SUGAR – Cantilever Simulation Manual

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Introduction

The study of micro beams is a difficult one because the fabrication of such devices is both expensive and arduous. An open source tool to simulate such beams would greatly help the progress of this field. However, because nanotechnology is among the newer sciences, not everywhere has the funding and resources necessary to adequately study this topic. This tool simulates micro beams without the hassle of fabrication. These simulations will use SUGAR, a language to work with MATLAB in order to perform various physical and electrical calculations and simulations. In order for this tool to be used by others, the Rappture program was used to design a user interface that would allow for the easy simulation of cantilever and fixed end micro beam structures under various force and moment generating loads. The interface allows the user to specify the materials and shape of the structure the load is being applied to, in addition to the type of load being applied, and the type of variable analysis that will be used in the simulation. The intended result of this project is that this tool will be used in the study and demonstration or teaching of Micro-Electro-Mechanical Systems (MEMS), specifically micro beam structures.

The simulator is currently designed to simulate cantilever beams. A cantilever beam is a beam that is anchored at one end while the tip of the beam is allowed to hang freely. (Figure 1) The tool is designed to simulate how the cantilever beam will act under various forces and moments. There are two different simulations can be done by the tool: static analysis and (up to two parameters) sweep analysis. In the static analysis, up to four sets of three dimensional (3-D) loads (forces and moments) can be applied on the cantilever at user defined positions (the last one set has to perform at the tip of the cantilever). The final output of the tool is graphic representation of the beam that shows deflection of the beam along the three primary axes as well as the numerical deflection value of the interested point in table format.

The netlist file which is used in SUGAR simulation is available to be downloaded in the final stage for user's future development.

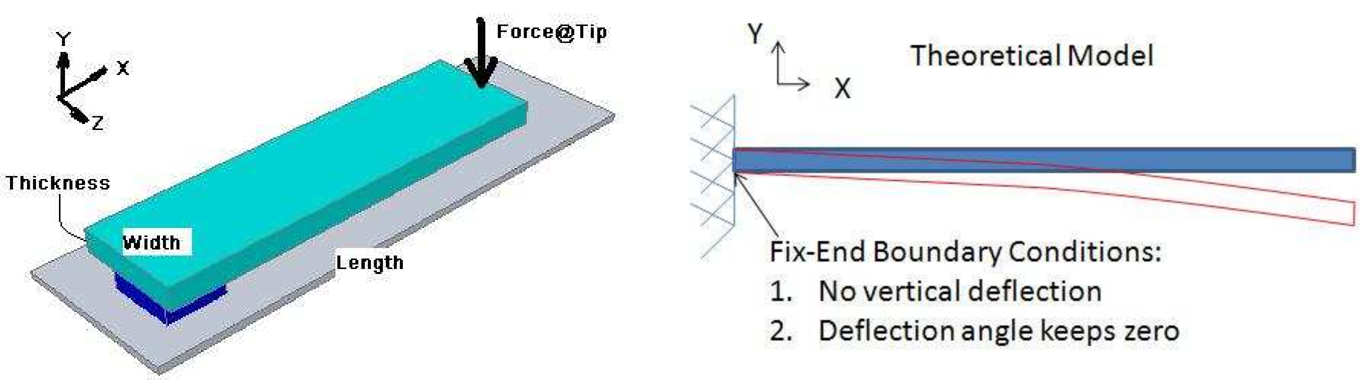


Figure 1: Practical (Left) & Theoretical (Right) Model of Cantilever

Theory

In this section, the physics behind the beam simulator is briefly discussed. We begin with a few assumptions made in this simulation and then move onto a mathematical explanation of the results generated by the tool.

Assumptions

There are various assumptions made throughout the simulation of these beams. Some of these assumptions are made purely for the sake of these simulations and others are more universal assumptions for the beam theory.

Assumptions for Simulation

- There are no external forces or moments other than those inputted by the user and those anchoring the beams

- The anchored end of the beam remains completely unmoved

- During static analysis all inputs are held constant

- On the micro scale gravitational forces are miniscule relative to electric forces

- The beam has a rectangular cross section

Mathematical Assumption

The only major assumption is that beam theory applies in all instances. For more detailed list of the mathematical assumptions entailed by this theory, see next section – Beam Theory.

