INTRODUCTION TO MATHCAD

By Thomas A. Cook, Ph.D.

This introduction to *Mathcad* is adapted from the book *Machine Design: An Integrated Approach—A Mathcad Supplement,* by Thomas A. Cook, Prentice-Hall, 1998, with the publisher's and author's permission. The examples used here are similar to those presented in "Introduction to *TKSolver* by Robert L. Norton."

Example 1	Units Conversion
Example 2	Simple Equation Solving Using *Mathcad* - Part A
Example 3	Simple Equation Solving Using *Mathcad* - Part B
Example 4	Simultaneous Equation Solving Using *Mathcad*
Example 5	List Solving and Plotting Using *Mathcad*
Example 6	List Solving and Functions Using *Mathcad*

EXAMPLE 1

Units Conversion

Problem **The weight of an automobile is known in lb_f. Convert it to mass units in the *SI*, *cgs*, *fps*, and *ips* systems. Also convert it to lb_m.**

Given **Automobile weight** $W := 4500 \cdot lb_f$

Assumptions **The automobile is on earth at sea level. So, gravitational acceleration is**

$$g := 32.174 \cdot \frac{ft}{\sec^2} \qquad g := 386.089 \cdot \frac{in}{\sec^2} \qquad g := 9.807 \cdot \frac{m}{\sec^2}$$

Defining the blob as a mass unit: $blob := \frac{lb_f \ \sec^2}{in}$

Defining N as a newton: $N := newton$

Solution

1 Equation 1.4*a* is valid for the first four systems listed.

For the *fps* system:

$$M := \frac{W}{g} \qquad M = 139.864 \cdot \frac{lb_f \ \sec^2}{ft} \qquad M = 139.864 \cdot slug \qquad (a)$$

For the *ips* system:

$$M := \frac{W}{g} \qquad M = 11.655 \cdot \frac{lb_f \ \sec^2}{in} \qquad M = 11.655 \cdot blob \qquad (b)$$

For the *SI* system:

$$M := \frac{W}{g} \qquad M = 2041.2 \cdot \frac{N \ \sec^2}{m} \qquad M = 2041.2 \cdot kg \qquad (c)$$

For the *cgs* system:

$$M := \frac{W}{g} \qquad M = 2041.2 \cdot 10^6 \cdot \frac{dyne \ \sec^2}{cm} \qquad M = 2041.2 \cdot 10^6 \cdot gm \qquad (d)$$

2 For mass expressed in lb_m, equation 1.4*b* must be used.

$$M := W \frac{g_c}{g} \qquad M = 4500 \cdot lb_m \qquad (e)$$

Note that lb_m is numerically equal to lb_f and so must not be used as a mass unit unless you are using the form of Newton's law expressed as equation 1.4*b*, (p. 24).

Mathcad Notes

At the end of each of the examples in this document are *Mathcad* notes such as this. Starting with Example 2, these notes will explain the *Mathcad* techniques used in the example that they follow. In this example the discussion is confined to how *Mathcad* handles units.

Mathcad has an extensive library of built-in units in the *mks*, *cgs*, and *U.S. Customary* systems. The names (usually abbreviated) of these units are predefined in terms of base units of mass, length, and time. For instance, *m* is predefined to be one meter. If you define a variable as *m*, it will lose its unit length and will take on the units of its definition. That is why, in the equations above, mass is defined with an uppercase *M*.

Mathcad treats units as if they were variables. For example, if you want to define a dimension that is given the symbol *A* and has units of 8 in, you simply type $A := 8 \cdot \mathrm{in}$. The ":=" is an assignment operator. The variable *A* is defined by putting it on the left-hand side of the assignment operator, and it is given a value by putting a number on the right-hand side if the assignment operator. The value "8" is given units by multiplying it by "in", which *Mathcad* recognizes as the inch-unit.

