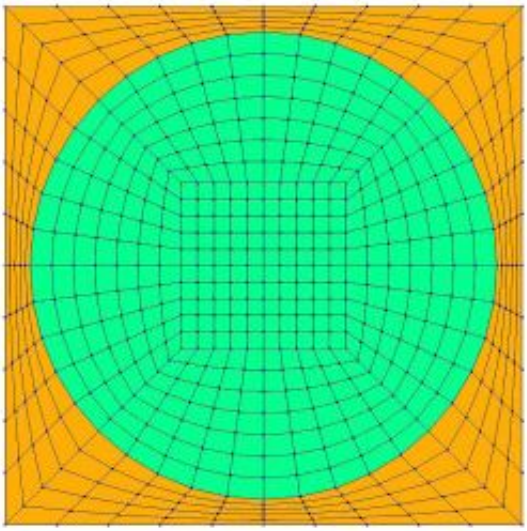
Computation of Viscoelastic Beam properties of a woven composite TRAC Boom using Abaqus SwiftComp GUI, Texgen4SC and Swift Comp 2.1

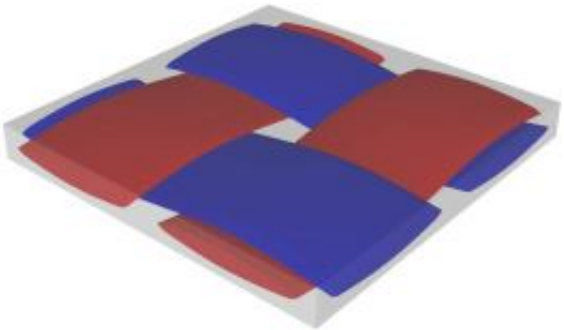
Viscoelastic Beam Properties of a TRAC Boom

In this example, we want to compute the Viscoelastic effective properties of a TRAC Boom fabricated from plain weave composite material made of isotropic viscoelastic matrix and transversely isotropic elastic fiber. The MSG solid model is used to predict the effective viscoelastic properties of a plain weave composite using a three part approach.

The first part predicts the effective viscoelastic yarn properties based on the elastic fiber and viscoelastic matrix properties at the microscale. The second part takes the effective yarn properties and matrix properties to predict the viscoelastic properties of weave composites. The third part takes the effective weave properties to predict the viscoelastic properties of the Trac Boom.



Yarn



Weave

Trac boom

Web height: 10 mm, Subtended angle: 90 degree, Radius of the flange (curved part): 25 mm, flange thickness is 1 mm.

The Layup is (0/45/-45/90/0)s , Ply thickness: 0.1 mm. The layup sequence is along with the direction pointing to the center of flange (Blue arrow).

The fiber properties are defined as transversely isotropic elastic by means of engineering constants and the matrix properties are given by means of the Prony coefficients with a constant Poisson's ratio equal to 0.33 as specified in the table below.

Fiber properties defined as transversely isotropic elastic

E1 (MPa)	E2 (MPa)	G12 (MPa)	G23 (MPa)	v12	v23
233,000.0	15,000.0	8,963.0	5639	0.23	0.33

Prony coefficients and relaxation times for the matrix

s	∞	1	2	3	4	5	6	7
λ	-	$10^{\wedge 3}$	$10^{\wedge 5}$	$10^{\wedge 6}$	$10^{\wedge 7}$	$10^{\wedge 8}$	$10^{\wedge 9}$	$10^{\wedge 10}$
E (MPa)	1,000.0	224.1	450.8	406.1	392.7	810.4	203.7	1486.0

Material Properties

We will use a square pack 2D SG with fiber volume fraction equal to $v_f = 0.64$.

Software Used

We will use TexGen4SC 2.0, SwiftComp 2.1 and Abaqus CAE with the Abaqus SwiftComp GUI for this tutorial. TexGen4SC 2.0 will be used to run the viscoelastic homogenization of the fiber-matrix square pack microstructure and also for the viscoelastic homogenization of the plain weave laminate. Abaqus CAE will be used to model the TRAC boom and to run the viscoelastic homogenization while SwiftComp runs in the background.

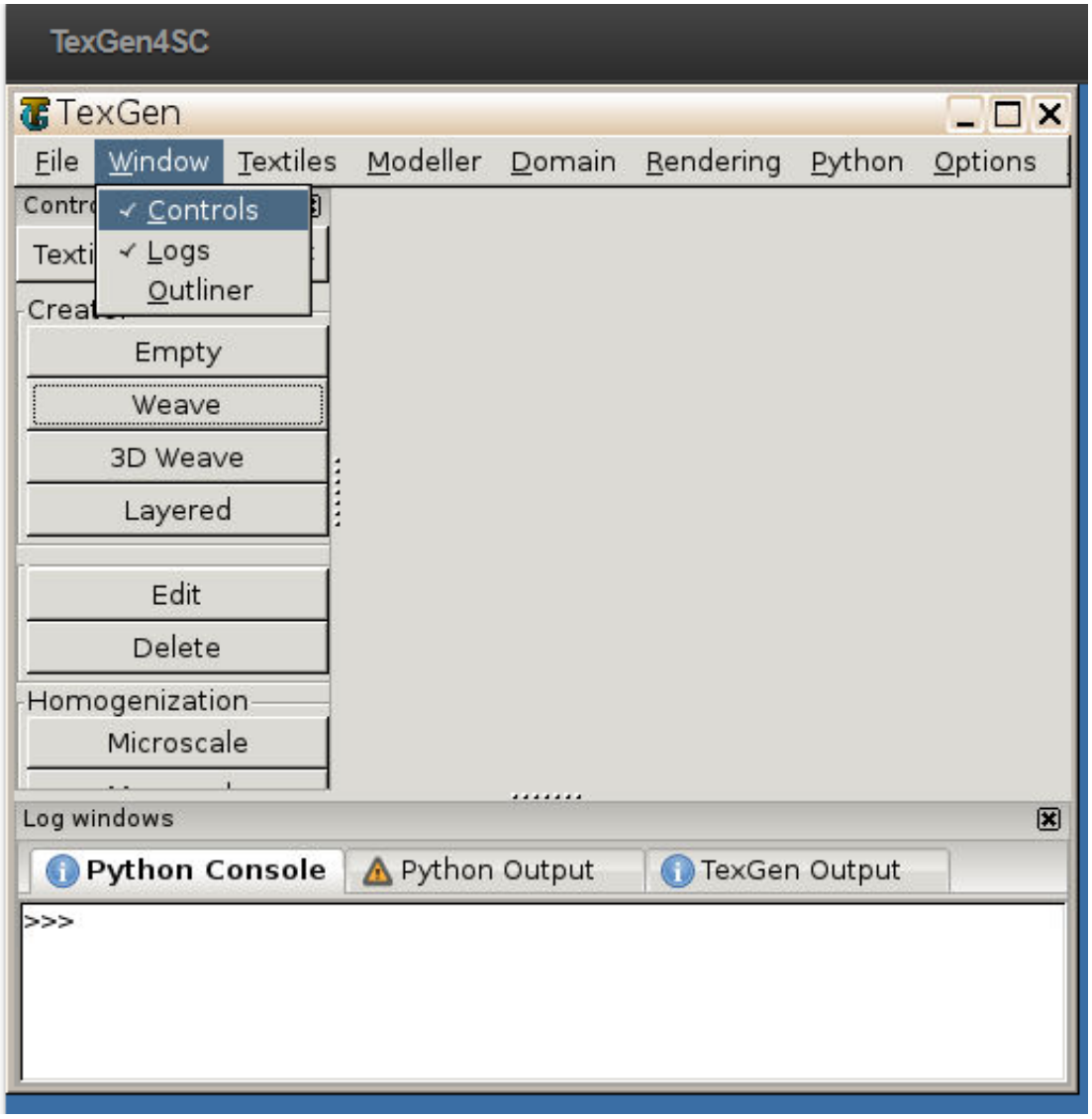
Solution Procedure

The problem is solved in the following three steps:
Part 1- Micro-scale analysis of the square-pack fiber matrix micro structure using Texgen4SC.
Part 2- Meso-scale analysis of the plain weave laminate using Texgen4SC.
Part 3- Macro-scale analysis of the Trac Boom using Abaqus CAE with the Abaqus SwiftComp GUI and SwiftComp 2.1.

Part 1- Micro-scale analysis of the square-pack fiber matrix micro structure using Texgen4SC.

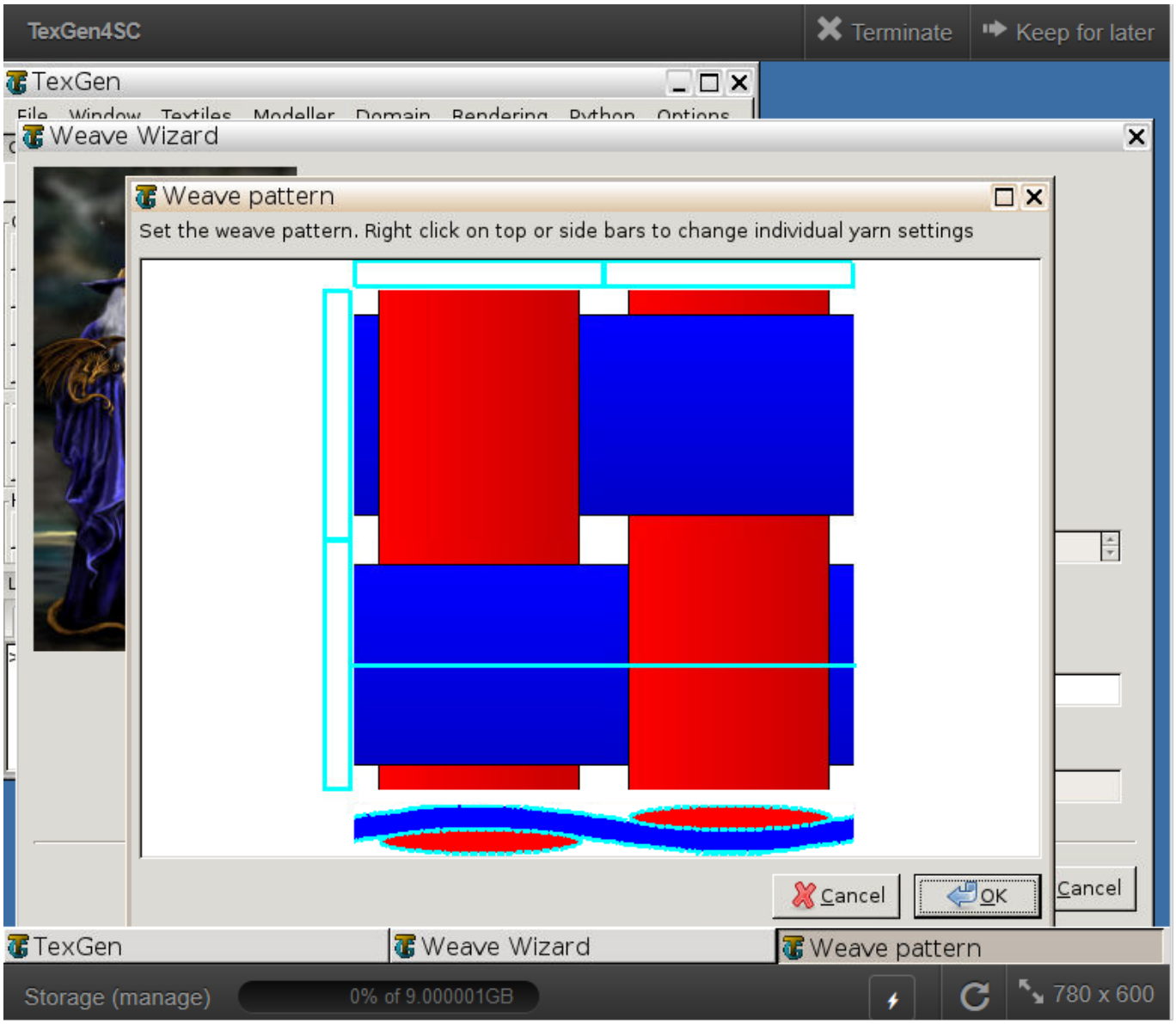
TexGen4SC 2.0 provides a function to let users import the material properties from a text file. Refer to the Predict viscoelastic plate properties of a single-layer plain weave laminate tutorials for more details regarding preparation of the materials text file.

