Solutions Manual

for

Fundamentals of Thermal Fluid Sciences

Fourth Edition

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Chapter 1

INTRODUCTION AND OVERVIEW

Thermodynamics, Heat Transfer, and Fluid Mechanics

1-1C On a downhill road the potential energy of the bicyclist is being converted to kinetic energy, and thus the bicyclist picks up speed. There is no creation of energy, and thus no violation of the conservation of energy principle.

1-2C There is no truth to his claim. It violates the second law of thermodynamics.

1-3C A car going uphill without the engine running would increase the energy of the car, and thus it would be a violation of the first law of thermodynamics. Therefore, this cannot happen. Using a level meter (a device with an air bubble between two marks of a horizontal water tube) it can shown that the road that looks uphill to the eye is actually downhill.

1-4C Thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another. Heat transfer, on the other hand, deals with the rate of heat transfer as well as the temperature distribution within the system at a specified time.

1-5C (a) The driving force for heat transfer is the temperature difference. (b) The driving force for electric current flow is the electric potential difference (voltage). (a) The driving force for fluid flow is the pressure difference.

1-6C Heat transfer is a non-equilibrium phenomena since in a system that is in equilibrium there can be no temperature differences and thus no heat flow.

1-7C No, there cannot be any heat transfer between two bodies that are at the same temperature (regardless of pressure) since the driving force for heat transfer is temperature difference.

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**.

Mass, Force, and Units

1-9C The "pound" mentioned here must be "**lbf**" since thrust is a force, and the lbf is the force unit in the English system. 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.

1-10C 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.

1-11C There is no acceleration, thus the net force is zero in both cases.

1-12E The weight of a man on earth is given. His weight on the moon is to be determined.

Analysis Applying Newton's second law to the weight force gives

$$W = mg \longrightarrow m = \frac{W}{g} = \frac{210\text{ lbf}}{32.10\text{ ft/s}^2}\left(\frac{32.174\text{ lbm}\cdot\text{ft/s}^2}{1\text{ lbf}}\right) = 210.5\text{ lbm}$$

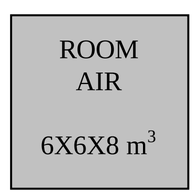
Mass is invariant and the man will have the same mass on the moon. Then, his weight on the moon will be

$$W = mg = (210.5\text{ lbm})(5.47\text{ ft/s}^2)\left(\frac{1\text{ lbf}}{32.174\text{ lbm}\cdot\text{ft/s}^2}\right) = \mathbf{35.8\text{ lbf}}$$

1-13 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

$$m = \rho V = (1.16\text{ kg/m}^3)(6\times6\times8\text{ m}^3) = \mathbf{334.1\text{ kg}}$$

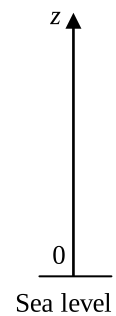
Thus,

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

1-14 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 0.5% 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,

$$W = 0.995 W_s = 0.995 m g_s = 0.995(m)(9.81)$$

Substituting,

$$0.995(9.81) = (9.81 - 3.32 \times 10^{-6} z) \longrightarrow z = 14{,}774 \text{ m} \cong \mathbf{14{,}770\ m}$$

1-15 The mass of an object is given. Its weight is to be determined.

Analysis Applying Newton's second law, the weight is determined to be

$$W = mg = (200 \text{ kg})(9.6 \text{ m/s}^2) = \mathbf{1920\ N}$$

1-16E The constant-pressure specific heat of air given in a specified unit is to be expressed in various units.

Analysis Applying Newton's second law, the weight is determined in various units to be

$$c_p = (1.005 \text{ kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1 \text{ kJ/kg}\cdot\text{K}}{1 \text{ kJ/kg}\cdot{}^\circ\text{C}}\right) = \mathbf{1.005\ kJ/kg\cdot K}$$

$$c_p = (1.005 \text{ kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1000 \text{ J}}{1 \text{ kJ}}\right)\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right) = \mathbf{1.005\ J/g\cdot{}^\circ C}$$

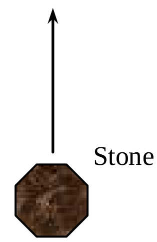
$$c_p = (1.005 \text{ kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1 \text{ kcal}}{4.1868 \text{ kJ}}\right) = \mathbf{0.240\ kcal/kg\cdot{}^\circ C}$$

$$c_p = (1.005 \text{ kJ/kg}\cdot{}^\circ\text{C})\left(\frac{1 \text{ Btu/lbm}\cdot{}^\circ\text{F}}{4.1868 \text{ kJ/kg}\cdot{}^\circ\text{C}}\right) = \mathbf{0.240\ Btu/lbm\cdot{}^\circ F}$$