You can define your own units and use them just as if they were built-in. For example, *Mathcad* does not have a *blob* as a mass unit, but if we define it as is done in the **Assumptions** section above, it can be used as shown in equation *(b)*. Or, you may wish to rename built-in units as is done for the case of a *newton* above. *Mathcad* uses *newton* instead of *N* for the *SI* force unit. To use *N* instead of *newton*, you can make the definition *N* := *newton* and then use *N* every time you need an *SI* force-unit. Of course, you will not be able to use *N* as a symbol for a variable if you use it as a unit.

When you want to display the value of a variable, you type the variable name followed by the equal sign. For instance, to display the value of *A*, type "*A* =". The result is $A = 0.203 \cdot \mathrm{m}$ ▪ . Notice that *Mathcad* responds with a value and a unit, followed by a small black square, known as a placeholder. Click on the placeholder and type the unit that you want displayed. When you press the Enter key, *Mathcad* will make the unit conversion for you. To display the value of *A* in inches, type *in* at the placeholder. The result is: $A := 8.000 \cdot \mathrm{in}$.

The *Mathcad* symbol for a gram is *gm*. This is used so that *g* can be used for gravitational acceleration, which is built-in.

EXAMPLE 2

Simple Equation-Solving Using Mathcad - Part A

Problem **Find the height and empty weight of an open-top, cylindrical container (a cooking pot) for a desired volume.**

Given **Volume** $vol := 1000 \cdot cm^3$

Inside diameter $D := 12 \cdot cm$

Wall thickness $thick := 0.1 \cdot cm$

Assumptions **The material is stainless steel with a mass density of**

$$dens := 7.75 \cdot \frac{gm}{cm^3}$$

Solution **See Figure 1 and *Mathcad* file EX-02.mcd.**

1 An equation for the volume of a cylinder can be expressed as

$$vol = basearea \cdot H \qquad (a)$$

where H is the height of the cylinder.

2 The area of the base can be found from

$$basearea := \frac{\pi \cdot D^2}{4} \qquad basearea = 113.097 \cdot cm^2 \qquad (b)$$

3 Since we want to know the weight of the cooking pot, we need its total surface area, which can be found from

$$surface = basearea + \pi \cdot D \cdot H \qquad (c)$$

4 The weight is then

$$surface \cdot thick \cdot dens = weight \qquad (d)$$

5 To solve this problem, first make guesses for the unknowns: H, *surface*, and *weight*.

$$H := 10 \cdot cm \qquad surface := 50 \cdot cm^2 \qquad weight := 200 \cdot gm$$

Then, use a solve block to find the values of the unknowns. A solve block begins with the word *Given* and ends with the function *find*(). In between are the *constraint equations*. In this case,

Given

$$vol = basearea \cdot H \qquad (a)$$

$$surface = basearea + \pi \cdot D \cdot H \qquad (c)$$

$$surface \cdot thick \cdot dens = weight \qquad (d)$$

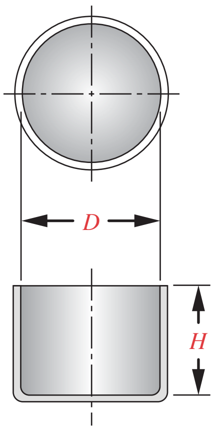

FIGURE 1

A Stainless Steel Cylindrical Container (Cooking Pot)

$$\begin{pmatrix} H \\ surface \\ weight \end{pmatrix} := find(H, surface, weight) \qquad (e)$$

6 Results:

Volume of container	$vol = 1000 \cdot cm^3$
Thickness of wall	$thick = 0.100 \cdot cm$
Density of material	$dens = 7.75 \cdot \frac{gm}{cm^3}$
Base diameter (inside)	$D = 12 \cdot cm$
Cylinder height (inside)	$H = 8.84 \cdot cm$
Area of base (inside)	$basearea = 113.1 \cdot cm^2$
Total surface area (inside)	$surface = 446.4 \cdot cm^2$
Weight of empty cylinder	$weight = 346.0 \cdot gm$

Mathcad Notes

There are three basic *Mathcad* modes: computation, text, and graphics. By default, you are in the computation mode unless you initiate either of the other two. In the computation mode you assign values to variables, solve sets of equations numerically and/or symbolically, or perform almost any kind of math or calculus operation. In the text mode you may type paragraphs or text regions, which may be placed anywhere in the document. (These notes were typed as a paragraph, while the left-hand column in step 6 above was typed as individual text regions.) Finally, you can create graphics by plotting functions that have been defined in calculation mode, or you may import graphic images such as Figure 1.