Beam Theory

The Euler-Bernoulli Beam equation is an equation used to analyze the deflection of and characteristics of beams under applied loads. The theory rests on five basic assumptions which will be detailed in section 2.2.1 Beam Theory Assumptions. This section will then proceed to detail the equation itself out.

Beam Theory Assumptions

Strictly stated, the beam theory assumptions are as follows:

- Continuum mechanics is valid for a bending beam.

- The stress at a cross section varies linearly in the direction of bending, and is zero at the center of every cross section.

- The bending moment at a particular cross section varies linearly with the second derivative of the deflected shape at that location.

- The beam is composed of an isotropic material.

- The applied load is orthogonal to the beam's neutral axis and acts in a unique plane.

In lames terms, the five assumptions are more simply put:

- Calculus applies to beams.

- Beam stress can be described in a particular mathematical fashion.

- The force that resists deflection is dependent on the deflection at any point in particular, mathematical way.

- The material acts the same in every direction.

- The beam only bends, it does not stretch or twist.

The Beam Equation

The beam equation is as stated below (Equation 1):

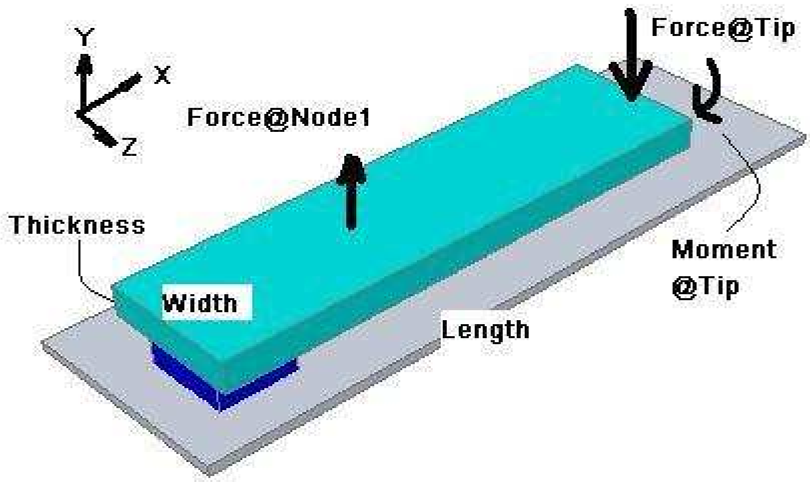
$$EI\frac{\partial^2 u}{\partial x^2} = M(x) ------ \text{Equation 1}$$

In this equation, $u(x)$ is an equation describing the deflection of the beam with respect to the variable x, which is the position along the beam. E is the elastic or Young's modulus of the material the beam is made of. I is the second moment of area of the cross section of the beam. $M(x)$ is the moment load applied to the beam at position x.

Example

Question#1: Find the tip deflection of the cantilever with following applied loads.

Question#2: Find the tip deflection of the cantilever in sweep analysis. The first sweep parameter is Node1 position from 5um to 10um with 1um step, while the second sweep parameter is tip force magnitude from 0uN to 10uN with 1uN step.



Material

- Silicon
- Young's Modulus = 165GPa
- Poisson Ratio = 0.3

Geometry

- Length = 100um
- Width = 2um
- Thickness = 2um
- Node1 @ 10um from the anchor

Load

- Force @ Node1 = 30uN (y-axis)
- Force @ Tip = 10uN (-y-axis), Moment @ Tip = 5uN-um (-z-axis)

Phase I – Model Description

1. Introduction to the tool. (Figure 2)
2. Links to an Example and Manual. (Figure 2)
3. Image of the cantilever with geometry & load information. Pay attention to the definition of the universal coordinate system (UCS) which will be consistently used throughout this tool. (Figure 2)

