SOLUTIONS MANUAL

for

THERMAL-FLUID SCIENCES:
An Integrated Approach

Chapter 1

Stephen R. Turns

Cambridge University Press
New York, NY

PROBLEM 1.1

THE THREE DISCIPLINES THAT COMPRISE THE THERMAL-FLUID SCIENCES ARE:

I. THERMODYNAMICS: THIS SUBJECT DEALS WITH HEAT AND MECHANICAL ENERGY AND CONVERSIONS BETWEEN THE TWO. IT IS OFTEN CONSIDERED SIMPLY THE STUDY OF INTERACTIONS BETWEEN ALL THE VARIOUS FORMS OF ENERGY.

II. HEAT TRANSFER: THIS SUBJECT ESSENTIALLY COVERS THE VARIOUS WAYS IN WHICH ENERGY CAN BE TRANSFERED DUE TO A DIFFERENCE IN TEMPERATURE.

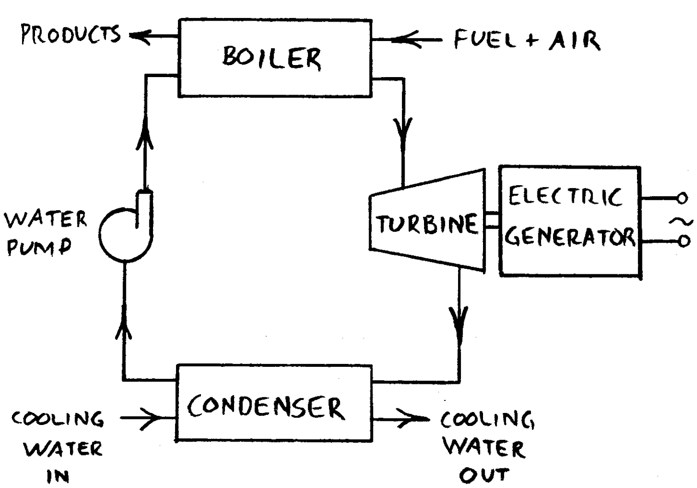
III. FLUID DYNAMICS: THIS SUBJECT IS CONCERNED WITH THE MOTION OF FLUIDS. IT HAS STRONG CONNECTIONS WITH THE OTHER AREAS, SINCE FLUIDS CARRY ENERGY FROM ONE LOCATION TO ANOTHER.

PROBLEM 1.2

DEVICES WHOSE DESIGN DEPENDS ON THE APPLICATION OF THE THERMAL-FLUID SCIENCES:

- INTERNAL COMBUSTION ENGINE
- POWER PLANT
- REFRIGERATOR
- ROCKET
- AIR CONDITIONING
- CPU COOLING SYSTEM
- TURBINE ENGINE
- HOME INSULATION
- ENGINE COOLANT SYSTEM

PROBLEM 1.3

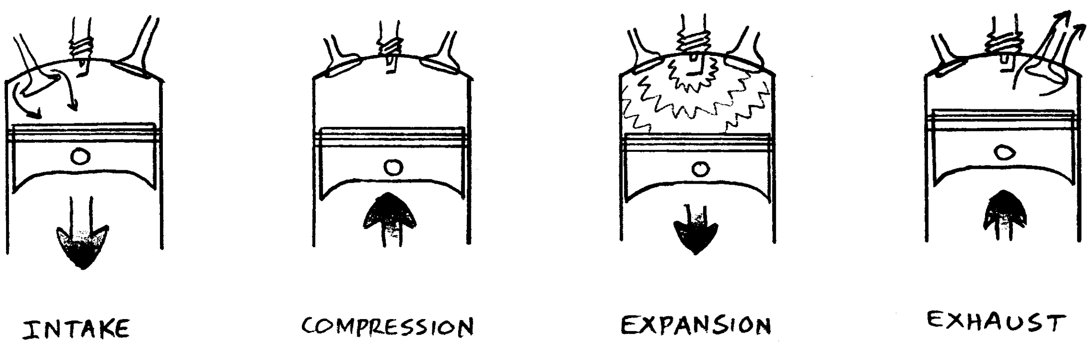


- WATER PUMP: RAISES WATER PRESSURE TO CREATE FLOW THROUGH THE SYSTEM.
- BOILER: USES HEAT FROM BURNING FUEL TO CREATE WATER VAPOR.
- TURBINE: CONVERTS THERMAL ENERGY OF STEAM INTO MECHANICAL SHAFT WORK.
- GENERATOR: CONVERTS SHAFT WORK TO USABLE ELECTRICAL ENERGY.
- CONDENSER: USES COOL WATER TO EXTRACT HEAT FROM WORKING FLUID TO CONVERT IT BACK TO A LIQUID IN PREPARATION TO REPEAT THE CYCLE.

PROBLEM 1.4

ACTIVE SOLAR HEATING INVOLVES A COMPLEX SYSTEM OF COMPONENTS IN ORDER TO HEAT WATER AND TO HEAT THE HOUSE. IN GENERAL, AN ACTIVE SYSTEM INVOLVES MOVING PARTS, WHILE A PASSIVE SYSTEM IS SIMPLER, WITHOUT MOVING PARTS OR CONTROLS. THE USE OF ONE TYPE OF SYSTEM OVER THE OTHER IS A MATTER OF THE HEATING DEMANDS OF THE USER.

