Matlab Code "Read Me"
for
Design of Bending Multi-Layer
Electroactive Polymer Actuators

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1 Credit

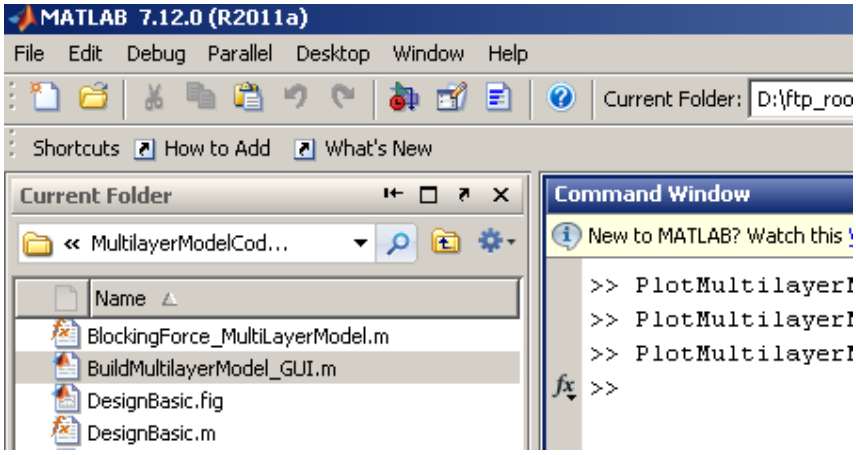
If you use this program to design a device, credit the following publication: "Design of Multi-Layer Bending Electroactive Polymer Actuators" by Bavani Balakrisnan, Alek Nacev, and Elisabeth Smela. Please look up the publication details, which were not known at the time this document was prepared.

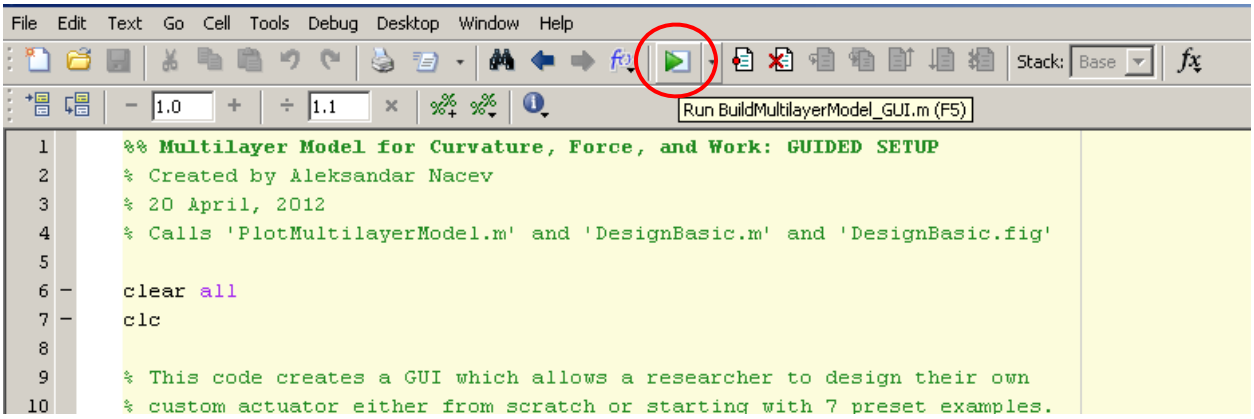
2 Using the Matlab GUI to Build Your Own Model

To start using this model, which includes a graphical user interface (GUI), copy the five .m files and the one .fig file into a single folder on your computer.

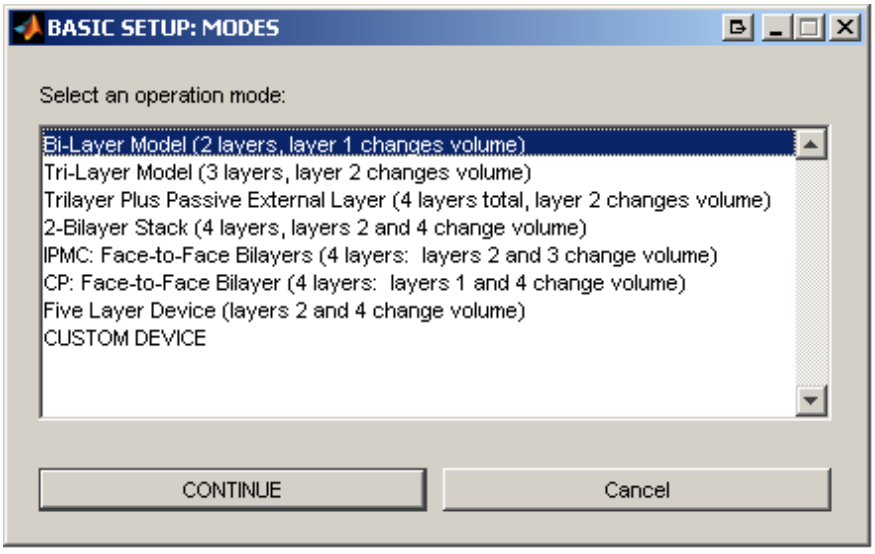
- BlockingForce_MultiLayerModel.m
- BuildMultilayerModel_GUI.m
- DesignBasic.fig
- DesignBasic.m
- MultiLayerModel.m
- PlotMultilayerModel.m

Start Matlab, which must be version 2007 or newer (for example by double-clicking BuildMultilayerModel_GUI.m). When Matlab opens, double click on this file again within the Current Folder window (see figure below) and then run the program by hitting the Run button (green arrow) in the Editor window, OR type "BuildMultilayerModel_GUI" (or copy from here and paste) into the Command Window. (Note, Mathematica may try to open this program if you double-click it. In that case, open Matlab first and then open the program from there.)

