INTRODUCTION TO MATHCAD
More on Plotting

In the *"Basic Concepts"* lesson you created an x-y graph by selecting the 'X-Y Plot' option from the Graphics palette. Also in that lesson, you plotted the results of a distance calculation vs. time, and made the graph "presentable" by labeling the axes, putting on a title and changing the size of the graph.

If you cannot remember how to do this, go back to the *"Basic Concepts"* lesson before proceeding with this lesson.

Start MathCAD and open your enclosures template file.
Immediately save it with the name **Mcad_Plot_01**

In this lesson, you will learn some more advanced plotting methods that you will need in later coursework. Additionally, you will start to develop one of your "firing curves" for the water balloon launcher project.

You need to do (at least) two things before you can plot a graph. First, you must define the range of the independent variable, say x, that is placed in the abscissa. Second, you need to define (or calculate) values for the dependant variable, y, that is placed on the ordinate. MathCAD "joins the dots" with straight lines, so you must have sufficient points to define a smooth curve. If you do not have enough points the graph will have a crude appearance rather than that of a smooth line. For example, we will plot the function

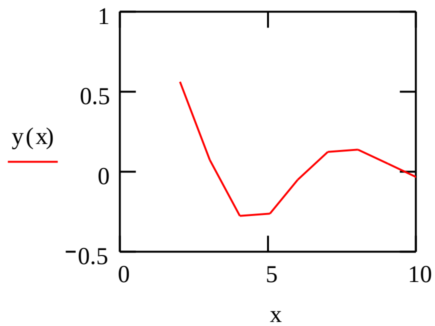
$$y = f(x) = e^{-0.25x}\sin(x)$$

over the range $2 \le x \le 10$ with x defined as the numbers 2, 3, 4, 5 . . . 10. Use the Calculator palette to enter the $\mathbf{e^x}$ exponential operator. Either type in the letters **sin**, or use the calculator palette.

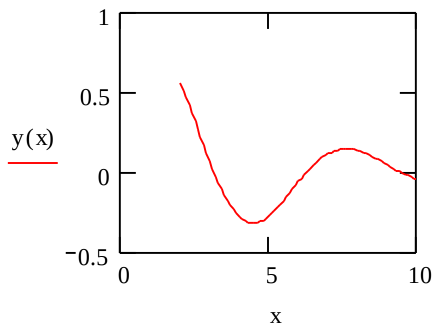
x:2;10

y(x): e$^{\text{x}}$-0.25*x®*sin(x)

Put an x-y graph on your worksheet, and put x on the abscissa (x-axis) and y(x) on the ordinate (y-axis). Your result should look something like this:



The result does not appear smooth. Change your definition of the range variable so that x now has the values 2, 2.1, 2.4, 2.6, 2.8 . . . 10, i.e., from 2 to 10 in increments of 0.1. The result gives a much smoother appearance! Always keep this important point in mind when you create a graph of a function.



Save this worksheet, and then close it. Create a new one ready for the next section. (Later, you will need to format this worksheet as an enclosure.)

<u>MORE COMPLICATED GRAPHING:</u> So far, you have used a simple range variable to define the independent variable. You can also use a vector to define the x-axis data. <u>This is the approach you will most likely use when you plot experimental data.</u>

As an example, we will use a vector to hold the x-axis data. Rather than plotting manually entered experimental data, we will automatically calculate values for the x-axis. We will also calculate data for the y-axis, such that when we plot x vs. y we obtain a Lissajous figure. A Lissajous figure is obtained by plotting cos(mπθ) vs. sin(nπθ) , where n and m are integers. First, let's create the x-axis. For experimental data you would just create an empty column vector, and type in the values. For this theoretical exercise, the easiest way to automatically generate the x-axis data is to define an integer range variable. We then use this range variable as a subscript. As you saw in Lesson #2, doing this makes MathCAD generate a vector.