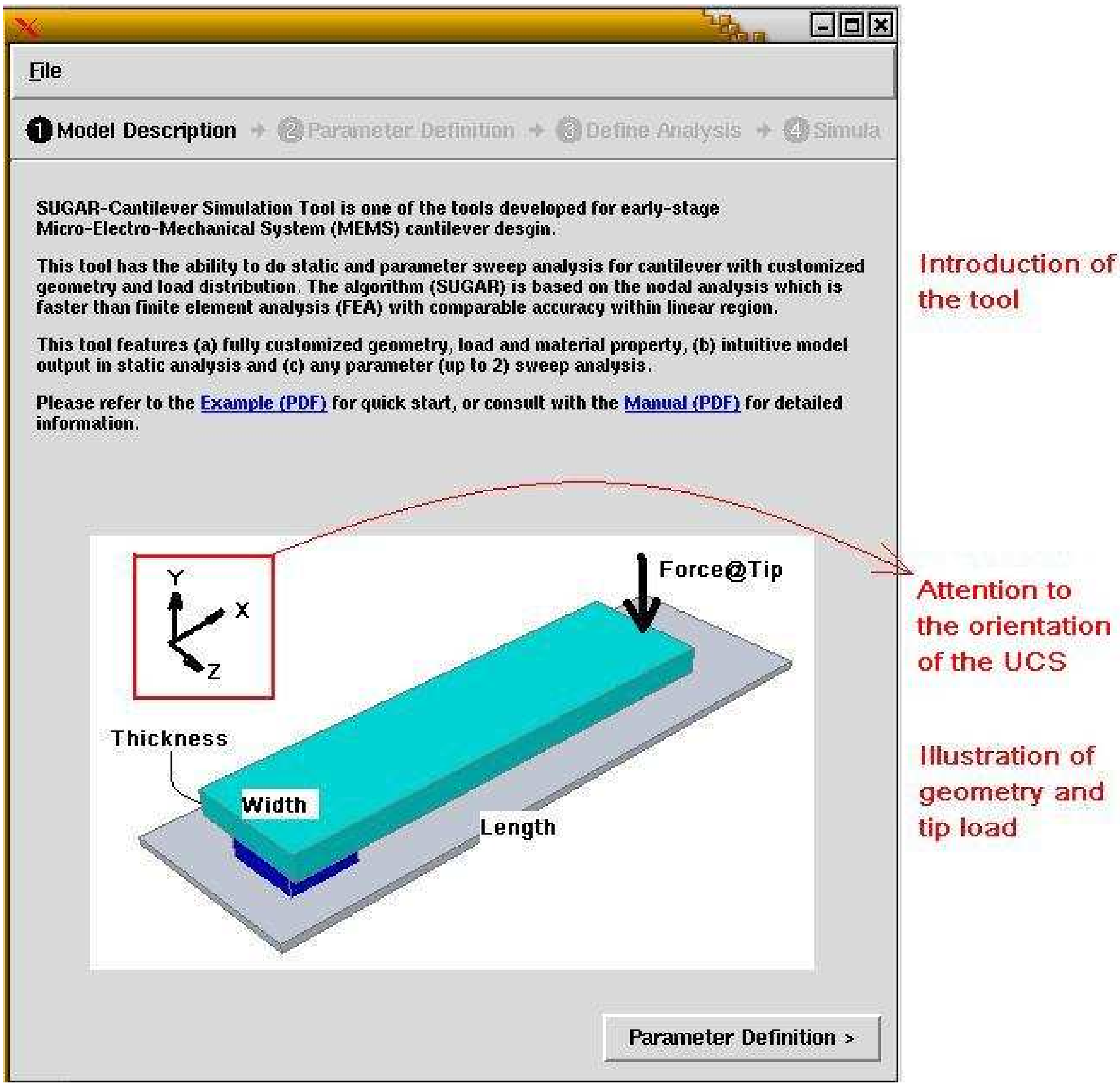


Figure 2: Model Description GUI with Comments

Phase II – Parameter Definition

1. Define the material, geometry and load properties. (Figure 3)
2. Add up to three additional loads to the tip load if desired. (Figure 3)
3. Define the directions of the applied loads. (Figure 3)