1-17 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

$$W = mg = (3\text{ kg})(9.79\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right) = 29.37\text{ N}$$



Then the net force that acts on the rock is

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} = 200 - 29.37 = 170.6\text{ N}$$

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

$$a = \frac{F}{m} = \frac{170.6\text{ N}}{3\text{ kg}}\left(\frac{1\text{ kg}\cdot\text{m/s}^2}{1\text{ N}}\right) = \mathbf{56.9\ m/s^2}$$

1-18 Problem 1-17 is reconsidered. The entire EES solution is to be printed out, including the numerical results with proper units.

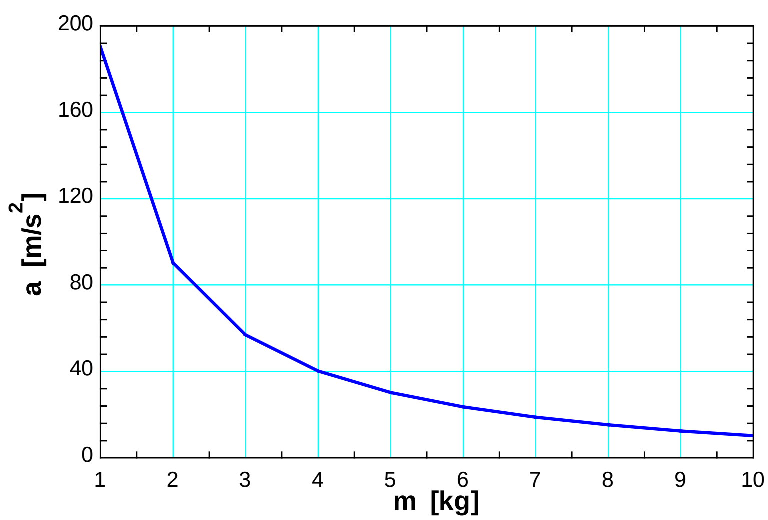
Analysis The problem is solved using EES, and the solution is given below.

```
"The weight of the rock is"
W=m*g
m=3 [kg]
g=9.79 [m/s2]
"The force balance on the rock yields the net force acting on the rock as"
F_up=200 [N]
F_net = F_up - F_down
F_down=W
"The acceleration of the rock is determined from Newton's second law."
F_net=m*a

"To Run the program, press F2 or select Solve from the Calculate menu."
```

SOLUTION
a=56.88 [m/s^2]
F_down=29.37 [N]
F_net=170.6 [N]
F_up=200 [N]
g=9.79 [m/s2]
m=3 [kg]
W=29.37 [N]

m [kg]	a [m/s^2]
1	190.2
2	90.21
3	56.88
4	40.21
5	30.21
6	23.54
7	18.78
8	15.21
9	12.43
10	10.21



1-19 During an analysis, a relation with inconsistent units is obtained. A correction is to be found, and the probable cause of the error is to be determined.

Analysis The two terms on the right-hand side of the equation

$$E = 25 \text{ kJ} + 7 \text{ kJ/kg}$$

do not have the same units, and therefore they cannot be added to obtain the total energy. Multiplying the last term by mass will eliminate the kilograms in the denominator, and the whole equation will become dimensionally homogeneous; that is, every term in the equation will have the same unit.

Discussion Obviously this error was caused by forgetting to multiply the last term by mass at an earlier stage.

1-20 A resistance heater is used to heat water to desired temperature. The amount of electric energy used in kWh and kJ are to be determined.

Analysis The resistance heater consumes electric energy at a rate of 4 kW or 4 kJ/s. Then the total amount of electric energy used in 2 hours becomes

$$\begin{aligned}\text{Total energy} &= (\text{Energy per unit time})(\text{Time interval}) \\ &= (4 \text{ kW})(2 \text{ h}) \\ &= \mathbf{8\ kWh}\end{aligned}$$

Noting that 1 kWh = (1 kJ/s)(3600 s) = 3600 kJ,

$$\begin{aligned}\text{Total energy} &= (8 \text{ kWh})(3600 \text{ kJ/kWh}) \\ &= \mathbf{28{,}800\ kJ}\end{aligned}$$

Discussion Note kW is a unit for power whereas kWh is a unit for energy.

