1.A-1

The U.S. Government Mint produces currency for circulation and takes old currency out of circulation and destroys it. Over the course of 1 month, the mint creates D_{gen} = 5.2 million dollars and destroys D_{des} = 4.2 million dollars. The total amount of currency that was removed from circulation and brought to the mint is D_{in} = 5.3 million dollars. The total amount of currency that leaves the mint and is put into circulation is D_{out} = 3.7 million dollars.

a.) What is the total amount of currency stored at the mint during the month (ΔD)?

The given information is entered in EES:

```
$UnitSystem SI MASS RAD PA  K J
$TABSTOPS   0.2 0.4 0.6 0.8 3.5 in

"Inputs"
D_gen=5.2e6 [$]                         "currently that is produced"
D_des=4.2e6 [$]                         "currency that is destroyed"
D_in=5.3e6 [$]                          "currency that enters the mint"
D_out=3.7e6 [$]                         "currency that leaves the mint"
```

Notice that the units of each of the inputs are indicated in square brackets immediately after the associated number; this is a convenient method of assigning units, but it only works for constants.

Figure 1 illustrates the mint and shows the boundaries of a system that I have defined which encompasses the mint; the various flows of currency are indicated.

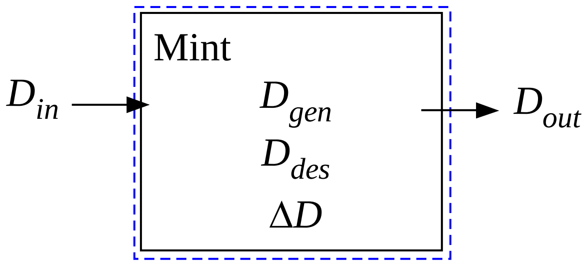


Figure 1: Mint and a system defined that encompasses the mint

The general balance equation is:

$$IN + PRODUCED = OUT + DESTROYED + STORED \tag{1}$$

The balance on the control volume shown in Figure 1 (on an increment basis since we are dealing with a finite period of time, 1 month) leads to:

$$D_{in} + D_{gen} = D_{out} + D_{des} + \Delta D \tag{2}$$

Solving for the amount of currency that is stored:

$$\Delta D = D_{in} + D_{gen} - D_{out} - D_{des} \tag{3}$$

```
DELTAD=D_in+D_gen-D_out-D_des                    "stored currency over the month"
```

which leads to ΔD = 2.6 million dollars.

At some instant in time, the mint machinery is generating new currency at a rate of $\dot{D}_{gen}$ = 1000 \$/s and destroying old currency at a rate of $\dot{D}_{des}$ = 800 \$/s. The rate that currency is entering the mint is $\dot{D}_{in}$ = 900 \$/s and currency is leaving the mint at a rate of $\dot{D}_{out}$ = 900 \$/s.

b.) Is the mint operating at steady-state? If not, then what is the rate of storage within the mint ($\frac{dD}{dt}$)?

The inputs are entered in EES:

```
D_dot_gen=1000 [$/s]                             "rate that currency is being produced"
D_dot_des=800 [$/s]                              "rate that currency is being destroyed"
D_dot_in=900 [$/s]                               "rate of currency inflow"
D_dot_out=900 [$/s]                              "rate of currency outflow"
```

The same balance equation applies:

$$IN + PRODUCED = OUT + DESTROYED + STORED \tag{4}$$

However, this time the balance is written on a rate basis:

$$\dot{D}_{in} + \dot{D}_{gen} = \dot{D}_{out} + \dot{D}_{des} + \frac{dD}{dt} \tag{5}$$

Solving for the rate of currency storage:

$$\frac{dD}{dt} = \dot{D}_{out} + \dot{D}_{des} - \dot{D}_{in} - \dot{D}_{gen} \tag{6}$$

```
dDdt=D_dot_out+D_dot_des-D_dot_in-D_dot_gen      "rate of currency storage"
```

which leads to $\frac{dD}{dt}$ = 200 \$/s. The mint is not operating at steady state because the amount of currency in the mint is changing with time.

1.A-2

A mixing tank in a chemical processing plant is shown in Figure 1.A-2.

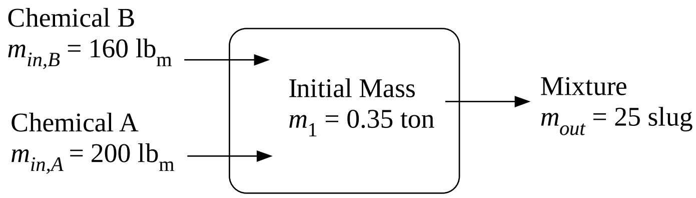


Figure 1.A-2: Mixing tank in a chemical processing plant.

Two chemicals enter the tank, mix, and leave. Initially, the tank contains m_1 = 0.35 tons. Over an hour of operation, $m_{in,A}$ = 200 kg of chemical A enter and $m_{in,B}$ = 160 lb_m of chemical B enter while m_{out} = 25 slug of the mixture leaves.

a.) Sketch the system that you will use to carry out a mass balance for this problem. Is your system open or closed?

Figure 2 illustrates an open system that includes the internal volume of the tank. The mass balance terms are also shown.

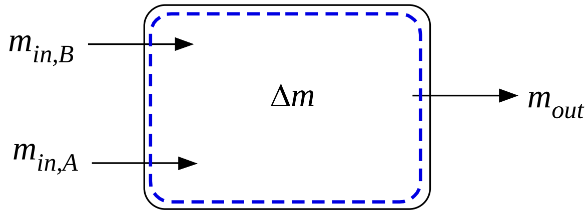


Figure 2: System used to do a mass balance.

b.) What is the final mass in the tank (ton)?

The inputs are entered in EES and converted to base SI units (kg).

```
$UnitSystem SI MASS RAD PA  K J
$TABSTOPS   0.2 0.4 0.6 0.8 3.5 in

"Inputs"
m_1 = 0.35 [ton]*convert(ton,kg)                "initial mass"
m_in_A=200 [kg]                                 "mass of chemical A that enters"
m_in_B=160 [lbm]*convert(lbm,kg)                "mass of chemical B that enters"
m_out=25 [slug]*convert(slug,kg)                "mass of mix that leaves"
```

A general balance equation is:

IN + PRODUCED = DESTROYED + OUT + STORED

Mass can neither be produced or destroyed so our mass balance can be simplified to:

IN = OUT + STORED

or, for the system in Figure 2:

$$m_{in,A} + m_{in,B} = m_{out} + \Delta m$$

```
m_in_A+m_in_B=m_out+DELTAm          "mass balance"
```

which leads to Δm = -92.3 kg (the tank *loses* 92.3 kg of mass). The mass storage term is used to compute the final mass:

$$\Delta m = m_2 - m_1$$

```
DELTAM=m_2-m_1       "final mass"
```

which leads to m_2 = 225.2 kg. This is converted to ton in order to satisfy the problem statement:

```
m_2_ton=m_2*convert(kg,ton)                                  "in ton"
```

which leads to m_2 = 0.248 ton.

c.) Is the tank operating at steady state?

No, the mass storage term is not zero so the system is changing in time.

1.A-3

Figure 1.A-3 illustrates a company that manufactures gadgets.

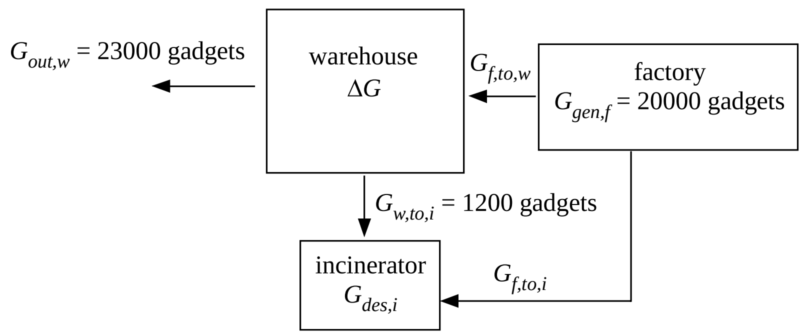


Figure 1.A-3: A company manufacturing gadgets.

Initially we will analyze the company on an incremental basis; the increment of time for the analysis will be one day. Raw materials enter the factory where $G_{gen,f}$ = 20,000 gadgets are produced during the day. The functional gadgets are sent to the warehouse building ($G_{f,to,w}$) and the defective gadgets are sent to the incinerator to be destroyed ($G_{f,to,i}$). Approximately 5% of the gadgets produced in the factory are found to be defective. Neither the factory nor the incinerator can store gadgets (i.e., they operate always at steady state). Gadgets can be stored in the warehouse. The number of gadgets that are shipped from the warehouse during the day is $G_{out,w}$ = 23,000 gadgets. Every day, $G_{w,to,i}$ = 1200 gadgets that are old (beyond their expiration date) are pulled from the warehouse shelves and sent to the incinerator to be destroyed.

a.) Determine the number of gadgets destroyed in the incinerator during the day, $G_{des,i}$.

The inputs are entered in EES:

```
G_gen_f=20000                 "amount of gadgets produced in factory"
G_f_to_i=0.05*G_gen_f         "gadgets sent from factory to incinerator"
G_out_w=23000                 "gadgets shipped out"
G_w_to_i=1200                 "gadgets sent from warehouse to incinerator"
```

A general gadget balance is:

$$\text{IN} + \text{PRODUCED} = \text{DESTROYED} + \text{OUT} + \text{STORED}$$

A gadget balance on the factory is shown in Figure 2 and leads to:

$$G_{gen,f} = G_{f,to,w} + G_{f,to,i}$$

Notice that the stored term is zero (the factory is at steady state), the destroyed term is zero (gadgets are produced, not destroyed in the factory), and the in term is zero (gadgets flow out of, not into the factory).

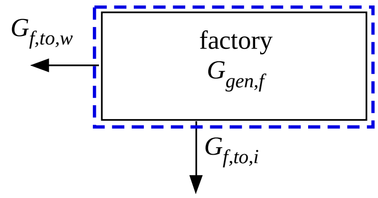


Figure 2: Gadget balance on the factory.

```
G_gen_f=G_f_to_w+G_f_to_i                    "gadget balance on the factory"
```

which leads to $G_{f,to,w}$ = 19,000 gadgets are sent to the warehouse from the factory each day. A gadget balance on the incinerator is shown in Figure 3 and leads to:

$$G_{w,to,i} + G_{f,to,i} = G_{des,i}$$

Notice that the stored term is again zero (the incinerator is at steady state), the generated term is zero (gadgets are destroyed, not produced in the incinerator), and the out term is zero (gadgets flow into, not out of the factory).

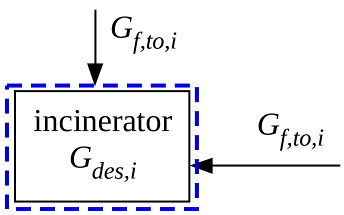


Figure 3: Gadget balance on the incinerator.

```
G_w_to_i+G_f_to_i=G_des_i                    "gadget balance on the incinerator"
```

which leads to $G_{des,i}$ = 2200 gadgets are destroyed in the incinerator during the day.

b.) Is the warehouse operating at steady state? If not then determine the storage of gadgets in the warehouse during the day, ΔG_w.

A gadget balance on the warehouse is shown in Figure 4 and leads to:

$$G_{f,to,w} = G_{w,to,i} + G_{out,w} + \Delta G_w$$

Notice that the stored term is not necessarily zero because the warehouse may not be at steady state. The generated and destroyed terms are zero (gadgets are neither destroyed nor produced in the warehouse).

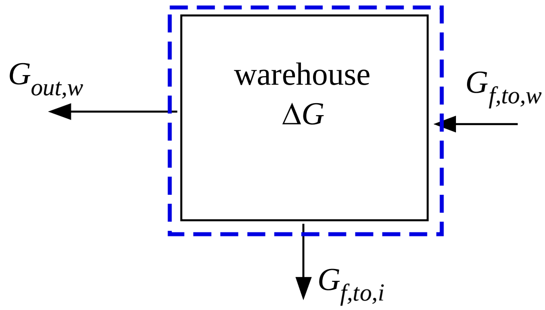


Figure 4: Gadget balance on the warehouse.

```
G_f_to_w=G_w_to_i+G_out_w+DeltaG_w          "gadget balance on the warehouse"
```

which leads to ΔG_w = -5200 gadgets are stored in the warehouse during the day; this means that the number of gadgets in the warehouse decreased during the day.

Let's next analyze the company on a rate basis. At a particular instant of time, the rate at which gadgets are shipped from the warehouse is $\dot{G}_{out,w}$ = 1500 gadgets/hr and the rate at which gadgets are being pulled off the warehouse shelves and sent to the incinerator is $\dot{G}_{w,to,i}$ = 50 gadgets/hr. Assume that the defect rate associated with gadgets produced in the factory remains at 5% (i.e., 5% of the gadgets produced by the factory are sent to the incinerator rather than the warehouse).

c.) Determine the rate at which gadgets must be produced in the factory and destroyed in the incinerator in order for the warehouse to operate at steady state (i.e., in order to maintain a constant inventory of gadgets).

The additional inputs are entered in EES:

```
G_dot_out_w=1500 [1/hr]          "gadget flow rate shipped out of warehouse"
G_dot_w_to_i=50 [1/hr]           "gadget flow rate from warehouse to incinerator"
```

A gadget balance on the warehouse (on a rate basis) is shown in Figure 5 and leads to:

$$\dot{G}_{f,to,w} = \dot{G}_{w,to,i} + \dot{G}_{out,w}$$

Notice that the stored term is zero because the warehouse is operating at steady state. The generated and destroyed terms are zero (gadgets are neither destroyed nor produced in the warehouse).

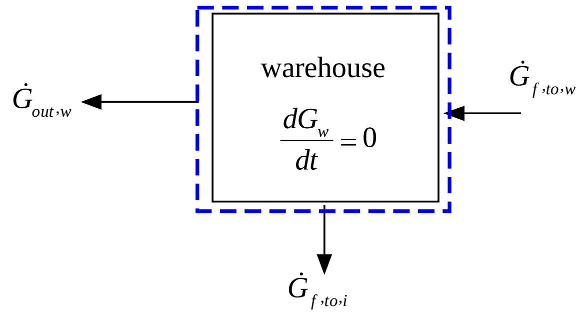


Figure 5: Gadget balance on the warehouse at steady state.

```
G_dot_f_to_w=G_dot_out_w+G_dot_w_to_i        "gadget balance on warehouse - steady state"
```

which leads to $\dot{G}_{f,to,w}$ = 1550 gadgets/hr must be transferred from the factory to the warehouse. According to the problem statement, 95% of the gadgets generated by the factory are good and are shipped to the warehouse; therefore:

$$\dot{G}_{f,to,w} = 0.95\,\dot{G}_{gen,f}$$

```
G_dot_f_to_w=0.95*G_dot_gen_f        "rate of gadget production required"
```

which leads to $\dot{G}_{gen,f}$ = 1632 gadgets/hr must be produced by the factory. The defective gadgets produced by the factory are sent to the incinerator:

$$\dot{G}_{f,to,i} = 0.05\,\dot{G}_{gen,f}$$

A gadget balance on the incinerator (on a rate basis) is shown in Figure 6 and leads to:

$$\dot{G}_{w,to,i} + \dot{G}_{f,to,i} = \dot{G}_{des,i}$$

Notice that the stored term is zero because the incinerator is operating at steady state.

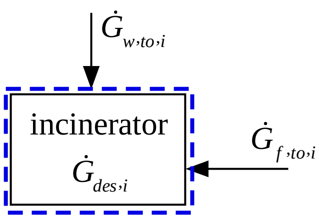


Figure 6: Gadget balance on the incinerator.

```
G_dot_f_to_i=0.05*G_dot_gen_f        "rate of defective gadgets sent from factory to incinerator"
G_dot_w_to_i+G_dot_f_to_i=G_dot_des_i        "rate of gadget destruction in the incinerator"
```

which leads to $\dot{G}_{des,i}$ = 131.6 gadgets/hr must be destroyed in the incinerator.

1.B-1

a.) Solve the equation $a/x + b + c\,x^2 = 1$ using EES with a = 1, b = 2, and c = 0.5.

Start EES and enter the specifications for a, b, and c and the equation.

```
a=1
b=2
c=0.05

a/x+b+c*x^2=1
```

Select Solve from the Calculate menu (or press F2). The Solution window should appear as shown in Figure 1. The solution is x = -0.9563.

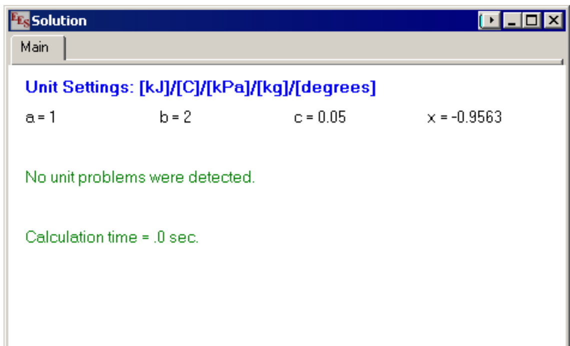


Figure 1: Solution window.

b.) Make a plot showing how the solution varies as the value of c changes from 0.1 to 10. Label your axes.

Comment out the equation that sets c.

```
{c=0.05}
```

Select New Parametric Table from the Tables menu. Click on variables c and x and add them to the list of variables in the table, as shown in Figure 2. Click OK.