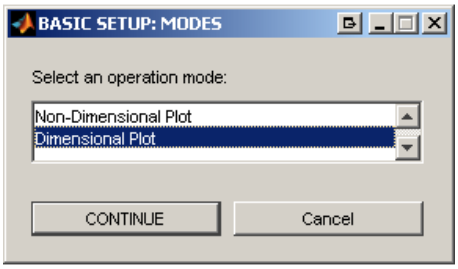




After the startup screen, you will be asked to choose a mode. These modes correspond to the devices in the paper, or you can generate your own custom device, which will take any number of layers. In the following example, we chose a bilayer.

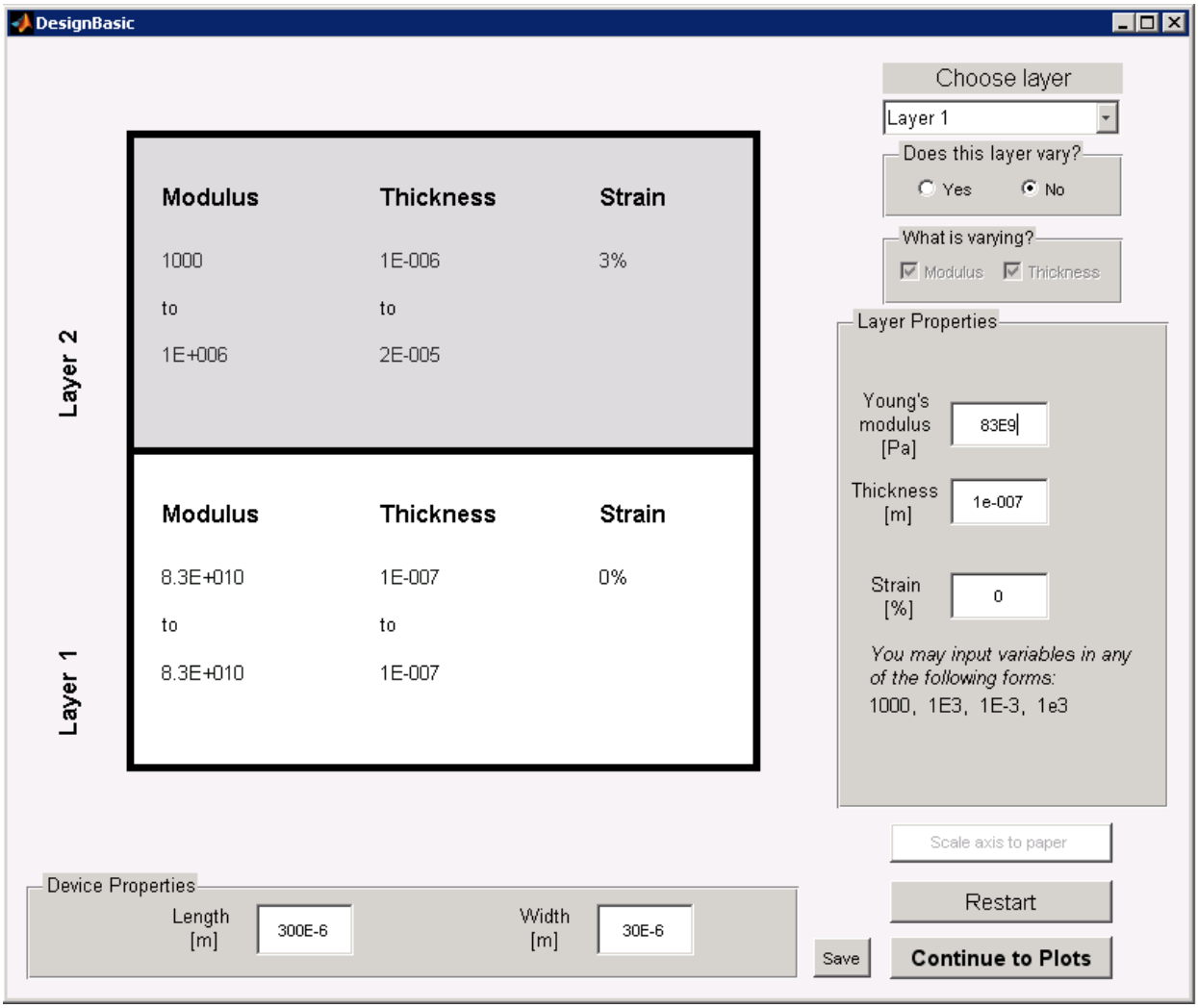


You will then be asked to choose between a non-dimensional plot, as used in the paper, or a dimensional plot, which uses real numbers. The latter is better for designing an actual device, and it is used in the following examples.



At this point, you will enter the layer information, one layer at a time.

- On the upper right is the layer number. You will fill out one sheet for each layer.



- The first question is whether the layer will vary.
  - At least one layers of the device must not vary. The program needs a reference layer.
  - All of the other layers can vary, but *in tandem*. This means that if you vary the modulus of layers 2 and 4 between 10 and 100, they will be increased together from 10 to 20, etc. to 100. The plots will show the result of their *simultaneous* variation.