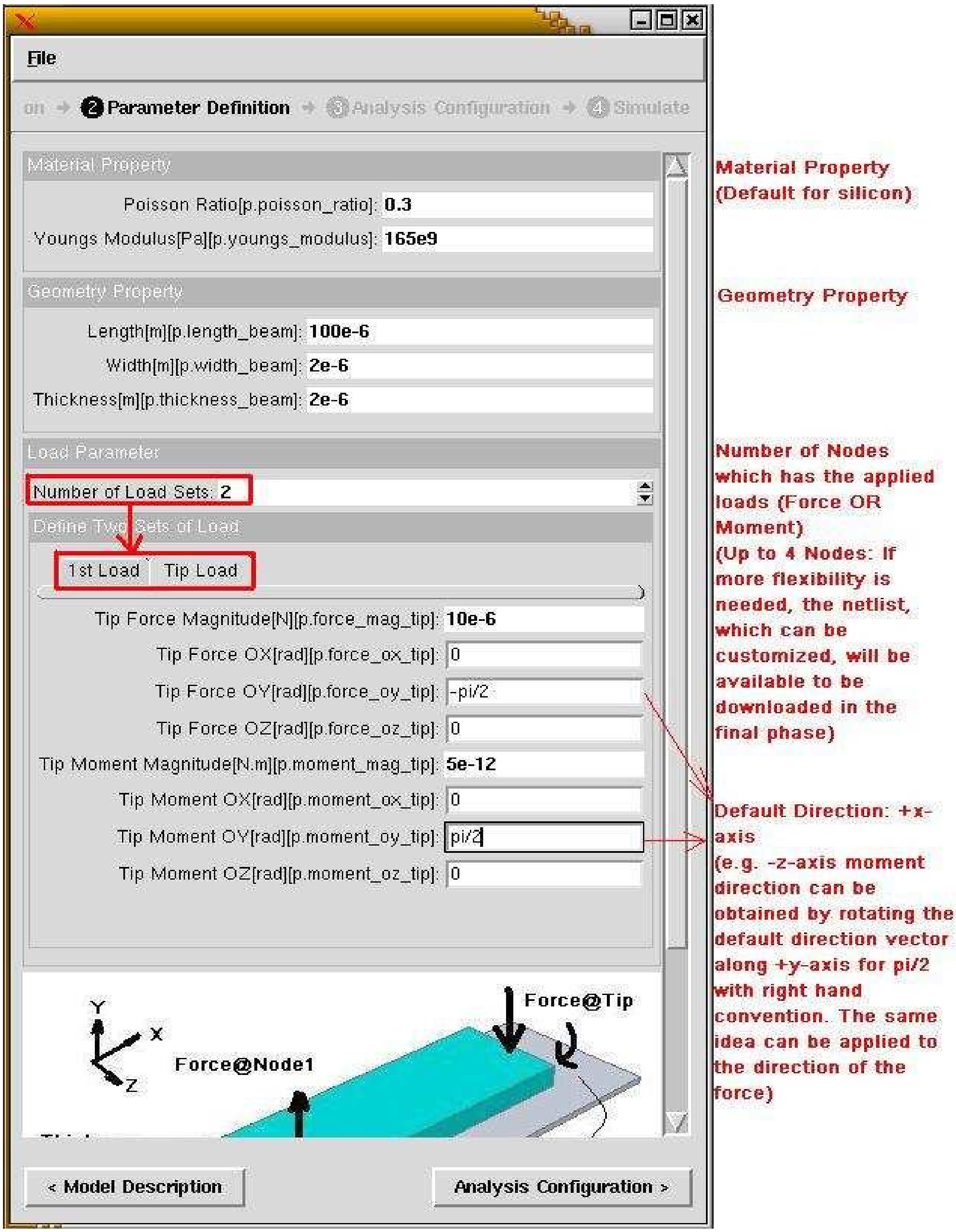


Figure 3: Parameter Definition GUI with Comments

Phase III – Analysis Configuration

1. Two types of analysis (static analysis, parameter sweep analysis) can be done by this tool.
2. Customized view angle can be defined for output plot.
3. Up to two parameters can be swept in analysis.