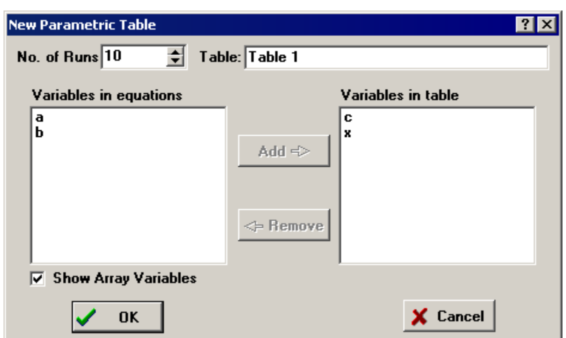


Figure 2: New Parametric Table dialog.

The values of *c* in the Parametric table can be automatically set by clicking on the triangular icon at the upper right of the c column header cell. Enter a first value of 0.1 and a last value of 10, as shown in Figure 3, and then click OK.

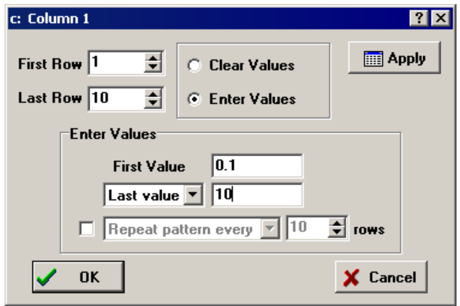


Figure 3: Alter values dialog.

Select Solve Table (or press F3) to calculate values of *x* for each value of *c*. The table should appear as shown in Figure 4 after the calculations are completed.

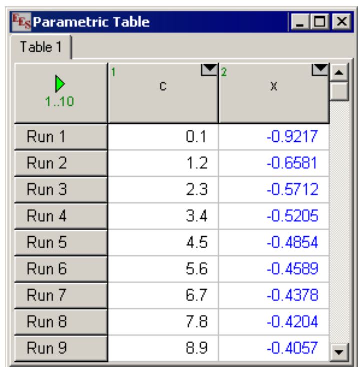

Parametric Table

Table 1

1..10	c	x
Run 1	0.1	-0.9217
Run 2	1.2	-0.6581
Run 3	2.3	-0.5712
Run 4	3.4	-0.5205
Run 5	4.5	-0.4854
Run 6	5.6	-0.4589
Run 7	6.7	-0.4378
Run 8	7.8	-0.4204
Run 9	8.9	-0.4057

Figure 4: Parametric table.

Select New Plot Window -> X-Y plot from the Plots menu. Click the Grid lines controls, as shown in Figure 5, if you wish to have grid lines appear.

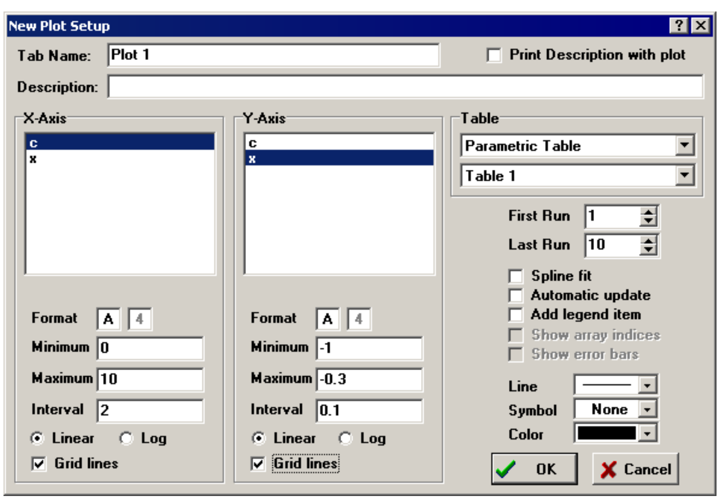


Figure 5: New Plot Setup dialog.

Click OK and the plot will appear as shown in Figure 6.

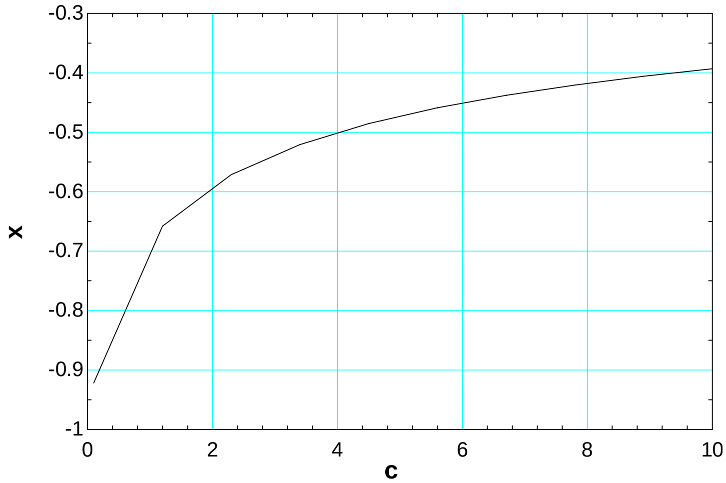


Figure 6: Plot.

The appearance of the plot can be improved by spline fitting the data. Right-click anywhere in the plot. The Modify Plot dialog will appear, as shown in Figure 7. Click the Cubic Spline option and then OK. The improved plot will appear as shown in Figure 8.

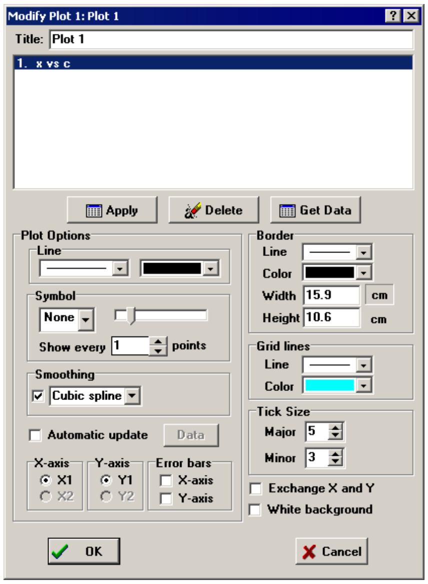


Figure 7: Modify Plot dialog.

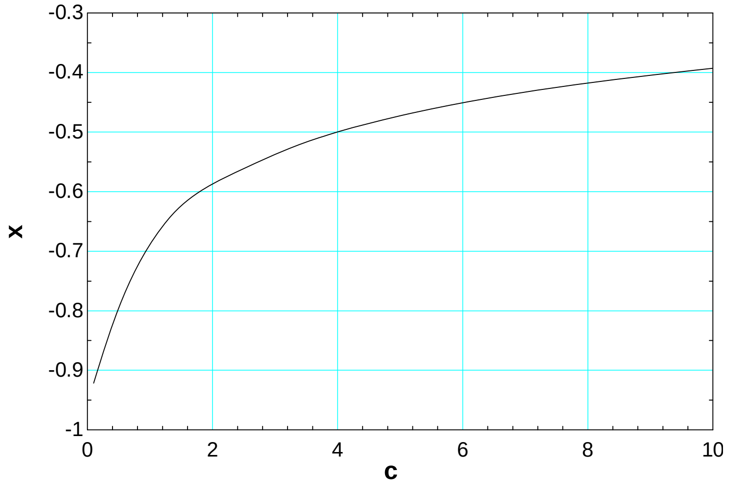


Figure 8: Plot with spline fit.

1.B-2

The Beattie-Bridgeman equation relates pressure (*P*), specific volume (*v*), and temperature (*T*) according to:

$$P = \frac{RT\left(1-\frac{c}{vT^3}\right)}{v^2}\left[v + B_0\left(1-\frac{b}{v}\right)\right] - \frac{A_0}{v^2}\left(1-\frac{a}{v}\right) \tag{1}$$

The parameters corresponding to carbon dioxide are a = 1.62129x10^{-3} m^3/kg, A_0 = 262.07 N-m^4/kg^2, b = 1.6444x10^{-3} m^3/kg, B_0 = 2.3811x10^{-3} m^3/kg, c = 1.4997x10^4 m^3-K^3/kg, and R = 188.9 J/kg-K.

a.) Determine the specific volume of carbon dioxide at a temperature of T = 350 K and a pressure of P = 10 MPa.

Enter the Beattie-Bridgeman equation of state and constants into EES. Include the unit specifications.

```
"Constants for the Beattie-Bridgeman Equation of State"
a=1.62129e-3 [m^3/kg]
A_0=262.07 [N-m^4/kg^2]
b=1.6444e-3 [m^3/kg]
B_0=2.3811e-3 [m^3/kg]
c=1.4997e4 [m^3-K^3/kg]
R=188.9 [J/kg-K]

P=R*T*(1-c/(v*T^3))/v^2*(v+B_0*(1-b/v))-A_0/v^2*(1-a/v)
```

Enter the temperature and pressure in K and Pa, respectively. Note that the convert function can be used to conveniently convert units as needed.

```
T=350 [K]                                              "temperature in K"
P=10 [MPa]*convert(MPa,Pa)     "pressure in Pa"
```

Solve the equations to obtain the solution window shown in Figure 1. The specific volume is computed, but a unit error may be displayed. Right click on the variable v in the Solution window and set the units in the resulting dialog, as shown in Figure 2.

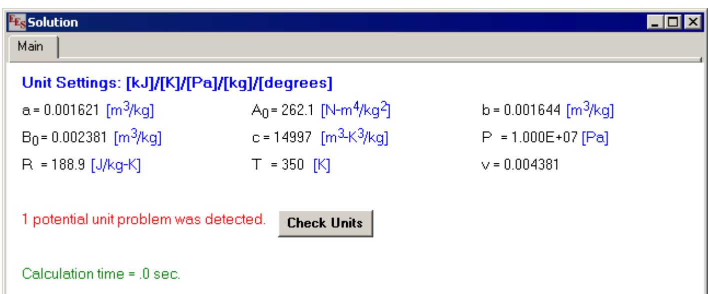


Figure 1: Solution window.

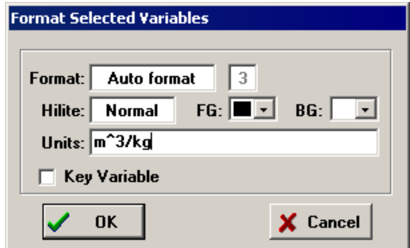


Figure 2: Set units for specific volume.

The Solution window should now show v = 0.004381 m^3/kg with no unit errors.

b.) Overlay on one plot the pressure (Pa) as a function of specific volume for two different temperatures, 350 K and 400 K, for specific volumes ranging between 0.01 m^3/kg and 1 m^3/kg. The plot should have log-log coordinates. Label the two isotherms and the axes, including units.

Comment out the equations that set the values of `P` and `T` since we will calculate pressure as a function of temperature and specific volume using a Parametric table.

```
{T=350 [K]                                    "temperature in K"}
{P=10 [MPa]*convert(MPa,Pa)                   "pressure in Pa"}
```

Select New Parametric Table from the Tables menu, as shown in Figure 3.

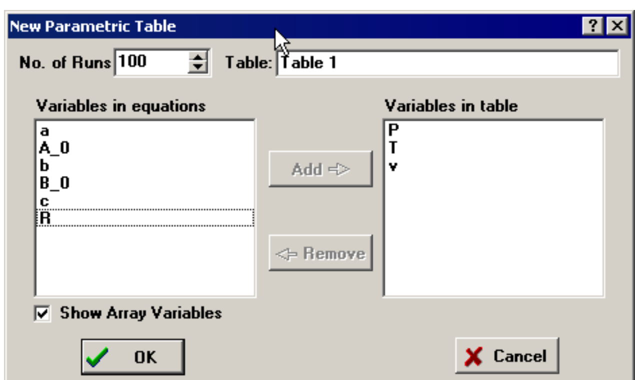


Figure 3: New Parametric Table.

Include P, T, and v in the table and use 100 runs. Fill the T column with 350 K for each row. The easiest way to do this is to click on the triangular icon at the upper right of the T-column header and select 350 K for the first and last values, as shown in Figure 4.

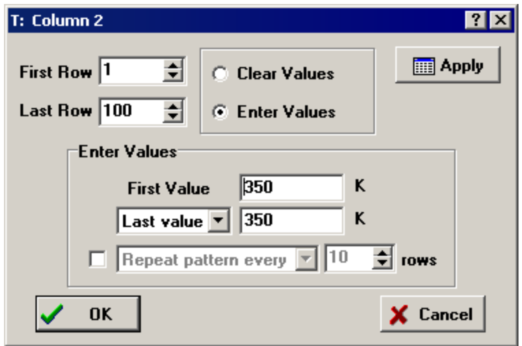


Figure 4: Set values for *T*.

We need to provide values for v between 0.01 and 1 m^3/kg, but it would be best to distribute them logarithmically for our eventual log-log plot. This can be done by setting each new value in the table to the product of the value in the previous row and a scaling factor. By trial, a suitable scaling factor is 1.05, as shown in Figure 5.

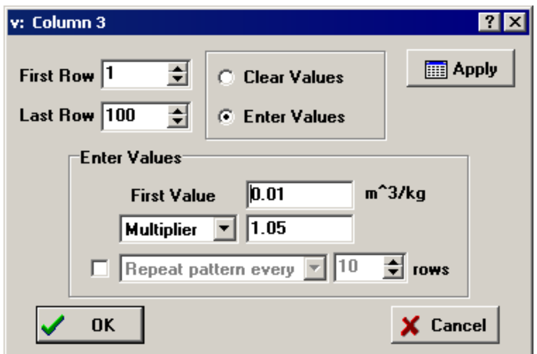


Figure 5: Set value of *v*.

Select Solve Table (or press F3) to solve for the pressure values in the table. Select New Plot Window -> X-Y Plot from the Plots menu, as shown in Figure 6. Choose to have v on the x-axis and P on the y-axis. Select log scales. Adjust the plot range for v to be between 0.01 and 1 m^3/kg. Click OK. The resulting plot is shown in Figure 7.

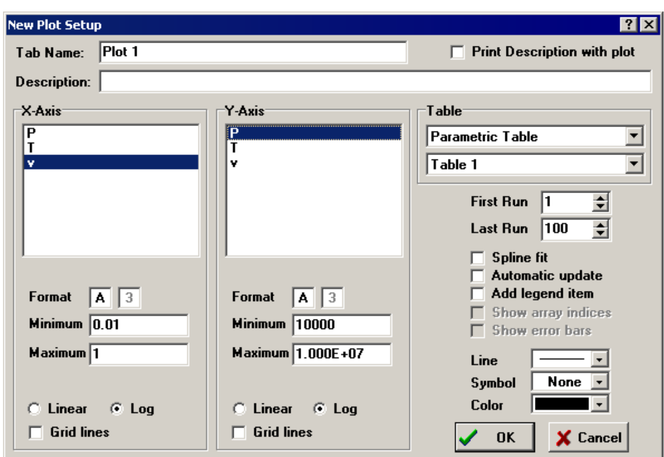


Figure 6: New Plot Setup dialog.

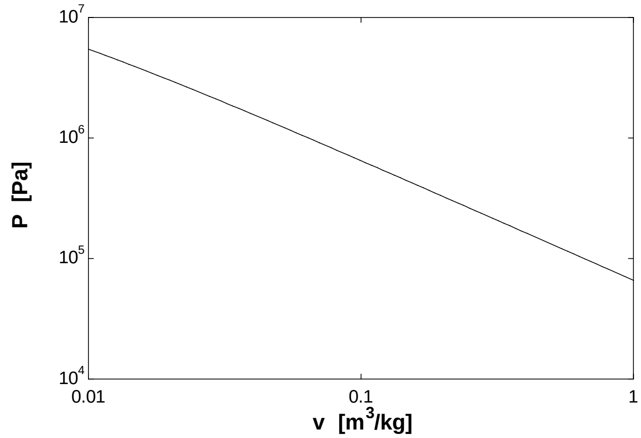


Figure 7: Plot showing pressure as a function of specific volume.

To improve the plot, right click on the numbers for the y-axis. This will bring up the Modify Axis dialog where grid lines and improved number formatting can be selected as shown in Figure 8. Do the same for the x-axis. The new plot is shown in Figure 9.

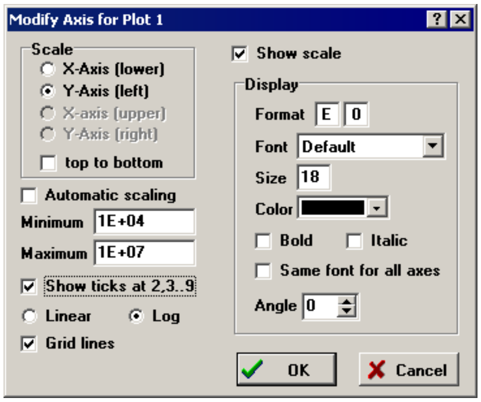


Figure 8: Modify Axis dialog.

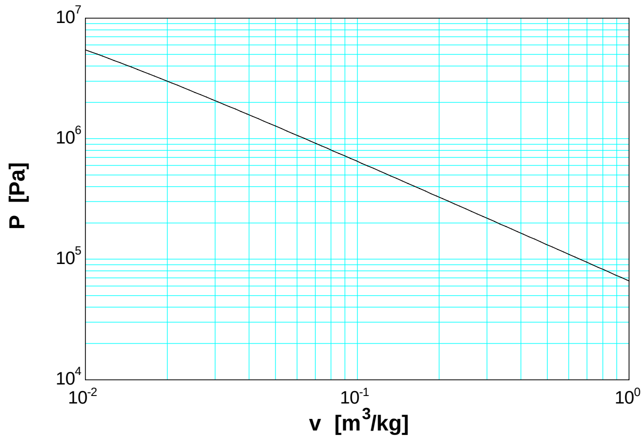


Figure 9: Plot with grid lines.

Duplicate the Parametric table by right clicking on the Parametric table tab, as shown in Figure 10.