You create a text paragraph by placing the cursor at the point where you want it to begin and then either click the paragraph icon in the tool bar or choose **Create Text Paragraph** from the **Text** pull-down menu. A text region is created by clicking on the "A" icon (just to the left of the paragraph icon) or clicking **Create Text Region** in the **Text** pull-down menu. The basic difference between the two is that a text paragraph runs from the left to the right margin while a text region runs from the point started to the right margin or to any width that is set by the user. In this document only the headline and these *Mathcad* Notes are text paragraphs. All other text is in text regions.

Mathcad evaluates expressions using numerical procedures. Thus, if we type $a := b + c$, we must first assign values to b and c. If we don't, *Mathcad* won't know what to do with b and c, since they are not defined. To define b and c we give them values. For example, say $b := 2$ and $c := 5$. This must be done above or to the left of the statement $a := b + c$. Notice that at the beginning of this document *vol*, *D*, *thick*, and *dens* are defined by assigning values to them. The assignment operator (colon-equal) is gotten by typing a colon (shift ;).

You can use *Mathcad*'s equation formatting capability without its trying to evaluate an expression by using CTRL= for the equal sign in the equation. This is done in steps 1, 3, and 4 above. Notice that the result is a bold equal sign. In step 1 there are four text regions and one computation region (the equation).

In step 2 the expression for *basearea* is defined and the resulting value is displayed in separate computation regions. To display the result of an expression evaluation, type the variable name followed by the equal (=) sign. See Example 1-1 for a discussion of units.

In step 5 we solve three equations simultaneously for the three unknowns *H*, *surface*, and *weight*. This is done with a solve block, and the procedure is described in step 5. The values determined for the unknowns in step 5 are displayed in step 6.

If you have not created the *Mathcad* document that you are reading, you may have difficulty, at first, differentiating between text and computational regions. If you have access to the *Mathcad* files, load them into *Mathcad* and display them on the screen. When you do, you will see that the text regions and computation regions appear in different colors. Depending how the color preferences are set, the text may be blue or red, while the computation regions may be black. In this book, the variables in computation regions are displayed in *italics* while text is displayed in straight roman characters.

EXAMPLE 3

Simple Equation-Solving Using Mathcad - Part B

Problem	**Find the diameter and weight of an open-top, cylindrical container (a cooking pot) for a desired volume.**	
Given	**Volume**	$vol := 1000 \cdot cm^3$
	Inside height	$H := 10 \cdot cm$
	Wall thickness	$thick := 0.1 \cdot cm$
Assumptions	**The material is stainless steel with a mass density of**	

$$dens := 7.75 \cdot \frac{gm}{cm^3}$$

Solution **See Figure 1 and Mathcad file EX-03.mcd.**

1 An equation for the volume of a cylinder can be expressed as

$$vol = basearea \cdot H \qquad (a)$$

where H is the height of the cylinder.

2 The only difference between this example and the previous one is that we have specified the pot's height and asked for the diameter needed to match a given volume.

3 Using *Mathcad* this is a simple change. In the *Given* section above, *Inside diameter* is changed to be *Inside height*, and in the *solve block* below H is changed to D. Also, equation b is changed from an assignment statement to a function definition and corresponding changes are made in the solve block.