PROBLEM 1.5



- INTAKE: THE INTAKE VALVE(S) IS OPENED NEAR TOP DEAD CENTER AND THE PISTON MOVES DOWN, DRAWING IN FRESH AIR AND FUEL.
- COMPRESSION: WITH ALL VALVES CLOSED, THE CRANKSHAFT CONTINUES TO ROTATE, FORCING THE PISTON BACK UP AND COMPRESSING THE FUEL-AIR MIXTURE.
- EXPANSION: NEAR TOP DEAD CENTER (USUALLY SLIGHTLY BEFORE), THE SPARK PLUG IS FIRED, CAUSING THE FUEL AND AIR TO BURN. THE PRESSURE IN THE CYLINDER RISES DRAMATICALLY, FORCING THE PISTON BACK DOWN. THIS IS THE ONLY STROKE WHERE POWER IS PRODUCED BY THE ENGINE, SO IT IS ALSO KNOWN AS THE POWER STROKE.
- EXHAUST: NEAR BOTTOM DEAD CENTER, THE EXHAUST VALVE(S) OPEN, AND AS THE CRANKSHAFT CONTINUES TO ROTATE, THE PISTON MOVES UP, FORCING THE PRODUCTS INTO THE EXHAUST SYSTEM AND PREPARING THE CYLINDER FOR THE NEXT CYCLE.

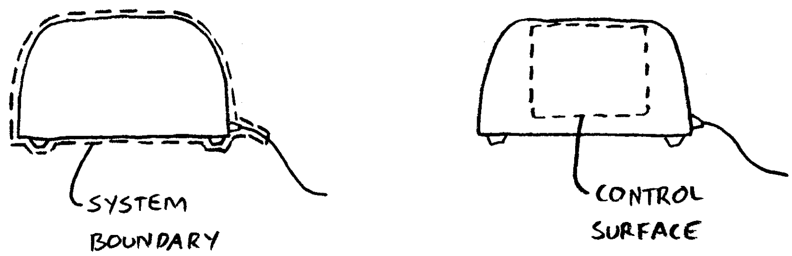
PROBLEM 1.6

IN A TURBOJET ENGINE, ALL OF THE THRUST COMES FROM THE COMBUSTION PRODUCTS PASSING THROUGH AN EXHAUST NOZZLE. IN A TURBOFAN, A BYPASS AIR JET CREATED BY A FAN NEAR THE FRONT OF THE ENGINE PRODUCES A SIGNIFICANT PORTION OF THE THRUST. TURBOFANS ARE MORE POPULAR FOR COMMERCIAL FLIGHTS.

Problem 1.7

A SYSTEM IS MERELY A SPECIFICALLY IDENTIFIED MASS THAT IS DIFFERENTIATED FROM ITS SURROUNDINGS. A CONTROL VOLUME IS A SPECIFIC REGION WHICH CAN HAVE MASS ENTER OR LEAVE THROUGH A CONTROL SURFACE. THE CONTROL VOLUME CAN MOVE OR CHANGE SIZE, AS CAN A SYSTEM.

Problem 1.8

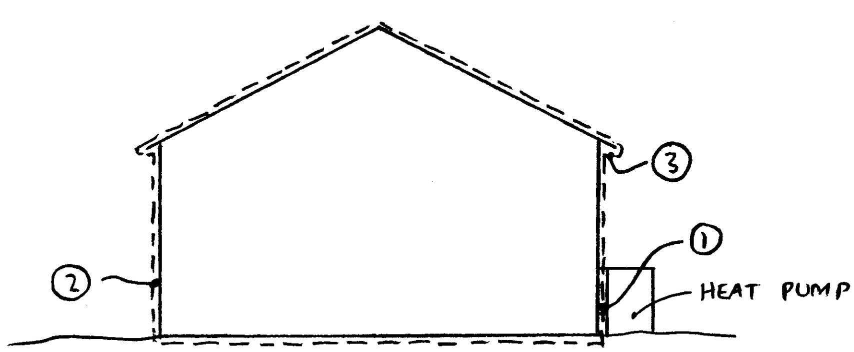


THE SYSTEM INCLUDES THE ENTIRE TOASTER, ENERGY COMES IN THROUGH THE POWER CORD AND LEAVES BY HEAT TRANSFER ACROSS THE SYSTEM BOUNDARY. THE CONTROL VOLUME CONSISTS OF THE AIR INSIDE THE TOASTER. ENERGY ENTERS AND EXITS THE FIXED CONTROL VOLUME BY HEAT TRANSFER ACROSS THE CONTROL SURFACE. AIR ENTERS AT BASE & EXITS AT TOP CARRYING MOISTURE FROM BREAD.

Problem 1.9

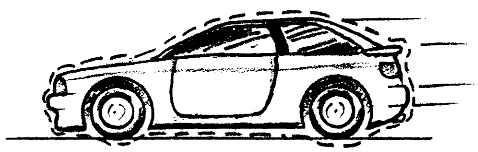
THE SYSTEM MUST BE DEFINED SUCH THAT NO MASS CROSSES THE SYSTEM BOUNDARY. THIS COULD BE DONE BY DEFINING THE SYSTEM AS ONLY THE COFFEE, OR ONLY THE MUG, OR THE MUG AND COFFEE TOGETHER, BUT EXCLUDING THE MOVING WATER VAPOR HOVERING OVER THE COFFEE.