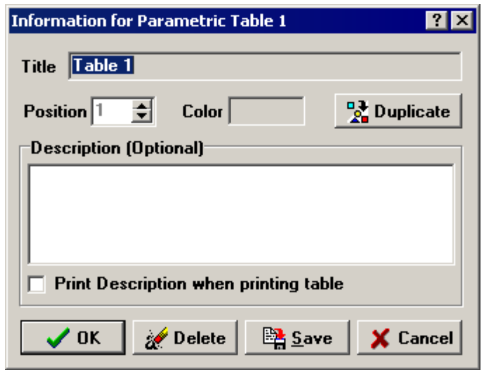


Figure 10: Duplicate the plot.

A new table will appear. Right click on the tab of the new table and change the name to 400 K, as shown in Figure 11. You may wish to also rename the original table to be 350 K.

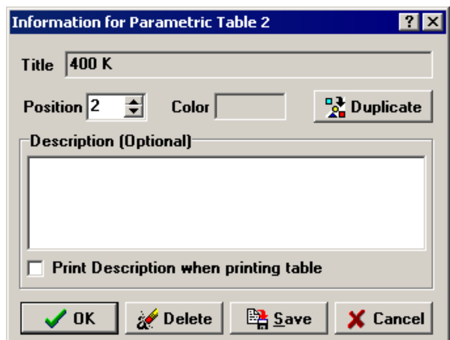


Figure 11: Name new parametric table.

Fill the *T* column in the 400 K with temperatures of 400 K and solve the table. Select Overlay Plot from the Plots menu, as shown in Figure 12. The new plot is shown in Figure 13.

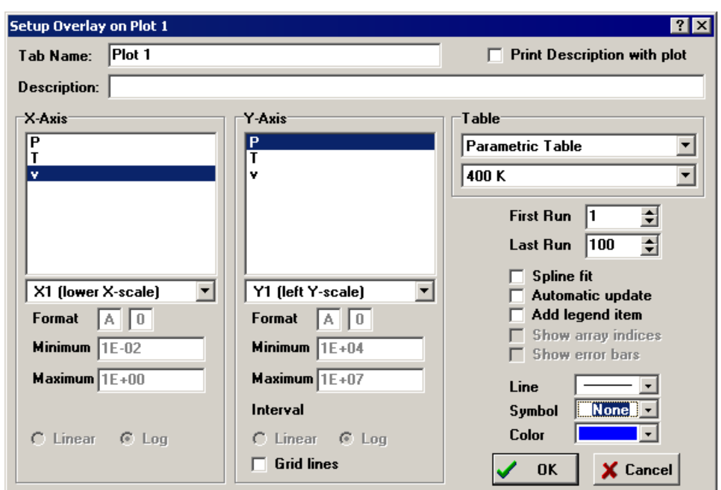


Figure 12: Overlay plot dialog.

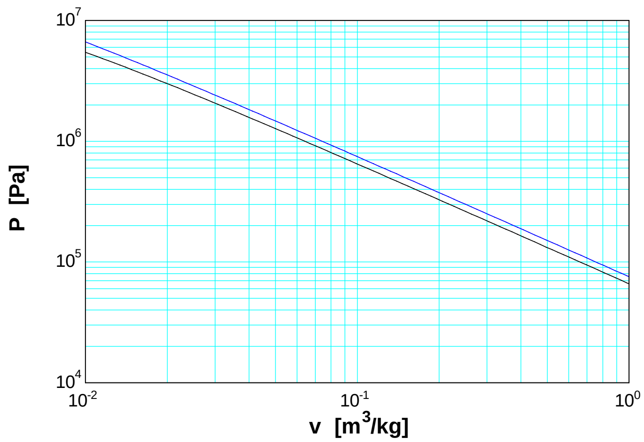


Figure 13: Overlaid plot.

Add text to label the two plots by selecting the text button (abc) from the floating plot tool bar shown in Figure 14. If the menu is not visible, select Show Tool bar in the Plots menu. The text dialog is shown in Figure 15.

Figure 14: Toolbar.

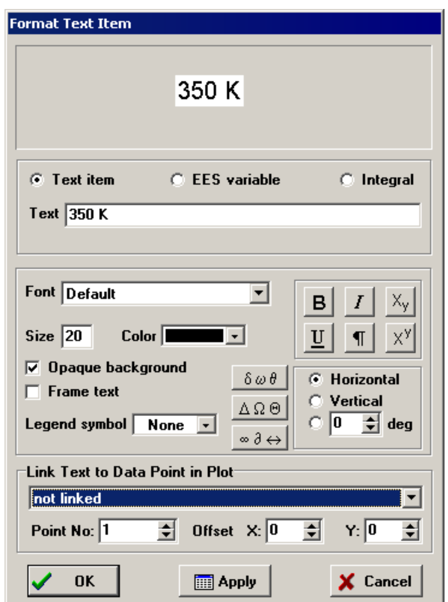


Figure 15: Format text item dialog.

Drag the text to the desired location. Create an arrow by selecting the line button in the plot tool bar. Right click on the line and select Properties from the pop-up menu to change it to be an arrow, as shown in Figure 16.

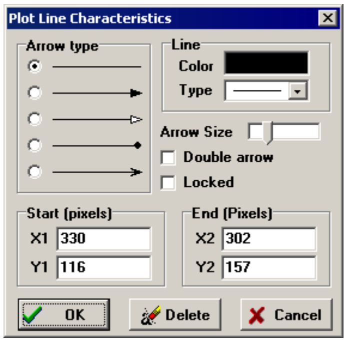


Figure 16: Plot line characteristics dialog.

Repeat for 400 K. The plot should appear something like what is shown in Figure 17.

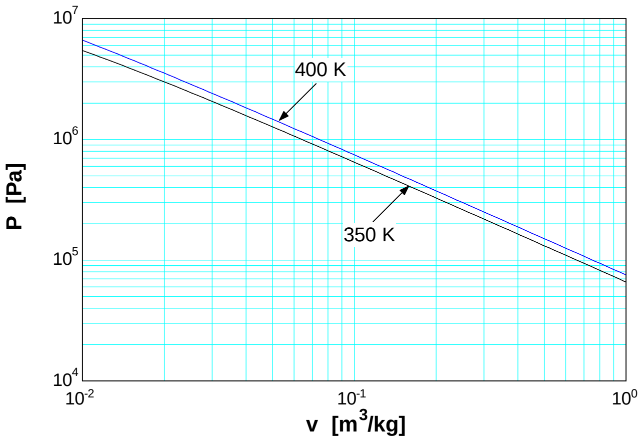


Figure 17: Final version of the plot.

1.B-3

A thermistor is an electrical resistor that is made of temperature-dependent materials. Properly calibrated, the thermistor can be used measure temperature. The relation between resistance (R, ohms) and temperature (T, K) for a thermistor is given by:

$$R = R_o \exp\left[\alpha\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$$

where R_o is the resistance in ohms at temperature T_o in K and α is a material constant. For a particular resistor, it is known that R_o = 2.6 ohm with T_o =298.15 K (25°C). A calibration test indicates that R_1 = 0.72 ohm at T_1 = 60°C.

a.) Determine the value of α.

Start EES and enter the known information. Note that the temperature must be converted into K. The ConvertTemp function can be used for this purpose.

```
$UnitSystem SI Radian Mass J K Pa
T_0=298.15 [K]                          "reference temperature"
R_0=2.6 [ohm]                           "reference resistance"
R_1=0.72 [ohm]                          "known resistance"
T_1=convertTemp(C,K,60 [C])             "temperature in K"
```

The thermistor equation is evaluated in order to determine α.

$$R_1 = R_o \exp\left[\alpha\left(\frac{1}{T_1} - \frac{1}{T_o}\right)\right]$$

```
R_1=R_0*exp(alpha*(1/T_1-1/T_0))        "thermistor relation"
```

Solve the equations. The Solution window will appear showing one unit error. Right click on alpha and set its units to K, as shown in Figure 1.

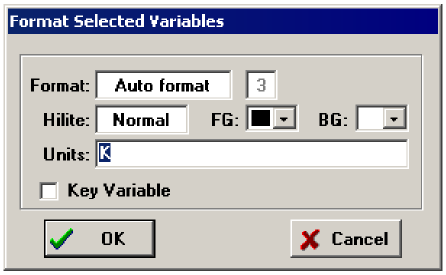


Figure 1: Format Selected Variables dialog.

The Solution window will now appear as shown in Figure 2.

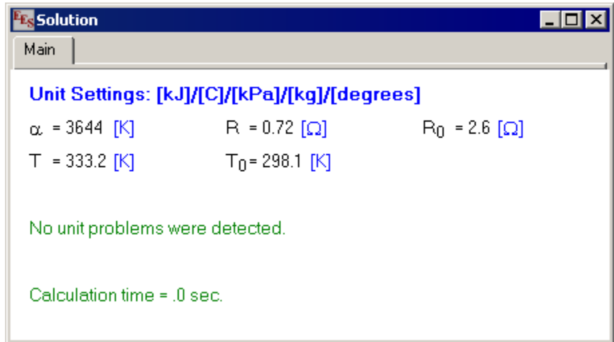


Figure 2: Solution window.

The value of α is 3644 K.

b.) Prepare a plot of R versus T (in °C) for temperatures between 0° and 100°C. Indicate the range over which this instrument will work best.

Enter the thermistor equation, Eq. (1) and convert the resulting temperature to °C.

```
R=R_0*exp(alpha*(1/T-1/T_0))          "thermistor relation"
T_C=ConvertTemp(K,C,T)                "temperature, in C"
```

Select New Parametric Table from the Tables menu to create a Parametric table with columns for the variables R and T_C that contains 11 rows, as shown in Figure 3.

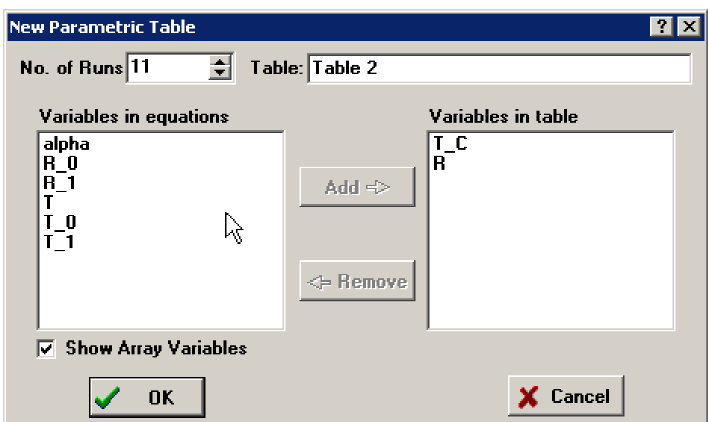


Figure 3: New Parametric Table dialog.

Fill the T_C column with values between 0°C and 100°C. The easiest way to do this is to click on the triangular icon at the upper right of the T_C header cell and enter 0 and 100 for the first and last values, as shown in Figure 4.

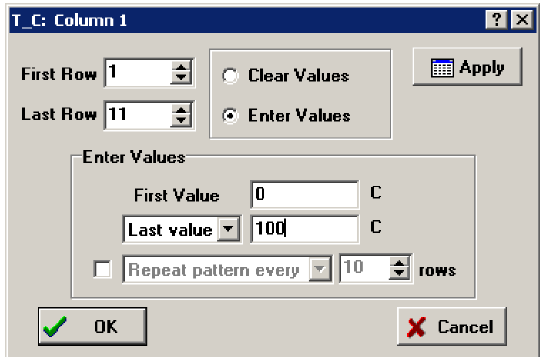


Figure 4: Set values for temperature.

Select Solve Table from the Calculate menu (or press F3) to solve the table. Select New Plot Window -> X-Y plot from the Plots menu. Choose T_C to be on the x-axis and R to be on the y-axis. Click OK and the plot will appear as shown in Figure 5.

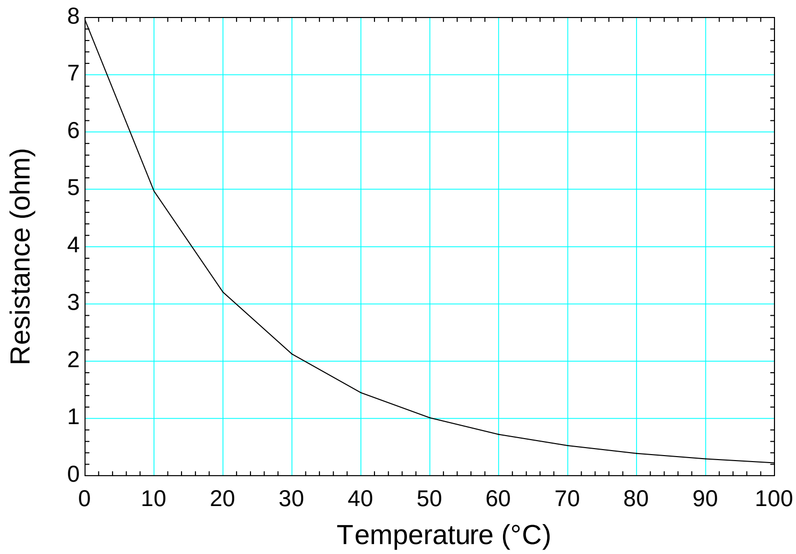


Figure 5: Resistance as a function of temperature.

Note that the slope of the plot is highest at low temperatures. This is where the thermistor will be most sensitive (i.e., the resistance will change substantially with temperature) and therefore the most accurate for determining temperature. In this region, a small temperature change results in a relatively large resistance change.

1.B-4

Tabular data are often used to solve engineering problems. Typically, the required data do not coincide exactly with the values that are provided in the table and therefore interpolation between entries in the table is necessary. Linear interpolation is usually sufficient. Linear interpolation can be implemented with the following equation.

$$\frac{y-y_1}{y_2-y_1}=\frac{x-x_1}{x_2-x_1}$$

where *y* is the variable that is to be determined at a specified value of *x* and the subscripts 1 and 2 refer to two entries in the table. Table 1.B-4 contains the temperature and specific volume at two pressures.

Table 1.B-4: Specific volume at various values of temperature for two values of pressure.

P = 0.10 MPa		*P* = 0.12 MPa	
T (°C)	*v* (m^3/kg)	*T* (°C)	*v* (m^3/kg)
200	2.172	200	1.808
240	2.359	240	1.965
280	2.546	280	2.120

Use these data to determine:

a.) The specific volume at *T* = 200°C and *P* = 0.107 MPa

The calculations can be done with a calculator or with EES. We will use EES here and compare the results done in two ways.

Start EES. For part (a), we can see that the specific volume lines between the two values specific volume in the first row the table. Linear interpolation is provided by the following equations.

```
"a.)"
T_a=200 [C]
P_a=0.107 [MPa]
(v_a-2.172 [m^3/kg])/(1.808 [m^3/kg]-2.172 [m^3/kg])=(P_a-0.1 [MPa])/(0.12 [MPa]-0.1 [MPa])
```

The result is v_a = 2.045 [m^3/kg]

b.) The temperature at *P* = 0.12 MPa, *v* = 1.84 m^3/kg

For part (b), we can see by inspection that the result must between 200°C and 240°C at *P* = 0.12 MPa. Interpolation is provided by the following equations.

```
"b.)"
P_b=0.12 [MPa]
v_b=1.84 [m^3/kg]
(T_b-200 [C])/(240 [C]-200 [C])=(v_b-1.808 [m^3/kg])/(1.965 [m^3/kg]-1.808 [m^3/kg])
```

The result is T_b = 208.2°C.

c.) The temperature at P = 0.115 MPa, v = 2.20 m^3/kg

Part (c) requires several interpolations. First, interpolate to find the specific volume at P_c = 0.115 MPa at all three temperatures.

```
"c.)"
"First, interpolate the table for values at P=0.115"
P_c=0.115 [MPa]
(v_200-2.172 [m^3/kg])/(1.808 [m^3/kg]-2.172 [m^3/kg])=(P_c-0.1 [MPa])/(0.12 [MPa]-0.1 [MPa])
(v_240-2.359 [m^3/kg])/(1.965 [m^3/kg]-2.359 [m^3/kg])=(P_c-0.1 [MPa])/(0.12 [MPa]-0.1 [MPa])
(v_280-2.546 [m^3/kg])/(2.120 [m^3/kg]-2.546 [m^3/kg])=(P_c-0.1 [MPa])/(0.12 [MPa]-0.1 [MPa])
```

The results are:
v_200 = 1.899 m^3/kg
v_240 = 2.064 m^3/kg
v_280 = 2.226 m^3/kg

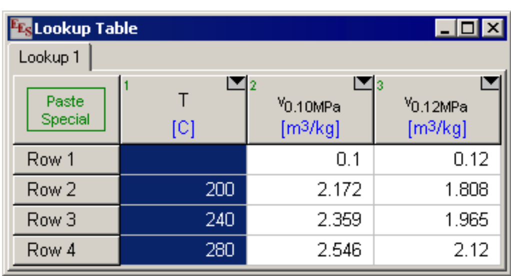
We wish to determine the temperature for which v_c = 2.20 m^3/kg, which must be between 240°C and 280°C. Interpolation provides the final result.

```
v_c=2.20 [m^3/kg]
(T_c-240 [C])/(280 [C]-240 [C])=(v_c-v_240)/(v_280-v_240)
```

The interpolated temperature is T_c = 273.5°C.

d.) Compare your results with those obtained using the EES Interpolate2DM function. Documentation on the use of the function is provided in the online help.

EES is able to interpolate data in a table in several ways. One way is through use of the Interpolate2DM function. Enter the data into a Lookup table. Select New Lookup Table from the Tables menu and create a Lookup table with four rows and three columns. Enter the data as shown in the table, as shown in Figure 1. Note that the first row holds the pressures and the first column holds the temperatures. The remainder of the table holds the specific volume data at each pressure and temperature. The names and units of the header cells are edited by right-clicking in the cell and selecting Properties from the drop-down menu that appears.