1-21 A gas tank is being filled with gasoline at a specified flow rate. Based on unit considerations alone, a relation is to be obtained for the filling time.

Assumptions Gasoline is an incompressible substance and the flow rate is constant.

Analysis The filling time depends on the volume of the tank and the discharge rate of gasoline. Also, we know that the unit of time is 'seconds'. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$$t \text{ [s]} \quad \leftrightarrow \quad V \text{ [L]}, \text{ and } \dot{V} \text{ [L/s}\}$$

It is obvious that the only way to end up with the unit "s" for time is to divide the tank volume by the discharge rate. Therefore, the desired relation is

$$t = \frac{V}{\dot{V}}$$

Discussion Note that this approach may not work for cases that involve dimensionless (and thus unitless) quantities.

1-22 A pool is to be filled with water using a hose. Based on unit considerations, a relation is to be obtained for the volume of the pool.

Assumptions Water is an incompressible substance and the average flow velocity is constant.

Analysis The pool volume depends on the filling time, the cross-sectional area which depends on hose diameter, and flow velocity. Also, we know that the unit of volume is m^3. Therefore, the independent quantities should be arranged such that we end up with the unit of seconds. Putting the given information into perspective, we have

$\mathcal{V}$ [m^3] is a function of t [s], D [m], and V [m/s}

It is obvious that the only way to end up with the unit "m^3" for volume is to multiply the quantities t and V with the square of D. Therefore, the desired relation is

$$\boldsymbol{\mathcal{V} = CD^2Vt}$$

where the constant of proportionality is obtained for a round hose, namely, $C = \pi/4$ so that $\boldsymbol{\mathcal{V} = (\pi D^2/4)Vt}$.

Discussion Note that the values of dimensionless constants of proportionality cannot be determined with this approach.

Solving Engineering Problems and EES

1-23C 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.

1-24 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 line 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)

1-25 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

1-26 Solve the following system of 3 equations with 3 unknowns using EES:

$$2x - y + z = 7$$

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

$$xy + 2z = 4$$

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

```
2*x-y+z=7
3*x^2+2*y=z+3
x*y+2*z=4
```

Answer x=1.609, y=-0.9872, z=2.794

1-27 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

1-28E Specific heat of water is to be expressed at various units using unit conversion capability of EES.

Analysis The problem is solved using EES, and the solution is given below.

EQUATION WINDOW

```
"GIVEN"
C_p=4.18 [kJ/kg-C]

"ANALYSIS"
C_p_1=C_p*Convert(kJ/kg-C, kJ/kg-K)
C_p_2=C_p*Convert(kJ/kg-C, Btu/lbm-F)
C_p_3=C_p*Convert(kJ/kg-C, Btu/lbm-R)
C_p_4=C_p*Convert(kJ/kg-C, kCal/kg-C)
```

FORMATTED EQUATIONS WINDOW

GIVEN

$$C_p = 4.18 \quad \text{[kJ/kg-C]}$$

ANALYSIS

$$C_{p,1} = C_p \cdot \left| 1 \cdot \frac{\text{kJ/kg–K}}{\text{kJ/kg–C}} \right|$$

$$C_{p,2} = C_p \cdot \left| 0.238846 \cdot \frac{\text{Btu/lbm–F}}{\text{kJ/kg–C}} \right|$$

$$C_{p,3} = C_p \cdot \left| 0.238846 \cdot \frac{\text{Btu/lbm–R}}{\text{kJ/kg–C}} \right|$$

$$C_{p,4} = C_p \cdot \left| 0.238846 \cdot \frac{\text{kCal/kg–C}}{\text{kJ/kg–C}} \right|$$

SOLUTION

```
C_p=4.18 [kJ/kg-C]
C_p_1=4.18 [kJ/kg-K]
C_p_2=0.9984 [Btu/lbm-F]
C_p_3=0.9984 [Btu/lbm-R]
C_p_4=0.9984 [kCal/kg-C]
```

Review Problems

1-29 The weight of a lunar exploration module on the moon is to be determined.