- The next questions is "What is varying?" For the layers that vary, you can vary either the modulus or the thickness, or both.
  - You cannot vary thickness in one layer and modulus in another.

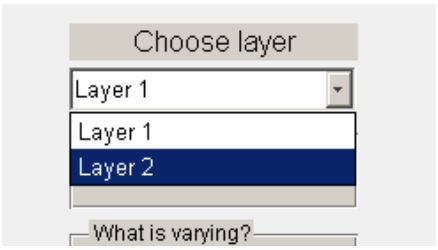
- Next comes the layer information.
  - In the GUI, a Poisson's ratio of 0.5 is used. We show you below how to change this later.
  - In the non-dimensional mode, the default values will produce the plots in the paper.
  - The units are MKS, so all distances are in meters, moduli in Pa, etc. The strain is in percent.
  - You can enter numbers in the following formats. (The latter two are convenient if you are thinking in mm or μm.)
  - 0.00001
  - 0.1E-3
  - 10E-6
  - If layers 2 and 4 vary, and if you write a thickness range for layer 2 and later write another thickness range for layer 4, the range for layer 2 will be overwritten.
  - The sign of the strain will determine the direction of bending. To get a positive curvature, you may need to reverse the sign (see below).

- As you enter information into the boxes, the figure will update.
  - Layers that have an actuation strain will be shaded gray. Others will be white.

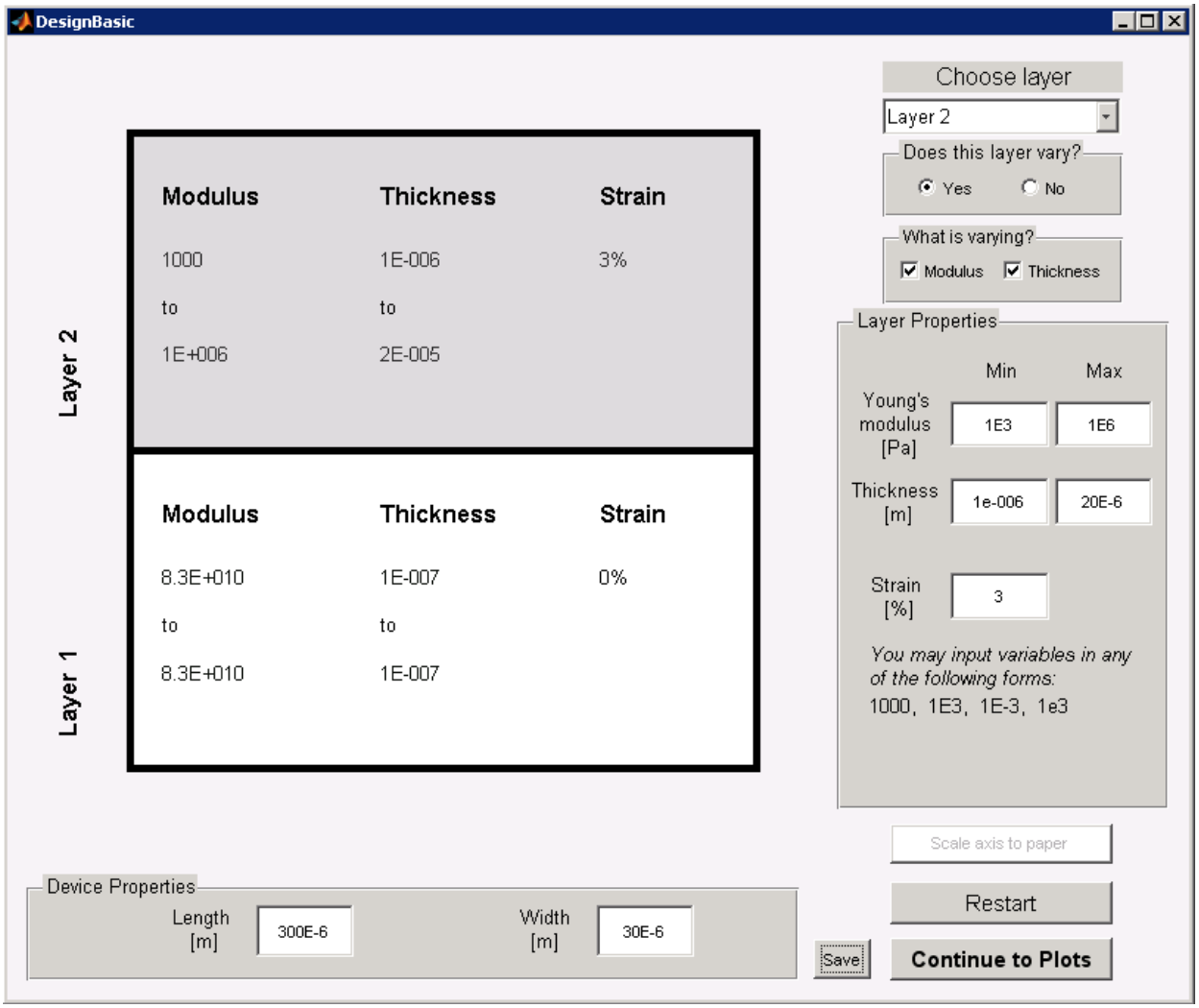
- At the bottom left, enter the length and width of the device. If you change the length or width in a screen for another layer, all the layers will update to the new values. (Within this GUI, all the layers will have the same dimensions. Below we will show how to input different widths.)