	T [C]	$v_{0.10MPa}$ [m3/kg]	$v_{0.12MPa}$ [m3/kg]
Row 1		0.1	0.12
Row 2	200	2.172	1.808
Row 3	240	2.359	1.965
Row 4	280	2.546	2.12

Figure 1: Lookup Table.

By default, the name of the table is Lookup 1. The specific volume at 200 C and 0.107 [MPa] is obtained by directly applying the Interpolate2DM function.

```
"Alternative using Interpolate2DM"
v_a_alt= Interpolate2DM ('Lookup 1', P_a, T_a)
```

Note that the _ant at the end of the variable names refers to the 'alternate' method of calculating the value using the Interpolate2DM function. Note that the solution for v_a_alt is the same value as v_a.

For case, b, we known the specific volume, but not the temperature. Again, directly apply the Interpolate2DM function and set it equal to the known specific volume for case b.

```
v_b= Interpolate2DM ('Lookup 1',P_b,T_b_alt)
```

This problem will likely not solve. Instead, you will see the error message shown in Figure 2.

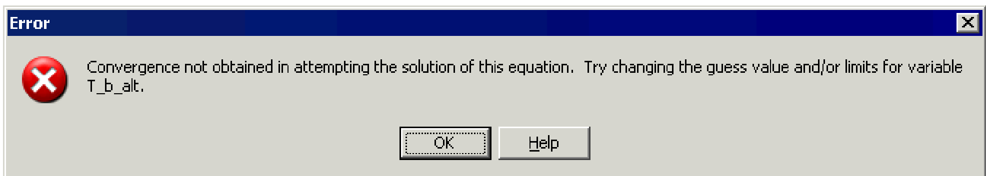


Figure 2: Error message.

The problem is that EES solves this interpolation by trial and error and the guess provided for T_b_alt is 1°C, which is not within the range of the table. Select Variable Info form the Options menu and set the guess value for T_b_alt to 240°C, as shown in Figure 3.

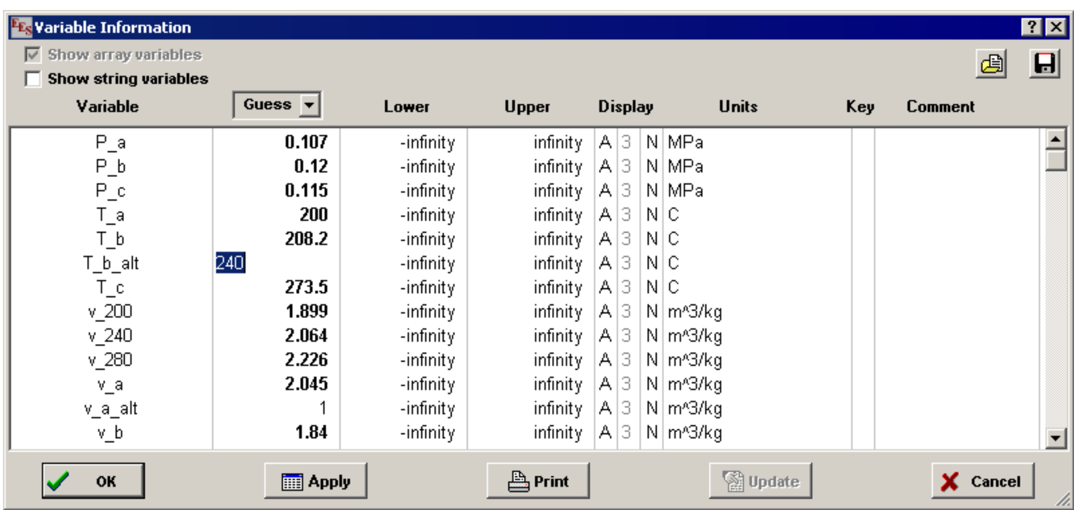


Figure 3: Set guess value.

Solve again. This time, T_b_alt should be the same as the value of T_b determined earlier.

Part (c) is solved in the same manner. EES will automatically do the 2D interpolation.

```
v_c=Interpolate2DM ('Lookup 1',P_c,T_c_alt)
```

Again, it will be necessary to set the guess value for T_c_alt to 240°C. Solving will result in the same values for T_c_alt and T_c.

1.C-1

The damage that a bullet does to a target is largely dictated by the kinetic energy of the bullet. A 0.22 caliber bullet is fired from a handgun with a muzzle velocity of approximately $\tilde{V}$ = 1060 ft/s and has a mass of m = 40 grains. A 0.357 magnum bullet is fired with a muzzle velocity of approximately $\tilde{V}$ = 1450 ft/s and has a mass of m = 125 grains. Grains is the typical unit that is used to report the mass of a bullet, there are 7000 grains in a lb_m. The kinetic energy of an object (EK) is given by:

$$EK = \frac{m\tilde{V}^2}{2}$$

a.) Determine the kinetic energy of the 0.22 and 0.357 caliber bullets (in lb_f-ft) as they are fired.

The kinetic energy of the 0.22 caliber bullet is:

$$KE = \frac{m\tilde{V}^2}{2} = \frac{40\text{ grains}}{2}\left|\frac{(1060)^2\text{ ft}^2}{\text{s}^2}\right\|\frac{1\text{ lb}_m}{7000\text{ grains}}\left|\frac{1\text{ lb}_f\text{-s}^2}{32.17\text{ lb}_m\text{-ft}}\right. = \boxed{99.8\text{ lb}_f\text{-ft}}$$

and for the 0.357 caliber bullet is:

$$KE = \frac{125\text{ grains}}{2}\left|\frac{(1450)^2\text{ ft}^2}{\text{s}^2}\right\|\frac{1\text{ lb}_m}{7000\text{ grains}}\left|\frac{1\text{ lb}_f\text{-s}^2}{32.17\text{ lb}_m\text{-ft}}\right. = \boxed{584\text{ lb}_f\text{-ft}}$$

1.C-2

Water flows through a pipe with a volumetric flow rate of $\dot{V}$ = 20 gal/min. The inner diameter of the pipe is D = 2.25 inch and the pipe is L = 50 ft long. The properties of water include density ρ = 1000 kg/m^3 and viscosity μ = 0.001 kg/m-s.

a.) Determine the pressure drop across the pipe (i.e., the amount of pressure rise that your pump will need to provide) using the formula:

$$\Delta P = \frac{\rho \tilde{V}^2}{2} f \frac{L}{D}$$

where $\tilde{V}$ is the average velocity of the flow in the pipe (the ratio of the volumetric flow rate to the pipe cross-sectional area) and f = 0.016 is the friction factor (a dimensionless number). Provide your answer in units of N/m^2 and psi (lbf/inch^2).

The first step in a solution using a computer program is to enter the known information and convert each input to base SI units (i.e., kg, N, m, s, etc.). Each of the input information is entered in the Equations window and converted using the convert function, as necessary.

```
"Inputs"
V_dot = 20 [gal/min]*convert(gal/min, m^3/s)          "volumetric flow rate"
D=2.25 [inch]*convert(inch,m)                         "diameter"
L=50 [ft]*convert(ft,m)                               "length"
rho=1000 [kg/m^3]                                     "density of water"
mu=0.001 [kg/m-s]                                     "viscosity of water"
f=0.016 [-]                                           "friction factor"
```

Notice that the convert function requires two inputs; the first input is the unit(s) to convert "from" and the second is the unit(s) to convert "to". If you are not sure about what units are available in EES and what the symbols are, select Unit Conversion Info from the Options menu. Also notice that a description of each input is enclosed in quotes; things enclosed in quotes or curly braces, {}, are called comments and do not affect the solution but do make the code more understandable.

The units of each of the variables should be set before proceeding. Select Solve from the Calculate menu and the Solution window should become visible and each of the variables should be shown (Figure 1).

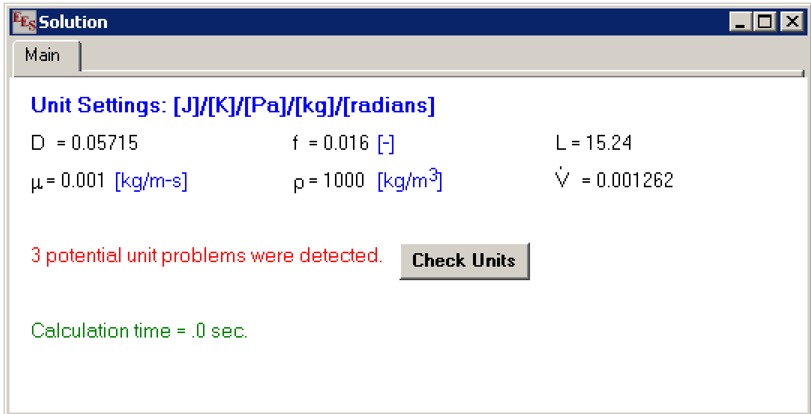


Figure 1: Solution window.

Right-click on any of the variables that you would like to set the units for. For example, right click on the variable D and enter the unit; note that you have converted the variable to base SI units and the base SI unit for length is m, therefore the unit for D is m (Figure 2).

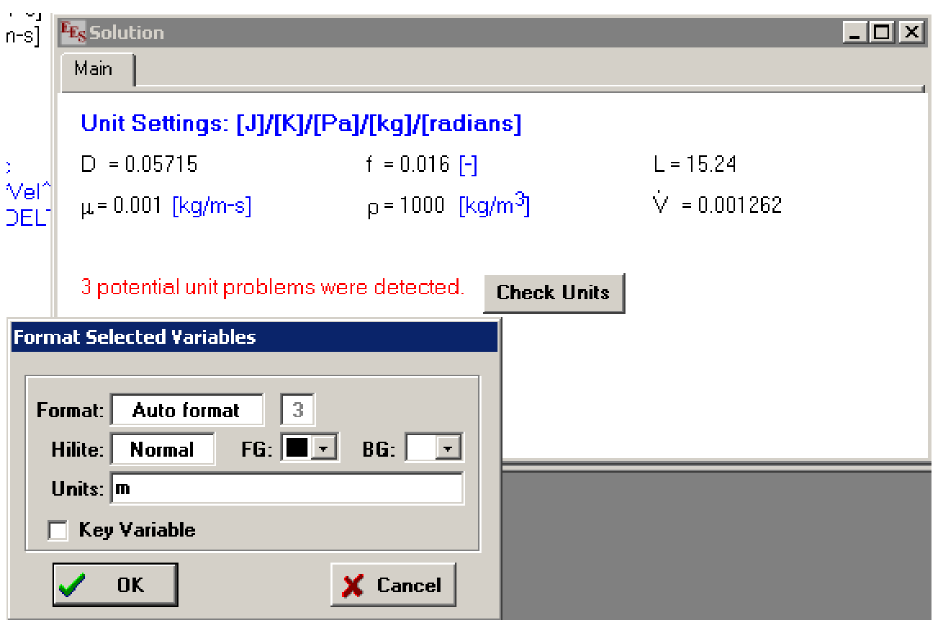


Figure 2: Right-click on the variable D to set its units.

Continue this process for each of the variables; when you have finished, the "No unit errors were detected" message should be evident (Figure 3).

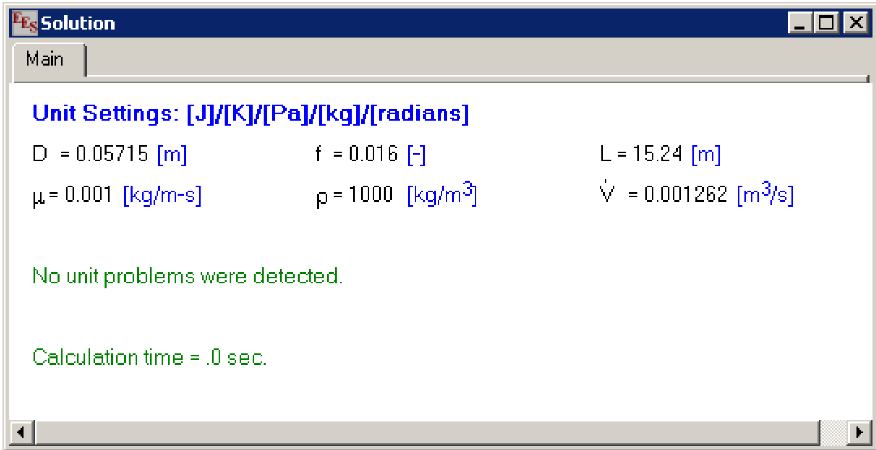


Figure 3: Solutions window with units set for each variable.

The next step in the solution is to enter each of the equations required to solve the problem in a sequential fashion. Sequential means that each equation can be added and immediately solved. The units for each new variable can be set and the entire program is functional before you move on to the next equation. (There will be problems where this is not possible.)

The cross-sectional area of the pipe is calculated:

$$A_c = \frac{\pi D^2}{4} \tag{1}$$

```
"Calculations"
A_c=pi*D^2/4               "cross-sectional area of pipe"
```

The solution should immediately be obtained (select Solve from the Calculate menu) and the units for the new variable (A_c) should be set in the Solutions Window; the SI unit for area is m^2 (Figure 4).

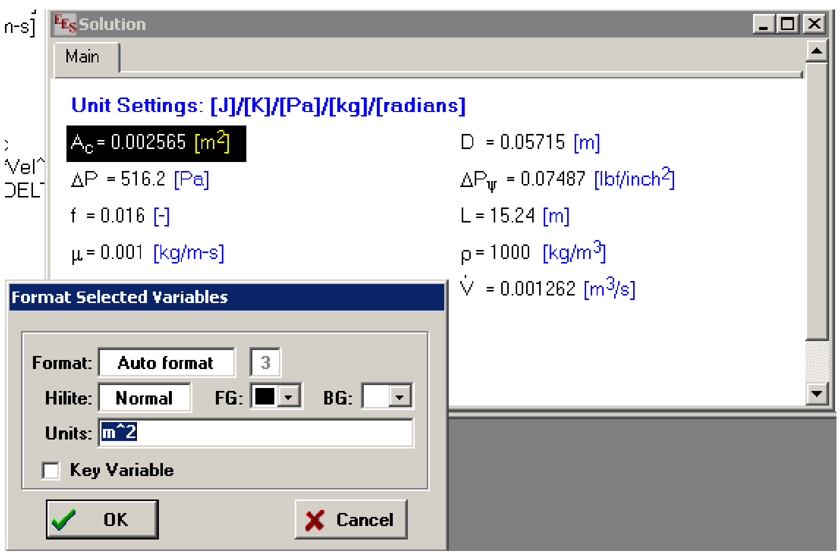


Figure 4: Set units for the variable A_c.

The units can be checked by selecting Check Units from the Calculate menu; you should not proceed with any further calculations until you obtain the "No unit problems detected" message.

The average velocity in the pipe is calculated according to:

$$\tilde{V} = \frac{\dot{V}}{A_c} \tag{2}$$

```
Vel=V_dot/A_c                                   "average velocity"
```

The pressure drop is obtained using Eq. **Error! Reference source not found.**:

```
DELTAP=(rho*Vel^2/2)*(f*L/D)                    "pressure drop"
```

The SI units for pressure (and pressure drop) is N/m^2; therefore, the units of the variable DELTAP should be set to N/m^2 (also known as a Pascal, Pa). In order to obtain the answer in units of lb$_f$/inch^2 (also known as psi) it is easy to use the convert function:

```
DELTAP_psi=DELTAP*convert(N/m^2,lbf/inch^2)     "in psi"
```

The Equations and Solution windows should appear as shown in Figure 5.

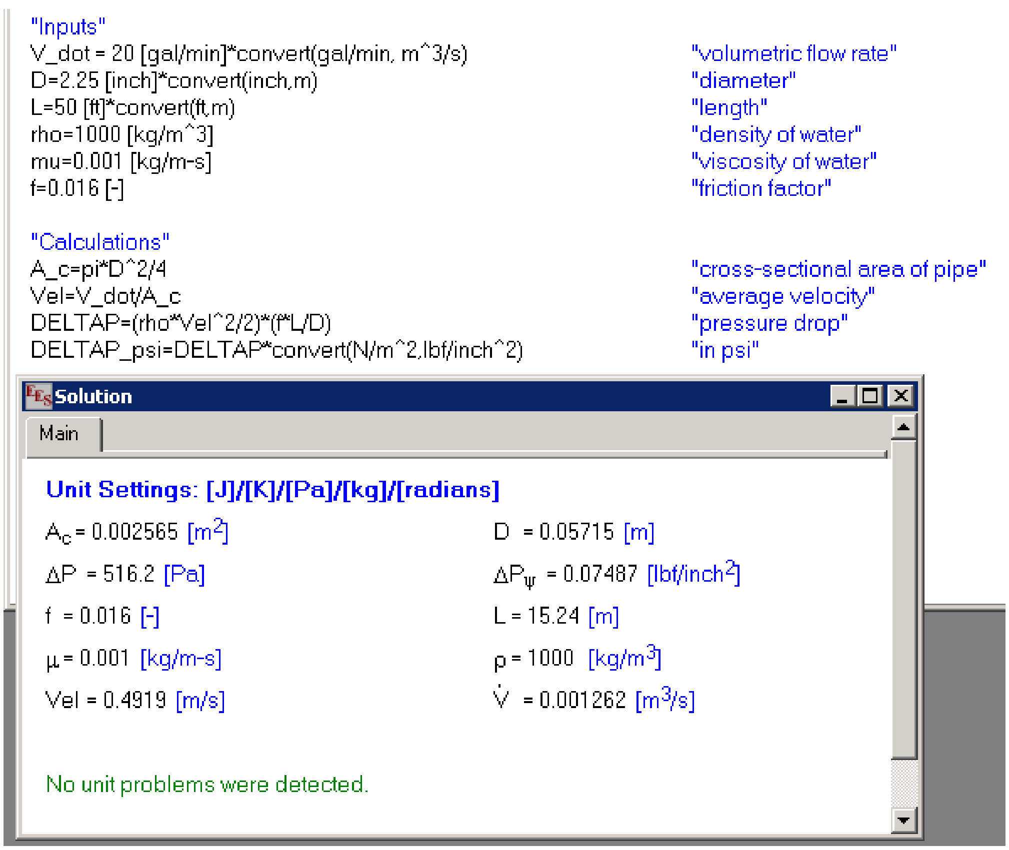


Figure 5: Equations and Solution windows.