Analysis Applying Newton's second law, the weight of the module on the moon can be determined from

$$W_{\text{moon}} = mg_{\text{moon}} = \frac{W_{\text{earth}}}{g_{\text{earth}}} g_{\text{moon}} = \frac{2800\ \text{N}}{9.8\ \text{m/s}^2}(1.64\ \text{m/s}^2) = \mathbf{469\ N}$$

1-30 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

$$W = mg = (80\text{kg})(9.807 - 3.32\times10^{-6} z\ \text{m/s}^2)\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right)$$

Sea level: (z = 0 m): W = 80×(9.807-3.32x10^{-6}×0) = 80×9.807 = **784.6 N**

Denver: (z = 1610 m): W = 80×(9.807-3.32x10^{-6}×1610) = 80×9.802 = **784.2 N**

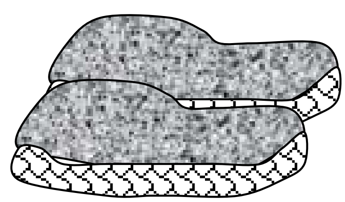
Mt. Ev.: (z = 8848 m): W = 80×(9.807-3.32x10^{-6}×8848) = 80×9.778 = **782.2 N**

1-31E A man is considering buying a 12-oz steak for \$3.15, or a 300-g steak for \$2.95. 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 ounce steak:



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

300 gram steak:

$$\text{Unit Cost} = \left(\frac{\$2.95}{300\ \text{g}}\right)\left(\frac{1000\ \text{g}}{1\ \text{kg}}\right) = \mathbf{\$9.83/kg}$$

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

1-32E The mass of a substance is given. Its weight is to be determined in various units.

Analysis Applying Newton's second law, the weight is determined in various units to be

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

$$W = mg = (1\text{ kg})(9.81\text{ m/s}^2)\left(\frac{1\text{ kN}}{1000\text{ kg}\cdot\text{m/s}^2}\right) = \mathbf{0.00981\ kN}$$

$$W = mg = (1\text{ kg})(9.81\text{ m/s}^2) = \mathbf{1\ kg\cdot m/s^2}$$

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

$$W = mg = (1\text{ kg})\left(\frac{2.205\text{ lbm}}{1\text{ kg}}\right)(32.2\text{ ft/s}^2) = \mathbf{71\ lbm\cdot ft/s^2}$$

$$W = mg = (1\text{ kg})\left(\frac{2.205\text{ lbm}}{1\text{ kg}}\right)(32.2\text{ ft/s}^2)\left(\frac{1\text{ lbf}}{32.2\text{ lbm}\cdot\text{ft/s}^2}\right) = \mathbf{2.21 lbf}$$

1-33 The flow of air through a wind turbine is considered. Based on unit considerations, a proportionality relation is to be obtained for the mass flow rate of air through the blades.

Assumptions Wind approaches the turbine blades with a uniform velocity.

Analysis The mass flow rate depends on the air density, average wind velocity, and the cross-sectional area which depends on hose diameter. Also, the unit of mass flow rate $\dot{m}$ is kg/s. Therefore, the independent quantities should be arranged such that we end up with the proper unit. Putting the given information into perspective, we have

$\dot{m}$ [kg/s] is a function of ρ [kg/m^3], D [m], and V [m/s}

It is obvious that the only way to end up with the unit "kg/s" for mass flow rate is to multiply the quantities ρ and V with the square of D. Therefore, the desired proportionality relation is

$\dot{m}$ is proportional to $\rho D^2 V$

or,

$$\dot{m} = C\rho D^2 V$$

where the constant of proportionality is $C = \pi/4$ so that $\dot{m} = \rho(\pi D^2/4)V$

Discussion Note that the dimensionless constants of proportionality cannot be determined with this approach.

1-34 A relation for the air drag exerted on a car is to be obtained in terms of on the drag coefficient, the air density, the car velocity, and the frontal area of the car.

Analysis The drag force depends on a dimensionless drag coefficient, the air density, the car velocity, and the frontal area. Also, the unit of force F is newton N, which is equivalent to kg·m/s^2. Therefore, the independent quantities should be arranged such that we end up with the unit kg·m/s^2 for the drag force. Putting the given information into perspective, we have

$$F_D \text{ [kg·m/s}^2] \leftrightarrow C_{\text{Drag}} \text{ [], } A_{\text{front}} \text{ [m}^2\text{], } \rho \text{ [kg/m}^3\text{], and } V \text{ [m/s]}$$

It is obvious that the only way to end up with the unit "kg·m/s^2" for drag force is to multiply mass with the square of the velocity and the fontal area, with the drag coefficient serving as the constant of proportionality. Therefore, the desired relation is

$$F_D = C_{\text{Drag}} \rho A_{\text{front}} V^2$$

Discussion Note that this approach is not sensitive to dimensionless quantities, and thus a strong reasoning is required.

1-35 Design and Essay Problems