = ma = m(6g) = (90 \text{ kg})(6 \times 9.81 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \mathbf{5297 \text{ N}}$$

1-19 [Also solved by EES on enclosed CD] A rock is thrown upward with a specified force. The acceleration of the rock is to be determined.

Analysis The weight of the rock is

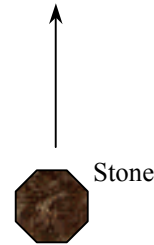
$$W = mg = (5 \text{ kg})(9.79 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \mathbf{48.95 \text{ N}}$$

Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 150 - 48.95 = 101.05 \text{ N}$$

From the Newton's second law, the acceleration of the rock becomes

$$a = \frac{F}{m} = \frac{101.05 \text{ N}}{5 \text{ kg}} \left(\frac{1 \text{ kg} \cdot \text{m/s}^2}{1 \text{ N}} \right) = \mathbf{20.2 \text{ m/s}^2}$$



1-20 Problem 1-19 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

```
W=m*g"[N]"
m=5"[kg]"
g=9.79"[m/s^2]"
```

"The force balance on the rock yields the net force acting on the rock as"

```
F_net = F_up - F_down"[N]"
F_up=150"[N]"
F_down=W"[N]"
```

"The acceleration of the rock is determined from Newton's second law."

```
F_net=a*m
```

"To Run the program, press F2 or click on the calculator icon from the Calculate menu"