1.C-3

Figure 1.C-3 illustrates a spring-loaded pressure relief valve.

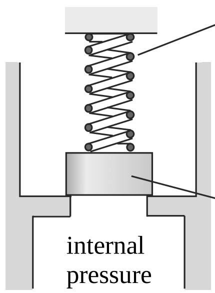


Figure 1.C-3: Spring-loaded valve

When the valve is seated as shown, the spring is compressed by x = 0.01 m and pushes down on a disk having a D = 1 cm diameter. The disk has a mass of m = 34 grams. One side of the valve is exposed to atmospheric pressure at P_o = 100 kPa and the other is exposed to an elevated internal pressure. The spring constant is K = 5000 N/m.

a.) Determine the pressure at which the valve opens (in kPa and lb_f/in^2).

The inputs are entered in EES; note that each input is converted to its base SI units. Also note that the units associated with each constant (e.g., 34 for the mass of the disk) are assigned directly using square brackets. This is not necessary but helps readability.

```
D=1 [cm]*convert(cm,m)                          "disk diameter"
P_atm=100 [kPa]*convert(kPa,Pa)                 "atmospheric pressure"
x=0.01 [m]                                      "spring compression distance"
m=34 [g]*convert(g,kg)                          "mass of disk"
K=5000 [N/m]                                    "spring constant"
```

The disk will lift when the force below it resulting from the internal pressure just exceeds the forces that are pushing the disk down related to atmospheric pressure and the spring constant. First, calculate the area of the disk:

$$A = \frac{\pi D^2}{4} \tag{1}$$

where D is the diameter of the disk. The force related to atmospheric pressure is:

$$F_1 = P_{atm} A \tag{2}$$

where P_{atm} is the pressure associated with the atmosphere. Note that because I am working in base SI units, the force F_1 is in N.

```
A=pi*D^2/4                     "disk area"
F_1=P_atm*A                    "force due to atmospheric pressure"
```

The second force on the disk is due to the spring.

$$F_2 = K\,x \tag{3}$$

where x is the compression of the spring.

```
F_2=K*x                         "spring force"
```

The third force is due to gravity acting on the disk. It may be negligible, but we have the information to calculate it.

$$F_3 = m\,g \tag{4}$$

where m is the mass of the disk and g is the acceleration of gravity.

```
F_3=m*g#                        "gravitational force on disk"
```

Note that g# is a built-in constant that returns standard gravitational acceleration. To see a complete list of the built-in constants in EES select Constants from the Options menu. The force balance at the point in which the value just opens is then:

$$P\,A = F_1 + F_2 + F_3 \tag{5}$$

```
P*A=F_1+F_2+F_3                                  "force balance"
```

where P is the pressure at which the valve opens (in Pa). We can convert P to kPa easily using the convert function.

```
P_kPa=P*convert(Pa,kPa)                          "convert to kPa"
```

We can also convert the pressure to psia and the spring constant from N/m to lb_f/in.

```
P_psia=P*convert(Pa,psia)                        "pressure in psia"
K_eng=K*convert(N/m,lb_f/in)                     "K in english units"
```

This problem should run and checked for unit consistency as well as against your intuition. The solution is P = 740.9 kPa or 107.5 lb_f/in^2.

b.) Generate a plot showing how the opening pressure and spring constant are related.

Comment out the specification of the spring constant:

```
{K=5000 [N/m]}                                   "spring constant"
```

and create a parametric table with 25 rows containing variables P_kPa, P_psia, K and K_eng (select New Parametric Table from the Tables menu). Right click on the column for K and select

Alter Values in order to fill the cells for K in the table with values ranging between 0 and 10,000 N/m. Run the table (select Solve Table from the Calculate menu) and plot the results. The plots should appear as shown in Figures 2 and 3.

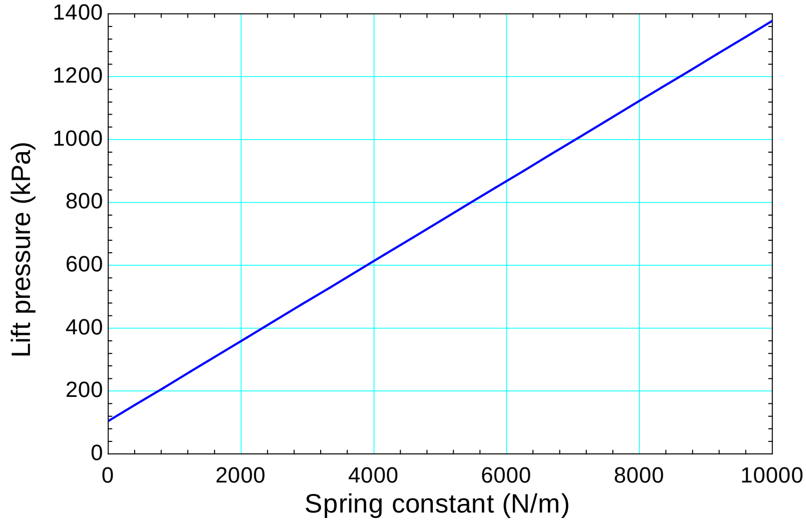


Figure 2: Lift pressure as a function of the spring constant (SI).

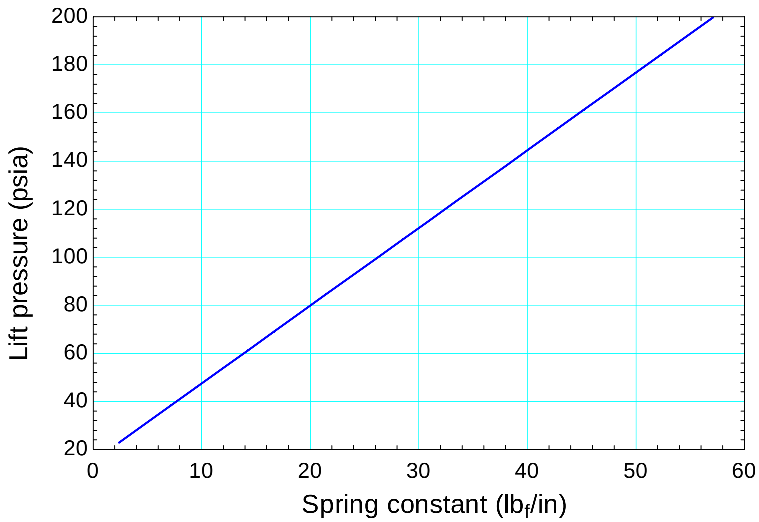


Figure 3: Lift pressure as a function of spring constant (English).

1.C-4

The flight deck on an aircraft carrier is relatively short and therefore a tailhook is required in order to land a plane, as shown in Figure 1.C-4. The tailhook snags one of several arresting wires that are attached to hydraulic cylinders. The system can bring an m = 27 ton aircraft traveling at $\tilde{V}_{ini}$ = 150 mph to rest in approximately t_{stop} = 2 s. Assume that the plane experiences a constant rate of deceleration during this process.

Figure 1.C-4: Tailhook and arresting wire on an aircraft carrier.

Hand in your EES program; make sure that you print out the Equations and Solutions Window and check that there are no unit warnings.

a.) What is the deceleration experienced by the pilot (in m/s^2 and g's - multiples of the acceleration of gravity)?

The inputs are entered in EES:

```
"Inputs"
m=27 [ton]*convert(ton,kg)                     "mass of aircraft"
Vel_ini=150 [mph]*convert(mph,m/s)             "initial velocity of aircraft"
t_stop=2 [s]                                   "stop time"
```

The rate of deceleration is the ratio of the change in velocity to the time:

$$dec = \frac{\tilde{V}_{ini}}{t_{stop}} \tag{1}$$

```
dec=Vel_ini/t_stop                             "rate of deceleration"
dec_g=dec/9.81 [m/s^2]                         "in g"
```

Note that the units of the variable dec are automatically in m/s^2 as these are the base SI unit for acceleration. There is no built-in unit corresponding to a 'g' and therefore it is necessary to divide by the deceleration of gravity. This leads to dec = 33.5 m/s^2 or 3.42 g's.

b.) How far does the aircraft travel during the landing (in ft)?

The deceleration rate is constant and equal to *dec*; therefore:

$$\frac{d}{dt}\left(\frac{dx}{dt}\right) = -dec \tag{2}$$

where x is the distance traveled by the plane. Integrating Eq. (2) one time leads to:

$$\int d\left(\frac{dx}{dt}\right) = -dec\int dt \tag{3}$$

or

$$\frac{dx}{dt} = -dec\,t + C_1 \tag{4}$$

where C_1 is a constant of integration. Substituting the initial velocity ($\frac{dx}{dt} = \tilde{V}_{ini}$ at $t = 0$) into Eq. (4) leads to:

$$\tilde{V}_{ini} = C_1 \tag{5}$$

or

$$\frac{dx}{dt} = -dec\,t + \widehat{V}_{ini} \tag{6}$$

Integrating Eq. (6) leads to:

$$\int dx = \int\left(-dec\,t + \tilde{V}_{ini}\right)dt \tag{7}$$

or

$$x = -dec\frac{t^2}{2} + \tilde{V}_{ini}\,t + C_2 \tag{8}$$

where C_2 is a second undetermined constant of integration. Substituting the initial position ($x = 0$ at $t = 0$) into Eq. (8) leads to:

$$C_2 = 0 \tag{9}$$

Therefore:

$$x = -dec\frac{t^2}{2} + \tilde{V}_{ini}\, t \qquad (10)$$

The distance traveled at the time the plane comes to rest is:

$$x_{stop} = -dec\frac{t_{stop}^2}{2} + \tilde{V}_{ini}\, t_{stop} \qquad (11)$$

```
x_stop=-dec*t_stop^2/2+Vel_ini*t_stop          "distance traveled"
x_stop_ft=x_stop*convert(m,ft)                 "in ft"
```

Note that the variable x_stop is in m and must be converted to ft using the convert command. This calculation leads to x_{stop} = 220 ft.

c.) Estimate the force that the tailhook exerts on the plane in the direction that opposes its forward motion (in lb_f).

The force on the plane is:

$$F = m\, dec \qquad (12)$$

```
F=m*dec                                        "force exerted on plane"
F_lbf=F*convert(N,lbf)                         "in lbf"
```

which leads to F = 184,600 lb_f.

d.) What is the change in the kinetic energy of the airplane (in MJ)?

The kinetic energy of the plane changes by:

$$\Delta KE = -m\frac{\tilde{V}_{ini}^2}{2} \qquad (13)$$

```
DELTAKE=-m*Vel_ini^2/2                         "change in kinetic energy"
DELTAKE_MJ=DELTAKE*convert(J,MJ)               "in MJ"
```

which leads to ΔKE = - 55.1 MJ.

e.) Generate a parametric table that includes the deceleration experienced by the pilot (in g's,multiples of the acceleration of gravity on earth), the stop time, t_{stop}, and the distance that the aircraft travels (in ft). Vary the stop time from t_{stop} = 0.5 s to t_{stop} = 5 s and solve the table. Plot the deceleration experienced by the pilot (in g's) as a function of the distance that the aircraft travels (in ft). If the pilot cannot experience more than 4 g's during landing then how long must the flight deck be?

A parametric table is created by selecting New Parametric Table from the Tables menu. The variables t_stop, x_stop_ft, and dec_g are selected (Figure 2) and a new parametric table is generated (Figure 3).

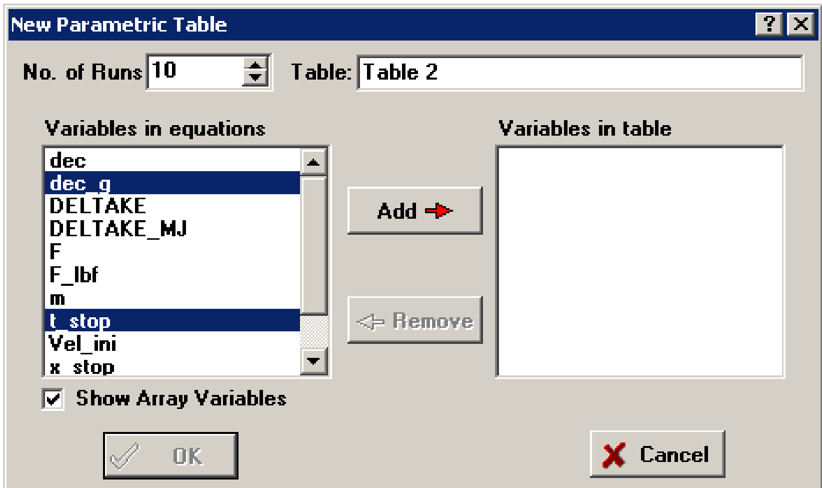


Figure 2: New Parametric Table dialog.

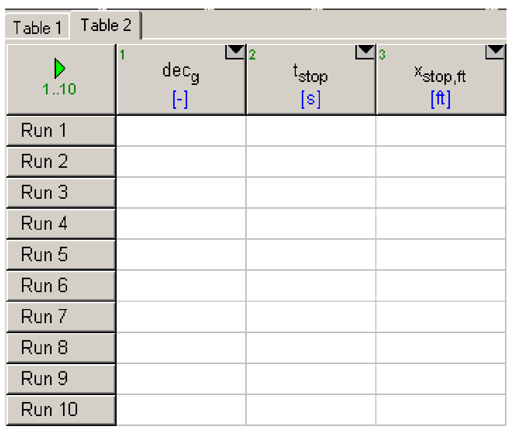


Figure 3: New parametric table.

The value of t_{stop} in the Equations Window is commented out by highlighting the line and right-clicking (Figure 4) and then selecting comment.

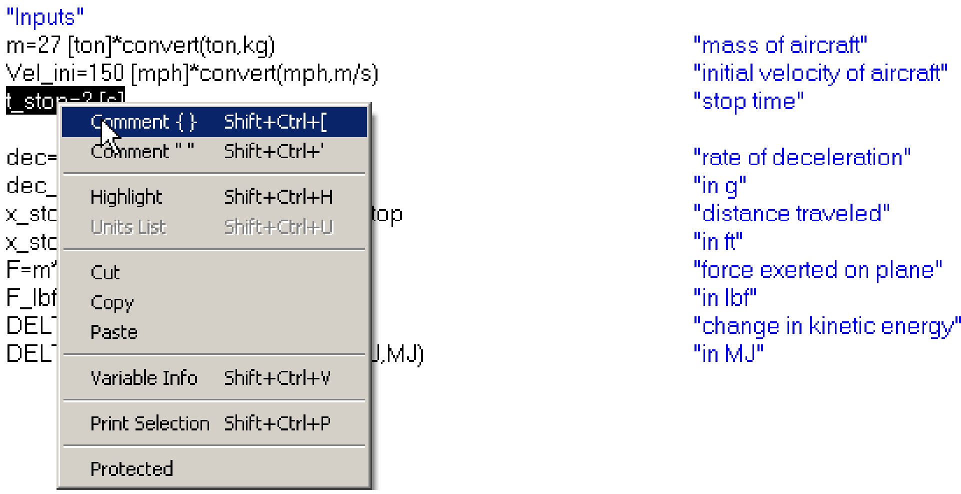


Figure 4: Comment out the value of t_{stop}.

The code should become:

```
{t_stop=2 [s]}          "stop time"
```

The value of the variable t_stop is varied in the parametric table by right-clicking on the header for the column and selecting Alter Values (Figure 5).

Figure 5: Alter values dialog.

The entries in the column should go from 0.5 s to 5.0 s in equal intervals (Figure 6).

1..10	dec_g [-]	t_{stop} [s]	$x_{stop,ft}$ [ft]
Run 1		0.5	
Run 2		1	
Run 3		1.5	
Run 4		2	
Run 5		2.5	
Run 6		3	
Run 7		3.5	
Run 8		4	
Run 9		4.5	
Run 10		5	

Figure 6: Parametric table with t_{stop} set.

Select Solve Table from the Calculate menu to obtain the solution for deceleration and stopping distance. Select plot in order to create Figure 7.

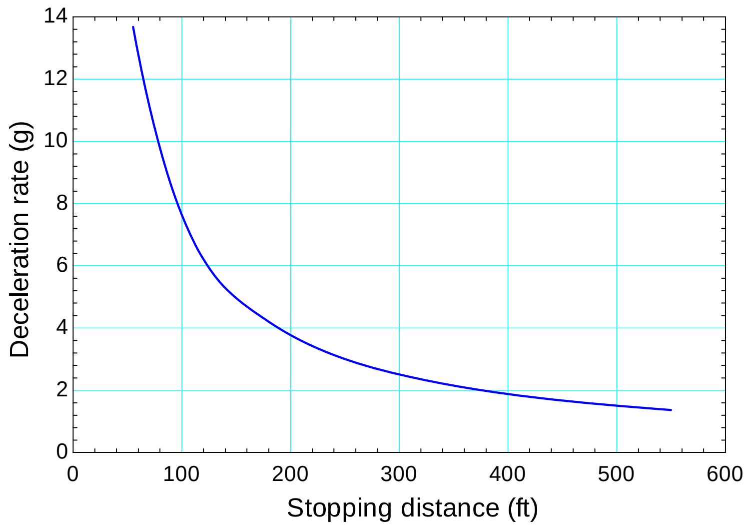


Figure 7: Deceleration rate as a function of stopping distance.