- Hit an "enter" after the last value for each layer, before proceeding to the next layer or proceeding to "Continue".

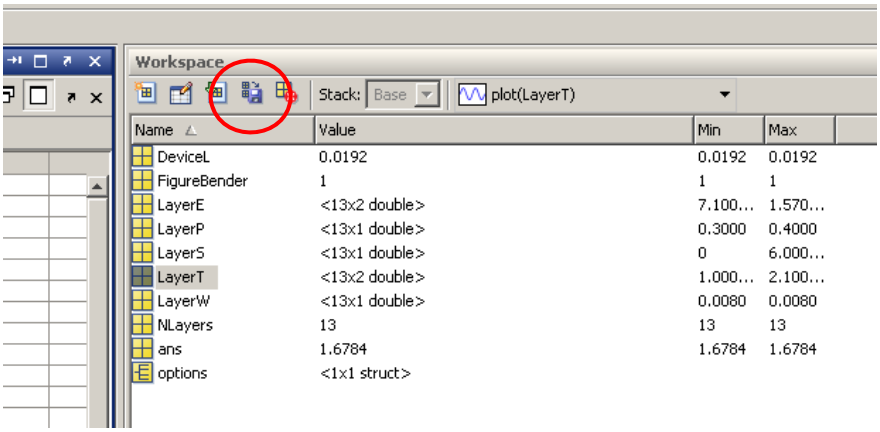
- Choose another layer using the pull-down menu and enter the information for that layer. Repeat until all the information has been added.
  - If you do not enter all the necessary information, the program might crash. Restart the program and restart your model-building in that case.



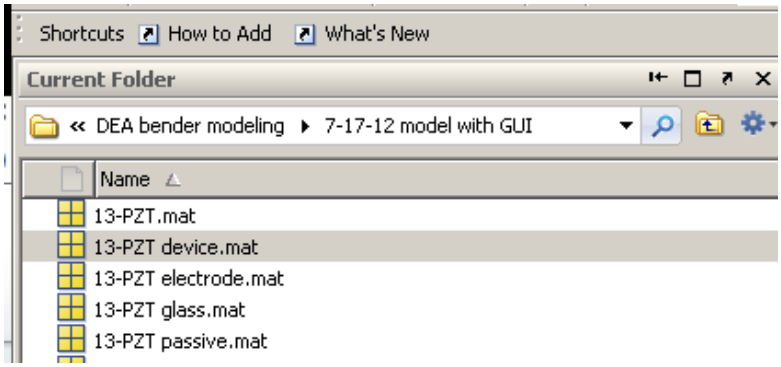
- You may go back and forth between layers, which can be completed in any order and edited until you hit "Continue to Plots".



Hitting "Save" will produce a .mat file that saves the model, which can then be loaded again at a later time. You can also choose to save the model later from the Workspace pane in the Matlab window.

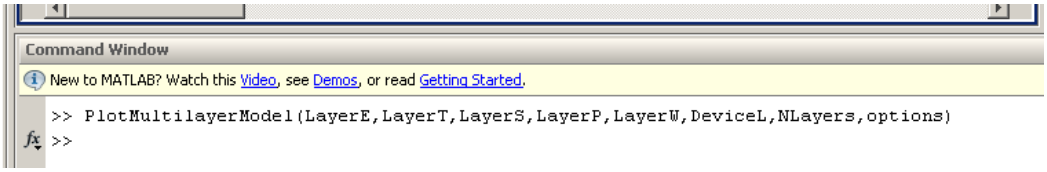


To load a previously made model, type "clear all" into the command window and then double-click the saved filename.

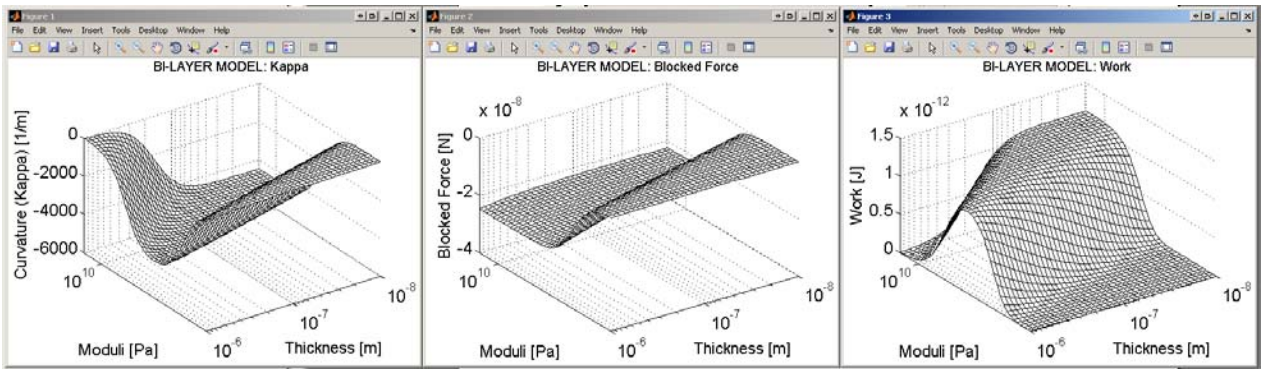


To run this model (without the GUI), type this into the command line:

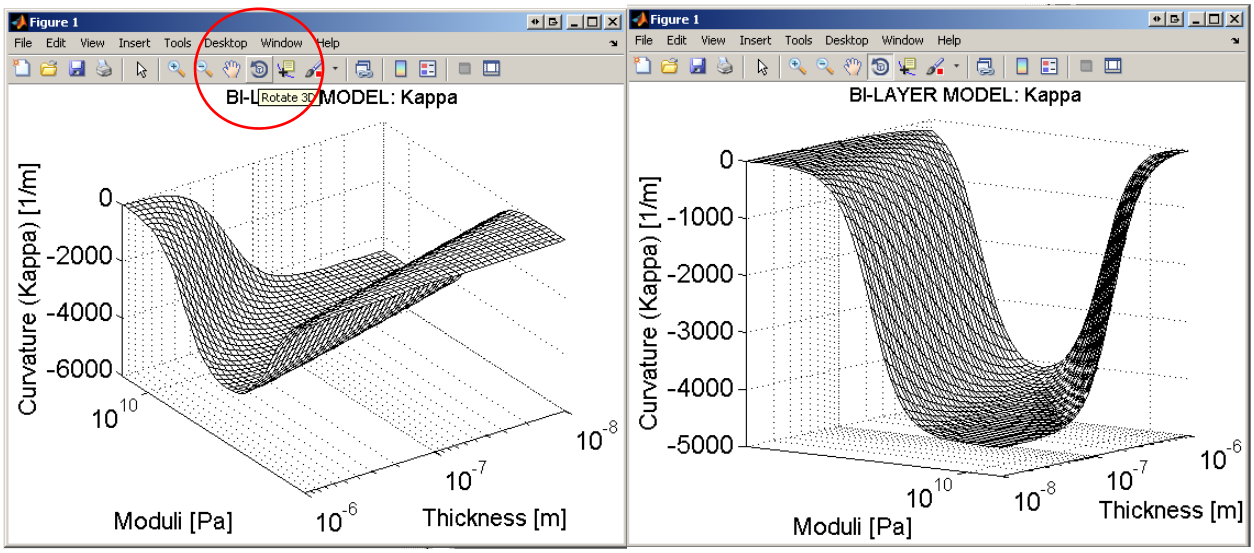
"**PlotMultilayerModel(LayerE,LayerT,LayerS,LayerP,LayerW,DeviceL,NLayers,options)**"



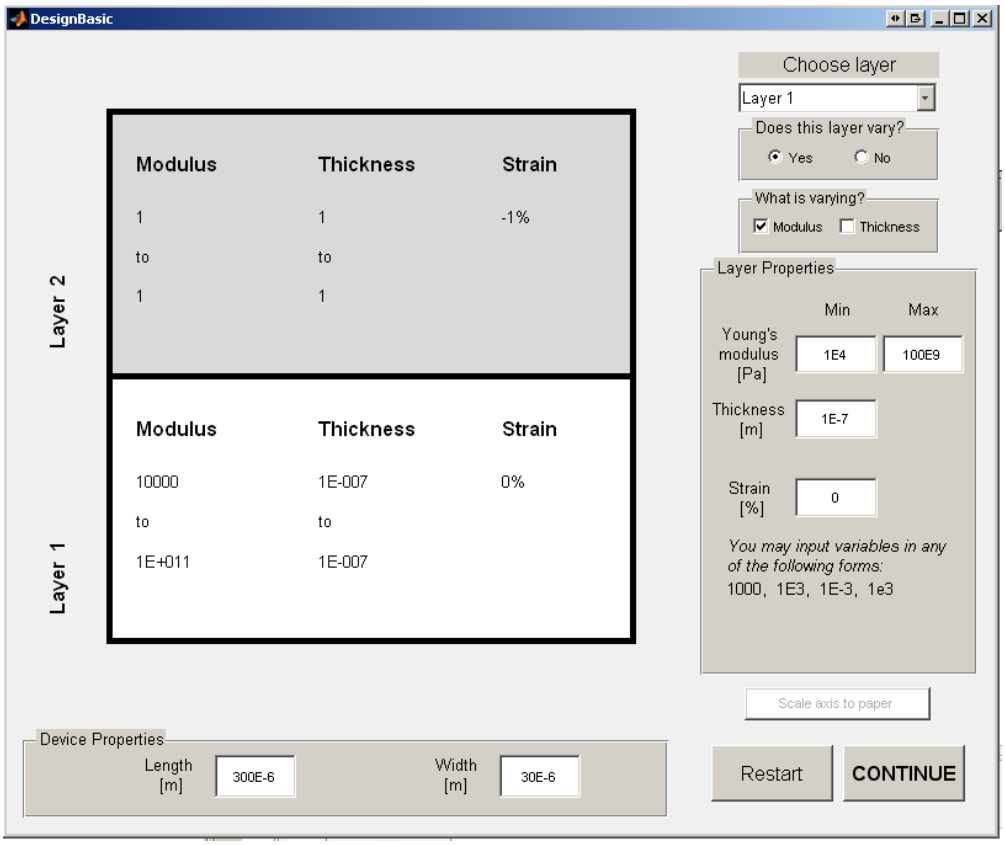
When you hit "Continue to Plots", the plots (or single values) will be generated. In this example, both modulus and strain were varied, so 3D plots were produced. A figure of your model showing the layers and their values will also be produced, which can be saved for reference.