Follow the step-by-step procedure to solve the problem.
 # Step 1.1. Create the plain weave pattern using TexGen4SC 2.0. Launch TexGen4SC 2.0 on cdmHUB, then Go to window-> controls-> “Weave” to create mesoscale plain weave SG.



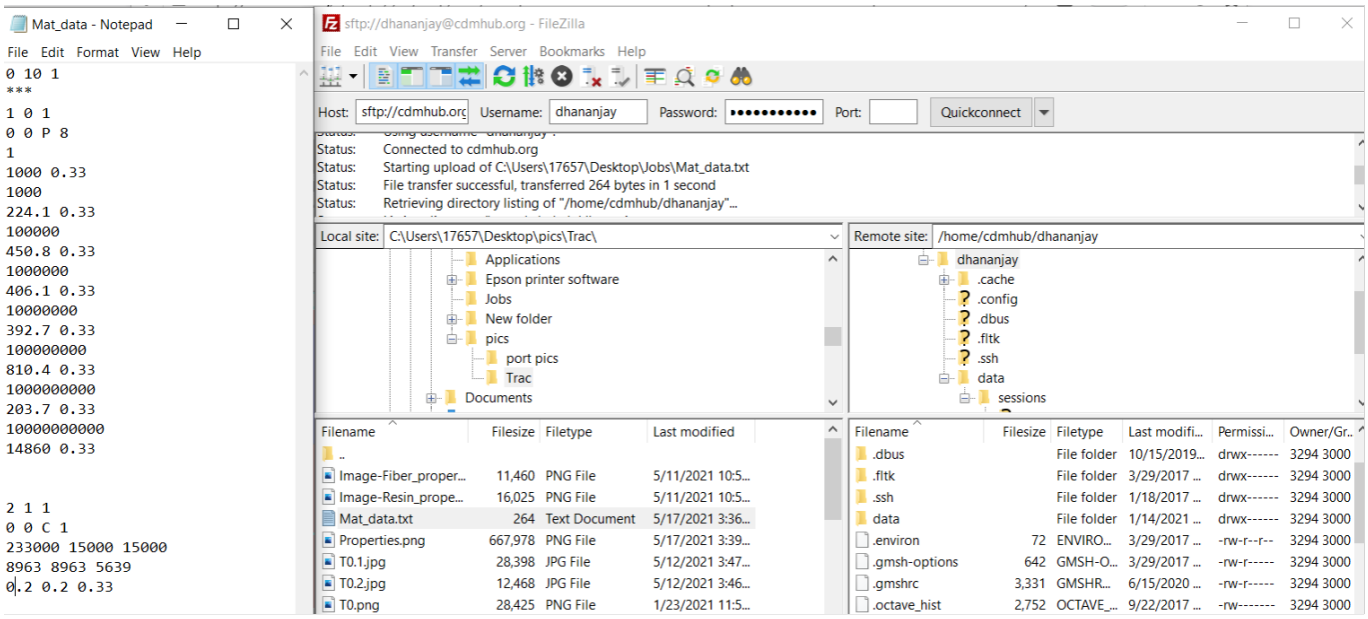
Weave Wizard

 # Step 1.2. Keeping the geometric properties as required, Click on the upper-right and lower-left squares to get the woven pattern.



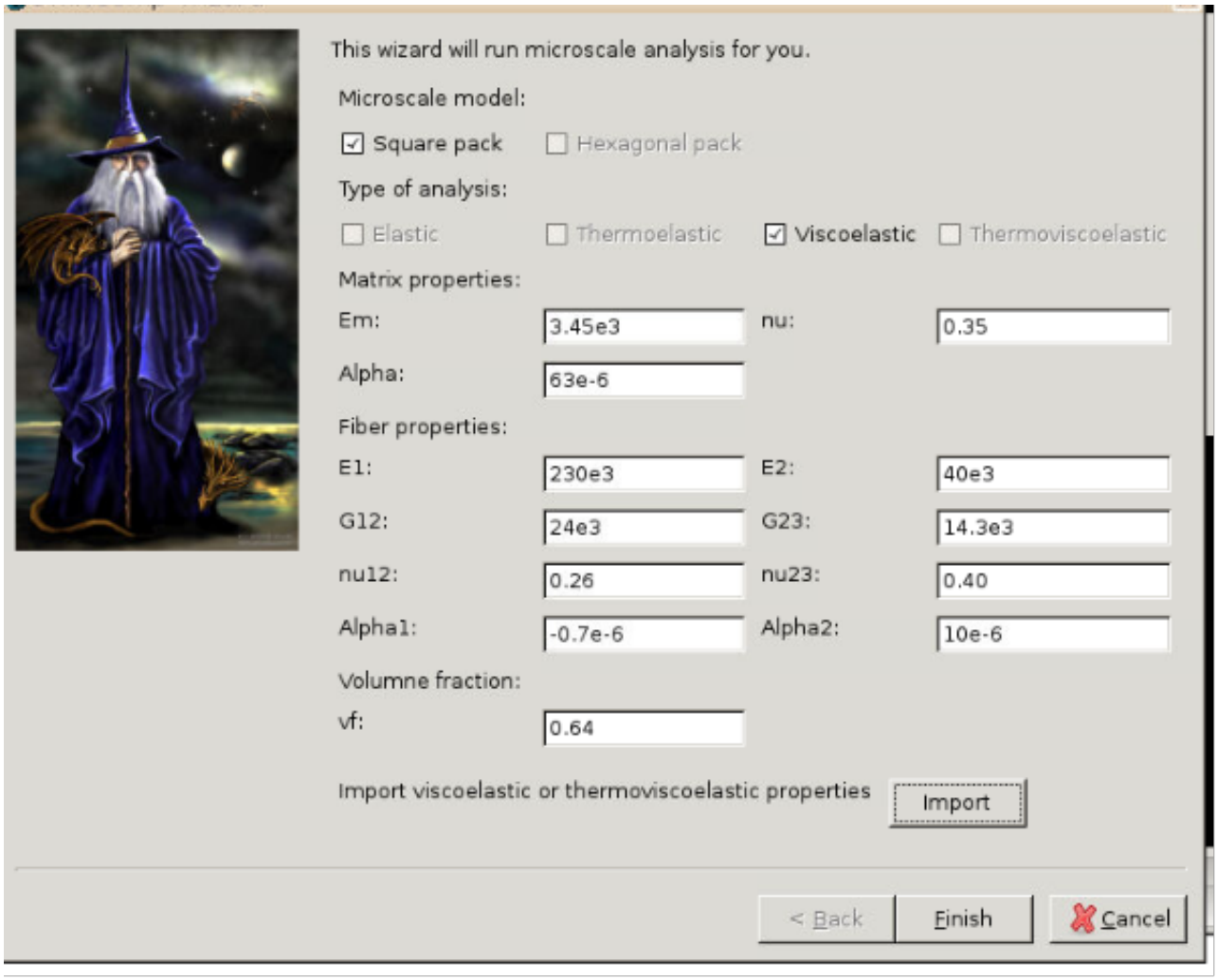
Weave Pattern

 # Step 1.3. Upload the .txt file containing matrix and fiber properties to the current session, using any FTP app, for example, FileZilla, to set up connection with the current session. Refer to the[Predict viscoelastic plate properties of a single-layer plain weave laminate](#) Tutorials for more details.



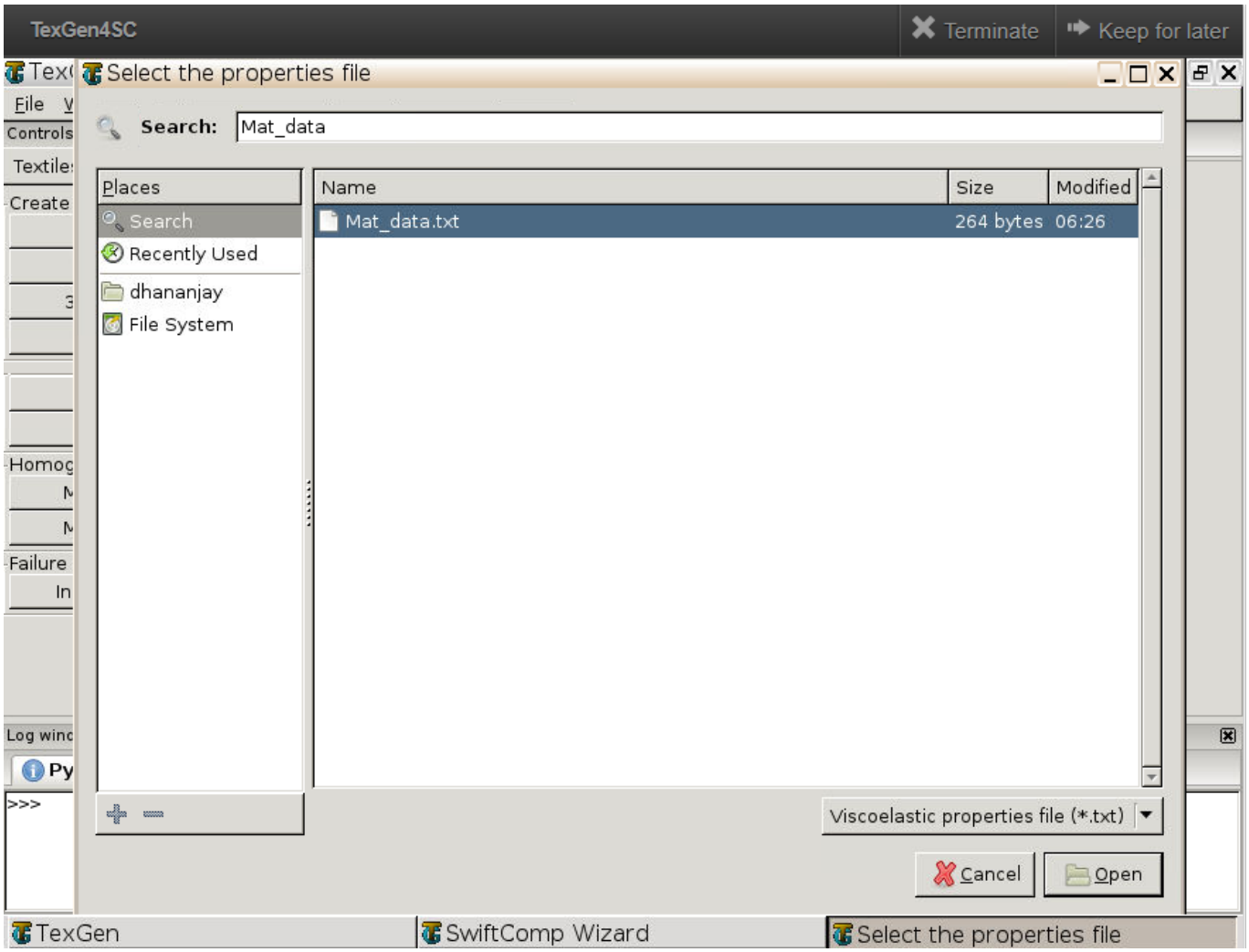
Importing Material properties text file

Step 1.4. Once you uploaded the .txt file, click “Microscale” under “Homogenization” tab for yarn property calculation. Select “Viscoelastic” as the type of analysis. Set fiber volume fraction to 0.64.



Homogenization

 # Step 1.5. Ignore the matrix and fiber properties in the window, since the material properties will be imported from the uploaded file.



Property file

Step 1.5. Click “Import” and select the uploaded .txt file and Click “Finish”. Now a .sc file (micro.sc) will be generated that SwiftComp will take as the input. SwiftComp will run on the cloud to calculate viscoelastic properties of yarns, e.g., effective microscale properties. In the pop-up window, you will find the analysis results.