4 The area of the base can be found from

$$basearea(D) := \frac{\pi \cdot D^2}{4} \qquad (b)$$

5 Since we want to know the weight of the cooking pot, we need its total surface area, which can be found from

$$surface = basearea(D) + \pi \cdot D \cdot H \qquad (c)$$

6 The weight is then

$$surface \cdot thick \cdot dens = weight \qquad (d)$$

7 To solve this problem, first make guesses for the unknowns: D, *surface*, and *weight*.

$$D := 10 \cdot cm \qquad surface := 50 \cdot cm^2 \qquad weight := 200 \cdot gm$$

Then, use a solve block to find the values of the unknowns. A solve block begins with the word *Given* and ends with the function *find*(). In between are the constraint equations. In this case,

Given

$$vol = basearea(D) \cdot H \qquad (a)$$

$$surface = basearea(D) + \pi \cdot D \cdot H \qquad (c)$$

$$surface \cdot thick \cdot dens = weight \qquad (d)$$

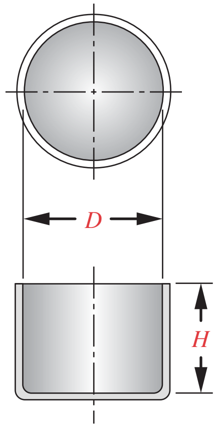

FIGURE 1

A Stainless Steel Cylindrical Container (Cooking Pot)

$$\begin{pmatrix} D \\ surface \\ weight \end{pmatrix} := find(D, surface, weight) \qquad (e)$$

8 Results:

Volume of container	$vol = 1000 \cdot cm^3$
Thickness of wall	$thick = 0.100 \cdot cm$
Density of material	$dens = 7.75 \cdot \frac{gm}{cm^3}$
Base diameter (inside)	$D = 11.28 \cdot cm$
Cylinder height (inside)	$H = 10 \cdot cm$
Area of base (inside)	$basearea(D) = 100 \cdot cm^2$
Total surface area (inside)	$surface = 454.5 \cdot cm^2$
Weight of empty cylinder	$weight = 352.2 \cdot gm$

Mathcad Notes

Equation *b* in step 4 is a *user-defined function*. It differs from a simple variable in that it has a *variable list* as part of the function name, and arguments in that list are used on the right-hand side of the assignment symbol without having been previously defined. For instance, in equation *b*, the function name is *basearea* and the argument list contains the variable name *D*. In any subsequent use of the function, *Mathcad* will substitute the current value of the argument and evaluate *basearea* according to the expression on the right-hand side of equation *b*. Notice that *basearea* is used in the solve block in step 7 to determine *D*, *surface*, and *weight*, and again in step 8 to display the results.

EXAMPLE 4

Simultaneous Equation Solving Using Mathcad

Problem **Find the diameter, height and weight of an open-top, cylindrical container (a cooking pot) for a desired volume and height/ diameter ratio (*H*/*D*).**

Given

Volume	$vol := 1000 \cdot cm^3$
Height/diameter	$ratio := 0.6$
Wall thickness	$thick := 0.1 \cdot cm$

Assumptions **The material is stainless steel with a mass density of**

$$dens := 7.75 \cdot \frac{gm}{cm^3}$$

Solution **See Figure 1 and Mathcad file EX-04.mcd.**

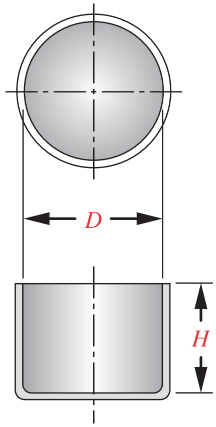

FIGURE 1

A Stainless Steel Cylindrical Container (Cooking Pot)

1 This example introduces a new constraint to the problem posed in the previous two examples, but is otherwise the same. Instead of specifying either the diameter or the height, we now specify the aspect ratio between those two parameters, and we want to find some combination of height and diameter that satisfies the two constraints of volume and aspect ratio. Defining the aspect ratio,

$$ratio = \frac{H}{D} \qquad (a)$$

2 Using *Mathcad* this is a simple change. In the *Given* section above *Inside height* is changed to be *Height/diameter*, and in the *solve block* below add equation *a* and change the list of unknowns in the *find* () function to include *H*.