Type the following. Recall that you can give MathCAD the "subscript" command either by using the Calculator palette x_n or using the shortcut key **[**. The p function is available on the Calculator palette.

i:0;50

creates range variable ‘i’ with numbers 0, 1, 2, …. 50

n:2

m:6

x[i:sin(n*p*i/50)

creates the x-axis data for all 51 points

y[i:cos(m*p*i/50)

creates the y-axis data for all 51 points

Now create an x-y graph. Put **x** on the abscissa (x-axis) and **y** on the ordinate. Your graph should have a Lissajous figure.

Try changing the values of ‘n’ and ‘m’ to see the effect on the figure. Remember, the new graph will not plot until you either click on a blank area of the worksheet, or press the **F9** key. When you have finished ‘playing’, return the values to n=2 and m=6.

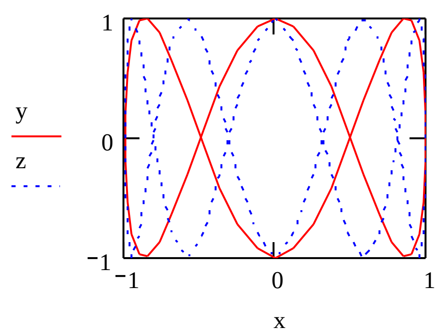
Save your work to file name **Mcad_Plot_02**. Keep the worksheet open and continue working the next section on the same worksheet.

MULTIPLE PLOTS: MathCAD can overlay many traces on one graph. The different ‘y’ functions can all plot against the same ‘x’ data. Or MathCAD can plot each ‘y’ against it’s own ‘x’ data. Here we just use one ‘x’ set of data.

Define variable r to have the value 10, and also define another vector z_i =cos(rπi/50). We now want to overlay this result on the same Lissajous figure. **Single-click** the graph. Now click the ‘y’ on the ordinate. Use the mouse or keyboard cursor keys to make sure the little blue vertical line is just after the ‘y’ by the ordinate axis. Now type the following:

,z

The comma **,** instructs MathCAD that you want to plot another vector. When you are done, your graph should look like:



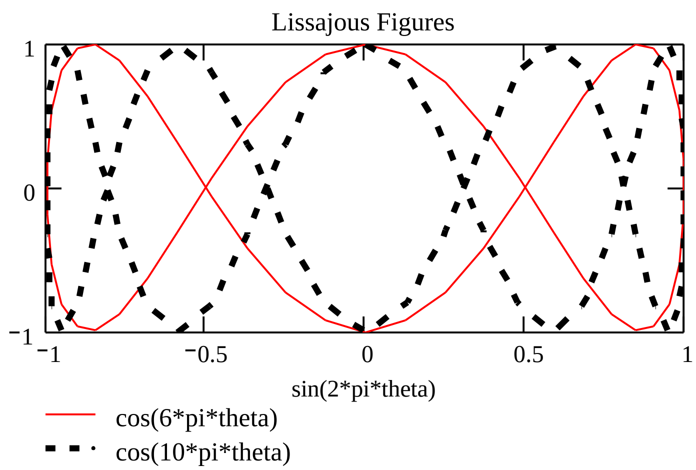
Combine the knowledge you have just learned with that from Lesson #1. Double-click on the graph. Create a title for your Lissajous figures, and label the abscissa as **sin 2**pq. (Notice you cannot enter Greek symbols into these labels.)

Change the second trace so that it is a black, dashed line with a weight (thickness) of 3. Click the "Legend" column and change the Legend Labels for the 1st and 2nd traces to **cos 6**pq and **cos 10**pq respectively.

Hide the arguments, but do not hide the legend.

Finally, change the size of your graph (make it BIGGER!).

You result should look like the following figure.



Make sure you understand the difference between the "Hide Arguments" and "Hide Legend" options. Try switching each on and off, and compare your results.

Save the changes to your worksheet (file **Mcad_Plot_02**)
Close your worksheet.