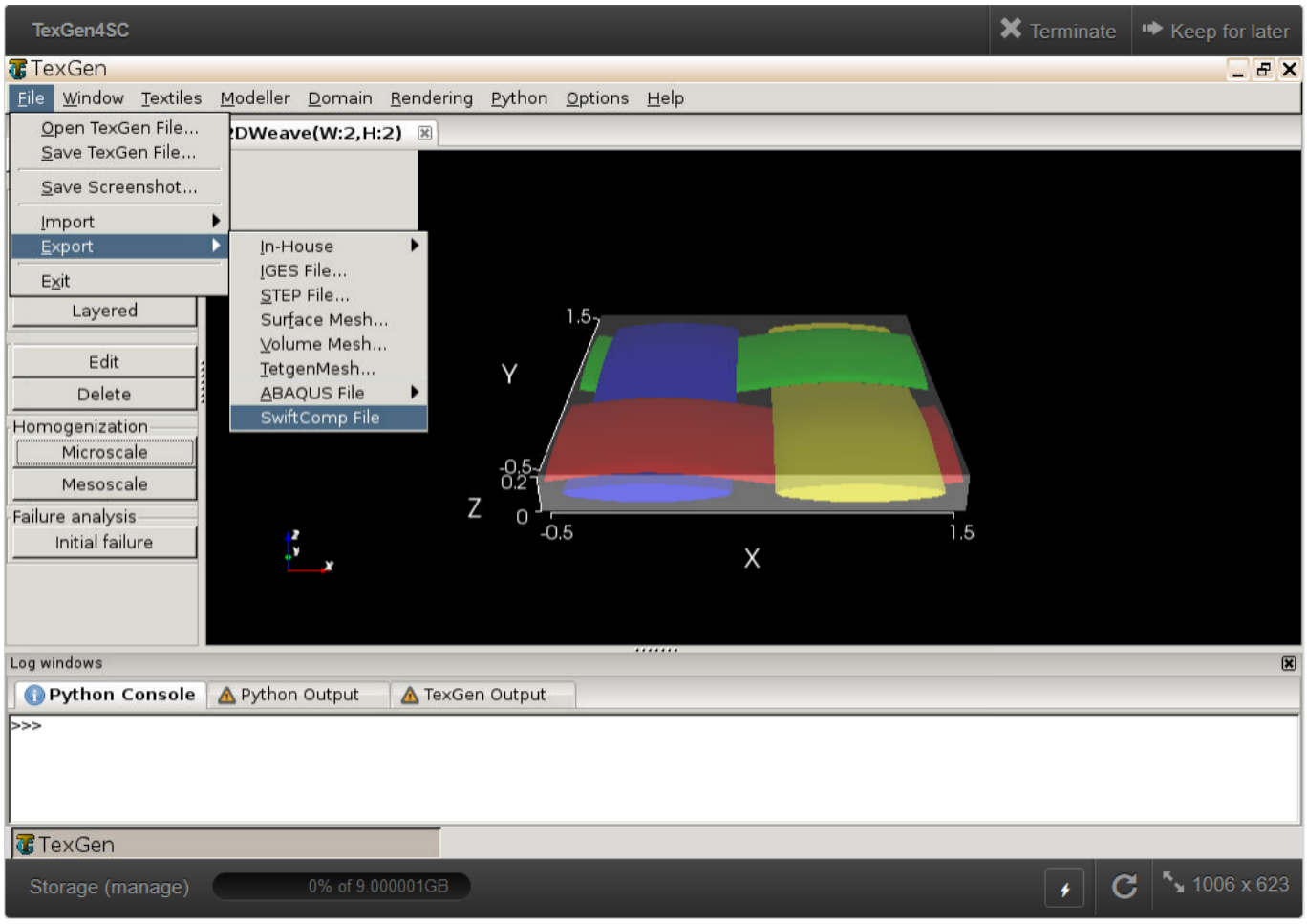
micro.sc.k

```
#-----------------------------------------------------#
Effective Viscoelastic Properties at Time: t =       1.0000000E+000

The Effective Stiffness Matrix
-------------------------------------------
      1.5905452E+005      6.9429652E+003      6.9429633E+003     -9.2747546E-004      0.0000000E+000      0.0000000E+000
      6.9429652E+003      1.9819295E+004      7.6742466E+003     -1.1722393E-002      0.0000000E+000      0.0000000E+000
      6.9429633E+003      7.6742466E+003      1.9819291E+004      9.8404582E-003      0.0000000E+000      0.0000000E+000
     -9.2747546E-004     -1.1722393E-002      9.8404582E-003      6.0440591E+003      0.0000000E+000      0.0000000E+000
      0.0000000E+000      0.0000000E+000      0.0000000E+000      0.0000000E+000      8.1507328E+003     -9.4817636E-005
      0.0000000E+000      0.0000000E+000      0.0000000E+000      0.0000000E+000     -9.4817636E-005      8.1507330E+003

The Effective Compliance Matrix
-------------------------------------------
      6.4288881E-006     -1.6234922E-006     -1.6234917E-006      4.8102178E-013      0.0000000E+000      0.0000000E+000
     -1.6234922E-006      5.9765115E-005     -2.2572976E-005      1.5241626E-010      0.0000000E+000      0.0000000E+000
     -1.6234917E-006     -2.2572976E-005      5.9765126E-005     -1.4133404E-010      0.0000000E+000      0.0000000E+000
      4.8102178E-013      1.5241626E-010     -1.4133404E-010      1.6545173E-004      0.0000000E+000      0.0000000E+000
      0.0000000E+000      0.0000000E+000      0.0000000E+000      0.0000000E+000      1.2268836E-004      1.4272360E-012
      0.0000000E+000      0.0000000E+000      0.0000000E+000      0.0000000E+000      1.4272360E-012      1.2268835E-004

The Engineering Constants (Approximated as Orthotropic)
-------------------------------------------------------
 E1  =       1.5554789E+005
 E2  =       1.6732169E+004
 E3  =       1.6732166E+004
 G12 =       8.1507330E+003
 G13 =       8.1507328E+003
 G23 =       6.0440591E+003
 nu12=       2.5253079E-001
 nu13=       2.5253072E-001
 nu23=       3.7769485E-001


Effective Density =       0.0000000E+000
#-----------------------------------------------------#
Effective Viscoelastic Properties at Time: t =       1.0000000E+001

The Effective Stiffness Matrix
-------------------------------------------
      1.5905361E+005      6.9426822E+003      6.9426803E+003     -9.2679192E-004      0.0000000E+000      0.0000000E+000
      6.9426822E+003      1.9818548E+004      7.6740087E+003     -1.1709267E-002      0.0000000E+000      0.0000000E+000
```

Micro scaleResuts

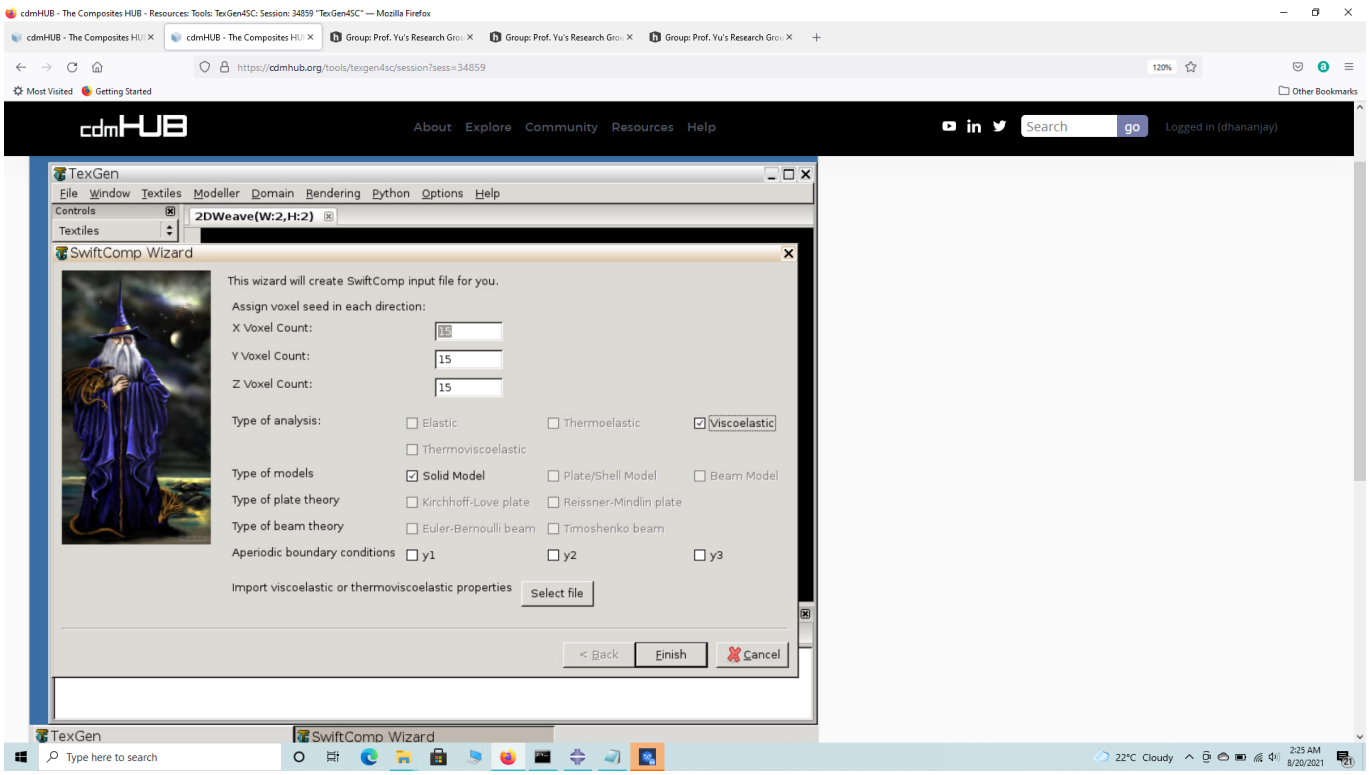
Part 2- Meso-scale analysis of the plain weave laminate using Texgen4SC.

 # Step 2.1. Go to “File->Export->SwiftComp File” to generate the .sc file for mesoscale analysis.

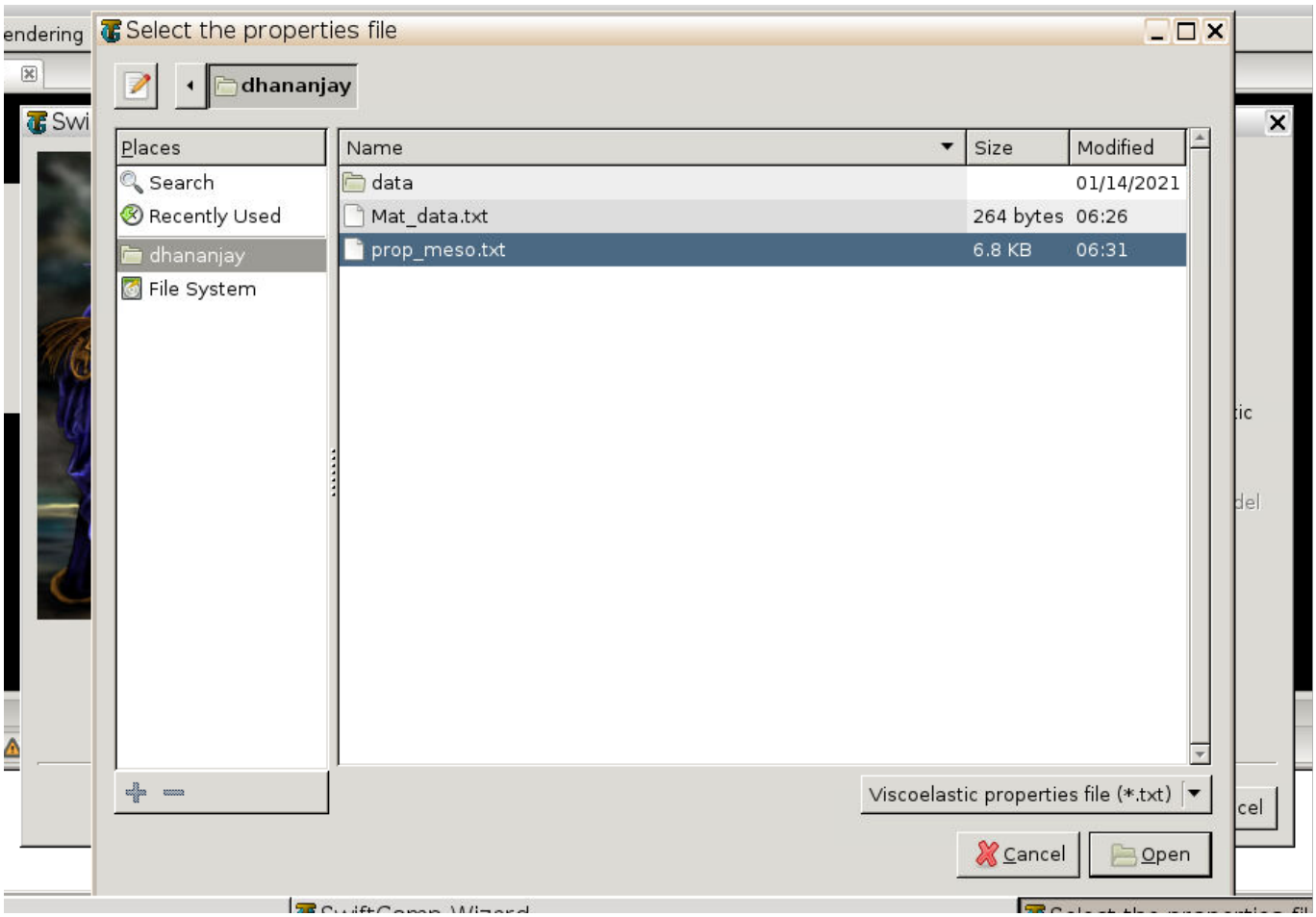


weave mesh

Step 2.2. Define the voxel mesh, Select “Viscoelastic” as Type of analysis and Select “solid model”. Click “Select file” and select “prop_meso.txt” which is automatically generated during microscale analysis, and will be used as part of mesoscale analysis input file.

