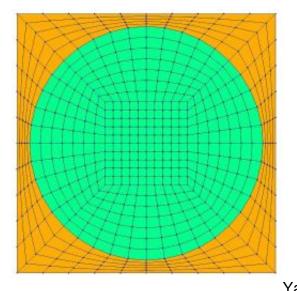
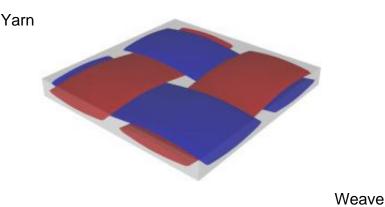
Elastic analysis of an Airfoil with uniform cross-section using Abaqus SwiftComp GUI and SwiftComp 2.1

Elastic analysis of an Airfoil with uniform cross-section

In this example, we want to compute the elastic effective properties of an Airfoil with uniform cross-section, fabricated from plain weave lamina made of isotropic elastic matrix and transversely isotropic elastic fiber. The MSG solid model is used to predict the effective elastic properties of a plain weave composite using a three part approach. The Airfoil model is derived from H. Chen, W. Yu and M. Capellaro and the Airfoil baselines taken from UIUC Airfoil Coordinate Database, mh104 model.

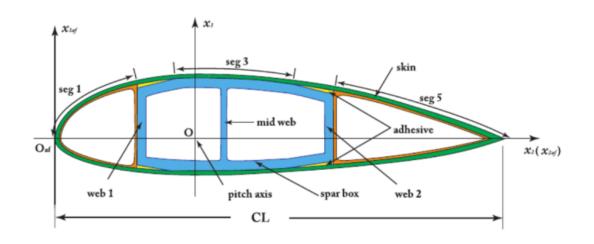
The first part predicts the effective elastic yarn properties based on the elastic fiber and matrix properties at the micro-scale. The second part takes the effective yarn properties and matrix properties to predict the elastic properties of weave composites. The third part uses the effective weave properties in the 3D Macro-scale analysis to predict the elastic properties of the Airfoil .





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H. Chen, W. Yu and M. Capellaro
```

A critical assessment of tools for blade modelling



Airfoil model taken from H. Chen, W. Yu and M. Capellaro

			мн	164 15.28	n.				_		
0.2											
0.1									-		
								_			
4.1											
42											
0.0	4.2	0.3	0.4	0.5	0.6	4.7	0.8	0.9	1		

Airfoil baselines taken from UIUC Airfoil Coordinate Database mh104 model' The fiber properties are defined as transversely isotropic elastic by means of engineering constants and the matrix properties are given by means of the elastic modulus 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	40,000.0	24000.0	14300.0	0.3	0.4

Isotropic Matrix properties

E (MPa)	ν
3500.0	0.35

Material Properties

We will use a square pack 2D SG with fiber volume fraction equal to vf = 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 elastic homogenization of the fiber-matrix square pack microstructure and also for the elastic homogenization of the plain weave laminate. Abaqus CAE will be used to model the tube and to run the homogenization while SwiftComp runs in the background.

Solution Procedure

The problem is divided into the following five sections:

Section 1- 2D Micro-scale analysis of the square-pack fiber matrix micro structure using Texgen4SC.

Section 2- 3D Meso-scale analysis of the plain weave laminate using Texgen4SC2.0.

Section 3- 3D Macro-scale analysis of the Airfoil using Abaqus CAE with the Abaqus SwiftComp GUI and SwiftComp 2.1.

Section1- Micro-scale analysis of the square-pack fiber matrix micro structure using Texgen4SC.

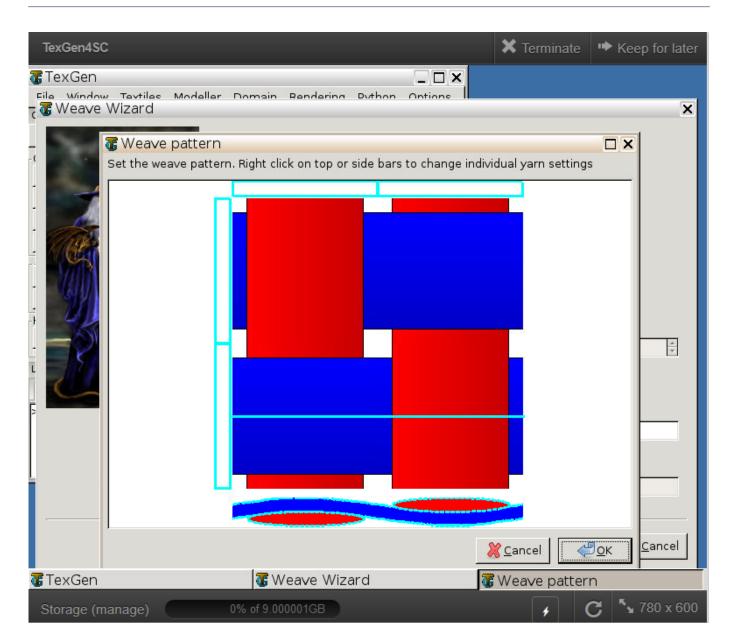
Step 1.1. Create the plain weave pattern using TexGen4SC 2.0. Launch TexGen4SC 2.0 on cdmHUB, the Go to window-> controls-> "Weave" to create mesoscale plain weave SG.