Problem 1.10



1: REFRIGERANT ENTERS AND LEAVES THE HOUSE
2: AIR ENTERS AND LEAVES THROUGH OPEN OR LEAKING WINDOWS AND DOORS
3: AIR ENTERS AND LEAVES THROUGH VENTS

PROBLEM 1.11



THIS IS A CONTROL VOLUME. MASS ENTERS THROUGH THE AIR INTAKE BEHIND THE GRILLE AND EXITS THROUGH THE TAILPIPE, AS WELL AS THROUGH THE CABIN VENTILATION SYSTEM. THIS BOUNDARY CAN BE CHANGED TO A SYSTEM BOUNDARY IF THIS AIRFLOW IS NEGLECTED. ADDITIONALLY, MANY OTHER SYSTEMS CAN BE CONSIDERED, FOR INSTANCE:

- A SLUG OF AIR MOVING THROUGH THE ENGINE
- THE FLUID IN THE COOLING SYSTEM
- THE DRIVE SYSTEM (TRANSMISSION, AXLES, TIRES, ETC.)

PROBLEM 1.12

THE INTEGRAL CONTROL VOLUME IS USED WHEN THE DETAILS WITHIN THE VOLUME ARE NOT IMPORTANT AND CAN GENERALLY BE MODELED AS UNIFORM. IN CONTRAST, THE DIFFERENTIAL SYSTEM ALLOWS PROPERTIES TO BE DESCRIBED AT EVERY POINT IN SPACE AND TIME.

INTEGRAL SYSTEMS ARE GENERALLY SIMPLER MATHEMATICALLY AND CAN BE SOLVED USING ALGEBRAIC EQUATIONS. DIFFERENTIAL SYSTEMS REQUIRE EITHER ORDINARY OR PARTIAL DIFFERENTIAL EQUATIONS TO BE SOLVED.

PROBLEM 1.13

THE CONSERVATION OF ENERGY PRINCIPLE STATES THAT FOR A GIVEN TIME INTERVAL, THE AMOUNT OF ENERGY STORED IN THE SYSTEM EQUALS THE AMOUNT OF ENERGY ADDED MINUS THE AMOUNT LOST PLUS THE AMOUNT GENERATED WITHIN THE SYSTEM.

PROBLEM 1.14

FOR AN INSTANT IN TIME, THE RATE AT WHICH ENERGY IS BEING STORED IN THE SYSTEM IS EQUAL TO THE RATE AT WHICH ENERGY IS COMING INTO THE SYSTEM MINUS THE RATE AT WHICH IT IS LEAVING PLUS THE RATE AT WHICH ENERGY IS BEING GENERATED WITHIN THE SYSTEM.

PROBLEM 1.15

FOR A FINITE TIME INTERVAL, THE AMOUNT OF MASS STORED IN THE SYSTEM IS EQUAL TO THE AMOUNT OF MASS THAT ENTERS THE SYSTEM MINUS THE AMOUNT THAT LEAVES THE SYSTEM PLUS THE AMOUNT OF MASS GENERATED WITHIN THE SYSTEM.

AT A PARTICULAR INSTANT, THE RATE AT WHICH MASS IS BEING STORED IN THE SYSTEM IS EQUAL TO THE RATE AT WHICH MASS ENTERS THE SYSTEM MINUS THE RATE AT WHICH IT LEAVES PLUS THE RATE AT WHICH MASS IS BEING GENERATED WITHIN THE SYSTEM.

NOTE THAT IN MOST SYSTEMS, MASS IS NOT GENERATED, SO THE $X_{GENERATED}$ OR $\dot{X}_{GENERATED}$ TERM IS FREQUENTLY ZERO.

PROBLEM 1.16

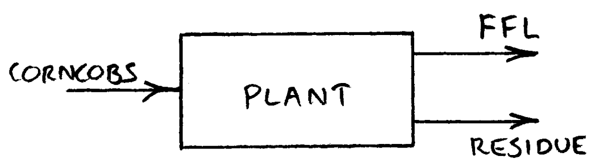
QUANTITY UNITS	MASS lbm	PERFECT \#	DAMAGED \#	VALUE \$
INFLOW	200	100	0	300
PRODUCED	0	0	0	0
OUTFLOW	16	8	0	24
STORED	184	78	14	248
DESTROYED	0	0	0	0

PROBLEM 1.17

QUANTITY UNITS	MASS kg	PRECISION \#	STANDARD \#	SUBSTANDARD \#	VALUE k\$
INFLOW	520	0	0	0	0
PRODUCED	0	3000	5000	2000	30
OUTFLOW	295	1500	2000	2000	13.5
STORED	225	1500	3000	0	16.5
DESTROYED	0	0	0	0	0

PROBLEM 1.18

QUANTITY UNITS	CORNCOBS lbm/hr	OUT HULLS lbm/hr	FFL lbm/hr	VALUE $/hr	MONEY $/hr
INFLOW	1000	200	0	140	250
PRODUCED	0	0	450	225	0
OUTFLOW	225	75	350	250	140
STORED	550	-100	100	85	110
DESTROYED	225	225	0	67.5	0