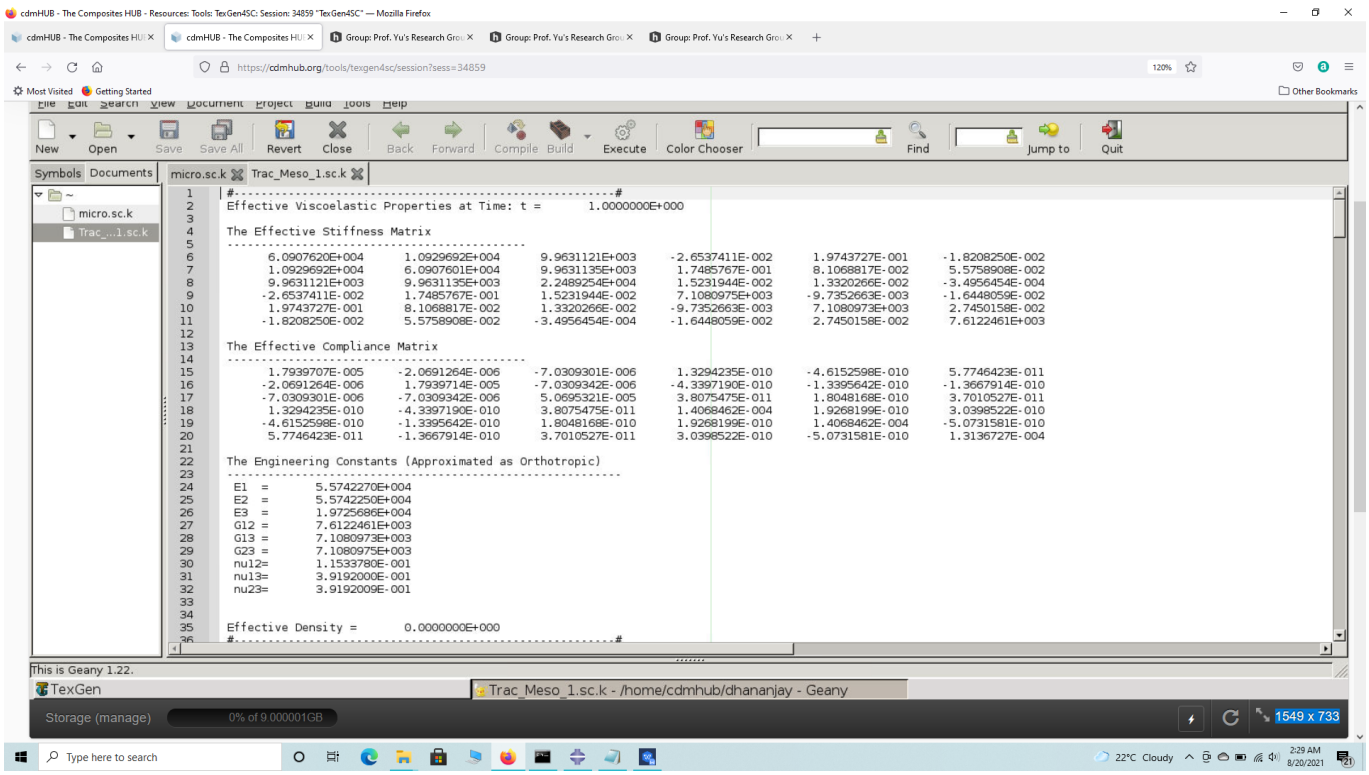


SwiftComp Wizard



Property file

Step 2.3. Save the .sc (SwiftComp input file) file with a filename of your choice. Click “Mesoscale” in “Homogenization” tab, which will call SwiftComp to calculate fabric properties.

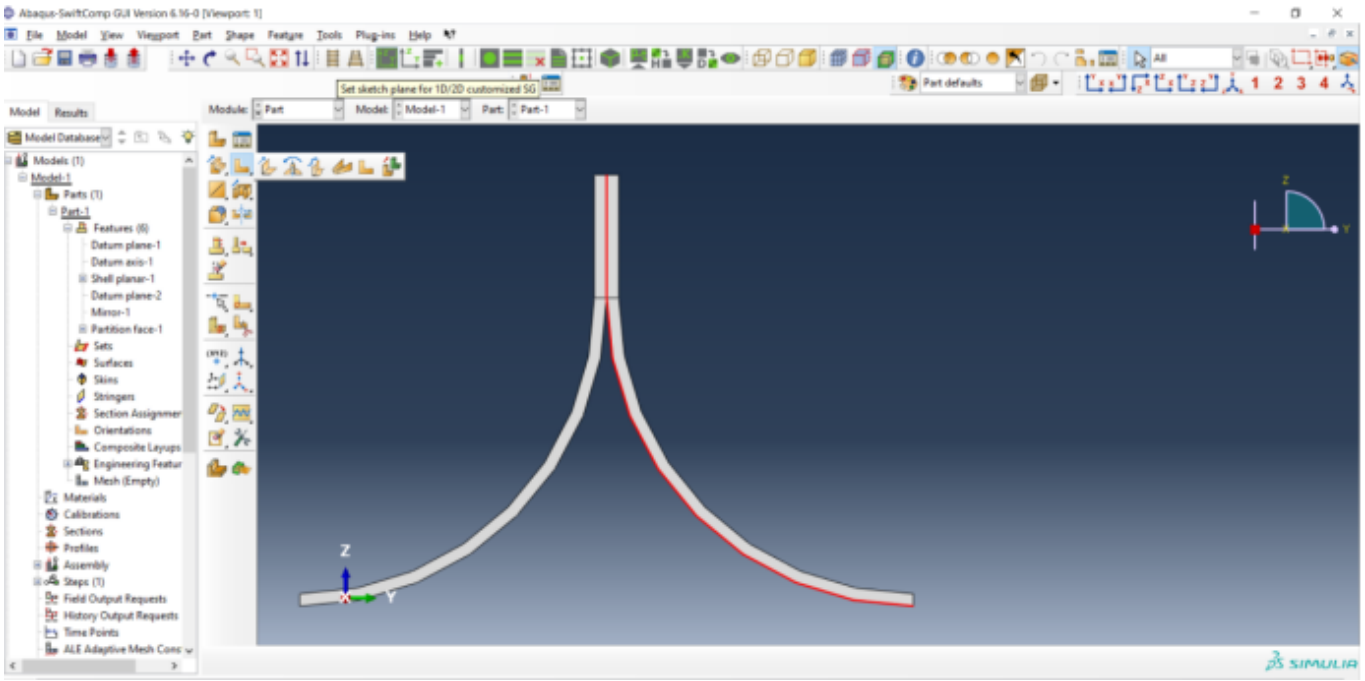


Meso Scale Results

Step 2.4. Transfer this file to your local computer for further analysis.

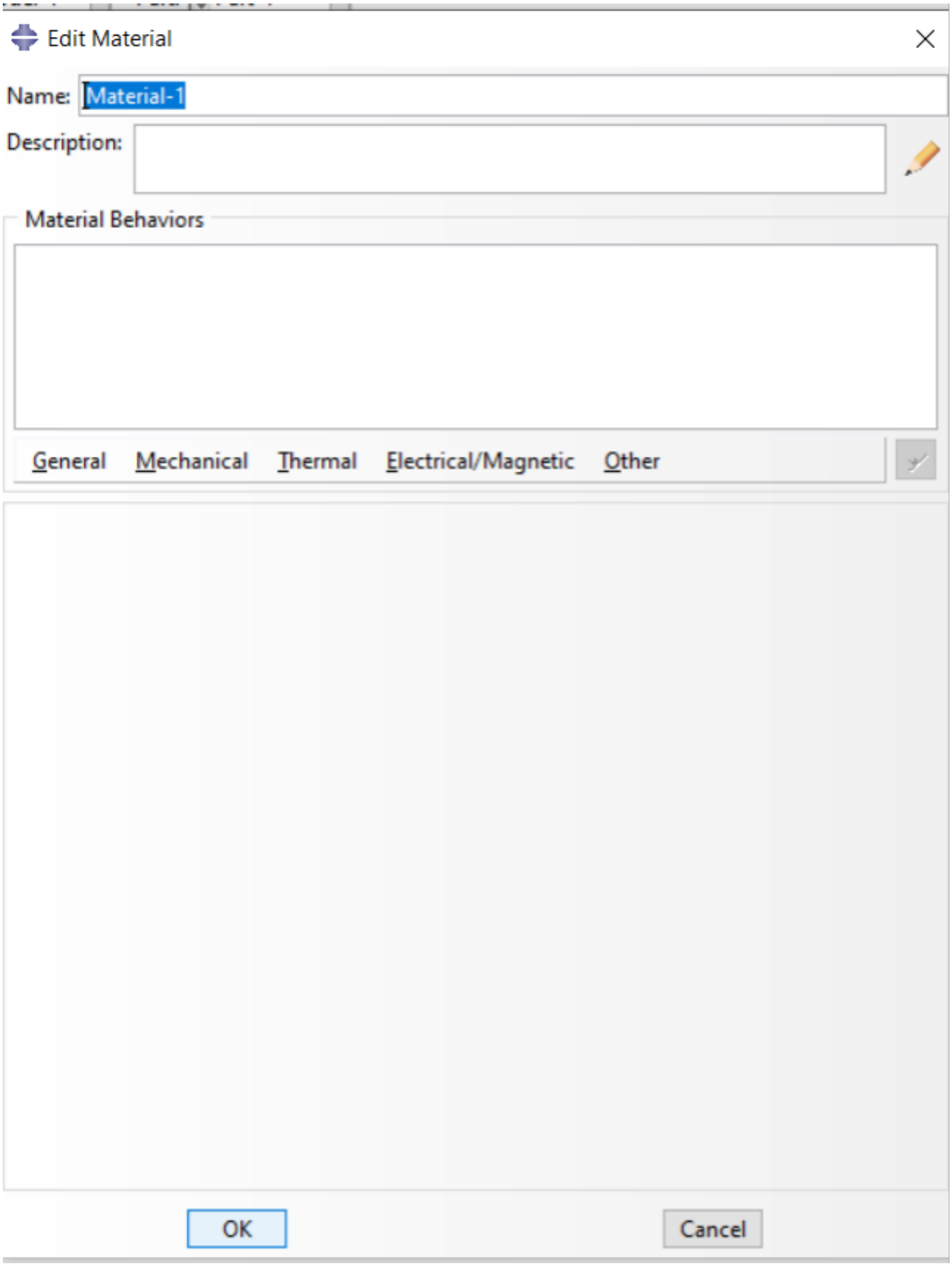
Part 3- Macro-scale analysis of the Trac Boom using Abaqus CAE with the Abaqus SwiftComp GUI and SwiftComp 2.1.

Step 3.1. Using Abaqus CAE with the Abaqus SwiftComp GUI plugin, Create the part geometry for the TRAC Boom. Use Set sketch plane for customized SG -> Create planar shell -> Select the plane and vertical axis -> Sketch half of the base line (Highlighted as a red line). Its geometry is a straight line (Web height) from (0,10) to (0,0) and a curved line (Flange) from (0,0) to (25,-25) centered at (25,0). Using points at (1,10), (1,0), (25,-24) set the flange thickness to 1 mm to the right of the baseline and create the part. Mirror the part about the vertical to get the geometry of the TRAC Boom. Partition the part to separate the web and flange and also the individual flanges.



Part Geometry

Step 3.2. To enter the material properties for the part, first we need to choose the material properties from the results of the computed effective viscoelastic properties in the meso scale analysis. Within the Materials section of Abaqus CAE, we create a dummy material called “Material”. Please note that we will not define the material properties using the Abaqus SwiftComp GUI. Refer to the Computation of effective viscoelastic properties with Abaqus SwiftComp GUI tutorial for more details.