If the pilot is limited to 4 g's then the stopping distance must be at least 180 ft according to Figure 7.

1.C-5

One of the main purposes of a seat belt is to ensure that the passenger stops with the car during a crash rather than flying freely only to be stopped more quickly by a hard object. Assume that a vehicle traveling at $\tilde{V}_{ini}$ = 30 mph comes to a halt in a distance of L = 0.75 ft during a crash. Assume that the vehicle and passenger experience a constant rate of deceleration during the crash. Do this problem using EES.

a.) The stopping distance of a passenger that is not wearing a seat belt is estimated to be 20% of the stopping distance of the vehicle. Calculate the force experienced by a M = 180 lb_m passenger (in lb_f and N) if he is not wearing a seat belt during the crash.

The inputs are entered in EES:

```
"Inputs"
Vel_ini=30 [mph]*convert(mph,m/s)          "initial vehicle velocity"
L=0.75 [ft]*convert(ft,m)                  "stopping distance of vehicle"
m=180 [lbm]*convert(lbm,kg)                "mass of passenger"
```

Notice that the units of each constant (e.g., 30 for the velocity) are set directly using square brackets and the units of the variables are converted to base SI units as needed. The unit of the variable Vel_ini is m/s - this is specified in the Solutions Window by right-clicking on the variable and entering the unit, as shown in Figure 1.

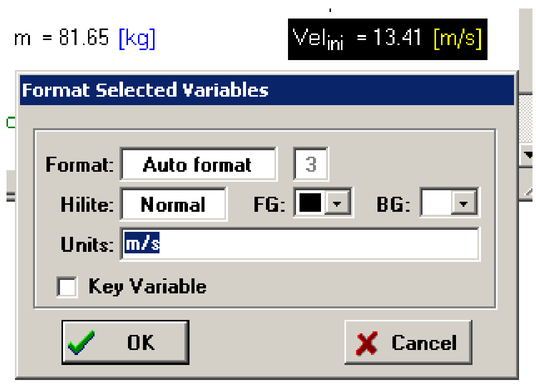


Figure 1: Setting the units of the variables.

In order to compute the force experienced by the passenger it is necessary to first determine the rate of deceleration experienced by the passenger.

The deceleration rate is constant and equal to *dec*; therefore:

$$\frac{d}{dt}\left(\frac{dx}{dt}\right) = -dec \tag{1}$$

where x is the distance traveled by the vehicle. Integrating Eq. (1) one time leads to:

$$\int d\left(\frac{dx}{dt}\right) = -dec \int dt \tag{2}$$

or

$$\frac{dx}{dt} = -dec\,t + C_1 \tag{3}$$

where C_1 is a constant of integration. Substituting the initial velocity ($\frac{dx}{dt} = \tilde{V}_{ini}$ at $t = 0$) into Eq. (3) leads to:

$$\tilde{V}_{ini} = C_1 \tag{4}$$

or

$$\frac{dx}{dt} = -dec\,t + \tilde{V}_{ini} \tag{5}$$

The stopping time is the time at which the velocity reaches zero:

$$0 = -dec\,t_{stop} + \tilde{V}_{ini} \tag{6}$$

or

$$t_{stop} = \frac{\tilde{V}_{ini}}{dec} \tag{7}$$

Integrating Eq. (5) leads to:

$$\int dx = \int \left(-dec\,t + v_{ini}\right) dt \tag{8}$$

or

$$x = -dec\frac{t^2}{2} + v_{ini}\,t + C_2 \tag{9}$$

where C_2 is a second undetermined constant of integration. Substituting the initial position ($x = 0$ at $t = 0$) into Eq. (9) leads to:

$$C_2 = 0 \tag{10}$$

Therefore:

$$x = -dec\frac{t^2}{2} + v_{ini}\,t \tag{11}$$

The stopping distance is the distance at which time the vehicle comes to rest:

$$L_{stop} = -dec \frac{t_{stop}^2}{2} + \tilde{V}_{ini}\, t_{stop} \tag{12}$$

Substituting Eq. (7) into Eq. (12) leads to:

$$L_{stop} = -\frac{dec}{2}\left(\frac{\tilde{V}_{ini}}{dec}\right)^2 + \tilde{V}_{ini}\frac{\tilde{V}_{ini}}{dec} \tag{13}$$

Solving Eq. (13) for the deceleration rate leads to:

$$dec = \frac{\tilde{V}_{ini}^2}{2\, L_{stop}} \tag{14}$$

The stopping distance for a passenger not wearing a seat belt is 20% of the vehicle stopping distance and the deceleration is computed according to Eq. (14).

```
L_stop=0.2*L                                    "stopping distance"
dec=Vel_ini^2/(2*L_stop)                        "deceleration"
dec_g=dec/g#                                        "deceleration in g's"
```

Notice that the units of the variables resulting from the computation must be the appropriate base SI units. The units for the variable L_stop must be m and the units for the variable dec must be m/s^2. The result of this calculation indicates that the passenger will experience a deceleration of 200.6 g's during the crash if he is not wearing a seatbelt. The force experienced by the passenger is:

$$F = dec\, m \tag{15}$$

```
F=dec*m                                         "force"
F_lbf=F*convert(N,lbf)                          "in N"
```

which leads to F = 160.6 kN (36,104 lb_f).

b.) Calculate the force experienced by an m = 180 lb_m passenger (in lb_f and N) if he is wearing a seat belt that does not stretch during the crash.

The stopping distance is changed so that it is equal to the stopping distance associated with the car; the calculations are otherwise unchanged:

```
L_stop=L                                        "stopping distance"
dec=V_ini^2/(2*L_stop)                          "deceleration"
dec_g=dec/g#                                    "deceleration in g's"
F=dec*m                                         "force"
F_lbf=F*convert(N,lbf)                          "in N"
```

which leads to F = 32.1 kN (7221 lb_f).

c.) Many seat belts are designed to stretch during a crash in order to increase the stopping distance of the passenger relative to that of the vehicle. Calculate the force experienced by the passenger (in lb_f and N) if his seat belt stretches by $L_{stretch}$ = 0.5 ft during the crash.

The stopping distance is changed so that it is equal to the sum of the stopping distance associated with the car and the stretch in the seat belt; the calculations are otherwise unchanged:

```
L_stretch=0.5 [ft]*convert(ft,m)          "stretch in the seat belt"
L_stop=L+L_stretch                        "stopping distance"
dec=V_ini^2/(2*L_stop)                    "deceleration"
dec_g=dec/g#                              "deceleration in g's"
F=dec*m                                   "force"
F_lbf=F*convert(N,lbf)                    "in N"
```

which leads to F = 19.3 kN (4332 lb_f).

d.) Plot the force experienced by the passenger as a function of the stretch in the seat belt.

A parametric table is created by selecting New Parametric Table from the Tables menu. The variables L_stop and F are selected (Figure 2) and a new parametric table is generated (Figure 3).

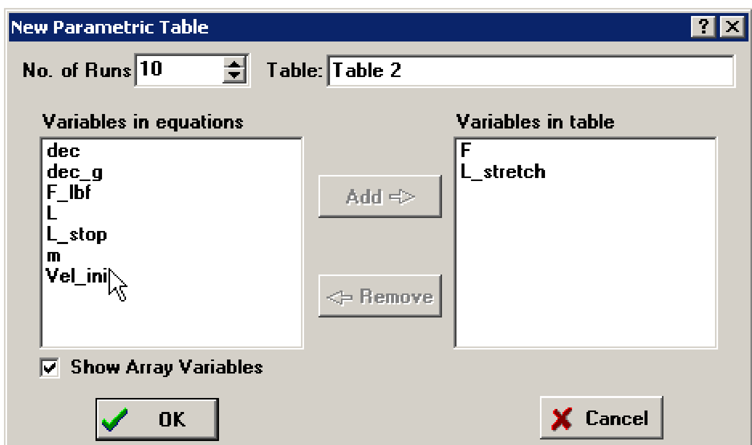


Figure 2: New Parametric Table dialog.

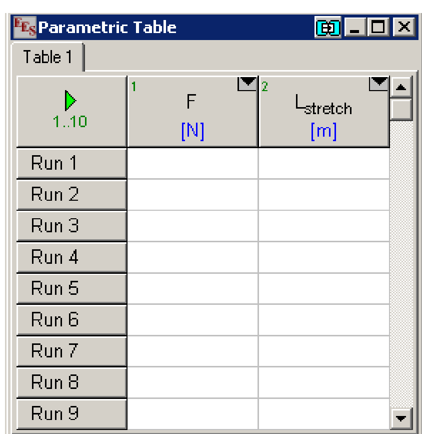


Figure 3: New parametric table.

The value of $L_{stretch}$ that was specified in the Equations window is commented out by highlighting the line and right-clicking (Figure 4) and then selecting comment.

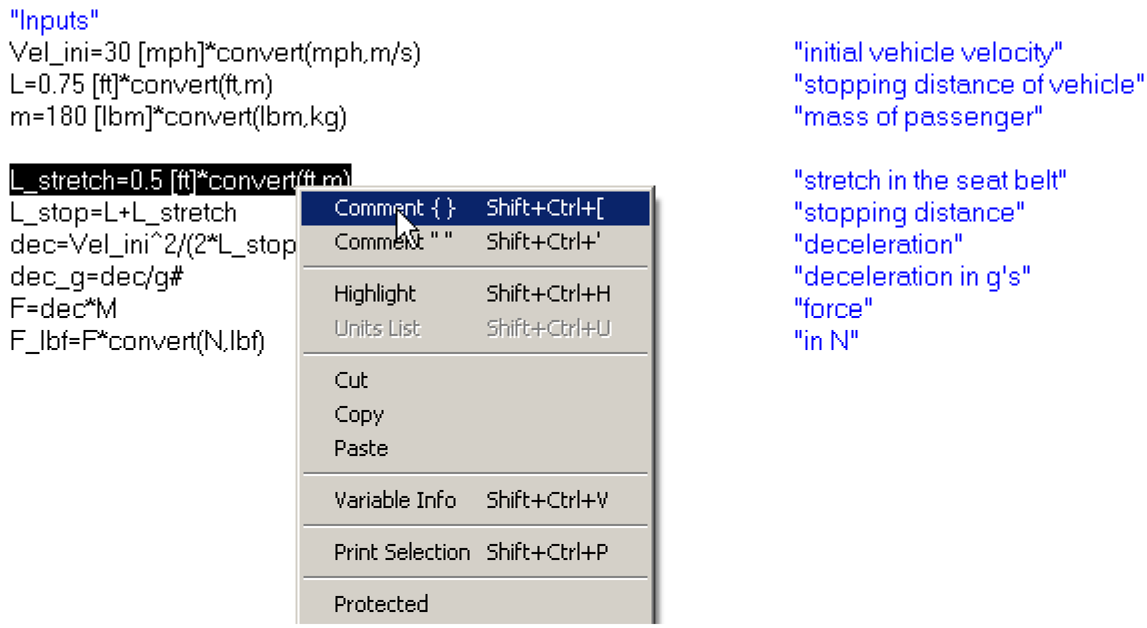


Figure 4: Comment out the value of $L_{stretch}$.

The code should become:

```
{L_stretch=0.5 [ft]*convert(ft,m)}                    "stretch in the seat belt"
```

The value of the variable L_stretch is varied in the parametric table by right-clicking on the header for the column and selecting Alter Values (Figure 5).

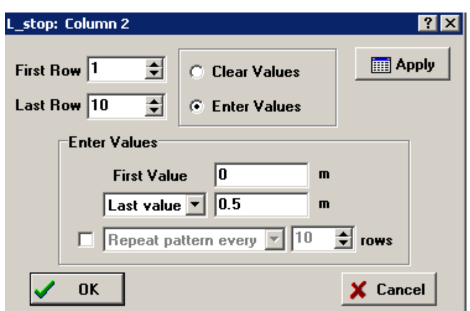
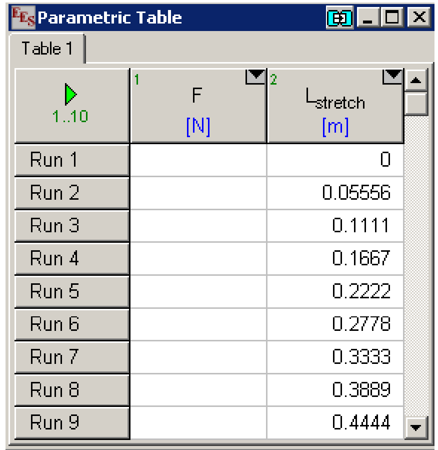


Figure 5: Alter values dialog.

The entries in the column should go from 0 m to 0.5 m in equal intervals (Figure 6).



1..10	F [N]	$L_{stretch}$ [m]
Run 1		0
Run 2		0.05556
Run 3		0.1111
Run 4		0.1667
Run 5		0.2222
Run 6		0.2778
Run 7		0.3333
Run 8		0.3889
Run 9		0.4444

Figure 6: Parametric table with $L_{stretch}$ set.

Select Solve Table from the Calculate menu to obtain the solution for force. Select plot in order to create Figure 7.

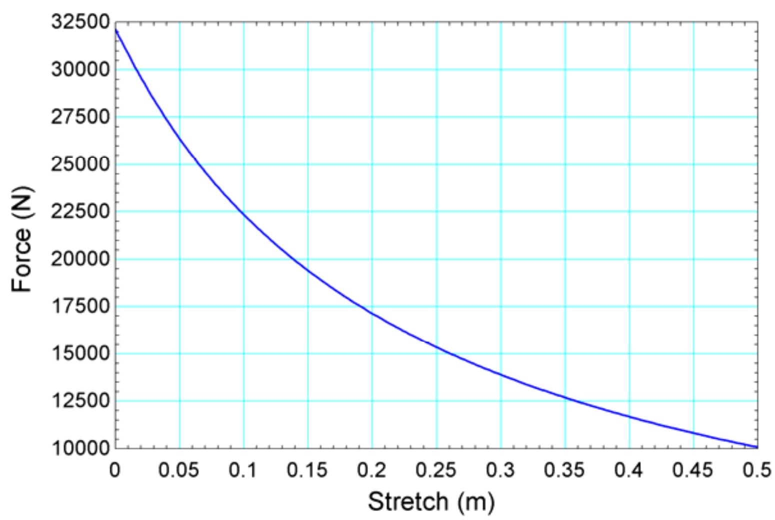


Figure 7: Force as a function of stretch.

1.C-6

Some hybrid and electric car manufacturers have begun to advertise that their cars are "green" because they can incorporate solar photovoltaic panels on their roof and use the power generated by the panel to directly power the wheels. For example, a solar array can be installed on the roof of the Fisker Karma car (see www.fiskerautomotive.com). In this problem we will assess the value of a solar panel installed on the roof of a car. Assume that the panel is L = 5 ft long and W = 4 ft wide. On a very sunny day (depending on your location), the rate of solar energy per area hitting the roof of the car is sf = 750 W/m^2. Assume that the panel's efficiency relative to converting solar energy to electrical energy is η_p = 10% (0.10). The cruising power required by the car is $\dot{W}_{car}$ = 20 hp.

a.) Estimate the rate of electrical power produced by the panel.

The inputs are entered in EES:

```
L=5 [ft]*convert(ft,m)                    "length of panel"
W=4 [ft]*convert(ft,m)                    "width of panel"
sf=750 [W/m^2]                            "solar flux"
eta_p=0.10 [-]                            "efficiency of solar panel"
W_dot_car=20 [hp]*convert(hp,W)           "cruising power required"
```

Notice that the units of each constant (e.g., 5 for the length of the panel) are set directly using square brackets and the units of the variables are converted to base SI units as needed. The unit of the variable L is m - this is specified in the Solutions Window by right-clicking on the variable and entering the unit, as shown in Figure 2.

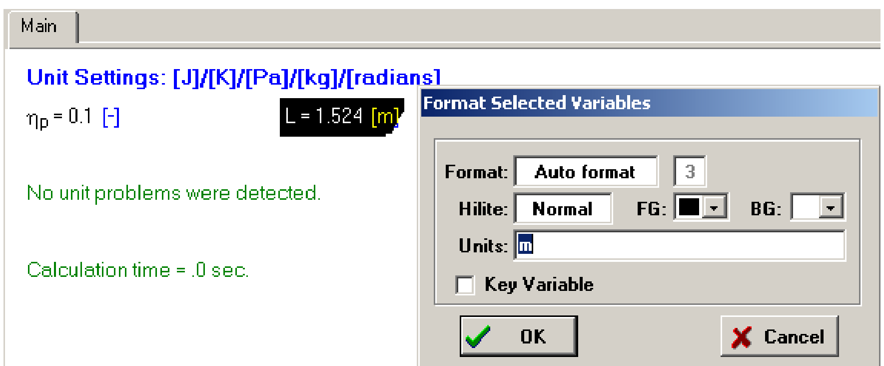


Figure 2: Setting the units of the variables.

The area of the solar panel is:

$$A_{panel} = L\,W \tag{1}$$

The power produced by the panel is given by:

$$\dot{W}_{panel} = A_{panel}\, sf\, \eta_p \tag{2}$$

```
A_panel=L*W                               "panel area"
W_dot_panel=A_panel*sf*eta_p              "power received from solar panel"
```

Notice that the units of the variables resulting from the computation must be the appropriate base SI units. The units for the variable A_panel must be m^2 and the units for the variable W_dot_panel must be W. The result of this calculation indicates that the solar panel will produce 139.4 W of electrical power.

b.) Calculate the fraction of the power required by the car that is produced by the solar panel.