INITIAL VALUE: 1 lbm CORNCOBS = \$0.10

OUTPUTS: 0.5 lbm FFL = \$0.25

0.5 lbm RESIDUE = \$0.125

ΔVALUE = \$0.275

PROBLEM 1.19

QUANTITY UNITS	MASS lbm/hr	ORANGES #/hr	JUICE CANS/hr	P&P lbm/hr	MONEY $/hr
INFLOW	500	1000	0	0	160
PRODUCED	0	0	140	70	0
OUTFLOW	350	0	150	50	250
STORED	150	300	-10	20	-90
DESTROYED	0	700	0	0	0

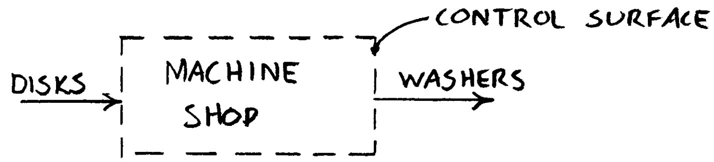
B. NO. THE PLANT IS RUNNING OUT OF JUICE CANS, COLLECTING MASS, AND LOSING MONEY. EVENTUALLY THE PLANT WILL STOP FUNCTIONING.

C. NO, BECAUSE THE P&P AND JUICE CANNOT BE FORMED BACK INTO AN ORANGE, JUST AS ONE CANNOT UNCOOK A STEAK OR UNSCRAMBLE AN EGG.

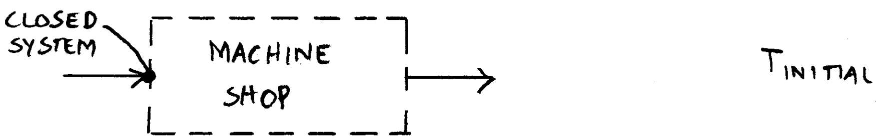
Problem 1.20

B: Quantity Units	Disks #	Washers #	Centers #	Mass g
Inflow	1000	0	0	2000
Produced	0	800	800	0
Outflow	0	1000	0	1500
Stored	200	−200	800	500
Destroyed	800	0	0	0

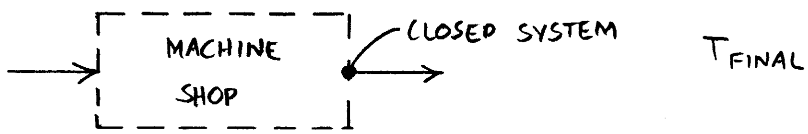
A:



C:



D:



E: Quantity Units	Disks #	Washers #	Centers #	Mass g
Inflow	1	0	0	2
Produced	0	0.8	0.8	0
Outflow	0	1	0	1.5
Stored	0	−0.2	1	0.2
Destroyed	1	0	0	0

Problem 1.21

Quantity Units	Mass lbm	Apples #	Sauce lbm
Inflow	460	100	0
Produced	0	0	23
Outflow	419	18	0
Stored	41	36	23
Destroyed	0	46	0

PROBLEM 1.22

PROPERTY: A QUANTIFIABLE MACROSCOPIC CHARACTERISTIC OF A SYSTEM.

STATE: DEFINED BY THE VALUES OF ALL THE PROPERTIES OF THE SYSTEM.

PROCESS: WHEN A SYSTEM MOVES FROM ONE STATE TO ANOTHER.

EACH OF THESE THREE TERMS BUILDS ON THE PREVIOUS TERM. STATES ARE DEFINED BY PROPERTIES, AND PROCESSES ARE DEFINED BY STATES.

PROBLEM 1.23

DEVICE	WORKING FLUID
• AIR CONDITIONER	• REFRIGERANT
• INTERNAL COMBUSTION ENGINE	• AIR (APPROXIMATION. IN REALITY THIS IS NOT A CYCLE SINCE THE AIR NEVER RETURNS TO ITS ORIGINAL STATE)
• RERIGERATOR	• REFRIGERANT
• STEAM POWER PLANT	• WATER

PROBLEM 1.24

IN A SYSTEM PROCESS, THE CONTROL VOLUME CHANGES IN SUCH A WAY THAT ITS ENTIRE CONTENTS CHANGES TO A NEW STATE. IN A FLOW PROCESS, MASS IS ENTERING THE CONTROL VOLUME AT ONE STATE AND LEAVING THE CONTROL VOLUME AT A DIFFERENT STATE.

PROBLEM 1.25

THERMAL EQUILIBRIUM:
- UNIFORM TEMPERATURE
- SAME TEMPERATURE AS SURROUNDINGS

MECHANICAL EQUILIBRIUM:
- UNIFORM PRESSURE
- NO UNBALANCED FORCES

PHASE EQUILIBRIUM:
- AMOUNTS OF SUBSTANCES IN EACH PHASE REMAIN CONSTANT WITH TIME.

PROBLEM 1.26

A QUASI-STATIC OR QUASI EQUILIBRIUM PROCESS IS ONE THAT OCCURS SLOWLY ENOUGH THAT AT ANY MOMENT IT IS VERY CLOSE TO THERMODYNAMIC EQUILIBRIUM, CLOSE ENOUGH THAT THE DIFFERENCE FROM EQUILIBRIUM CAN BE NEGLECTED. AN EXAMPLE MIGHT BE A POT OF WATER HEATING ON A STOVE. AN EXAMPLE OF A NON-QUASI-EQUILIBRIUM PROCESS WOULD BE THE COMBUSTION PROCESS IN AN AUTOMOBILE ENGINE.