Open a blank worksheet in preparation for the next section.

<u>**PLOTTING FUNCTIONS:**</u> In the previous example, you had to create two separate functions, 'y' and 'z', in order to plot two different Lissajous figures. We can make multiple plotting of essentially similar functions much easier if we define more general functions. Let's look at an example. Suppose we want to overlay three different

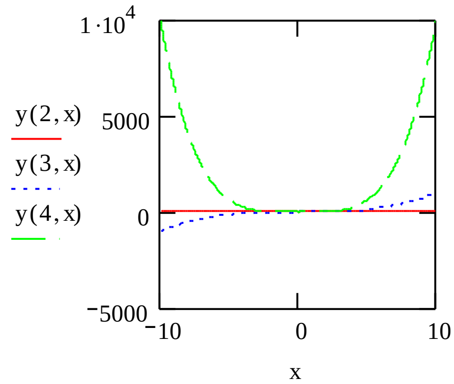
functions: x^2, x^3, and x^4. In your worksheet, define a single general function:

$$y(p,x) = x^p$$

What you are doing is telling MathCAD that *"y is a function of both 'p' and 'x'",* but you haven't decided, yet, what values of p and x you will use. Now the clever bit. Create an x-y plot, and put the following:

Abscissa: **x**
Ordinate: **y(2,x),y(3,x),y(4,x)**

Recall the **,** makes MathCAD generate multiple curves on the same axes.

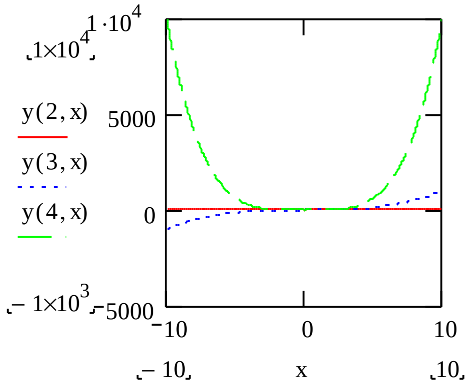


<u>What you did</u> was to save time and typing effort (both of which equate to less chance of making mistakes). You only had to define (type in) the 'y' function once, instead of typing it three times (once each for x^2, x^3, and x^4). Agreed, you have to plan your work a little more carefully, though!

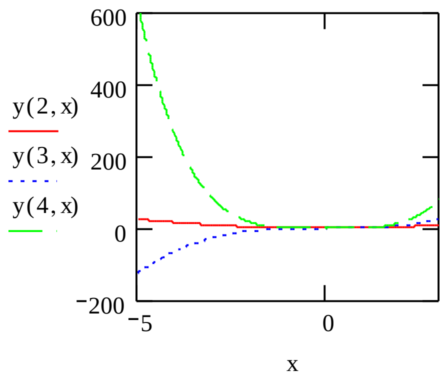
When you look at the homework for this tutorial, you will see that you have to duplicate a plot of the normal distribution function for a given mean, and for two different values of standard deviation. You may want to think about adapting the method you have just learned, rather than typing in the normal distribution function twice.

<u>SCALING THE GRAPH:</u> Now here's an interesting observation. In the previous example, you never defined what x-values were to be used! When you created the graph, MathCAD made some assumptions. Look carefully, and you will see that the x-range on the graph is $-10 \le x \le 10$. Here are two ways you can change the scaling on your graph. The tutorial only shows you how to change the x-axis scaling, but a similar method works for the y-axis as well.

Click on the graph, and you will see the '-10' and '10' values show twice, one set just above the other.



Click on the *lower* '-10' and change it to '-5'. Click on the *lower* '10' and change it to '3'. Now click on a blank area of your worksheet. You have manually changed the plotting scale to cover the range $-5 \le x \le 3$.