Edit Material
Name:
Material-1
Description:
Material Behaviors
General
Mechanical
Thermal
Electrical/Magnetic
Other
OK
Cancel

dd

Step 3.3. Use the material properties from the previous section . We need to convert the Constitutive relations provided as SwiftComp's results into Abaqus's Constitutive relations. This can be done by switching the 4th and 6th rows for the relation and also switching the 4th and 6th column of the stiffness matrix. The relations are provided below. Since the material properties are given as a time-dependent properties, We will create a text file to input the time-dependent material properties described row wise as –
D1111 (t) —- D1122 (t) —- D2222 (t) —- D1133 (t) —- D2233 (t) —- D3333 (t) —- D1112 (t) —- D2212 (t) —- D3312 (t) —- D1212 (t) —- D1113 (t) —- D2213 (t) —- D3313 (t) —- D1213 (t) —- D1313 (t) —- D1123 (t) —- D2223 (t) —- D3323 (t) —- D1223 (t) —- D1323 (t) —— D2323 (t) — Time, t for all 8 time intervals.

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{23} \end{Bmatrix} = \begin{bmatrix} D_{1111} & D_{1122} & D_{1133} & D_{1112} & D_{1113} & D_{1123} \\ & D_{2222} & D_{2233} & D_{2212} & D_{2213} & D_{2223} \\ & & D_{3333} & D_{3312} & D_{3313} & D_{3323} \\ & & & D_{1212} & D_{1213} & D_{1223} \\ & sym & & & D_{1313} & D_{1323} \\ & & & & & D_{2323} \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{12} \\ \gamma_{13} \\ \gamma_{23} \end{Bmatrix}$$

Abaqus's Constitutive relations

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{13} \\ \sigma_{12} \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{12} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ c_{13} & c_{23} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{14} & c_{24} & c_{34} & c_{44} & c_{45} & c_{46} \\ c_{15} & c_{25} & c_{35} & c_{45} & c_{55} & c_{56} \\ c_{16} & c_{26} & c_{36} & c_{46} & c_{56} & c_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ 2\varepsilon_{23} \\ 2\varepsilon_{13} \\ 2\varepsilon_{12} \end{Bmatrix}$$

SwiftComp's Constitutive relations

$$\begin{Bmatrix} \sigma 11 \\ \sigma 22 \\ \sigma 33 \\ \sigma 12 \\ \sigma 13 \\ \sigma 23 \end{Bmatrix} = \begin{pmatrix} C11 & C12 & C13 & C16 & C15 & C14 \\ C12 & C22 & C23 & C26 & C25 & C24 \\ C13 & C23 & C33 & C36 & C35 & C34 \\ C16 & C26 & C36 & C66 & C56 & C46 \\ C15 & C25 & C35 & C56 & C55 & C45 \\ C14 & C24 & C34 & C46 & C45 & C44 \end{pmatrix} \begin{Bmatrix} \varepsilon 11 \\ \varepsilon 22 \\ \varepsilon 33 \\ 2\varepsilon 12 \\ 2\varepsilon 13 \\ 2\varepsilon 23 \end{Bmatrix}$$

SwiftComp's

output stiffness matrix converted into Abaqus's input stiffness matrix

First Time Interval

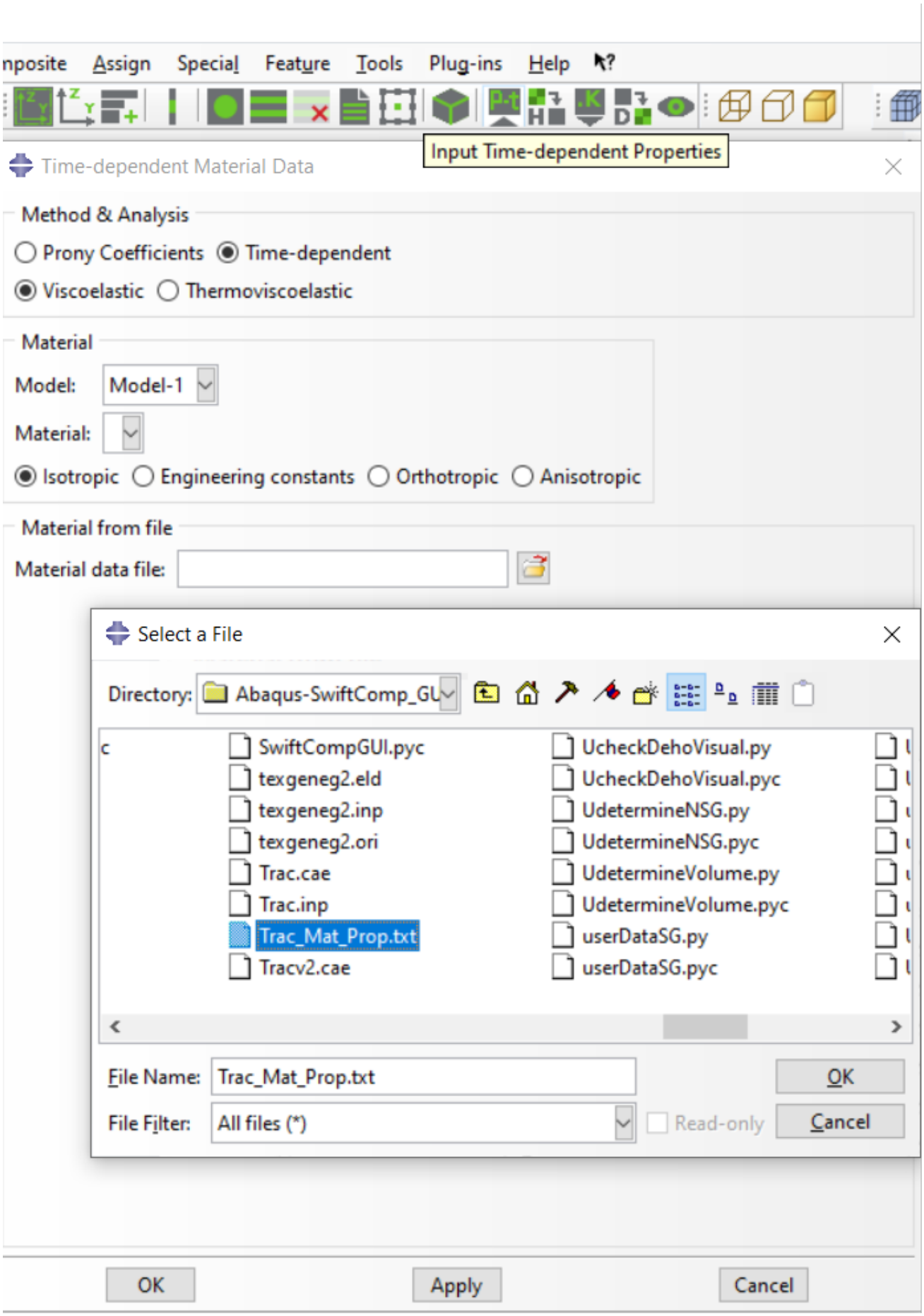
	60907	10929	9963	0	0	0
	10929	60907	9963	0	0	0
SwiftComp's output stiffness matrix	9963	9963	22489	0	0	0
	0	0	0	7108	0	0
	0	0	0	0	7108	0
	0	0	0	0	0	7612

	60907	10929	9963	0	0	0
	10929	60907	9963	0	0	0
Abaqus's input stiffness matrix	9963	9963	22489	0	0	0
	0	0	0	7612	0	0
	0	0	0	0	7108	0
	0	0	0	0	0	7108

Abaqus's input in the text file

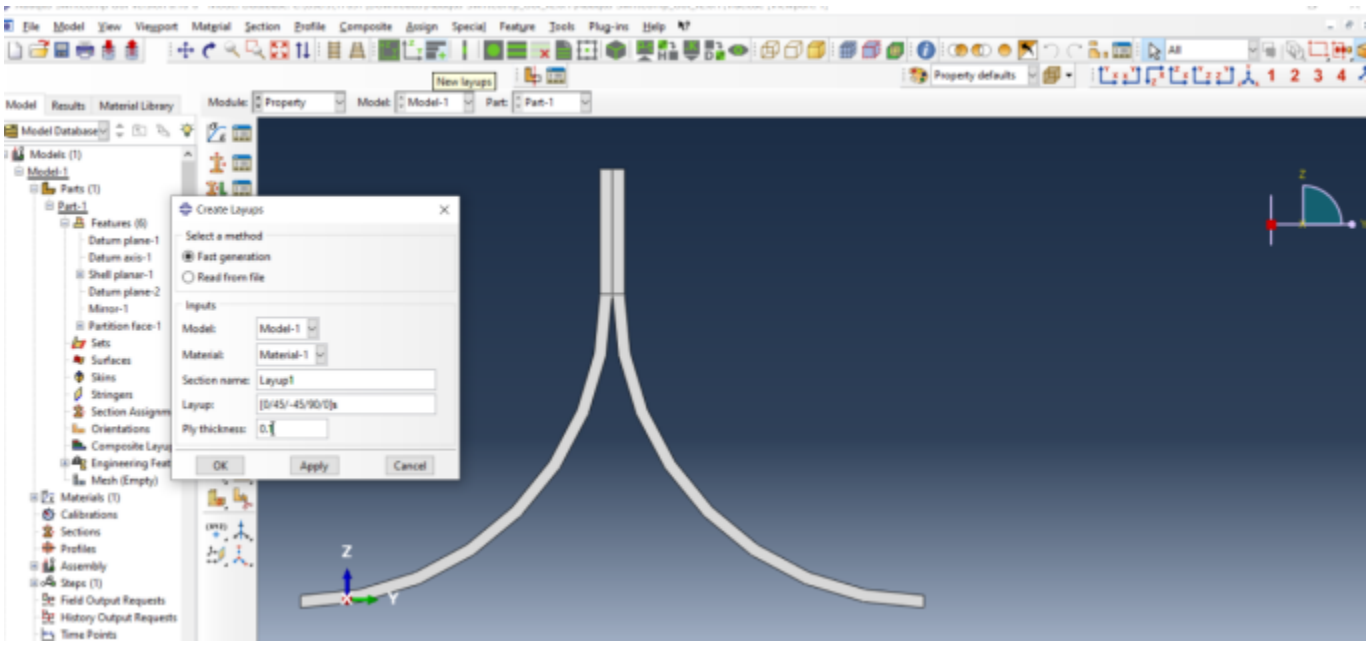
```
60907   10929   60907   9963    9963    22489   0       0       0       7612    0       0       0       0       7108    0       0       0       0       0       7108
```

Rearranged Material properties


nposite Assign Special Feature Tools Plug-ins Help
Input Time-dependent Properties
Time-dependent Material Data
Method & Analysis
Prony Coefficients
Time-dependent
Viscoelastic
Thermoviscoelastic
Material
Model:
Model-1
Material:
Isotropic
Engineering constants
Orthotropic
Anisotropic
Material from file
Material data file:
Select a File
Directory:
Abaqus-SwiftComp_GU
SwiftCompGUI.pyc
texgeneg2.eld
texgeneg2.inp
texgeneg2.ori
Trac.cae
Trac.inp
Trac_Mat_Prop.txt
Tracv2.cae
UcheckDehoVisual.py
UcheckDehoVisual.pyc
UdetermineNSG.py
UdetermineNSG.pyc
UdetermineVolume.py
UdetermineVolume.pyc
userDataSG.py
userDataSG.pyc
File Name:
Trac_Mat_Prop.txt
OK
File Filter:
All files (*)
Read-only
Cancel
OK
Apply
Cancel