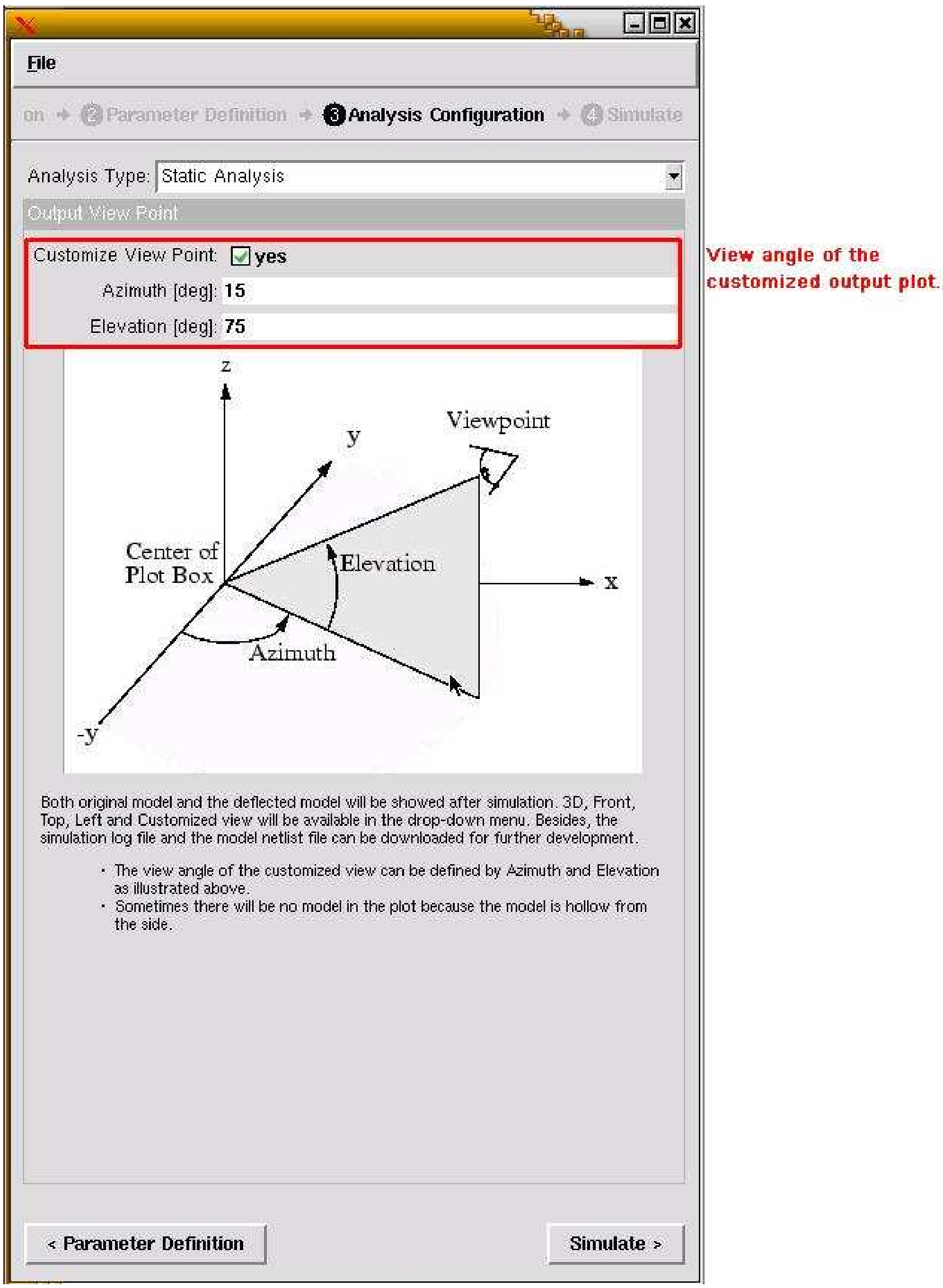


Figure 4: Static Analysis GUI with Comments

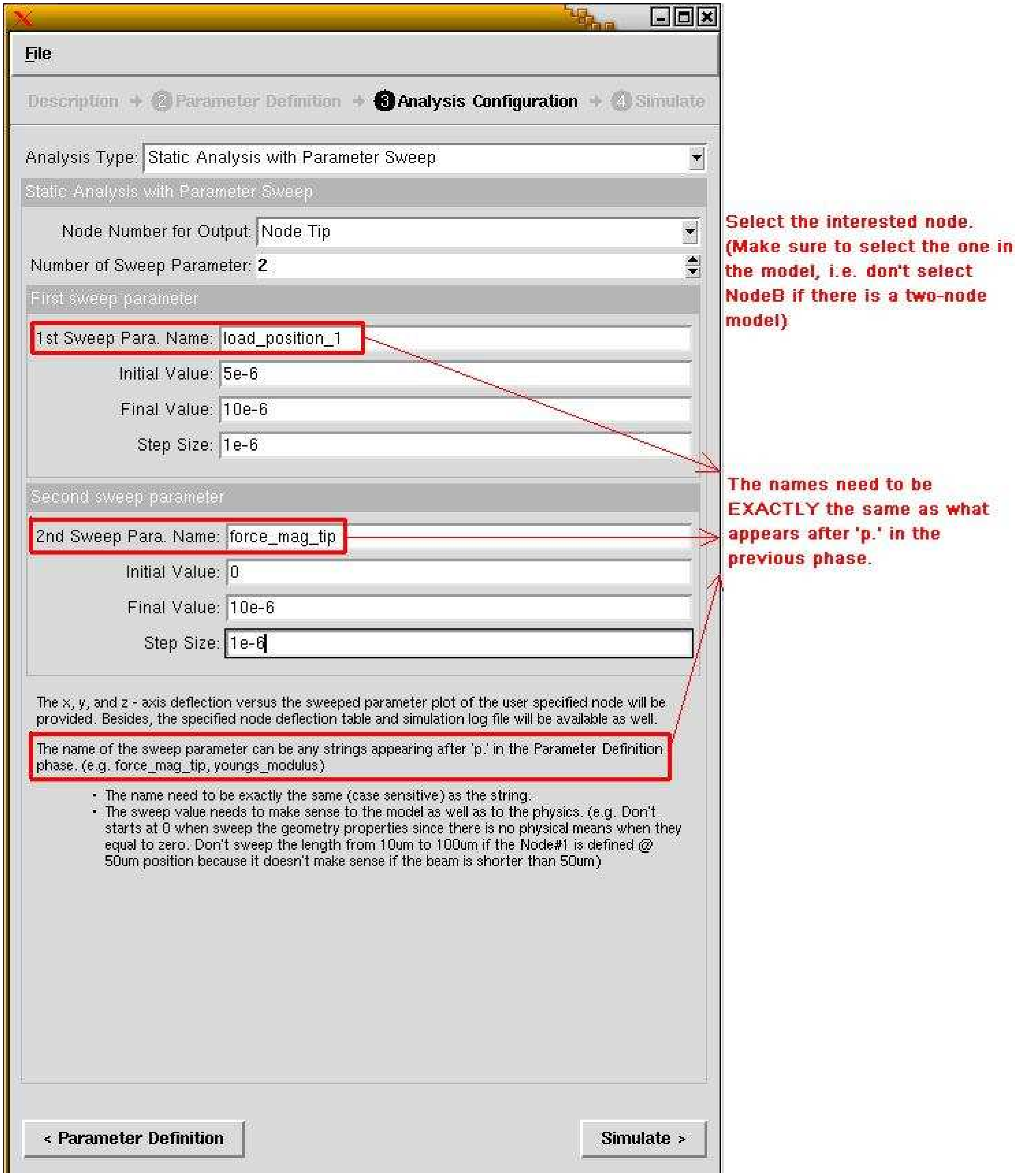


Figure 5: Parameter Sweep Analysis GUI with Comments

Phase IV – Simulation Result

1. All the results can be found through the drop-down menu.
2. All the results can be downloaded for further development. (image file or text file)
3. The curve images are dynamic (i.e. it can be zoomed in or out).