<u>Getting back to the 'automatic' scaling</u> is simple. Click on the graph, and then click on the axis scaling, just as if you were going to manually set the scale. This time, just **delete everything at the placeholder.** Leave the placeholder blank and then click on an empty part of your worksheet.

Make sure your graph is 'automatically' scaled with $-10 \le x \le 10$

<u>A more 'controllable' method</u> of changing the axis scaling (and probably a better way, too) is to define 'x' as a range variable. Above the graph, define x to be a range variable:

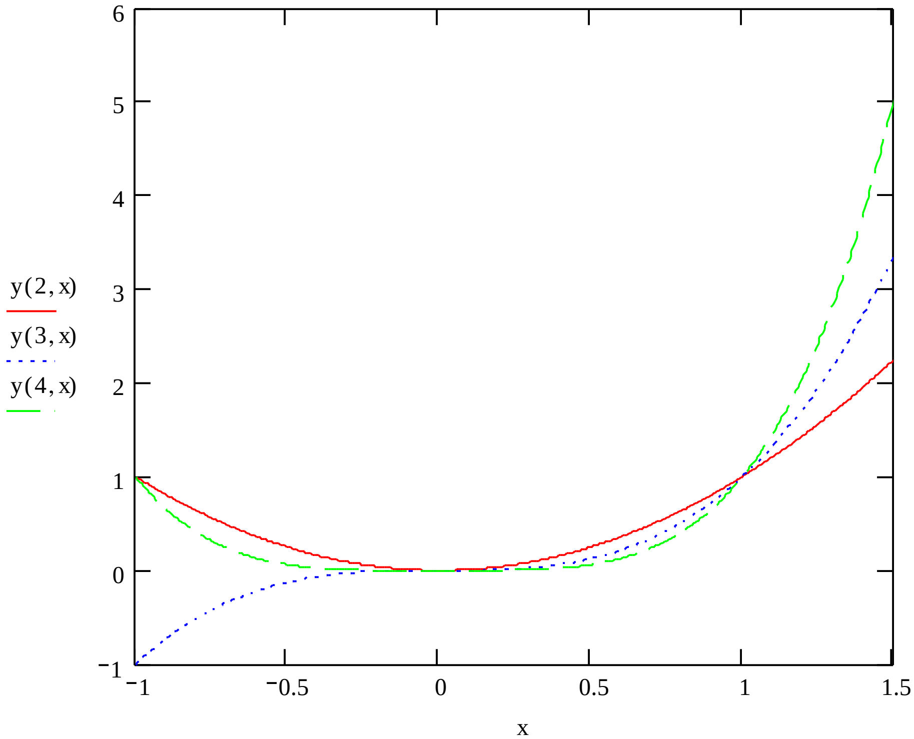
x:-1;1.5

But what an awful graph! Why? Type **x=** and see if you can work out what went wrong, and why the graph is not much use.

Try editing the range variable (or deleting it and reentering it) as:

x:-1,-0.995;1.5

Except that the graph is far too small to see anything useful (that was a hint, make it bigger NOW), you should now have a smooth set of curves.



Save your worksheet to file **Mcad_Plot_03** Close your worksheet

Start a new worksheet by opening your enclosures template file. Immediately save it with the name **LaunchAngle**

We will now start to develop your first water balloon launcher "firing curve". On the project field day one requirement is that you launch your water balloon at the correct angle. Rather than measuring angles, which is not easy to do, you will measure the height of the balloon above the ground. This angle relates directly back to the launch angle, and ensures you get the angle as accurately as possible. One of the project handouts derives the equation relating the different parameters with the initial balloon height, h_L. The equation is:

$$h_L = h_C - \frac{d_C}{2}\cos(b) - d_B\sin(b) - \sqrt{l^2 L_0^2 - \left(\frac{d_F - d_C}{2}\right)^2}\sin(b)$$

In this equation, h_C, d_C, d_B, L_0 and d_F are physical dimension of the launcher, b is the launch angle and l is the "stretch ratio". Based on the target range given to you on field day, you will be choosing values for b and l.