PROBLEM 1.27

LOCAL EQUILIBRIUM REFERS TO A SMALL VOLUME dV WHICH IS SMALL ENOUGH THAT VARIATIONS IN PROPERTIES WITHIN IT ARE SMALL, BUT IS LARGE ENOUGH TO HAVE A LARGE NUMBER OF MOLECULES WHICH INTERACT WITH AN IMAGINARY SENSOR WITHIN dV MORE RAPIDLY THAN MACROSCOPIC CHANGES OCCUR. THIS IS IMPORTANT BECAUSE IT ALLOWS SYSTEMS WHOSE PROPERTIES VARY IN SPACE AND TIME TO BE ANALYZED USING THE DEFINITIONS OF THERMODYNAMIC PROPERTIES AND PROPERTY RELATIONSHIPS.

PROBLEM 1.28

IN A LAMINAR FLOW, THE VELOCITY AT A GIVEN POINT IS PREDICTABLE AND IS CONSTANT IN A STEADY FLOW. IN A TURBULENT FLOW, THE VELOCITY AT A GIVEN POINT EXPERIENCES RANDOM FLUCTUATIONS. THIS CREATES EDDIES, WHICH ARE THE MOST PROMINENT CHARACTERISTIC OF TURBULENT FLOWS.

PROBLEM 1.29

$$\text{WEIGHT IN NEWTONS} = \text{WEIGHT IN POUNDS} \times \left(\frac{4.44822\ \text{N}}{1\ \text{lbf}}\right)$$

$$\underline{160\ \text{lbf}} = 160\ \text{lbf}\left(\frac{4.44822\ \text{N}}{1\ \text{lbf}}\right) = \underline{712\ \text{N}}$$

MASS IN lbm IS NUMERICALLY EQUAL TO WEIGHT IN lbf ASSUMING THE ACCELERATION DUE TO GRAVITY IS 1g. $\underline{160\ \text{lbm}}$

$$W = mg \Rightarrow m = \frac{W}{g} \qquad m_{slug} = \frac{160\ \text{lbm}}{32.17\ \frac{\text{ft}}{\text{s}^2}} = \underline{4.97\ \text{slug}}$$

$$m_{kg} = \frac{712\ \text{N}}{9.81\ \frac{\text{m}}{\text{s}^2}} = \underline{72.6\ \text{kg}}$$

PROBLEM 1.30

MASSES DO NOT CHANGE WITH GRAVITATIONAL FIELD, SO IT IS STILL

$\underline{4.97 \text{ SLUG}} = \underline{72.6 \text{ kg}} = \underline{160 \text{ lbm}}$

$F = ma \qquad F_N = (72.6 \text{ kg})(3.71 \text{ m/s}^2) = \underline{269 \text{ N}}$

$F_{lbf} = (4.97 \text{ SLUG})(3.71 \text{ m/s}^2)(3.28084 \text{ ft/m}) = \underline{60.5 \text{ lbf}}$

PROBLEM 1.31

$$\left(86{,}000 \frac{\text{BTU}}{\text{hr}}\right)\left(\frac{63.825 \text{ kJ}}{\text{BTU}}\right)\left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) = \boxed{25.2 \text{ kW}}$$

$$(25.2 \text{ kW})\left(\frac{1000 \text{ W}}{\text{kW}}\right)\left(\frac{1 \text{ BULB}}{100 \text{ W}}\right) = \boxed{252 \text{ BULBS}}$$

PROBLEM 1.32

Known: Volume, power, torque, distance, speed (US units)

Find: Same quantities in SI units

Analysis: Apply conversion factors at front of book

A. $389\ in^3 = ?\ m^3$

$$389\ (in)^3 \left[\frac{1\ (m)^3}{(39.370)^3\ in^3}\right] = 0.006375\ m^3$$

$$\text{or}\quad 0.006375\ m^3 \left[\frac{1000\ \ell}{m^3}\right] = 6.375\ \ell$$

B. $348\ HP = ?\ W$

$$348\ HP \left[\frac{1\ W}{1.341 \cdot 10^{-3}\ HP}\right] = 259{,}500\ W$$

$$\text{or}\quad 259.5\ kW$$

C. $428\ lb_f\text{-}ft = ?\ N\text{-}m$

$$428\ lb_f\text{-}ft \left[\frac{1\ m}{3.2808\ ft}\right]\left[\frac{1\ N}{0.224809\ lb_f}\right]$$

$$= 580\ N\text{-}m$$

Prob 1.32 – cont'd

D. 1/4 mi = ? km

$$0.25\,mi\left[\frac{5280\,ft}{mi}\right]\left[\frac{1\,m}{3.2808\,ft}\right]\left[\frac{1\,km}{1000\,m}\right]$$

$$= 0.402\,km$$

E. 95 mph = ? m/s

$$95\frac{mi}{hr}\left[\frac{5280\,ft}{mi}\right]\left[\frac{1\,m}{3.2808\,ft}\right]\left[\frac{1\,hr}{3600\,s}\right]$$

$$= 42.5\,m/s$$

or, more directly,

$$95\,mph\left[\frac{1\,m/s}{2.237\,mph}\right] = 42.5\,m/s$$

COMMENTS: This problem illustrates the use of the conversion factors provided inside the front cover and the application of the factor-label method ~~to keep~~ track of unit cancellations. Note the use of square brackets [—] to denote unity (≡ 1). A modern muscle car is the Chrysler/Dodge Viper GTS having the following specs.: 7.99 l, 450 HP, 490 lbf-ft, and 12.2 s @ 118 mph.