3 The area of the base can be found from

$$basearea(D) := \frac{\pi \cdot D^2}{4} \qquad (b)$$

4 The weight is then

$$surface \cdot thick \cdot dens = weight \qquad (c)$$

5 To solve this problem, first make guesses for the unknowns: *H*, *D*, *surface*, and *weight*.

$$D := 10 \cdot cm \qquad H := 10 \cdot cm \qquad surface := 50 \cdot cm^2 \qquad weight := 200 \cdot gm$$

Then, use a solve block to find the values of the unknowns. A solve block begins with the word *Given* and ends with the function *find*(). In between are the constraint equations. In this case,

Given

$$ratio = \frac{H}{D}$$

$$vol = basearea(D) \cdot H$$

$$surface = basearea(D) + \pi \cdot D \cdot H$$

$$surface \cdot thick \cdot dens = weight$$

$$\begin{pmatrix} H \\ D \\ surface \\ weight \end{pmatrix} := find(H, D, surface, weight)$$

6 Results:

Volume of container	$vol = 1000 \cdot cm^3$
Thickness of wall	$thick = 0.100 \cdot cm$
Density of material	$dens = 7.75 \cdot \frac{gm}{cm^3}$
Base diameter (inside)	$D = 12.85 \cdot cm$
Cylinder height (inside)	$H = 7.71 \cdot cm$
Area of base (inside)	$basearea(D) = 129.7 \cdot cm^2$
Total surface area (inside)	$surface = 441.0 \cdot cm^2$
Weight of empty cylinder	$weight = 341.8 \cdot gm$

EXAMPLE 5

List-Solving and Plotting Using Mathcad

Problem **Find the height/diameter ratio and dimensions of an open-top, cylindrical container that will minimize its weight for a given volume. Plot the variation of weight with the height/diameter ratio.**

Given **Volume** $vol := 1000 \quad cm^3$

Wall thickness $thick := 0.1 \quad cm$

Assumptions **The material is stainless steel with a mass density of**

$$dens := 7.75 \ \frac{gm}{cm^3}$$

The ratio *H/D* will be varied from 0.1 to 2.0 in increments of 0.1.

Solution **See Figures 1 and 2, Tables 1 and 2, and *Mathcad* file EX-05.mcd.**

1 There should be an optimum *H/D* ratio for this container that will minimize its surface area and weight. Since the material is sold by weight, its cost will then be minimized as well. This simple example could be optimized by writing an expression for the weight as a function of *H/D* ratio, differentiating it with respect to that ratio, setting the differential equal to zero, and solving for the ratio. However, we can also obtain a numerical approximation to that optimum ratio from the existing *Mathcad* model by creating a vector of variables and solving the model for all values in the vector.

2 One way to assign values to a vector is to first create an index variable and then use it to define the values assigned to the vector elements,

Index variable $i := 1..20$

Vector elements $\boldsymbol{ratio}_i := 0.1 \cdot i$

The results are shown in Table 1.

3 What we want to do now is to get a set of solutions to the solve block of Example 4 for each of the elements in the vector ratio. To do this we will have to modify the assignment expression that ends the solve block by changing the left-hand side to a function. We can then evaluate the function for each of the values of ratio, giving us a vector of solutions for each of the variables: *H*, *D*, *surface*, and *weight*.

4 As before, first make guesses for the unknowns: *H*, *D*, *surface*, and *weight*.

$D := 10 \qquad H := 10 \qquad surface := 50 \qquad weight := 200$

Then, define the *basearea* function and use the modified solve block

$$basearea(D) := \frac{\pi \cdot D^2}{4}$$

Given

$$ratio = \frac{H}{D}$$

$$vol = basearea(D) \cdot H$$

$$surface = basearea(D) + \pi \cdot D \cdot H$$

Table 1

Mathcad List for the Variable *ratio*

i	$\boldsymbol{ratio}_i$
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5
6	0.6
7	0.7
8	0.8
9	0.9
10	1.0
11	1.1
12	1.2
13	1.3
14	1.4
15	1.5
16	1.6
17	1.7
18	1.8
19	1.9
20	2.0

$$surface \cdot thick \cdot dens = weight$$

$$f(ratio) := find(H, D, surface, weight)$$

4 If we substitute the vector ratio as the argument in *f(ratio)*, the result will be a matrix with 20 rows (one for each value of the index *i*) and four columns. The columns will have the values for H, D, *surface*, and *weight,* respectively. Thus,