On your worksheet, define the following values. These are the *approximate* dimensions of the launcher (in inches)
.

L0:=72   hC:=80   dC:=6   dB:=5   dF:=48

Define l to be a range variable from 1 to 3 in increments of 0.1.

Create a single MathCAD function that determines h_L as a function of both b and l.

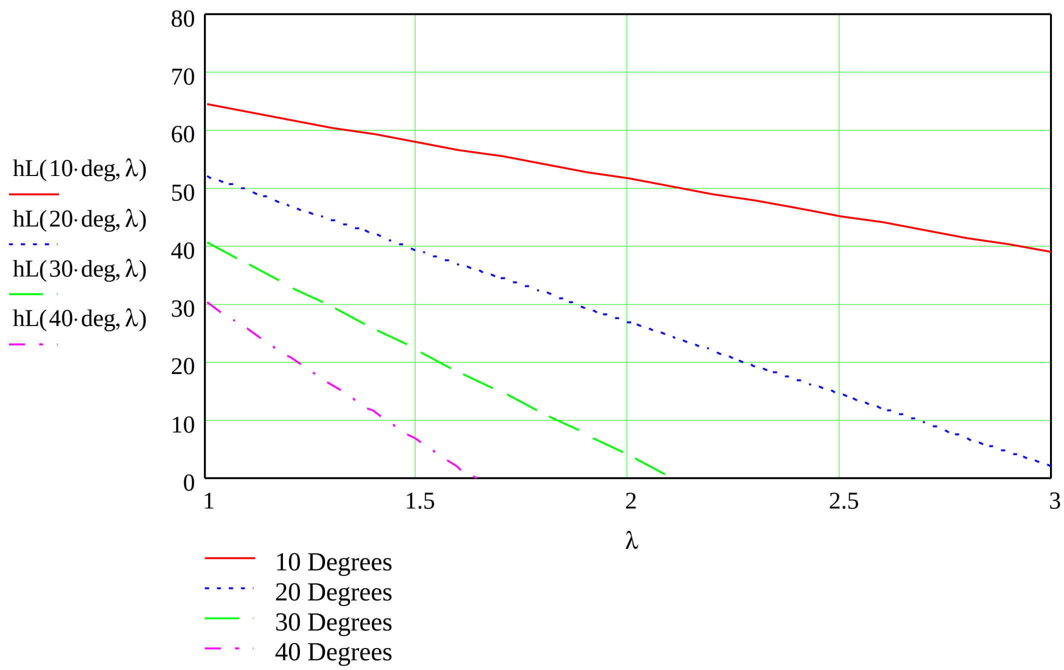
Plot and overlay graphs of h_L vs. l for launch angles of 10^O, 20^O, 30^O, and 40^O.

What does it mean if h_L goes negative? Change the scaling on your graph so that only positive values are plotted.

Put on some grid lines, making sure you have "sensible" values on each axis.

$L0 := 72 \qquad hC := 80 \qquad dC := 6 \qquad dB := 5 \qquad dF := 48 \qquad \lambda := 1, 1.1 .. 3$

$$hL(\beta, \lambda) := hC - \left(\frac{dC \cdot \cos(\beta)}{2}\right) - dB \cdot \sin(\beta) - \sqrt{\lambda^2 L0^2 - \left[\frac{(dF - dC)}{2}\right]^2} \cdot \sin(\beta)$$



SUBMIT to your instructor:
“Clean up” your **LaunchAngle** worksheet, and make everything fit on one page.

Make the graph BIG. The example in this handout is TOO SMALL.

Hide arguments, and show the Legend. Put on appropriate Legend Labels.

Format the page as an enclosure.

Submit the single printed page.

Save the cleaned-up worksheet. You will need it for your project!

Close MathCAD.
This introduction to plotting is finished!