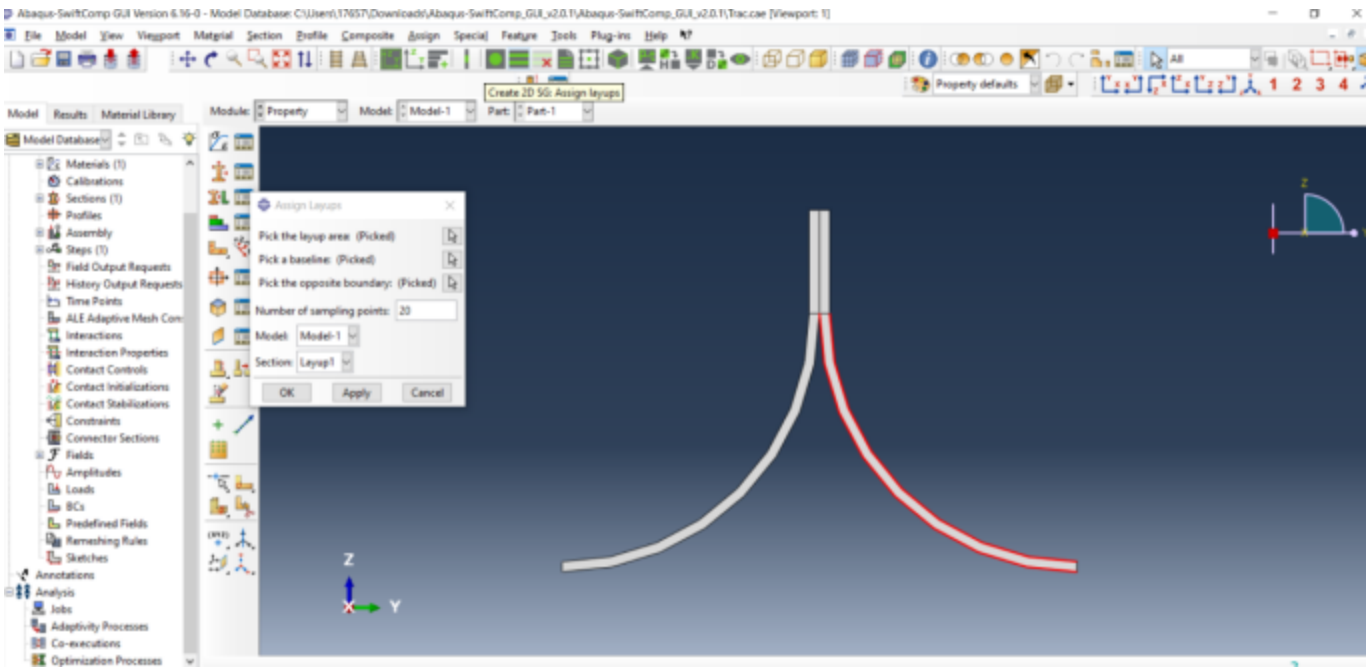
Material properties file

 # Step 3.4. Now go to New Layups and add the material, section name, Layup and thickness to create the required layup. This can be repeated if we have multiple layups. We will use (0/45/90/-45/0)s as the laminate for the Trac Boom.

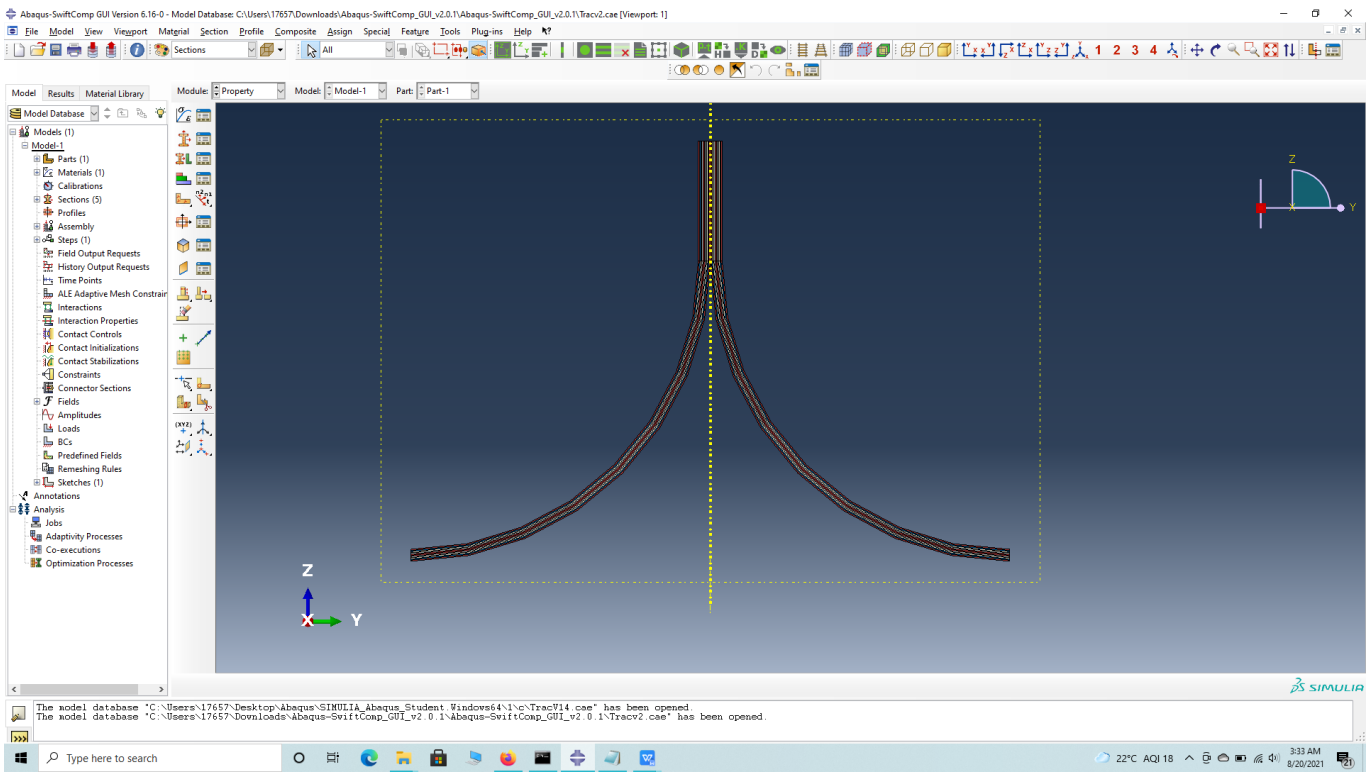


Layups

‘ *# Step 3.5.* To assign the layup, go to Create 2D SG: Assign Layups and the pick the baseline, the line opposite to the baseline and the area between the two picked line for the right flange as shown and then hit Ok. Do this for all four sections



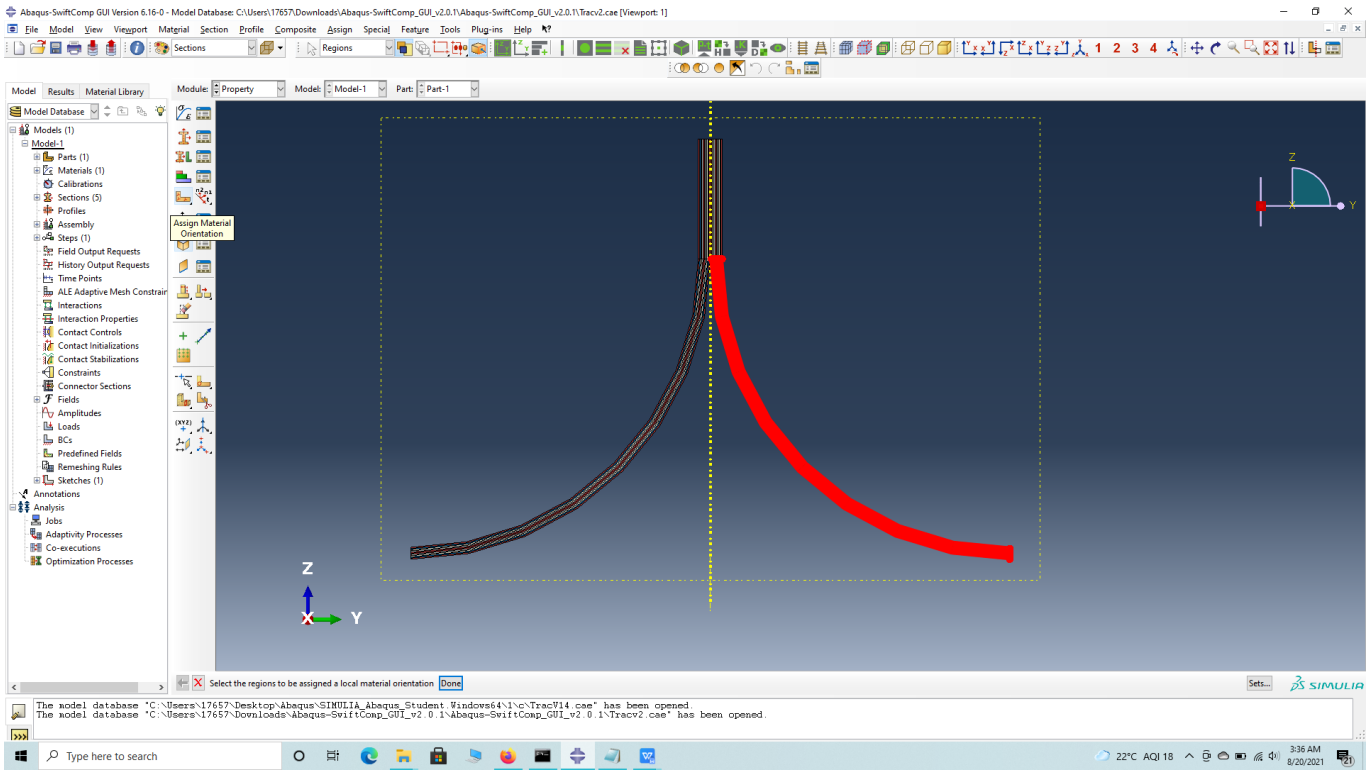
Assign Layups



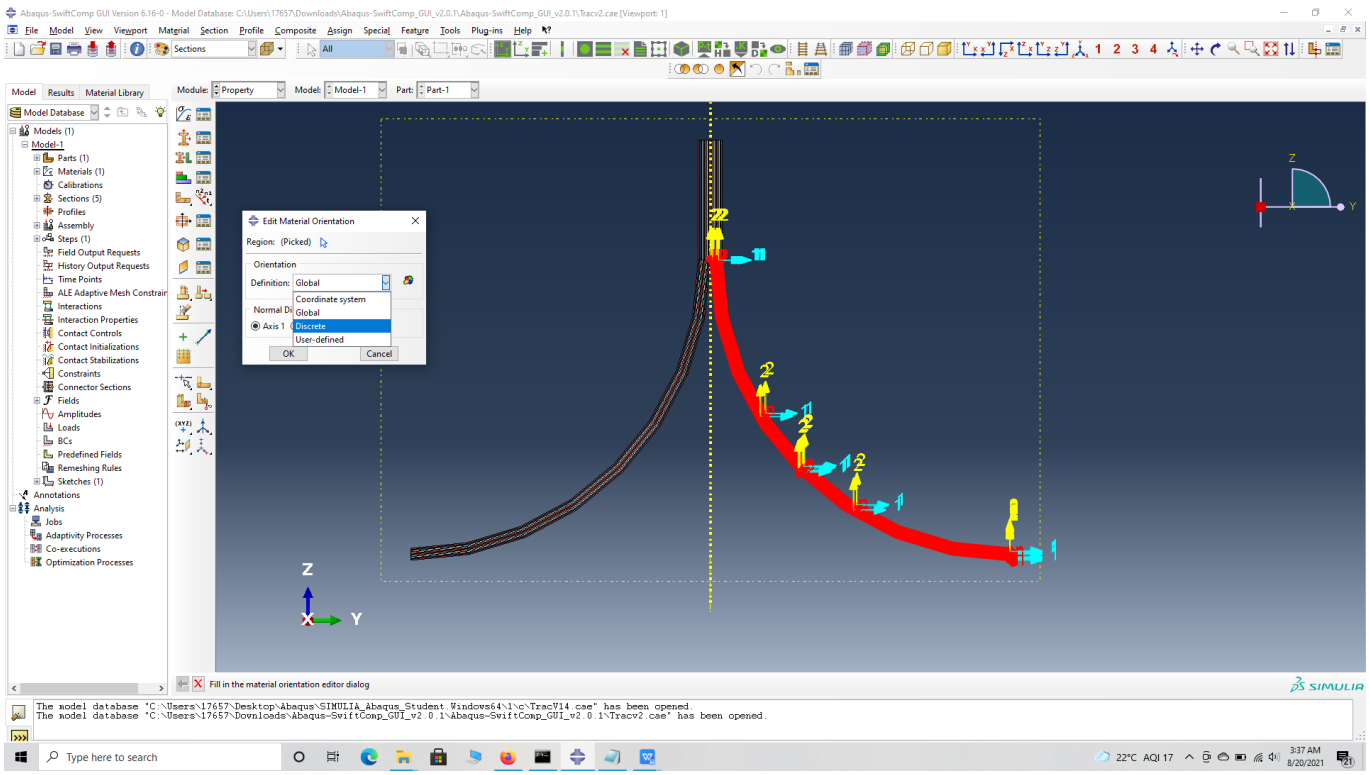
Assign Layups

‘ *# Step 3.6.*Now we assign the material orientation for the part. Go to Assign material orientation -> select the sections of the part with the same orientation -> Done -> Select a CSYS (use default orientation or other method) -> Definition (Discrete) -> Define -> Primary axis