PROBLEM 1.33

Known: SO_2 emission factor in U.S. units

Find: Factor in g/kJ

Analysis: Apply conversion factors at front of book

$$0.80 \frac{lb_m}{10^6\ BTU}\left[\frac{kg}{2.2046\ lb_m}\right]\left[\frac{1000g}{kg}\right]\left[\frac{0.9478\ BTU}{kJ}\right]$$

$$= 3.44 \cdot 10^{-4} \frac{g}{kW} \quad \text{or} \quad 0.344\ g/MW$$

Comment: In the power generation community, 10^6 BTU is frequently denoted MMBTU, i.e., a thousand Thousand BTUs. This use of "M" can result in confusion.

PROBLEM 1.34

Known: NAAQS for Pb in $\mu g/m^3$

Find: Pb standard in lb_m/ft^3

Analysis:

$$1.5 \frac{\mu g}{m^3} \left[\frac{g}{10^6 \mu g}\right]\left[\frac{2.2046\ lb_m}{10^3 g}\right]\left[\frac{1 m^3}{(3.2808)^3 ft^3}\right]$$

$$= 9.36 \cdot 10^{-11}\ lb_m/ft^3$$

Comment: Clearly, $\mu g/m^3$ is more convenient units than the lb_m/ft^3 units.

PROBLEM 1.35

Known: Mass of moon rocks, g_{moon}, g_{Earth}

Find: Weight of moon rocks on earth & moon; mass in lb_m units

Analysis: Apply $W = mg$:

a) Moon

$$W_M = 111 \text{ kg } 1.62 \frac{m}{s^2} \left[\frac{1N}{kg - m/s^2}\right] = 179.8 \text{ N}$$

$$W_m = 178.9 \text{ N} \left[\frac{0.224809 \text{ lb}_f}{N}\right] = 40.4 \text{ lb}_f$$

b) $$W_E = 111 \text{ kg } 9.807 \frac{m}{s^2} \left[\frac{1N}{kg - m/s^2}\right] = 1088 \text{ N}$$

$$= 244.7 \text{ lb}_f$$

c) $$m = \frac{F}{g_E} = \left\{\frac{244.7 \text{ lb}_f}{9.807 \frac{m}{s^2}\left[\frac{3.2808 \text{ ft}}{m}\right]}\right\}$$

$$\cdot \left[\frac{32.174 \text{ lb}_m}{\frac{lb_f}{ft/s^2}}\right] = 244.7 \text{ lb}_m$$

Comment: The formal determination of the mass in lb_m agrees with our knowledge that, on Earth, lb_m and lb_f are numerically equal.

PROBLEM 1.3 6

pi = 3.14159

Location	Latitude (deg)	Altitude (m)	g (m/s^2)	Mass (kg)	Weight (N)	Weight (lb_f)
Kilimanjaro	3.07	5895	9.76231	54	527.2	118.51
Aconcagua	32	6962	9.77335	54	527.8	118.65
Denali	63	6194	9.80227	54	529.3	119.00
Sea level	45	0	9.80616	54	529.5	119.04

Comment: Note that the latitude must be expressed in radians to evaluate sin(theta).

PROBLEM 1.37

Known:

Location	$g\ (m/s^2)$
Jupiter	23.12
Pluto	0.72
Sun	273.98

Find: Your weight (N, lb_f)

Assume: $m = 140\ lb_m$ or $63.5\ kg$

Analysis:

Jupiter: $W = mg$

$$= 63.5\ kg\ 23.12\ \frac{m}{s^2}\left[\frac{1\ N}{kg\text{-}m/s^2}\right]$$

$$= 1468.1\ N$$

or $1468.1\ N\left[\frac{0.224809\ lb_f}{N}\right] = 330\ lb_f$

Pluto: $W = 63.5(0.72) = 45.7\ N$

or $= 10.3\ lb_f$

Sun: $W = 63.5\ (273.98) = 17{,}398\ N$

or $3911\ lb_f$!

Comment: At the solar surface, molecules would dissociate/ionize.

PROBLEM 1.38

Known: $\dot{E}_{in} = 4845 \cdot 10^6$ BTU/hr (coal)
$\dot{E}_{out} = 500$ MW (electricity)

Find: Overall powerplant efficiency

Analysis:

$$\eta \equiv \frac{\dot{E}_{out}}{\dot{E}_{in}}$$

$$\eta = \frac{500 \cdot 10^6 \, W}{4845 \cdot 10^6 \, \frac{BTU}{hr} \left[\frac{1 \, W}{3.41214 \, BTU/hr} \right]}$$

$= 0.352$ (dim'less)

Comments: About 35% of the energy stored in the coal is converted to electricity - the useful output. The bulk of the remainder is rejected as heat to the surroundings and as thermal energy carried with the exhaust stack gases.