TexGen4SC					
🐻 TexGen					_ 🗆 X
<u>File Window Textiles</u>	<u>M</u> odeller	<u>D</u> omain	<u>R</u> endering	<u>P</u> ython	<u>O</u> ptions
Controls Texti ~ Logs Outliner Creat Empty Weave 3D Weave Layered Edit Delete					
Homogenization					
Log windows					×
Python Console	🛕 Python	Output	🚺 TexGer	n Output	
>>>					

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.

ELASTIC ANALYSIS OF AN AIRFOIL WITH UNIFORM CROSS-SECTION USING ABAQUS SWIFTCOMP GUI



Weave Pattern

Step 1.3.Click "Microscale" under "Homogenization" tab for yarn property calculation. Select "elastic" as the type of analysis and Enter the material properties for the fiber and matrix and set fiber Volume fraction as 0.64 and Click "Finish".

lexGel # 50							~ IC
T exGen							
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Empty		New PROPERTY.	This wizard will run r	microscale analysis fo	or you.		
Weave			Microscale model:				
3D Weave			🗹 Square pack	🗌 Hexagonal pack			
Layered			Type of analysis:				
Edit		CARE A	🗹 Elastic	Thermoelastic	Viscoelastic	Thermoviscoelastic	
Delete			Matrix properties:				
Homogenization			Em:	3500	nu:	0.35	
Microscale		The second	Alpha:	63e-6		,	
Mesoscale		_K NI		1036-0			
Failure analysis			Fiber properties:				
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			G12:	24e3	G23:	14.3e3	
			nu12:	0.3	nu23:	0.40	
			Alpha1:	-0.7e-6	Alpha2:	10e-6	
			Volumne fraction:				
			vf:	0.64			
Log windows							8
Python Console	🛕 Python Output 🛛 🛕 TexGen (Import viscoelastic	or thermoviscoelast	c properties	Import	
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					- Deals	<u>F</u> inish <u>X</u> ancel	
					< <u>B</u> ack	Einish Kancel	

Adding Material properties

Step 1.4. Now a .sc file (micro.sc) will be generated that SwiftComp will take as the input. SwiftComp will run on the cloud to calculate elastic properties of yarns, e.g., effective microscale properties. In the pop-up window, you will find the analysis results.

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	10	The Effective Complianc	e Matrix						
	9	6.6615614E-006 -2.0967067E-006 -2.0967070E-006 -1.5937951E-013 0.000000E+000 0.000000E+000 The Engineering Constan	-2.0967067E-006 6.9004020E-005 -2.3524104E-005 2.1572015E-008 0.0000000E+000 0.000000E+000	-2.0967070E-006 -2.3524104E-005 6.9004131E-005 -2.1523353E-008 0.0000000E+000 0.0000000E+000	-1.5937951E-013 2.1572015E-008 -2.1523353E-008 2.9063108E-004 0.0000000E+000 0.000000E+000	0.0000000E+000 0.0000000E+000 0.0000000E+000 1.9305453E-004 1.6586829E-011	0.0000000E+000 0.0000000E+000 0.0000000E+000 1.6586829E-011 1.9305453E-004		
	20								
	22 23 24 25 26 27 28 29 30 31	E1 = 1.501496E E2 = 1.4491900E E3 = 1.4491806E G12 = 5.1798338E G13 = 5.1798338E G13 = 5.1798338E nu12= 3.4407882E nu12= 3.1474703E nu13= 3.1474703E	+004 +004 +003 +003 +003 -001 -001						
	32 33	Effective Density =	0.000000E+000						

Micro scaleResuts

Section 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.

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🐻 TexGen		_ 8 ×
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Open TexGen File Save TexGen File		
Save Screenshot		
Import •		
Export In-House IGES File		
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Initial failure		
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>>>		
TexGen		
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weave mesh

Step 2.2. Define the voxel mesh, Select "elastic" as Type of analysis and Select "Solid Model".