SOLUTION

Variables in Main

```
a=20.21 [m/s^2]
F_down=48.95 [N]
F_net=101.1 [N]
F_up=150 [N]
g=9.79 [m/s^2]
m=5 [kg]
W=48.95 [N]
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1-21 Gravitational acceleration g and thus the weight of bodies decreases with increasing elevation. The percent reduction in the weight of an airplane cruising at 13,000 m is to be determined.

Properties The gravitational acceleration g is given to be 9.807 m/s^2 at sea level and 9.767 m/s^2 at an altitude of 13,000 m.

Analysis Weight is proportional to the gravitational acceleration g , and thus the percent reduction in weight is equivalent to the percent reduction in the gravitational acceleration, which is determined from

$$\% \text{Reduction in weight} = \% \text{Reduction in } g = \frac{\Delta g}{g} \times 100 = \frac{9.807 - 9.767}{9.807} \times 100 = \mathbf{0.41\%}$$

Therefore, the airplane and the people in it will weigh 0.41% less at 13,000 m altitude.

Discussion Note that the weight loss at cruising altitudes is negligible.



Modeling and Solving Problems, and Precision

1-22C Accuracy refers to the closeness of the measured or calculated value to the true value whereas precision represents the number of significant digits or the closeness of different measurements of the same quantity to each other. A measurement or calculation can be very precise without being very accurate. When measuring the boiling temperature of pure water at standard atmospheric conditions, for example, a temperature measurement of 97.86°C is very precise, but not as accurate as the imprecise measurement of 99°C .

1-23C The experimental approach (testing and taking measurements) has the advantage of dealing with the actual physical system, and getting a physical value within the limits of experimental error. However, this approach is expensive, time consuming, and often impractical. The analytical approach (analysis or calculations) has the advantage that it is fast and inexpensive, but the results obtained are subject to the accuracy of the assumptions and idealizations made in the analysis.

1-24C Modeling makes it possible to predict the course of an event before it actually occurs, or to study various aspects of an event mathematically without actually running expensive and time-consuming experiments. When preparing a mathematical model, all the variables that affect the phenomena are identified, reasonable assumptions and approximations are made, and the interdependence of these variables are studied. The relevant physical laws and principles are invoked, and the problem is formulated mathematically. Finally, the problem is solved using an appropriate approach, and the results are interpreted.

1-25C The right choice between a crude and complex model is usually the *simplest* model which yields *adequate* results. Preparing very accurate but complex models is not necessarily a better choice since such models are not much use to an analyst if they are very difficult and time consuming to solve. At the minimum, the model should reflect the essential features of the physical problem it represents.

1-26C The description of most scientific problems involve relations that relate the *changes* in some key variables to each other, and the smaller the increment chosen in the changing variables, the more accurate the description. In the limiting case of infinitesimal changes in variables, we obtain *differential equations*, which provide precise mathematical formulations for the physical principles and laws by representing the rates of changes as *derivatives*.

1-27C Despite the convenience and capability the engineering software packages offer, they are still just tools, and they will not replace the traditional engineering courses. They will simply cause a shift in emphasis in the course material from mathematics to physics. They are of great value in engineering practice, however, as engineers today rely on software packages for solving large and complex problems in a short time, and perform optimization studies efficiently.



1-28 Determine a positive real root of the following equation using EES:

$$2x^3 - 10x^{0.5} - 3x = -3$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

$$2*x^3-10*x^{0.5}-3*x = -3$$

Answer: $x = 2.063$ (using an initial guess of $x=2$)



1-29 Solve the following system of 2 equations with 2 unknowns using EES:

$$x^3 - y^2 = 7.75$$

$$3xy + y = 3.5$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

$$x^3-y^2=7.75$$

$$3*x*y+y=3.5$$

Answer $x=2$ $y=0.5$



1-30 Solve the following system of 3 equations with 3 unknowns using EES:

$$2x - y + z = 5$$

$$3x^2 + 2y = z + 2$$

$$xy + 2z = 8$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

$$2*x-y+z=5$$

$$3*x^2+2*y=z+2$$

$$x*y+2*z=8$$

Answer $x=1.141$, $y=0.8159$, $z=3.535$



1-31 Solve the following system of 3 equations with 3 unknowns using EES:

$$x^2y - z = 1$$

$$x - 3y^{0.5} + xz = -2$$

$$x + y - z = 2$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

$$x^2*y-z=1$$

$$x-3*y^{0.5}+x*z=-2$$

$$x+y-z=2$$

Answer $x=1$, $y=1$, $z=0$

Review Problems

1-32 The gravitational acceleration changes with altitude. Accounting for this variation, the weights of a body at different locations are to be determined.

Analysis The weight of an 80-kg man at various locations is obtained by substituting the altitude z (values in m) into the relation

$$W = mg = (80 \text{ kg})(9.807 - 3.32 \times 10^{-6} z \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right)$$

Sea level: ($z = 0 \text{ m}$): $W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 0) = 80 \times 9.807 = \mathbf{784.6 \text{ N}}$

Denver: ($z = 1610 \text{ m}$): $W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 1610) = 80 \times 9.802 = \mathbf{784.2 \text{ N}}$

Mt. Ev.: ($z = 8848 \text{ m}$): $W = 80 \times (9.807 - 3.32 \times 10^{-6} \times 8848) = 80 \times 9.778 = \mathbf{782.2 \text{ N}}$

1-33 A man is considering buying a 12-oz steak for \$3.15, or a 320-g steak for \$2.80. The steak that is a better buy is to be determined.

Assumptions The steaks are of identical quality.

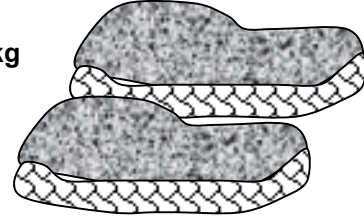
Analysis To make a comparison possible, we need to express the cost of each steak on a common basis. Let us choose 1 kg as the basis for comparison. Using proper conversion factors, the unit cost of each steak is determined to be

$$12 \text{ ounce steak: Unit Cost} = \left(\frac{\$3.15}{12 \text{ oz}} \right) \left(\frac{16 \text{ oz}}{1 \text{ lbm}} \right) \left(\frac{1 \text{ lbm}}{0.45359 \text{ kg}} \right) = \mathbf{\$9.26/\text{kg}}$$

320 gram steak:

$$\text{Unit Cost} = \left(\frac{\$2.80}{320 \text{ g}} \right) \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) = \mathbf{\$8.75/\text{kg}}$$

Therefore, the steak at the international market is a better buy.



1-34 The thrust developed by the jet engine of a Boeing 777 is given to be 85,000 pounds. This thrust is to be expressed in N and kgf.

Analysis Noting that 1 lbf = 4.448 N and 1 kgf = 9.81 N, the thrust developed can be expressed in two other units as

$$\text{Thrust in N: Thrust} = (85,000 \text{ lbf}) \left(\frac{4.448 \text{ N}}{1 \text{ lbf}} \right) = \mathbf{3.78 \times 10^5 \text{ N}}$$

$$\text{Thrust in kgf: Thrust} = (37.8 \times 10^5 \text{ N}) \left(\frac{1 \text{ kgf}}{9.81 \text{ N}} \right) = \mathbf{3.85 \times 10^4 \text{ kgf}}$$



1-35 Design and Essay Problem