PROBLEM 1.39

Known: Two measures of pressure: Pa and psi

Find: Conversion factor

Analysis:

$$1\ \text{Pa}\left[\frac{N/m^2}{1\ \text{Pa}}\right]\left[\frac{0.224809\ lb_f}{N}\right]\left[\frac{1\ m^2}{(39.370)^2\ in^2}\right]$$

$$= 1.4504 \cdot 10^{-4}\ \frac{lb_f}{in^2}\ \text{or psi}$$

Comment: This value agrees with the conversion factor presented at the front of the book.

PROBLEM 1.40

Known: SSME specifications (U.S. customary)

Find: specifications in SI units

Analysis: Apply various conversion factors -

Thrust: $408{,}750\ lb_f \left[\frac{1\ N}{0.224809\ lb_f}\right] = 1.8182 \cdot 10^6\ N$

$512{,}300\ lb_f \left[\frac{1N}{0.224809\ lb_f}\right] = 2.2788 \cdot 10^6\ N$

Pressures:

$6{,}872\ psi \left[\frac{1\ Pa}{1.4504 \cdot 10^{-4}\ psi}\right] = 4.738 \cdot 10^7\ Pa$

or 47.38 MPa

$7{,}936\ psi \left[\quad\right] = 54.71\ MPa$

$3{,}277\ psi \left[\quad\right] = 22.59\ MPa$

Flowrates:

$160\ \frac{lb_m}{s} \left[\frac{1\ kg}{2.2046\ lb_m}\right] = 72.6\ kg/s$

$970\ \frac{lb_m}{s} \left[\quad\right] = 440\ kg/s$

PROBLEM 1.40 - Continued

Power:

$$74{,}928\ hp\left[\frac{W}{1.341\cdot 10^{-3}\ hp}\right] = 5.58747\cdot 10^{7}\ W$$

or 55.8747 MW

$$28{,}229\ hp\left[\quad\right] = 2.10507\cdot 10^{7}\ W$$

or 21.0507 MW

Weight:

$$7000\ lb_f\left[\frac{1\ N}{0.224809\ lb_f}\right] = 31{,}140\ N$$

Dimensions:

$$14\ ft\left[\frac{1\ m}{3.2808\ ft}\right] = 4.27\ m$$

$$7.5\ ft\left[\quad\right] = 2.29\ m$$

Comments: This problem presents many quantities associated with thermal-fluids engineering and offers a lot of practice with units conversion.

Note the huge values of performance measures for this "small" engine.

Problem 1.41

$F = ma$, or in this case $W = mg$

For numerically equal weight (N) and mass (kg), $\frac{W}{m} = 1$

$$\boxed{\frac{W}{m} = g = 1\ m/s^2}$$

Problem 1.42

$F = ma \Rightarrow 200\ lbf = m(50\ ft/s) \Rightarrow m = 4\ slug = \boxed{129\ lbm}$

Problem 1.43

$F = ma \Rightarrow 1000N = m(15\ m/s^2) \Rightarrow m = \boxed{66.7\ kg}$

Problem 1.44

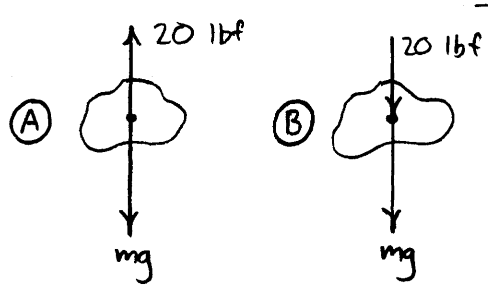
$$50\ lbf\left(\frac{4.44822\ N}{lbf}\right) = 222.4\ N$$

$F = ma \Rightarrow 222.4\ N = (50\ kg)\,a \Rightarrow \boxed{a = 4.45\ m/s^2}$

Problem 1.45

$F = ma = (92.99\ kg)(1.676\ m/s^2) \Rightarrow \boxed{F = 156\ N}$

Problem 1.46



$5\ lbm = 0.1554\ slug$

$$\Sigma F = ma \Rightarrow \frac{\Sigma F}{m} = a = \frac{mg \pm 20\,lbf}{m} = a$$

$$A: \frac{(0.1554)(30) - 20}{0.1554} = \boxed{a_A = 98.7\ \frac{ft}{s^2}\ \text{UP}}$$

$$B: \frac{(0.1554)(30) + 20}{0.1554} = \boxed{a_B = 159\ \frac{ft}{s^2}\ \text{DOWN}}$$

PROBLEM 1.47

DENSITY: $$120\ \frac{\text{lbm}}{\text{ft}^3}\left[\frac{0.45359\ \text{kg}}{\text{lbm}}\right]\left[\frac{1\ \text{ft}^3}{0.02832\ \text{m}^3}\right] = \boxed{1920\ \frac{\text{kg}}{\text{m}^3}}$$