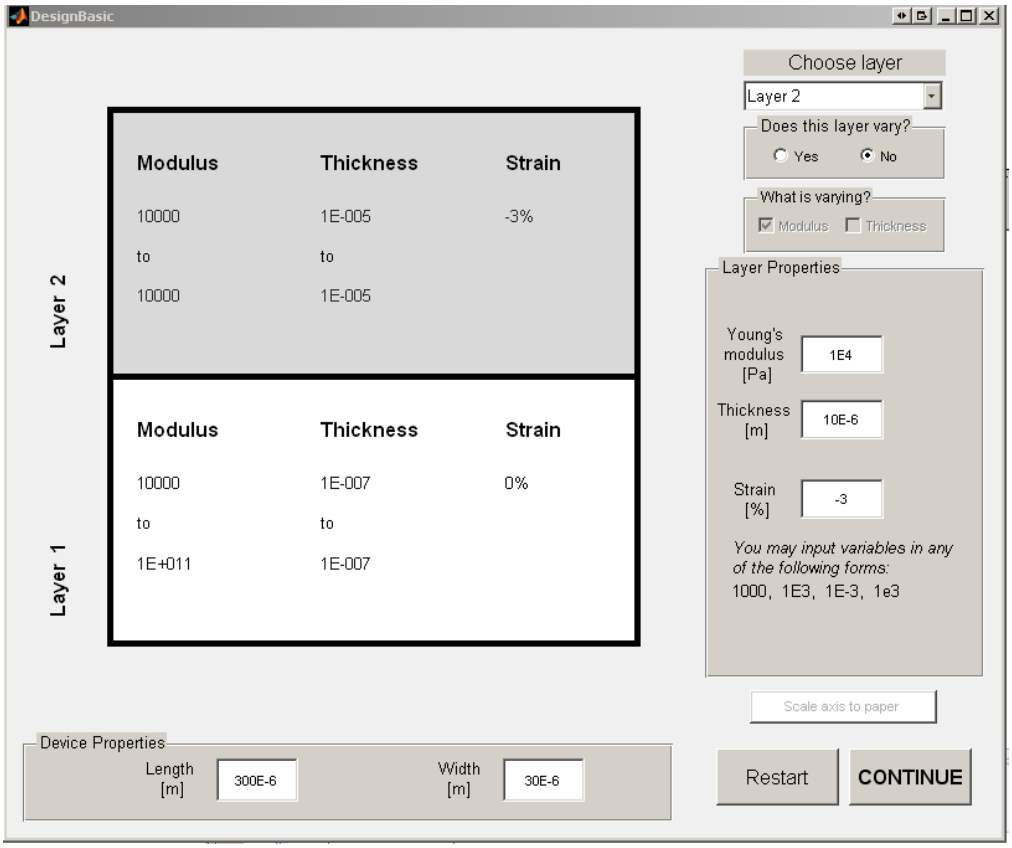


You can rotate the plot using the rotate option to better see the shape.

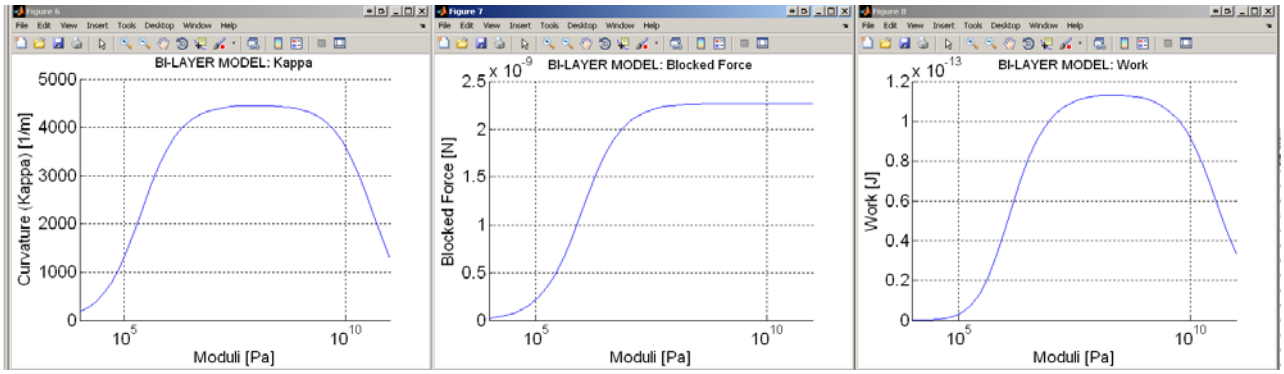


In the following example, only the modulus of Layer1 is varied. Layer 2 is not varied.


DesignBasic
Choose layer
Layer 1
Does this layer vary?
Yes
No
What is varying?
Modulus
Thickness
Layer Properties
Min
Max
Young's modulus [Pa]
1E4
100E9
Thickness [m]
1E-7
Strain [%]
0
You may input variables in any of the following forms:
1000, 1E3, 1E-3, 1e3
Layer 2
Modulus
Thickness
Strain
1
to
1
1
to
1
Layer 1
Modulus
Thickness
Strain
10000
to
1E+011
1E-007
to
1E-007
0%
Scale axis to paper
Device Properties
Length [m]
300E-6
Width [m]
30E-6
Restart
CONTINUE