Cylinder height (inside)	$H_i := f(\boldsymbol{ratio}_i)_1$
Base diameter (inside)	$D_i := f(\boldsymbol{ratio}_i)_2$
Total surface area (inside)	$surface_i := f(\boldsymbol{ratio}_i)_3$
Weight of empty cylinder	$weight_i := f(\boldsymbol{ratio}_i)_4$

5 The values calculated in step 4 are shown in Table 2 and a graph of *weight* versus H/D ratio is shown in Figure 2.

Mathcad Notes

Several new *Mathcad* features are shown in this example. Indexed variables are introduced in step 2, and displaying indexed variables and plotting are shown in step 5. In step 4 a solve block is used to define a function, *f(ratio)*, that returns a vector of values when the argument *ratio* is a scalar, and a matrix of values when it is a vector.

In step 2, ***ratio*** is a vector with 20 elements. The index variable is *i*, which is added to the variable name by typing a left square bracket ("[") immediately following ***ratio***, followed then by *i*. The 20 values of ***ratio*** are defined by the expression on the right-hand side of the assignment symbol. See Table 1.

The columns of the *f(**ratio**)*-matrix are extracted into named vectors in step 4. The first column contains the values of the height, H, the second contains D, and so on. The subscripts 1, 2, 3 and 4 are applied using the left square bracket as described above. Digressing for just a moment, *Mathcad* allows the user to set the index value of the first index in an array. Notice that, in this example, the index variable begins with 1. That means that the subscript of the first element in ratio is 1. We might have defined *i* to start with 0 instead of 1. If we had, the first element in ratio would have a subscript of 0. *Mathcad* uses the system variable *ORIGIN* to define the subscript (index value) of the first element in an array. By default, *ORIGIN* is set to 0. In this document it has been set to 1. This was done by changing the default value for *ORIGIN* in the **Built-In Variables** dialog box, which is in the **Math** pull-down menu.

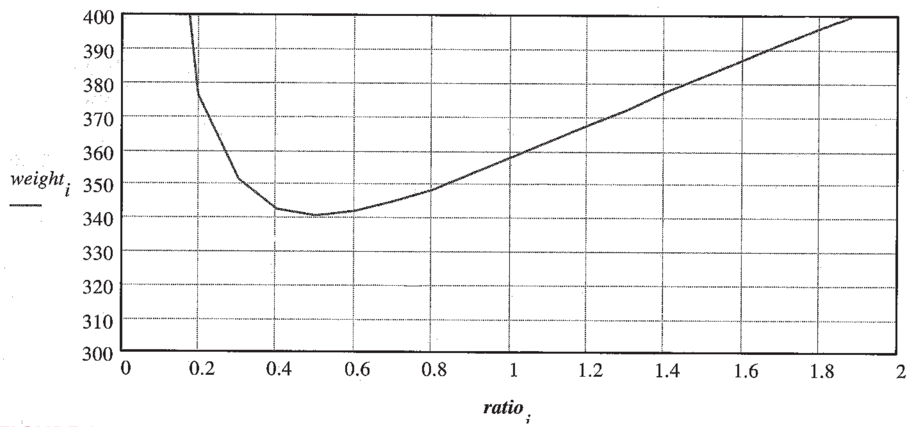

FIGURE 2

Variation of Weight-to-Diameter Ratio in Example 1-5

Table 2   Mathcad Interactive Table for Example 5

i	$ratio_i$	D_i	H_i	$weight_i$
1	0.1	23.4	2.3	464.7
2	0.2	18.5	3.7	376.3
3	0.3	16.2	4.9	351.0
4	0.4	14.7	5.9	342.5
5	0.5	13.7	6.8	340.5
6	0.6	12.9	7.7	341.8
7	0.7	12.2	8.5	344.7
8	0.8	11.7	9.3	348.5
9	0.9	11.2	10.1	352.9
10	1.0	10.8	10.8	357.5
11	1.1	10.5	11.5	362.4
12	1.2	10.2	12.2	367.3
13	1.3	9.9	12.9	372.2
14	1.4	9.7	13.6	377.1
15	1.5	9.5	14.2	382.0
16	1.6	9.3	14.8	386.8
17	1.7	9.1	15.4	391.6
18	1.8	8.9	16.0	396.2
19	1.9	8.8	16.6	400.9
20	2.0	8.6	17.2	405.4