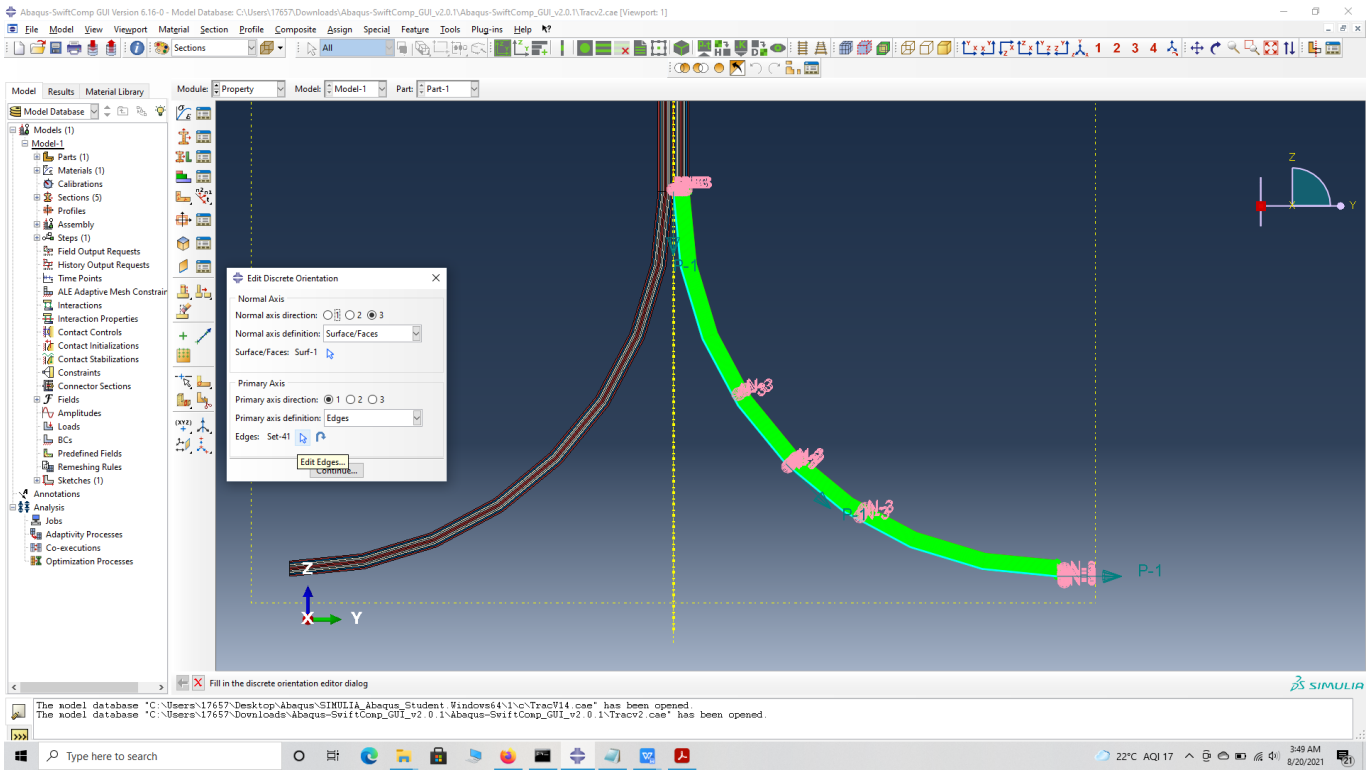
orientation -> choose edge and flip direction if needed to make the axis point towards a clockwise direction -> Choose the surfaces for the normal axis definition -> Continue -> OK. Orientation Axis 1 represents the y2 axis of SwiftComp's local orientation and orientation axis 2 represents y3 axis of SwiftComp's local orientation.