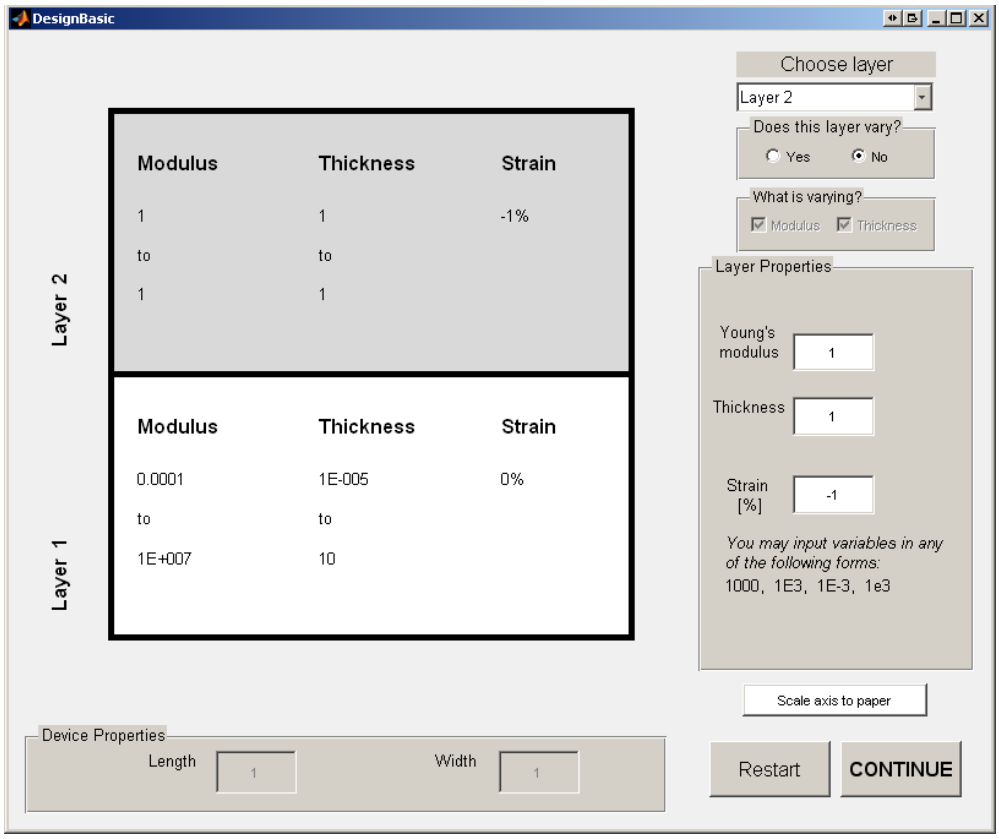

DesignBasic
Choose layer
Layer 2
Does this layer vary?
Yes
No
What is varying?
Modulus
Thickness
Layer Properties
Young's modulus [Pa]
1E4
Thickness [m]
10E-6
Strain [%]
-3
You may input variables in any of the following forms:
1000, 1E3, 1E-3, 1e3
Layer 2
Modulus
Thickness
Strain
10000
to
10000
1E-005
to
1E-005
-3%
Layer 1
Modulus
Thickness
Strain
10000
to
1E+011
1E-007
to
1E-007
0%
Scale axis to paper
Device Properties
Length [m]
300E-6
Width [m]
30E-6
Restart
CONTINUE

As a result, 2D plots are produced. If nothing is varied, then a single number is output and displayed in the command window.



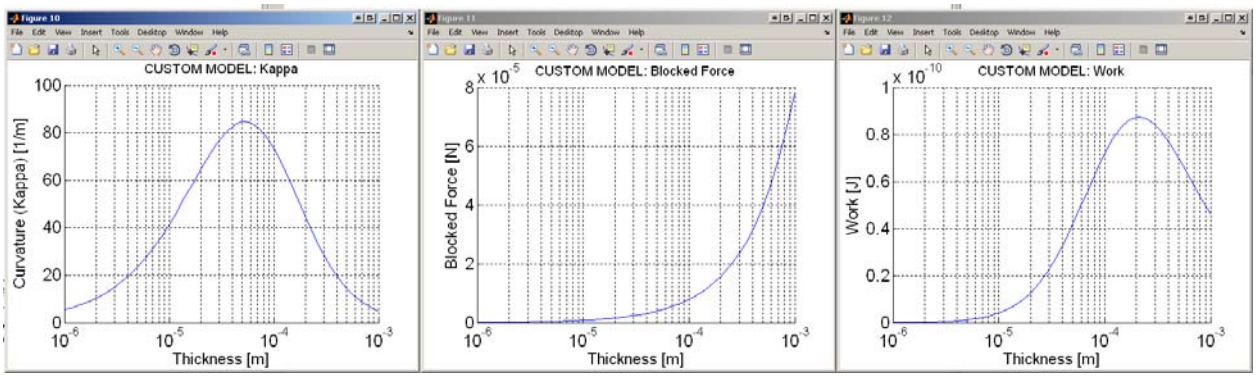
3 Non-Dimensional Example

The first time you run the nondimensional model, we recommend that you use the defaults for layer 2. Using the defaults also for layer 1 results in the plots in the paper.
Since these dimensions are relative, it is best for one layer to have values of 1 for everything. Then a modulus of 1E+007 for another layer means that its modulus is 10^7 times greater.