Table 2 was created by typing the variable names (with the index variable i as a subscript) that you see at the top of each column followed by "=." *Mathcad* displays the values of each variable in the vertical columns that you see and hides the equal sign. The graph of *weight* vs. ***ratio*** was created using the **Create X-Y Plot** in the **Graphics** pull-down menu.

The sharp-eyed reader will notice that there is no dot between the units and the values in this example. Look at the definition of *vol* in the Given section. You see that the units (cm^3) and value (1000) do not have a dot (indicating multiplication) between them, and the unit is a little further to the right of the value than is normal. The reason for this is that *Mathcad* requires that all elements in a matrix have the same units. The matrix created in the solve block in step 4 would have elements with units of length, area, and force if units were used. To avoid this problem, units were not defined in the computation regions. What you see are text regions in which appropriate units are typed as text. You must, of course, use a compatible set of units when you define the input values for the problems in which units are not a part of the computations.

EXAMPLE 6

List-Solving and Functions Using Mathcad

Problem **Find the height/diameter ratio and dimensions of an open-top, cylindrical container that will minimize its weight for a given volume. Plot the variation of weight with the height/diameter ratio. Extract the optimum values from the list of solution variables.**

Given **Volume** $vol := 1000 \quad cm^3$

Wall thickness $thick := 0.1 \quad cm$

Assumptions **The material is stainless steel with a mass density of**

$$dens := 7.75 \quad \frac{gm}{cm^3}$$

The ratio H/D will be varied from 0.4 to 0.6 in increments of 0.025.

Solution **See Figures 1 and 3, Table 3, and *Mathcad* file EX-06.mcd.**

1 In Example 1-5 we saw that the weight is optimized when the H/D ratio is approximately 0.5. We will fill an array (vector) with values of ratio from 0.4 to 0.6 in increments of 0.025:

Index variable $i := 1 .. 9$

Vector elements $\boldsymbol{ratio}_i := 0.40 + 0.025 \cdot (i - 1)$

2 As before, first make guesses for the unknowns: H, D, *surface*, and *weight*.

$D := 10$ $\quad H := 10$ $\quad surface := 50$ $\quad weight := 200$

Then, define the *basearea* function and use the modified solve block

$$basearea(D) := \frac{\pi \cdot D^2}{4}$$

Given

$$ratio = \frac{H}{D}$$

$$vol = basearea(D) \cdot H$$

$$surface = basearea(D) + \pi \cdot D \cdot H$$

$$surface \cdot thick \cdot dens = weight$$

$$f(ratio) := find(H, D, surface, weight)$$

3 The solution vectors are defined as in Example 1-5

Cylinder height (inside) $\quad H_i := f(\mathbf{ratio}_i)_1$

Base diameter (inside) $\quad D_i := f(\mathbf{ratio}_i)_2$

Total surface area (inside) $\quad surface_i := f(\mathbf{ratio}_i)_3$

Weight of empty cylinder $\quad weight_i := f(\mathbf{ratio}_i)_4$

4 The values calculated in step 3 are shown in Table 3, and a graph of weight versus H/D ratio is shown in Figure 3.

5 Inspection of Table 3 and Figure 3 shows that the minimum weight is approximately 340.5 *gm* and the *H*/*D* ratio that gives this minimum is 0.500. We can use the built-in *Mathcad* array function *min(**A**)* to extract the minimum value from the weight vector, but we will have to define a function program to get the corresponding value of the *H*/*D* ratio.