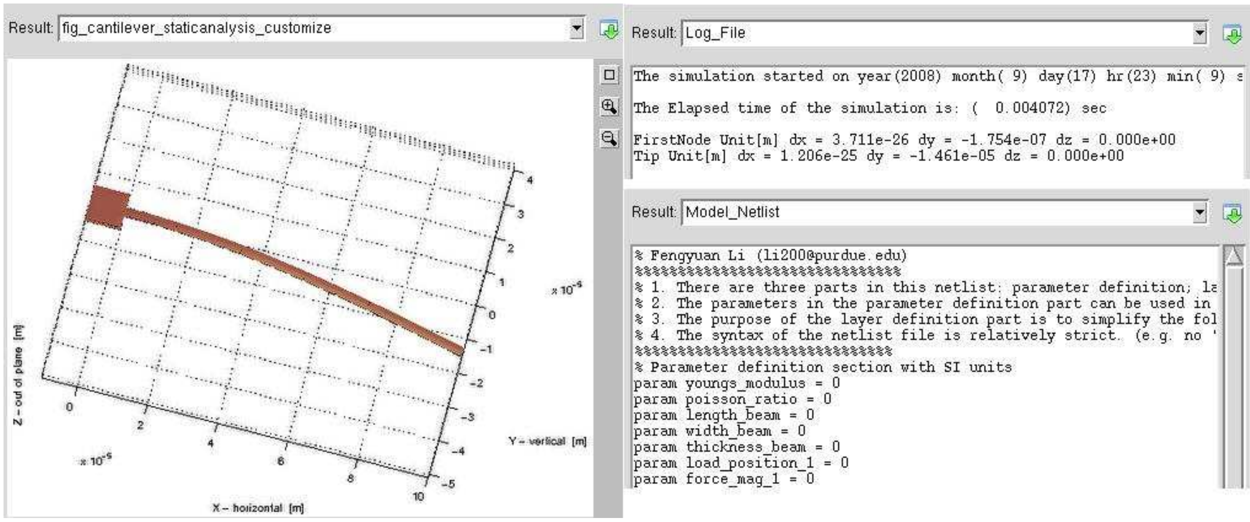


Figure 6: Screens of the Outputs of Static Analysis

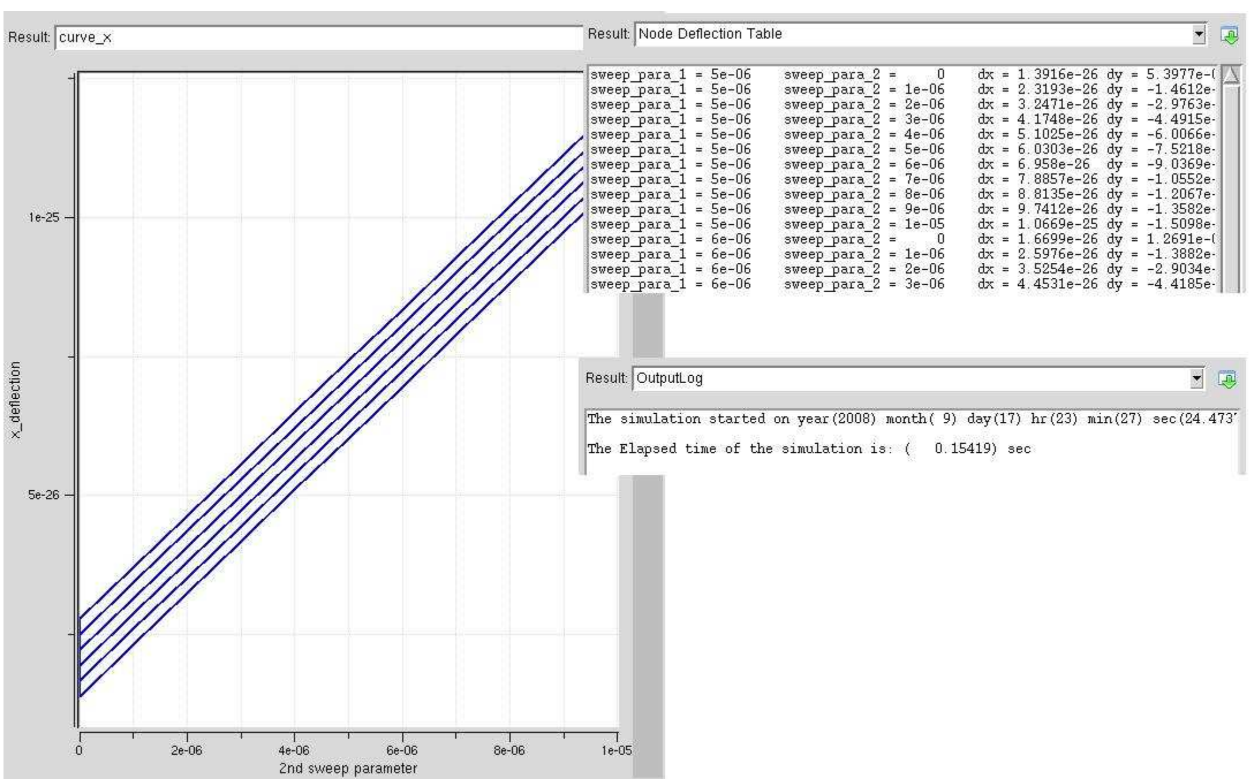


Figure 7: Screens of the Outputs of Sweep Analysis

FEA Result Comparison

Several tests have been done by commercial Finite Element Analysis (FEA) software – COMSOL3.4 and the SUGAR – Cantilever Simulation tool for result comparison (Table 1).

	condition	y-axis deflection			
Test	um, uN	ANALYTICAL	COMSOL	NANOHUB TOOL (um)	
1	cantilever (100L, 2W, 2T) silicon (0.3, 165GPa) force (10uN at tip in -y axis)	-15.151515	-15.014	-15.15	
2	cantilever (100L, 2W, 2T) silicon (0.3, 165GPa) moment (10uN-um at tip in +z axis)	0.227273	0.211422	0.2273	
3	cantilever (100L, 2W, 2T) silicon (0.3, 165GPa) node1 50um away from anchor force (10uN at node1 in +z axis) force (5uN at tip in +z axis) moment (10uN-um at tip in +z axis)	N/A N/A	4.247094 12.730499	4.318 12.54	node1 tip

Table 1: Result Comparison with FEA Software

The SUGAR – Cantilever simulation tool provides close results (relative error < 4%) compared to the FEA model in COMSOL3.4. The error comes from many different aspects. For example, the error could come from the accuracy of the FEA