4 Changing the Values in Your Model

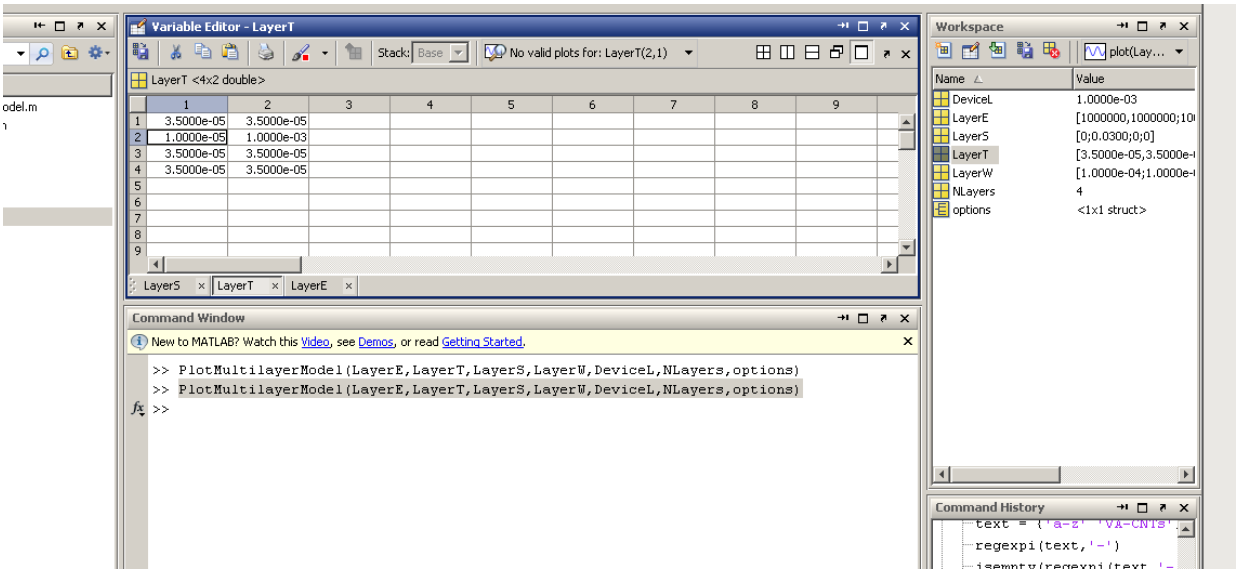
Below are plots from a 4-layer model. Suppose that I now wanted to zoom in, plotting from 10^{-5} to 10^{-3}, or suppose I wanted to change the modulus of layer 4, *without* retyping all the information into the GUI? Or suppose that the Poisson's ratio is not 0.5?



The values generated by the GUI are saved in these variables.

- DeviceL: device length
- LayerE: layer moduli
- LayerP: layer Poisson's ratios
- LayerS: layer actuation strains
- LayerT: layer thicknesses
- LayerW: layer widths (they don't all need to be the same)
- NLayers: number of layers

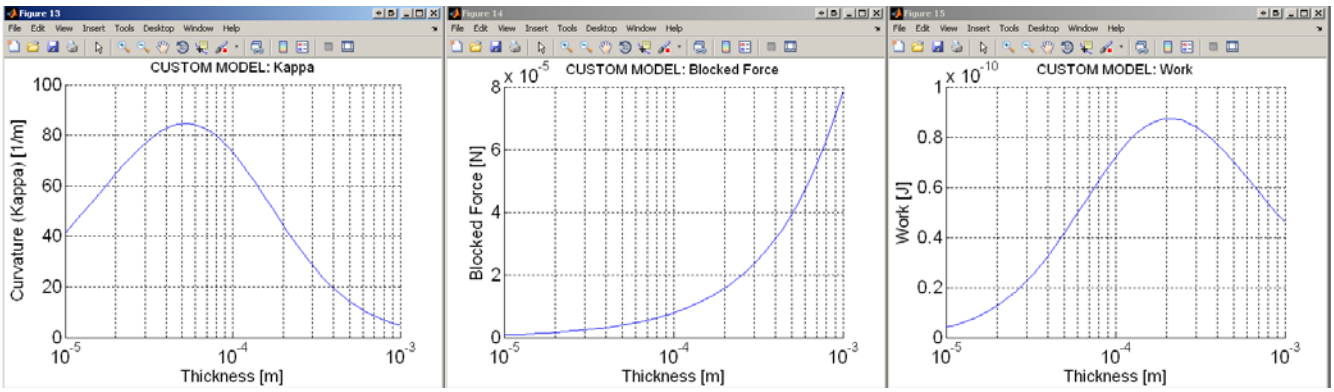
Thus, to change the values in the model, double-click the appropriate name in the Workspace window of Matlab. This opens a Variable Editor window, as shown in the figure. Row 1 holds the values for Layer 1, row 2 holds the values for Layer 2, etc. If a layer is constant, then the two columns show the same number. If a layer varies, column 1 shows the minimum value and column 2 shows the maximum value. *If the values are not in increasing order, the program will generate an error.*



In this example, the thickness of layer 2 is varied. To change the plot to go between 10^{-5} and 10^{-3}, edit the value in row 2, column 1 to read 1E-5 instead of 1E-6. Then type (or copy from here and paste) the following command into the command window,

"**PlotMultilayerModel(LayerE,LayerT,LayerS,LayerP,LayerW,DeviceL,NLayers,options)**".

This will re-run the program without the GUI and generate new plots.



- In the custom model (only), you can even change the number of layers, as long as you have entries for the correct number of layers in each variable and change NLayers. Within a particular model type (such as Trilayer), you cannot not change the number of layers.
- Editing in this way is a much faster way of playing with a model once it has been created.