Minimum weight $\quad min\,wt := \min(weight)$ $\qquad min\,wt = 340.52$

Optimum *H*/*D* ratio

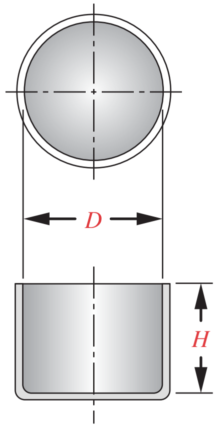

FIGURE 1

A Stainless Steel Cylindrical Container (Cooking Pot)

* Note that this problem could have been solved quickly and easily for the exact minimum weight using the calculus. We use a less-exact numerical method here to show the process. A numerical method is often the only possible solution to more complicated problems.

$$minr(w,r) := \left| \begin{array}{l} j \leftarrow 1 \\ a \leftarrow \min(w) \\ n \leftarrow \text{last}(w) \\ \textit{while } w_j \neq a \\ \quad \left| \begin{array}{l} j \leftarrow j+1 \\ \text{break} \quad \text{if} \quad j > n \end{array} \right. \\ r_j \end{array} \right.$$

$$minratio := minr(weight, \boldsymbol{ratio})$$

$$minratio = 0.500$$

Mathcad Notes

In step 5 we have used what *Mathcad* calls a "function program." The heavy, vertical line to the right of the assignment symbol indicates that a function program is being defined. The line and other symbols used in the program are applied using the programming icon in the tool bar. The function's argument list contains (in this case) two variables, w and r. These are dummy variables that will be used in the program, both as input.

Table 3 Mathcad Interactive Table for Example 6

i	$\boldsymbol{ratio}_i$	D_i	H_i	$weight_i$
1	0.400	14.7	5.9	342.5
2	0.425	14.4	6.1	341.5
3	0.450	14.1	6.4	340.9
4	0.475	13.9	6.6	340.6
5	0.500	13.7	6.8	340.5
6	0.525	13.4	7.1	340.6
7	0.550	13.2	7.3	340.9
8	0.575	13.0	7.5	341.2
9	0.600	12.9	7.7	341.8

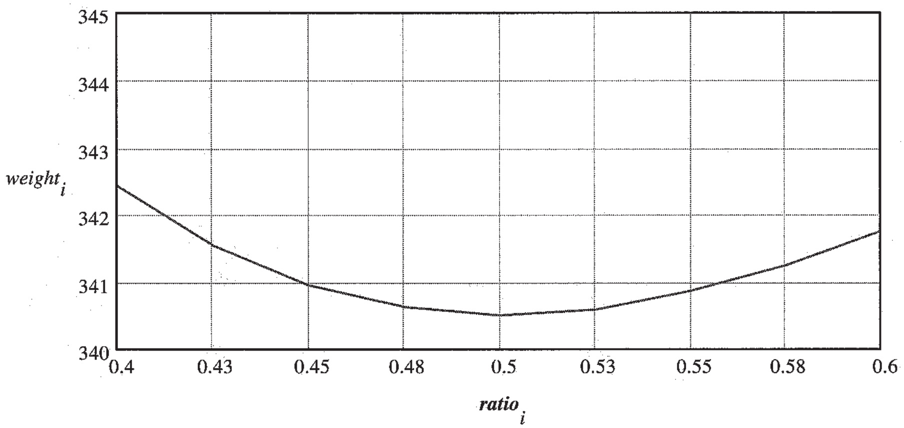

FIGURE 3

Variation of Weight-to-Diameter Ratio in Example 1-6

The variables *a*, *j*, and *n* used in the program are local to the program and are not defined outside of the program. The program is interpreted as follows:

- in the first line, set *j* equal to 1;
- in the second line, find the minimum value in the array *w* and put it into *a*;
- in the third line, take the last index value of *w* and put it into *n*;
- in line 4, a while-loop is created that will continue while w_j is not equal to *a*;
- in lines 5 and 6, the loop-index is incremented and the loop will be exited if the index exceeds *n*; finally,
- in line 7 the value r_j is returned.

Having been defined, the function program *minr* with arguments *weight* and ***ratio*** is used to find the ratio that corresponds to the minimum weight in the variable *minratio*.