model. Figure 8 shows the model for test3 in COMSOL. There is a short link bar at the end of the cantilever in order to apply moment at the tip position. Therefore, the results from the FEA model will include all real facts, boundary conditions while the SUGAR – Cantilever can only capture the basic physical phenomena. However, the accuracy of the SUGAR – Cantilever tool is more than enough to be accepted during the initial design stage. Plus, the computational memory and time consumption are smaller, especially for complex system – level device.

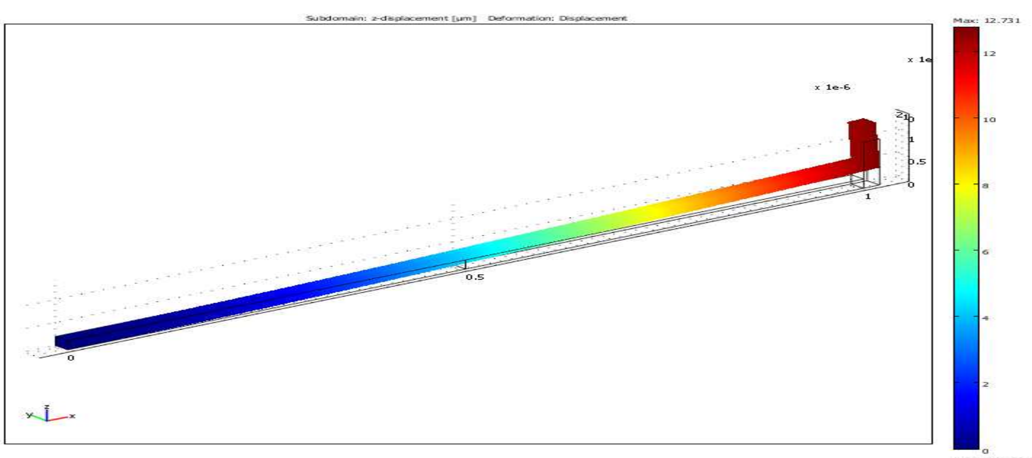


Figure 8: COMSOL FEA Model for Test3

Further Development

The netlist file will be available in the drop down menu of the last phase. User is welcome to reuse or further develop for more complex device. Another SUGAR based tool is currently under developing on nanoHub in which users can type in their own netlist to model and simulate their own device.

Please contact the develop team (Fengyuan Li, li200@purdue.edu) for any questions regarding this tool, the developing tool, and the SUGAR modeling and simulation process.

Acknowledgment

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