The parameter f_{power} is defined as the ratio of the power produced by the panel to the power required by the car.

$$f_{power} = \frac{\dot{W}_{panel}}{\dot{W}_{car}} \tag{3}$$

```
f_power=W_dot_panel/W_dot_car                    "fraction of power provided"
```

which leads to f_{power} = 0.0093 (0.93%).

c.) If the car (and therefore the panel) sits in the sun for t_{sit} = 6 hours during a typical day then determine the total amount of electrical energy produced by the panel and put into the car's battery.

The total amount of energy produced is:

$$W_{panel} = \dot{W}_{panel}\, t_{sit} \tag{4}$$

```
t_sit=6 [hr]*convert(hr,s)                       "sitting time"
W_panel=t_sit*W_dot_panel                        "energy collected by panel"
```

which leads to W_{panel} = 3.01x10^6 J.

d.) If the car is driven for t_{drive} = 30 minutes during a typical day then determine the total amount of energy required by the car.

The total amount of energy required by the car is:

$$W_{car} = \dot{W}_{car}\, t_{drive} \tag{5}$$

```
t_drive=30 [min]*convert(min,s)                  "driving time"
W_car=t_drive*W_dot_car                          "energy required by car"
```

which leads to W_{car} = 2.69x10^7 J.

e.) Calculate the fraction of the energy required by the car that is produced by the solar panel during a typical day.

The parameter f_{energy} is defined as the ratio of the energy produced by the panel to the energy required by the car.

$$f_{energy} = \frac{W_{panel}}{W_{car}} \tag{6}$$

```
f_energy=W_panel/W_car                                  "fraction of energy provided"
```

which leads to f_{energy} = 0.112 (11.2%). Clearly the solar panel only makes sense if the car is parked outside all day. Even then it doesn't contribute much to the energy required by the car.

f.) Create a plot showing the fraction of energy required by the car that is produced by the solar panel, your answer from part (e), as a function of the panel efficiency; note that achievable panel efficiencies range from near zero to at most about 0.20.

A parametric table is created by selecting New Parametric Table from the Tables menu. The variables eta_p and f_energy are selected (Figure 3) and a new parametric table is generated (Figure 4).

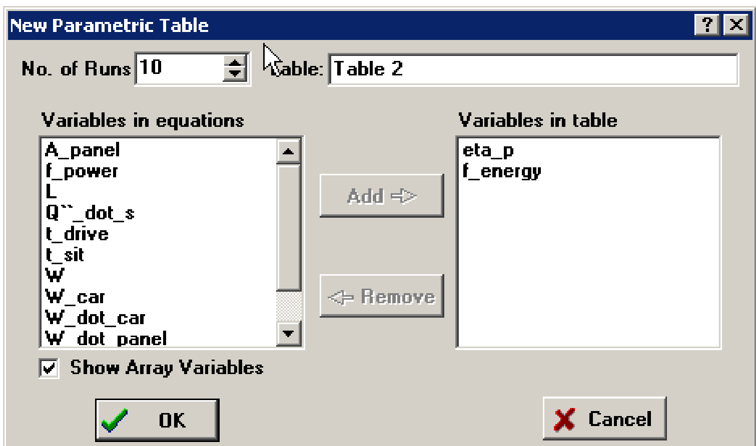


Figure 3: New Parametric Table dialog.

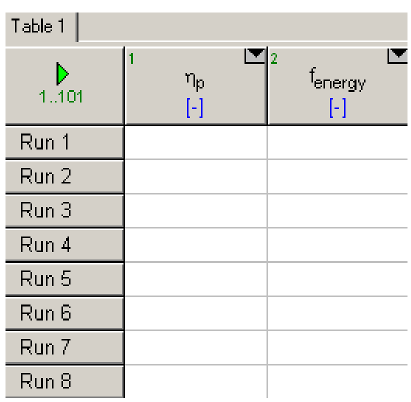


Table 1

1..101	η_p [-]	f_{energy} [-]
Run 1		
Run 2		
Run 3		
Run 4		
Run 5		
Run 6		
Run 7		
Run 8		

Figure 4: Parametric table.

The value of η_p that was specified in the Equations window is commented out by highlighting the line, right-clicking, and selecting Comment {} as shown in Figure 5.

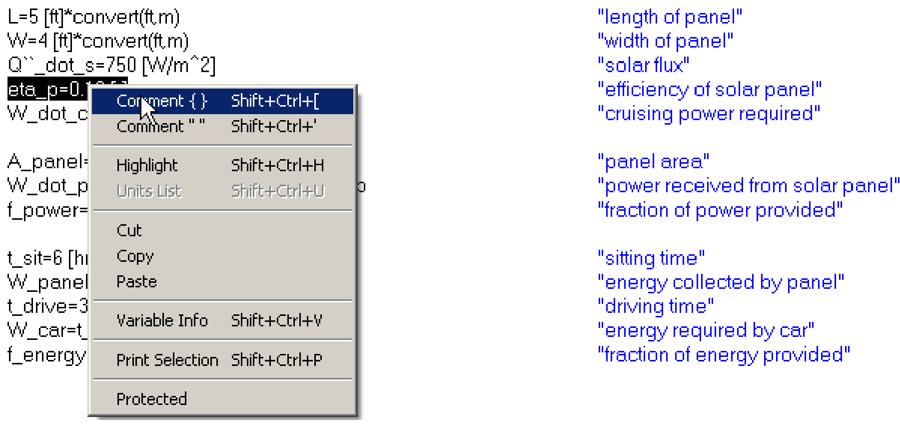


Figure 5: Comment out the value of η_p.

The code should become:

```
{eta_p=0.10 [-]}                                        "efficiency of solar panel"
```

The value of the variable eta_p is varied in the parametric table by right-clicking on the header for the column and selecting Alter Values (Figure 6).

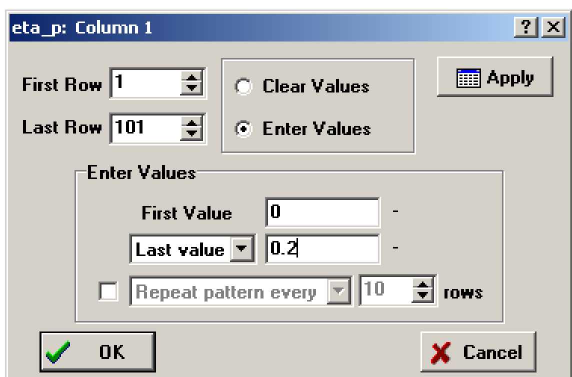


Figure 6: Alter values dialog.

The entries in the column should go from 0 to 0.5 in equal intervals (Figure 7).

Table 1

1..101	η_p [-]	f_{energy} [-]
Run 1	0	
Run 2	0.002	
Run 3	0.004	
Run 4	0.006	
Run 5	0.008	
Run 6	0.01	
Run 7	0.012	
Run 8	0.014	

Figure 7: Parametric table with η_p set.

Select Solve Table from the Calculate menu to obtain the solution for force. Select plot in order to create Figure 8.

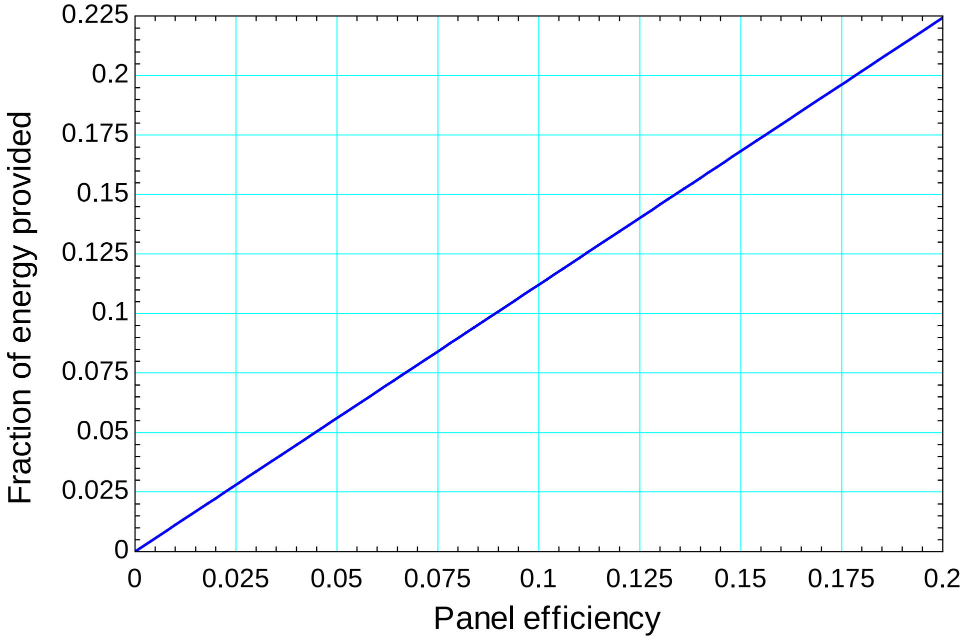


Figure 8: Fraction of energy provided as a function of the panel efficiency.

1.C-7

A man's weight is W_{earth} = 160 lb_f on earth where gravity is g_{earth} = 32.174 ft/s^2.
a.) Determine the mass of the man (in lb_m and in kg).

Mass and weight are related according to:

$$W_{earth} = m\, g_{earth} \tag{1}$$

solving for mass leads to:

$$m = \frac{W_{earth}}{g_{earth}} = \frac{160\ \text{lb}_\text{f}}{}\left|\frac{\text{s}^2}{32.174\ \text{ft}}\right\|\frac{32.174\ \text{lb}_\text{m}\text{-ft}}{\text{lb}_\text{f}\text{-s}^2} = 160\,\text{lb}_\text{m} \tag{2}$$

or, in kg:

$$m = \frac{160\ \text{lb}_\text{m}}{}\left\|\frac{0.4526\ \text{kg}}{1\ \text{lb}_\text{m}}\right. = 72.57\ \text{kg} \tag{3}$$

b.) Determine the weight of the man on the surface of venus where g_{venus} = 8.87 m/s^2 (in both N and lb_f).

Using Eq. (1):

$$W_{venus} = m\, g_{venus} = \frac{72.57\ \text{kg}}{}\left|\frac{8.87\,\text{m}}{\text{s}^2}\right\|\frac{\text{N-s}^2}{\text{kg-m}} = 643.7\ \text{N} \tag{4}$$

or, in lb_f:

$$W_{venus} = \frac{643.7\ \text{N}}{}\left\|\frac{0.22481\ \text{lb}_\text{f}}{1\ \text{N}}\right. = 144.7\ \text{lb}_\text{f} \tag{5}$$

1.D-1

This problem should be done using EES.

a.) The measured gage pressure and temperature in a container are *P* = 20 inch Mercury and *T* = 189.2°F. Determine the absolute pressure (in Pa) and temperature (in K).

The inputs are entered in EES:

```
"Inputs"
T_F=189.2 [F]                          "temperature in F"
P_g_inchHg=20 [inHg]                   "gage pressure in inHg"
```

The temperature is converted to K using the converttemp function:

```
T=converttemp(F,K,T_F)      "temperature"
```

and the pressure is converted to absolute pressure in Pa by adding atmospheric pressure and converting from units of inch Hg to Pa:

```
P=1 [atm]*convert(atm,Pa)+P_g_inchHg*convert(inHg,Pa)      "pressure"
```

which leads to *T* = 360.5 K and *P* = 169053 Pa.

1.D-2

A manometer is a device that is commonly used to measure gage pressure and a barometer is used to measure absolute pressure. In your lab there is a mercury barometer that is used to measure ambient pressure and a water manometer that is used to measure the gage pressure in a tank, as shown in Figure 1.D-2. The temperature in the tank is also measured.

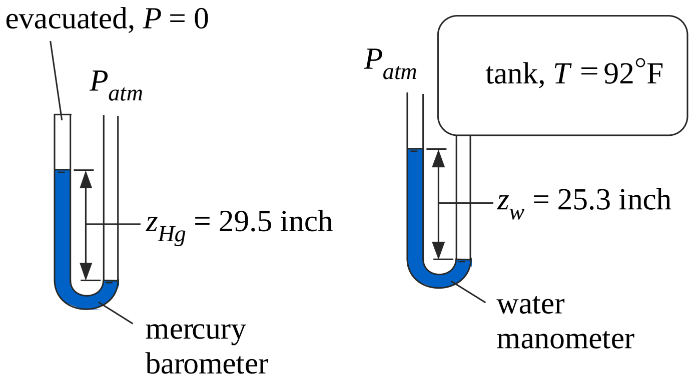


Figure 1.D-2: Mercury barometer and water manometer.

The mercury barometer consists of a tube that is open at one end and contains a column of mercury. The closed end of the tube is evacuated. Therefore, the height of the mercury column can be related to the absolute pressure that is applied to the open end using a force balance. The height of the mercury column is z_{Hg} = 29.5 inch and the density of mercury is ρ_{Hg} = 13,530 kg/m^3.

The water manometer is a U-shaped tube that is open at both ends. One end of the tube is exposed to the pressure in the tank and the other end is exposed to local atmospheric pressure. Therefore, the height of the column of water can be related to the pressure difference between the tank and ambient (i.e., the gage pressure). The height of the water column is z_w = 25.3 inch and the density of water is ρ_w = 996.6 kg/m^3. The temperature in the tank is 92ºF.

a.) Determine the gage pressure in the tank in Pa and psi.

The inputs are entered in EES:

```
z_Hg=29.5 [inch]*convert(inch,m)          "height of mercury column"
rho_Hg=13530 [kg/m^3]                     "density of mercury"
z_w=25.3 [inch]*convert(inch,m)           "height of water column"
rho_w=996.6 [kg/m^3]                      "density of water"
g=9.81 [m/s^2]                            "acceleration of gravity"
```

A force balance on the column of water leads to an expression for the difference between the tank pressure (P) and the atmospheric pressure (P_o), which is the definition of the gage pressure (P_g):

$$P_g = P - P_o = \rho_w \, g \, H_w \tag{1}$$

```
P_g=rho_w*z_w*g                 "gage pressure in the tank"
P_g_psi=P_g*convert(Pa,psi)     "in psi"
```

which leads to P_g = 6280 Pa or 0.911 psi. Note that manometers are so commonly used that "inches of water" is an accepted unit of pressure; therefore, it is possible to obtain the same answer using the convert command.

```
P_g2=25.3 [inH2O]*convert(inH2O,Pa)   "gage pressure in the tank"
```

which leads to $P_{g,2}$ = 6300 Pa.

b.) Determine the absolute pressure in the tank in Pa and psi.

The atmospheric pressure is obtained from a force balance on the column of liquid mercury:

$$P_o = \rho_{Hg}\, g\, H_{Hg} \tag{2}$$

```
P_o=rho_Hg*z_Hg*g#                    "atmospheric pressure"
```

which leads to P_o = 99424 Pa. Note that the unit "inches of Mercury" is also an accepted pressure unit; therefore the same answer can be obtained from:

```
P_o2=29.5 [inHg]*convert(inHg,Pa)     "atmospheric pressure"
```

which leads to $P_{o,2}$ = 99898 Pa. The absolute pressure in the tank is:

$$P_{abs} = P_o + P_g \tag{3}$$

```
P_abs=P_g+P_o                         "absolute pressure in tank"
P_abs_psia=P_abs*convert(Pa,psi)      "in psi"
```

which leads to P_{abs} = 105704 Pa or 15.33 psi.

c.) Determine the temperature in the tank in ºC, K, and R.

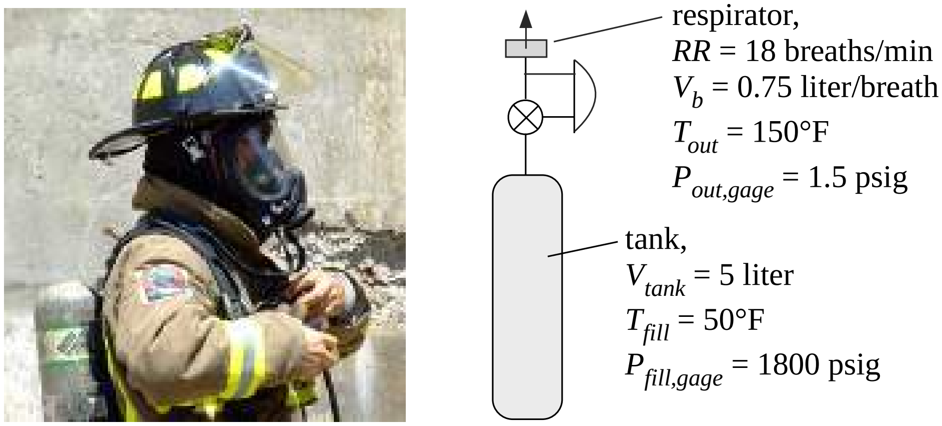
The converttemp function is used to convert between temperature scales.

```
T_C=converttemp(F,C,92 [F])           "temperature, in C"
T_K=converttemp(F,K,92 [F])           "temperature, in K"
T_R=converttemp(F,R,92 [F])           "temperature, in R"
```

which leads to T = 33.33ºC, 306.5 K, or 551.7 R.

1.D-3

We are going to analyze the self-contained breathing apparatus worn by a fire-fighter, shown in Figure 1.D-3(a).



(a) **(b)**

Figure 1.D-3 (a) A fire-fighter wearing a self-contained breathing apparatus (b) a schematic of the apparatus.

A schematic of the device is shown in Figure 1.D-3(b). The volume of the air tank is V_{tank} = 5 liter and the tank is initially filled with air at $P_{fill,gage}$ = 1800 psig (i.e., psi gage - this is a gage pressure) at T_{fill} = 50ºF. The fire-fighter enters a burning building and the temperature of the air in the tank increases to T_{fire} = 150ºF. The fire-fighter breaths from the respirator for *time* = 20 minutes. The air leaves the respirator at temperature T_{out} = T_{fire} and $P_{out,gage}$ = 1.5 psig (i.e., again - this is a gage pressure). The atmospheric pressure is P_{atm} = 14.7 psi. The respiration rate of the fire-fighter is RR = 18 breaths/minute and the volume of air inhaled during each breath is V_b = 0.75 liter. You should model air as an ideal gas for this problem; the ideal gas law relates pressure, temperature, and specific volume according to:

$$v = \frac{R\,T}{P}$$

where R = 287 N-m/kg-K is the gas constant for air and T and P are the absolute temperature and pressure.

a.) Determine the absolute pressure of the air initially in the tank and the absolute pressure of the air leaving the respirator (in Pa).