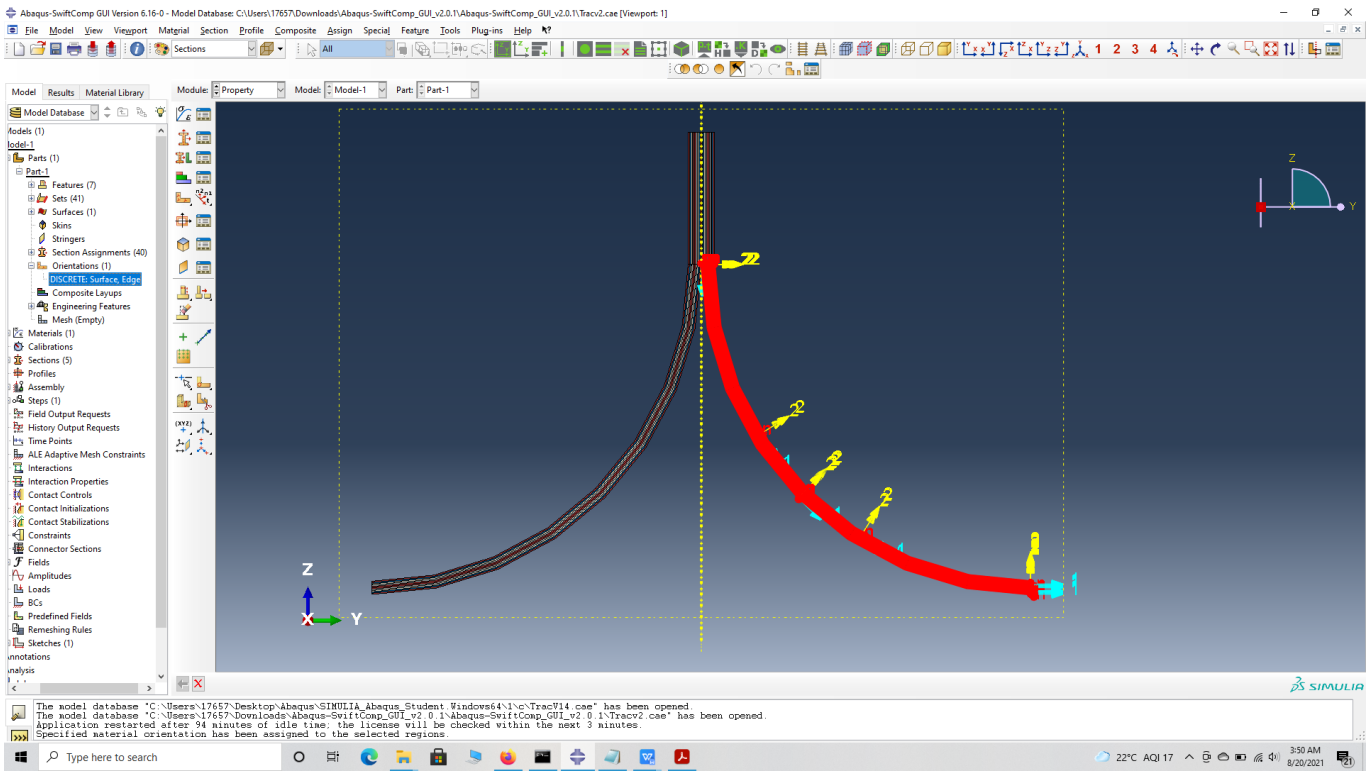
Define material orientation



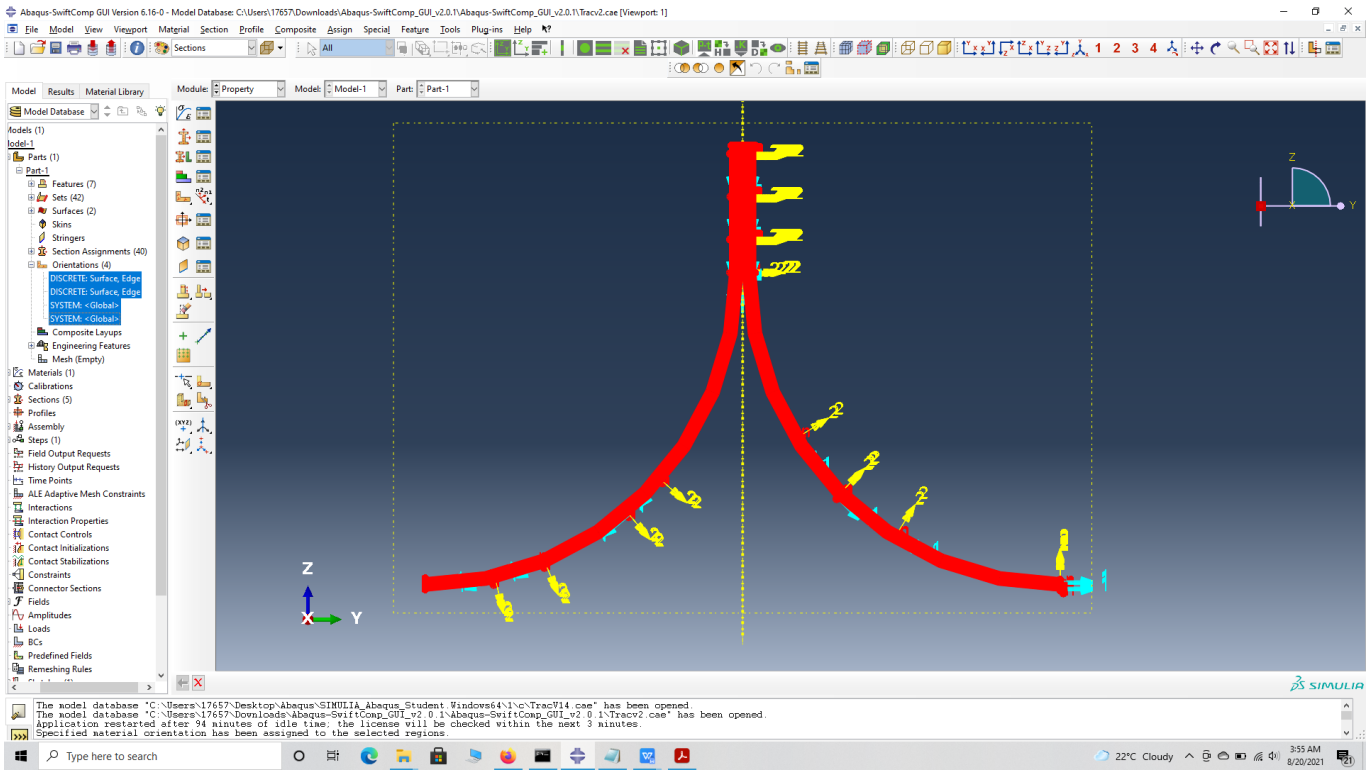
Define material orientation



Edit edges

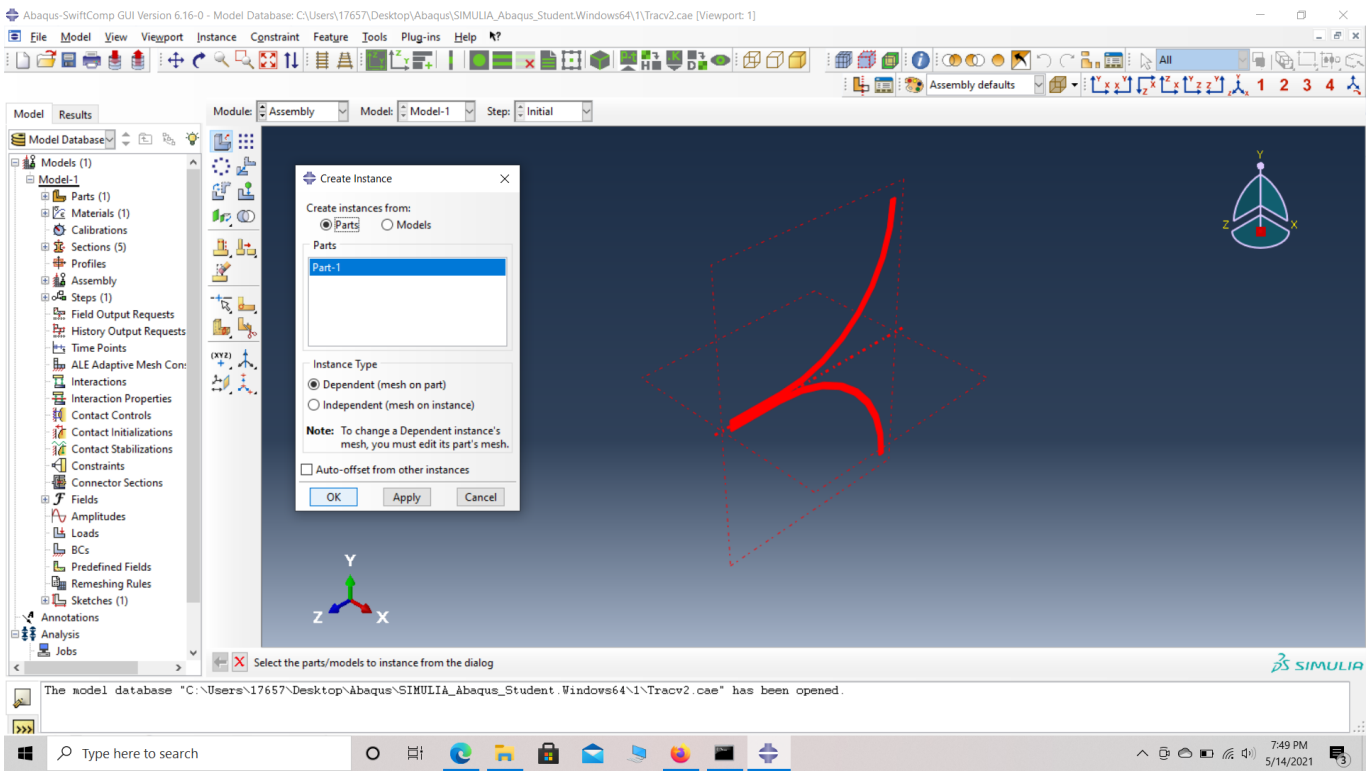


flange orientation



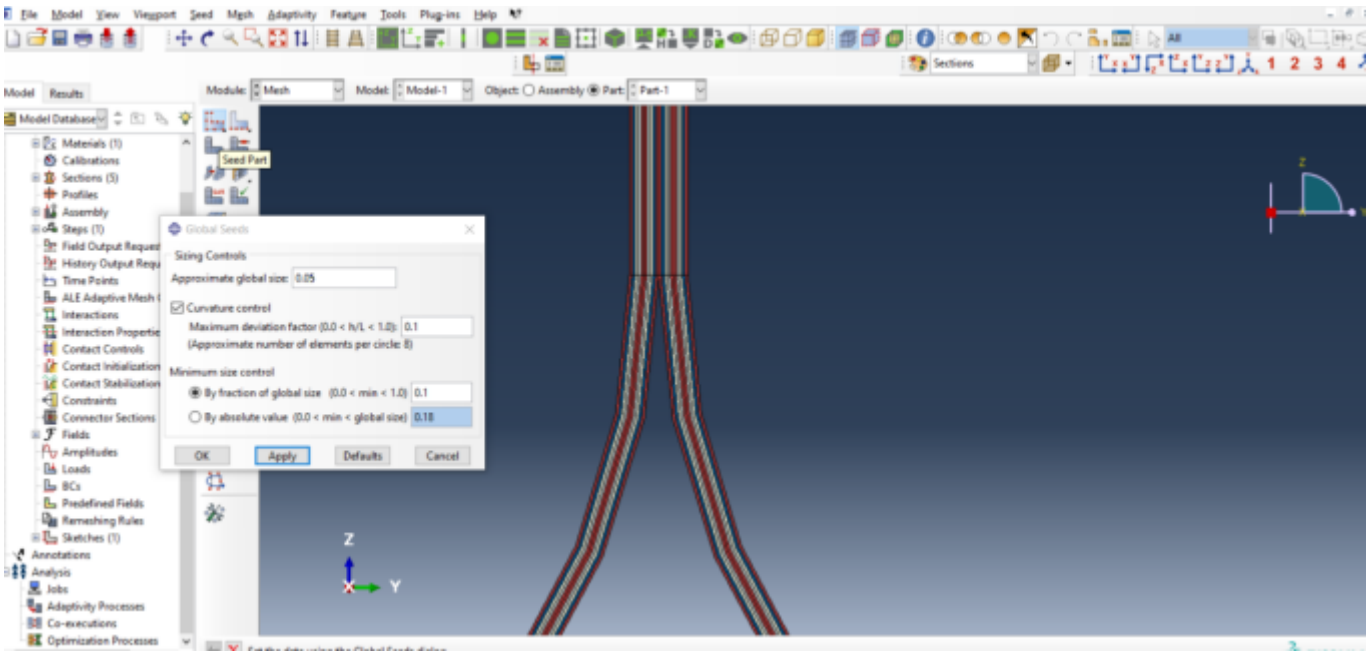
part orientation

‘ *# Step 3.7.* Now go to Assemble, create the part instance with dependent mesh.



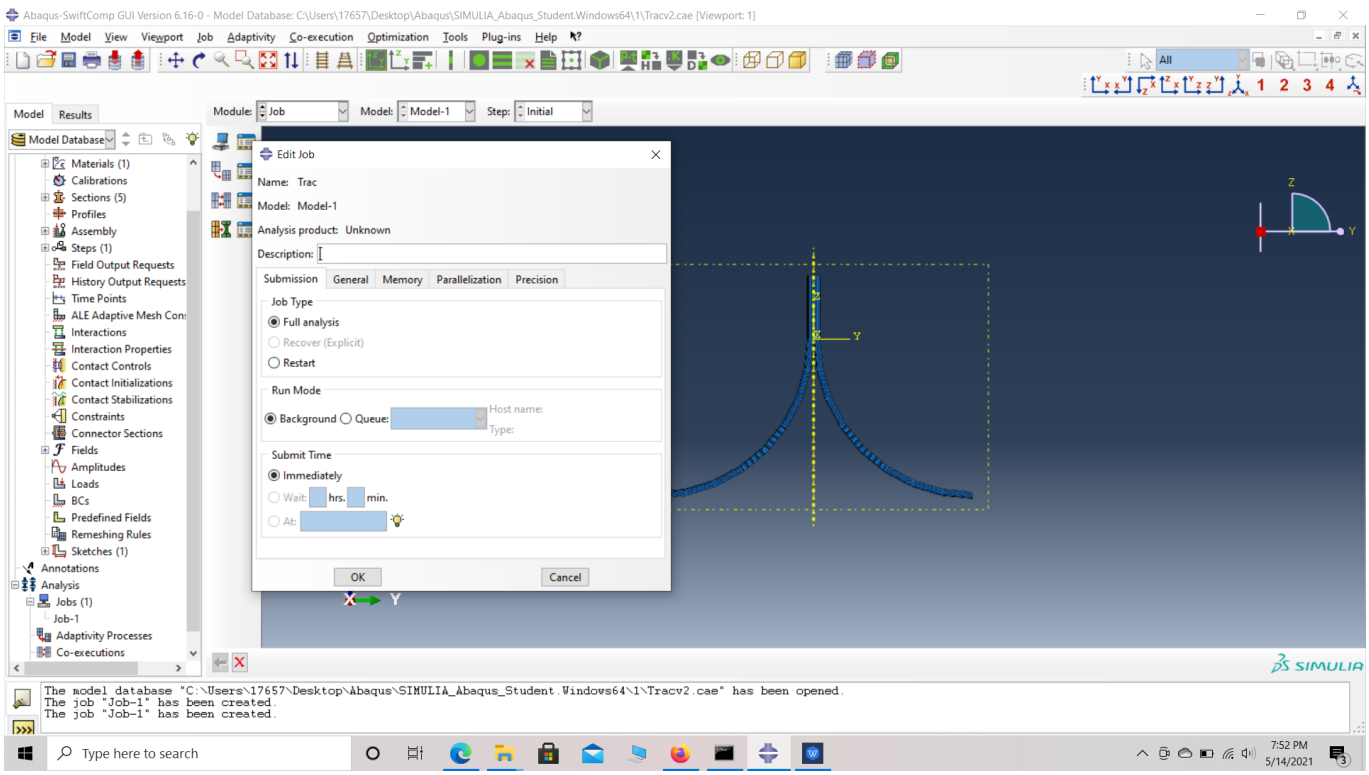
assembly

Step 3.8. In the Mesh section, Seed the Part and set approximate global mesh size, then Click ‘Mesh Part’



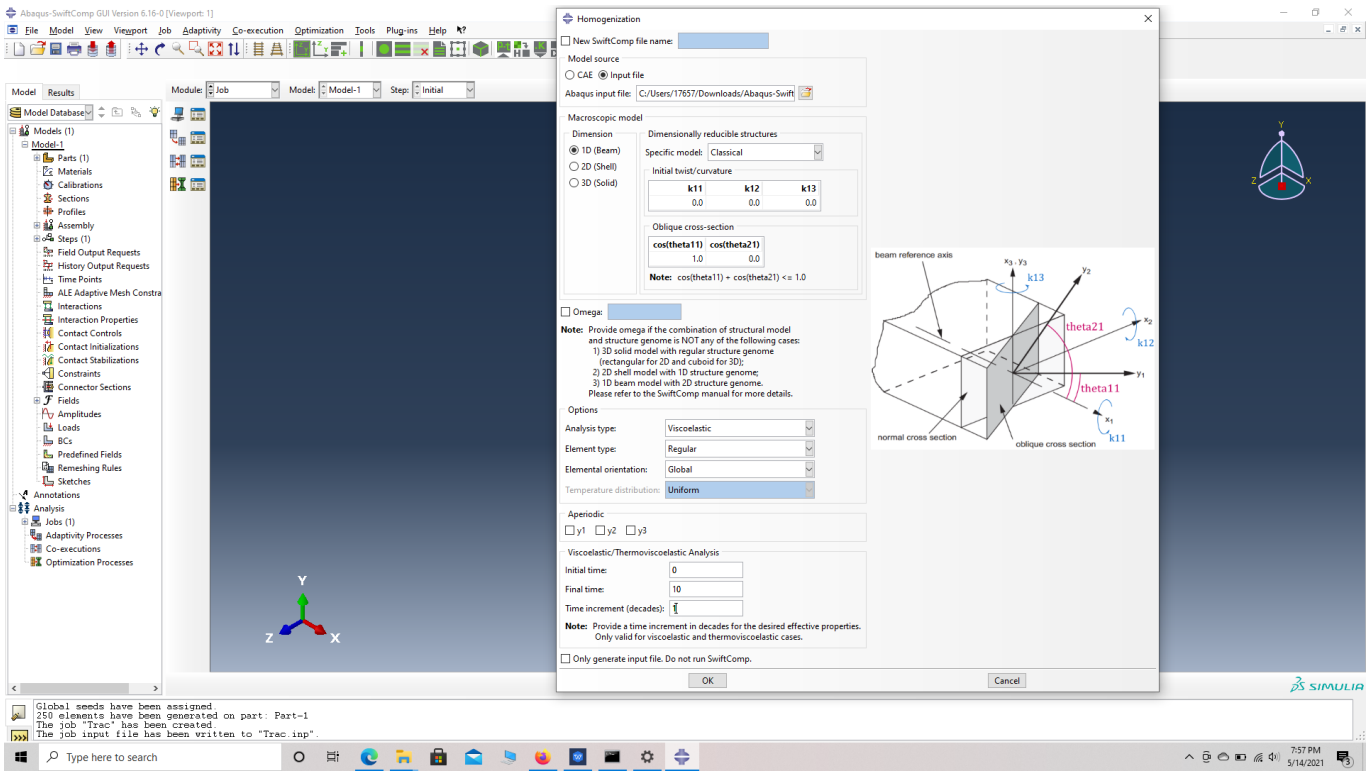
Mesh

Step 3.9. Create a job and write its input file.



ip file

Step 3.10. Homogenize the part preferably as a 1D beam using the Homogenization via input file option to get the final results. In the Viscoelastic/Thermoviscoelastic Analysis section, we define the range of the time (i.e. Initial time" and Final time") in which we want to output the effective properties as well as the frequency (i.e. Time increment" defined in decades). Homogenize the part preferably as a beam using the Homogenization via input file option to get the final results.



Homogenization

References

Rique, O.; Liu, X.; Yu, W., Pipes, R. B.: “Constitutive modeling for time- and temperature-dependent behavior of composites,” Composites Part B: Engineering, Vol 184, March 2020, DOI: 10.1016/j.compositesb.2019.107726.