THERMAL CONDUCTIVITY: $$170\ \frac{\text{BTU}}{\text{hr}\cdot\text{ft}\cdot\text{F}}\left[\frac{1\ \text{J}}{9.47817\times10^{-4}\ \text{BTU}}\right]\left[\frac{1\ \text{ft}}{0.3048\ \text{m}}\right]\left[\frac{1\ \text{F}}{5/9\ \text{K}}\right]\left[\frac{1\ \text{hr}}{3600\ \text{s}}\right]\left[\frac{1\ \text{W}}{1\ \text{J/s}}\right] =$$

$$= \boxed{294\ \frac{\text{W}}{\text{m}\cdot\text{K}}}$$

CONVECTIVE HEAT TRANSFER COEFFICIENT: $$211\ \frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot\text{F}}\left[\frac{1\ \text{J}}{9.47817\times10^{-4}\ \text{BTU}}\right]\left[\frac{1\ \text{ft}^2}{0.0929\ \text{m}^2}\right]\left[\frac{1\ \text{F}}{5/9\ \text{K}}\right]\left[\frac{1\ \text{hr}}{3600\ \text{s}}\right]\left[\frac{1\ \text{W}}{1\ \text{J/s}}\right] =$$

$$= \boxed{1200\ \frac{\text{W}}{\text{m}^2\cdot\text{K}}}$$

SPECIFIC HEAT: $$175\ \frac{\text{BTU}}{\text{lbm}\cdot\text{F}}\left[\frac{1\ \text{J/kg}\cdot\text{K}}{2.3886\times10^{-4}\ \text{BTU/lbm}\cdot\text{F}}\right] = 732{,}646\ \frac{\text{J}}{\text{kg}\cdot\text{K}}\ \text{OR}\ \boxed{733\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}}$$

VISCOSITY: $$20\ \text{CENTIPOISE}\left[\frac{1\times10^{-3}\ \text{Pa}\cdot\text{s}}{\text{CENTIPOISE}}\right] = \boxed{2\times10^{-2}\ \text{Pa}\cdot\text{s}}$$

VISCOSITY: $$77\ \frac{\text{lbf}\cdot\text{s}}{\text{ft}^2}\left[\frac{1\ \text{N}}{0.22481\ \text{lbf}}\right]\left[\frac{10.76391\ \text{ft}^2}{1\ \text{m}^2}\right]\left[\frac{1\ \text{Pa}}{1\ \text{N/m}^2}\right] = \boxed{3690\ \text{Pa}\cdot\text{s}}$$

KINEMATIC VISCOSITY: $$3.0\ \frac{\text{ft}^2}{\text{s}}\left[\frac{1\ \text{m}^2}{10.76391\ \text{ft}^2}\right] = \boxed{0.279\ \frac{\text{m}^2}{\text{s}}}$$

STEFAN-BOLTZMANN CONSTANT: $$0.1713\times10^{-8}\ \frac{\text{BTU}}{\text{ft}^2\cdot\text{hr}\cdot\text{R}^4}\left[\frac{1\ \text{J}}{9.478\times10^{-4}\ \text{BTU}}\right]\left[\frac{1\ \text{ft}^2}{0.0929\ \text{m}^2}\right]\left[\frac{1\ \text{hr}}{3600\ \text{s}}\right]\left[\frac{1\ \text{R}}{5/9\ \text{K}}\right]^4\left[\frac{1\ \text{W}}{1\ \text{J/s}}\right] =$$

$$= \boxed{5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}}$$

ACCELERATION: $$12.0\ \text{ft/s}^2\left[\frac{1\ \text{m}}{3.28084\ \text{ft}}\right] = \boxed{3.66\ \text{m/s}^2}$$

PROBLEM 1.46

B = 8	cm		pi =	3.14159
S = 7	cm			
L/a = 3.4	dim'less	RPM =		2000
CR = 7.5	dim'less	rev/s =		33.333333

V_{disp} = 351.85808 cm^3

V_{TC} = 54.13201231 cm^3

Theta (rad)	Theta (deg)	V (theta) (cm^3)	dV/dt (cm^3/s)
0	0	54.13201231	0
0.174532778	10	57.5854071	8254.005129
0.349065556	20	67.77594368	16102.98373
0.523598333	30	84.20531783	23167.43701
0.698131111	40	106.0784231	29118.7063
0.872663889	50	132.355918	33703.11544
1.047196667	60	161.8256851	36762.66102
1.221729444	70	193.1888383	38248.51775
1.396262222	80	225.1524502	38222.95716
1.570795	90	256.5178439	36846.4759
1.745327778	100	286.251938	34350.43351
1.919860556	110	313.5313377	31000.20704
2.094393333	120	337.7546518	27057.3119
2.268926111	130	358.5258426	22748.97014
2.443458889	140	375.6172522	18250.22658
2.617991667	150	388.9232581	13679.06527
2.792524444	160	398.4143052	9101.528967
2.967057222	170	404.0979237	4542.694891
3.14159	180	405.9900923	0.069017924
3.316122778	190	404.0980388	-4542.556574
3.490655556	200	398.4145358	-9101.390015
3.665188333	210	388.9236048	-13678.92596
3.839721111	220	375.6177147	-18250.08823
4.014253889	230	358.5264191	-22748.83549
4.188786667	240	337.7553374	-27057.18542
4.363319444	250	313.5321232	-31000.09489
4.537852222	260	286.2528085	-34350.34326
4.712385	270	256.5187776	-36846.41572
4.886917778	280	225.1534188	-38222.93481
5.061450556	290	193.1898075	-38248.53937
5.235983333	300	161.8266167	-36762.73009
5.410516111	310	132.356772	-33703.23219
5.585048889	320	106.079161	-29118.86754
5.759581667	330	84.20590489	-23167.6364
5.934114444	340	67.77635173	-16103.2123
6.108647222	350	57.58561626	-8254.251972
6.28318	360	54.13201231	-0.253065722

PROBLEM 1.48 ~ Continued