The inputs are entered in EES:

```
RR=18 [1/min]*convert(1/min,1/s)                  "respiratory rate - frequency of breaths"
Vol_b=0.75 [liter]*convert(liter,m^3)             "volume per breath"
Vol_tank=5 [liter]*convert(liter,m^3)             "volume of tank"
T_fill=converttemp(F,K,50 [F])                    "initial temperature of tank"
T_fire_F=150 [F]                                  "final temperature of tank, in F"
T_fire=converttemp(F,K,T_fire_F)                  "final temperature of tank"
T_out=T_fire                                      "temperature of air leaving respirator"
P_fill_gage=1800 [psi]*convert(psi,Pa)            "fill gage pressure of tank"
P_out_gage=1.5 [psi]*convert(psi,Pa)              "gage pressure at respirator"
R=287 [N-m/kg-K]                                  "gas constant"
Po=14.7 [psi]*convert(psi,Pa)                     "atmospheric pressure"
```

```
time=20 [min]*convert(min,s)                         "time"
```

The absolute pressure in the tank when it is filled is given by:

$$P_{fill} = P_{fill,gage} + P_{atm} \quad (1)$$

Similarly, the absolute pressure of the air leaving the respirator is:

$$P_{out} = P_{out,gage} + P_{atm} \quad (2)$$

```
"a"
P_fill=Po+P_fill_gage                                "fill absolute pressure of tank"
P_out=Po+P_out_gage                                  "absolute pressure at respirator"
```

which leads to P_{fill} = 1.251x10^7 Pa and P_{out} = 1.12x10^5 Pa.

b.) Determine the volume of air that passes through the respirator and is supplied to the fire-fighter (in liter).

The volume of air is the product of the breathing rate, the volume per breath, and time:

$$V_{out} = RR\ V_b\ time \quad (3)$$

```
"b"
Vol_out=RR*Vol_b*time                                "volume of air passing through the respirator"
Vol_out_liter=Vol_out*convert(m^3,liter)             "in liter"
```

which leads to V_{out} = 270 liter.

c.) Determine the mass of air that passes through the respirator.

The mass of air is given by:

$$m_{out} = \frac{V_{out}}{v_{out}} \quad (4)$$

where v_{out} is the specific volume of the air leaving the respirator, calculated using the ideal gas law:

$$v_{out} = \frac{R\,T_{out}}{P_{out}} \quad (5)$$

```
"c"
v_out=R*T_out/P_out                          "specific volume of air leaving respirator"
m_out=Vol_out/v_out                          "mass of air leaving respirator"
```

which leads to m_{out} = 0.310 kg.

d.) Determine the initial mass of air that is in the tank.

The specific volume of the air initially in the tank is:

$$v_1 = \frac{R\,T_{fill}}{P_{fill}} \tag{6}$$

The mass of air initially in the tank is:

$$m_1 = \frac{V_{tank}}{v_1} \tag{7}$$

```
"d"
v_1=R*T_fill/P_fill                     "specific volume of air in tank"
m_1=Vol_tank/v_1                        "initial mass of air in tank"
```

which leads to m_1 = 0.770 kg.

e.) Determine the final mass of air that is in the tank.

A mass balance on the system consisting of the tank and the respirator is shown in Figure 2.

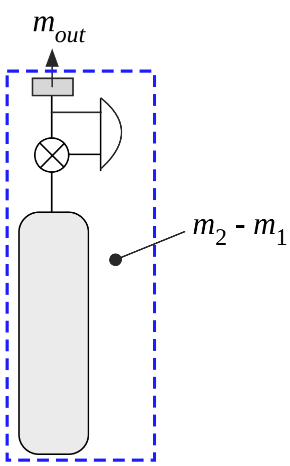


Figure 2: Mass balance.

The mass balance leads to:

$$0 = m_{out} + m_2 - m_1 \tag{8}$$

```
"e"
0=m_out+m_2-m_1                         "mass balance on tank"
```

which leads to m_2 = 0.460 kg.

f.) Determine the final gage pressure in the tank (in psig).

The specific volume of the air left in the tank at the end of the process is:

$$v_2 = \frac{V_{tank}}{m_2} \tag{9}$$

The absolute pressure is related to the specific volume according to:

$$v_2 = \frac{R\,T_{fire}}{P_2} \tag{10}$$

The gage pressure is related to the absolute pressure according to:

$$P_{2,gage} = P_2 - P_{atm} \tag{11}$$

```
"f"
v_2=Vol_tank/m_2                              "specific volume of air in tank"
v_2=R*T_fire/P_2                              "final absolute pressure"
P_2_gage=P_2-Po                               "final gage pressure"
P_2_gage_psi=P_2_gage*convert(Pa,psi)         "in psi"
```

which leads to $P_{2,gage}$ = 1281 psig.

g.) Plot the final gage pressure in the tank as a function of T_{fire}.

The specified value of T_{fire} is commented out in the equations window:

```
{T_fire_F=150 [F]}                  "final temperature of tank, in F"
T_fire=converttemp(F,K,T_fire_F)    "final temperature of tank"
```

and a parametric table is generated. Figure 3 illustrates the final gage pressure in the tank as a function of T_{fire}.

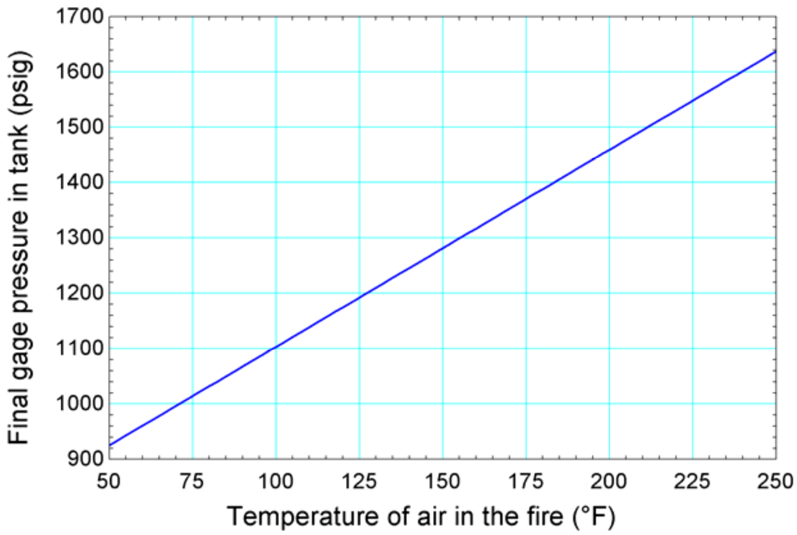


Figure 3: Final gage pressure in tank as a function of the temperature of the air in the fire.

1.D-4

You are working on an experimental fission reactor that is fueled by deuerium. The deuterium gas is very valuable and is delivered in V = 1 liter tanks, as shown in Figure 1.D-4. You would like to remove as much of the deuterium that is initially in the tank and transfer it to your experiment as possible.

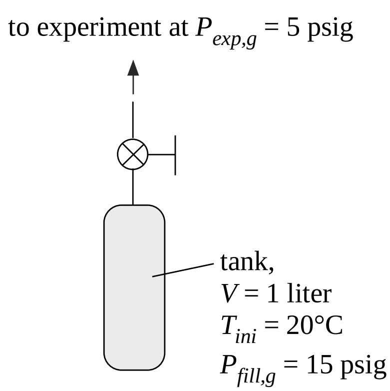


Figure 1.D-4: Deuterium tank connected to your experiment.

The initial temperature of the tank is T_{ini} = 20ºC and the initial pressure is $P_{fill,g}$ = 15 psig (i.e., pounds per square inch *gage* pressure). The experiment is always maintained at pressure $P_{exp,g}$ = 5 psig (also a gage pressure). The atmospheric pressure is P_{atm} = 1 atm. You should model deuterium as an ideal gas for this problem; the ideal gas law relates pressure, temperature, and specific volume according to:

$$v = \frac{R\,T}{P}$$

where R = 2064 N-m/kg-K is the ideal gas constant for deuterium and T and P are the absolute temperature and pressure.

a.) Determine the absolute pressure of the deuterium initially in the tank and the absolute pressure of the deuterium in the experiment (in Pa).

The inputs are entered in EES:

```
$UnitSystem SI Radian Mass J K Pa

T_ini=converttemp(C,K,20[C])                    "initial temperature"
R=2064 [J/kg-K]                                 "gas constant"
P_fill_gage=15 [psi]*convert(psi,Pa)            "initial gage pressure"
Vol=1 [liter]*convert(liter,m^3)                "volume of tank"
P_exp_gage=5 [psi]*convert(psi,Pa)              "gage pressure in the experiment"
P_o=1 [atm]*convert(atm,Pa)                     "atmospheric pressure"
```

The absolute pressure in the tank when it is filled is given by:

$$P_{fill} = P_{fill,gage} + P_{atm} \tag{1}$$

Similarly, the absolute pressure of the deuterium in the experiment is:

$$P_{exp} = P_{exp,gage} + P_{atm} \tag{2}$$

```
P_fill=P_fill_gage + P_atm                     "initial pressure in tank"
P_exp=P_exp_gage + P_atm                       "pressure in experiment"
```

which leads to P_{fill} = 204746 Pa and P_{exp} = 135799 Pa.

Initially, the valve connecting the tank to the experiment is opened and deuterium flows from the tank to the experiment until the tank pressure reaches P_{exp} (note that the pressure in the experiment does not change). The temperature of the tank remains at T_{ini} during this process.
b.) Determine the mass of deuterium that passes from the tank to the experiment.

State 1 is defined as the state of the deuterium in the tank initially; therefore, $P_1 = P_{ini}$ and $T_1 = T_{ini}$. The mass of deuterium is given by:

$$m_1 = \frac{V}{v_1} \tag{3}$$

where v_1 is the specific volume of the deuterium in the tank at state 1, calculated using the ideal gas law:

$$v_1 = \frac{R\,T_1}{P_1} \tag{4}$$

```
"State 1"
P_1=P_fill                                     "pressure"
T_1=T_ini                                      "temperature"
v_1=R*T_1/P_1                                  "specific volume"
m_1=Vol/v_1                                    "mass"
```

State 2 is defined as the state of the deuterium in the tank after the pressure reaches the pressure of the experiment; therefore, $P_2 = P_{exp}$ and $T_2 = T_{ini}$. The mass of deuterium is given by:

$$m_2 = \frac{V}{v_2} \tag{5}$$

where v_2 is the specific volume of the deuterium in the tank at state 2, calculated using the ideal gas law:

$$v_2 = \frac{R\,T_2}{P_2} \tag{6}$$

```
"State 2"
P_2=P_exp                                      "pressure"
T_2=T_ini                                      "temperature"
v_2=R*T_2/P_2                                  "specific volume"
m_2=Vol/v_2                                    "mass"
```

A mass balance on the system consisting of the tank is shown in Figure 2.

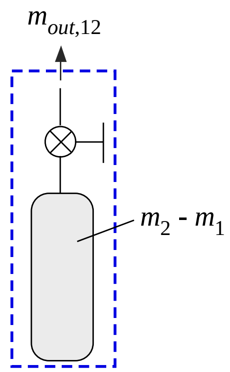


Figure 2: Mass balance.

The mass balance leads to:

$$0 = m_{out,12} + m_2 - m_1 \tag{7}$$

```
0=m_out_12+m_2-m_1                                  "mass balance"
```

which leads to $m_{out,12}$ = 0.000114 kg (0.114 g).

c.) Determine the fraction of the mass of deuterium that is initially in the tank that passes to the experiment during this process.

The fraction of deuterium utilized by this process is:

$$f_{12} = \frac{m_{out,12}}{m_1} \tag{8}$$

```
f_12=m_out_12/m_1                                   "fraction removed in 1-2"
```

which leads to f_{12} = 0.3367.

In order to get an additional transfer of deuterium from the tank to the experiment you have decided to heat the tank to T_{heat} = 50ºC while the valve remains open. The tank is connected to the experiment during this process so that the pressure in the tank remains at P_{exp}.

d.) Determine the mass of deuterium that passes from the tank to the experiment during the heating process.

The additional input is entered in EES:

```
T_heat_C=50 [C]                                     "temperature of heated tank, in C"
T_heat=converttemp(C,K,T_heat_C)                    "temperature of heated tank"
```

State 3 is defined as the state of the deuterium in the tank after the temperature is elevated; therefore, $P_3 = P_{exp}$ and $T_3 = T_{heat}$. The mass of deuterium is given by:

$$m_3 = \frac{V}{v_3} \tag{9}$$

where v_3 is the specific volume of the deuterium in the tank at state 3, calculated using the ideal gas law:

$$v_3 = \frac{R\,T_3}{P_3} \tag{10}$$

```
"State 3"
P_3=P_exp                                  "pressure"
T_3=T_heat                                 "temperature"
v_3=R*T_3/P_3                              "specific volume"
m_3=Vol/v_3                                "mass"
```

A mass balance leads to:

$$0 = m_{out,23} + m_3 - m_2 \tag{11}$$

```
0=m_out_23+m_3-m_2                         "mass balance"
```

which leads to $m_{out,23}$ = 0.0002084 kg (0.021 g).

e.) Determine the total fraction of the mass of deuterium that is initially in the tank that passes to the experiment during the entire process.

The fraction of deuterium utilized by this process is:

$$f_{total} = \frac{\left(m_{out,12} + m_{out,23}\right)}{m_1} \tag{12}$$

```
f_total=(m_out_12+m_out_23)/m_1            "total fraction of mass removed"
```

which leads to f_{total} = 0.3983.

f.) Plot the total fraction of the mass of deuterium that is initially in the tank that passes to the experiment during the entire process as a function of the temperature of the tank at the conclusion of the heating process for 20ºC < T_{heat} < 100ºC.

The requested plot is generated using a Parametric table and shown in Figure 3.

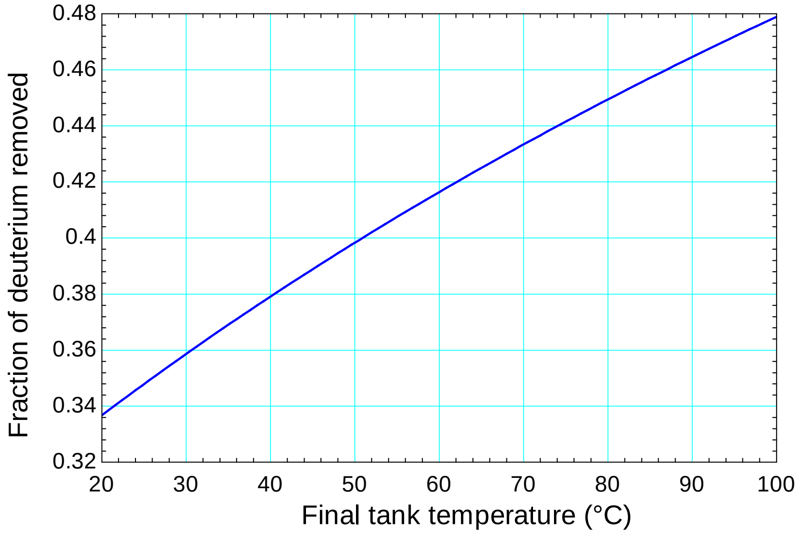


Figure 3: f_{total} as a function of T_{heat}.

1.D-5

The water pressure for water in a city water system is provided by a water tower, which consists of a tank located above ground level. In a particular case, the level of water in the tower is L_w = 200 ft above ground level and the pressure of the enclosed air above the water is P_{air} = 20 psia, as shown in Figure P1.D-5. The density of water is ρ_w = 62.4 lb_m/ft^3.

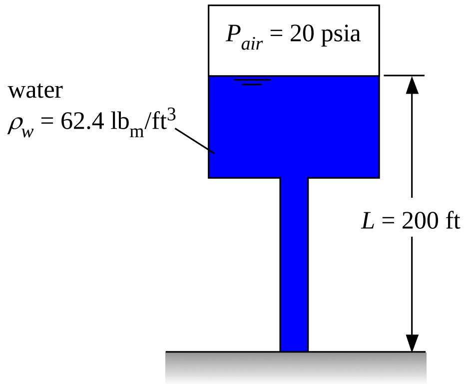


Figure P1.D-5: Water tower

a.) What is the gage pressure that a home owner can expect to have at a water tap located at ground level?

The pressure at ground level will be the pressure of the air above the tank plus the additional pressure resulting from the weight of the water.

$$P = P_{air} + \rho_w \, g \, L \tag{1}$$

The gage pressure is the pressure less the atmospheric pressure:

$$\begin{aligned} P_{gage} &= P_{air} + \rho_w \, g \, L - P_{atm} \\ &= 20 \text{ psi} + \frac{62.4 \text{ lb}_m}{\text{ft}^3}\left|\frac{32.17 \text{ ft}}{\text{s}^2}\right|\frac{200 \text{ ft}}{}\left\|\frac{\text{lb}_f\text{-s}^2}{32.17 \text{ lb}_m\text{-ft}}\right|\frac{\text{ft}^2}{(12)^2 \text{in}^2}\left|\frac{\text{psi-in}^2}{\text{lb}_f}\right. - 14.695 \text{ psi} \\ &= 92 \text{ psi} \end{aligned} \tag{2}$$