TexGen4SC							🗙 Ter
🐻 TexGen							
	<u>M</u> odeller <u>D</u> omain <u>R</u> er	dering <u>P</u> ython <u>O</u> ptions <u>H</u> e	elp				
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Create: Empty							
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3D Weave		Sec. Including	This wizard will create SwiftCom	p input file for you.			
Layered			Assign voxel seed in each direc	tion:			
			X Voxel Count:	15			
Edit		78					
Delete			Y Voxel Count:	15			
Homogenization			Z Voxel Count:	15			
Microscale			man of an all all a		_		
Mesoscale		CHUN HILL	Type of analysis:	🗹 Elastic	Thermoelastic	Viscoelastic	
Failure analysis Initial failure				Thermoviscoelastic			
			Type of models	🗹 Solid Model	🗌 Plate/Shell Model	🗌 Beam Model	
			Type of plate theory	🗌 Kirchhoff-Love plate	🗌 Reissner-Mindlin plate		
	1		Type of beam theory	🗌 Euler-Bernoulli beam	🗌 Timoshenko beam		
			Aperiodic boundary conditions	🗌 yl	□ y2	🗆 уз	
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Log windows				_			×
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>>>					< <u>B</u> ack <u>F</u> inish	<u>Scancel</u>	
	-						

SwiftComp Wizard

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.

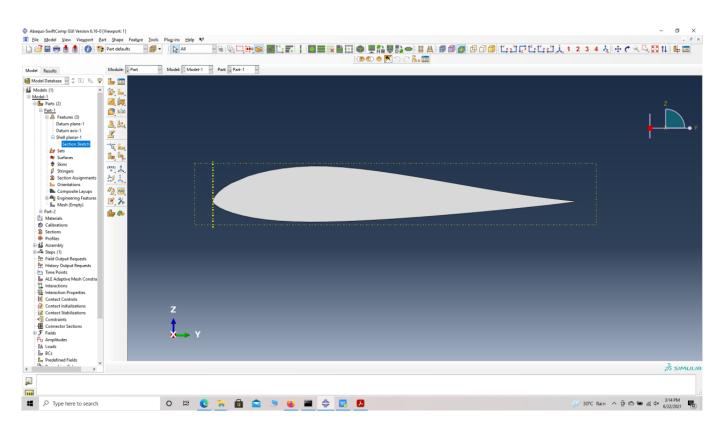
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	1 2	The Effective Stiffness Matrix				
3 4 5 6 7 8 9	3 4 5 6 7 8 9	7.2870428E+003 4.5125958E+004 3 3.1363640E+003 3.136303E+003 8 -1.2007942E+002 7.7258810E-002 -3 8.6035555E+002 6.5560247E+002 7 -3.2187334E+002 6.8590815E+002 1	1363640E+003 -1.2007942E- 1363603E+003 7.7258810E- .2683742E+003 -3.9044190E- .9044190E-003 2.5247759E+ .3024112E-003 -2.103239EE- .2290230E-003 -2.3958664E-	002 6.5860247E-002 003 7.3024112E-003 003 -2.1032396E-003 003 2.5247760E+003	- 3.2187334E-002 6.8590815E-002 1.2290230E-003 -2.3958664E-002 3.1806199E-002 3.2109492E+003	
	10 11	The Effective Compliance Matrix				
	12 13 14 15 16 17 18 19 20	-3.2206282E-006 2.3207187E-005 -7 -7.5813070E-006 -7.5813015E-006 1 1.9720464E-010 -7.3719294E-010 3 -6.8488376E-010 44.7369176E-010 8	.5813070E-006 1.9720464E- .5813015E-006 -7.3719294E- .2669424E-004 3.9185852E- .9185652E-010 3.9607476E- .9669170E-011 2.99503067E- .7459946E-011 2.9553467E- otropic)	010 -4.7369176E-010 010 8.9669170E-011 004 3.2992030E-010 010 3.9607474E-004	3.0434196E-010 -5.2512457E-010 3.7459946E-011 2.9553467E-009 -3.923301E-009 3.1143439E-004	
	20 21 22 23 24 25 26 27 28 29 30 31 32 33	E1 = 4.3090131E+004 E2 = 4.309009E+004 E3 = 7.8930185+003 G12 = 3.2109492E+003 G13 = 2.5247750E+003 G23 = 2.5247750E+003 mu12= 1.387729E+001 mu23= 3.2667951E+001 mu23= 3.2667964E+001 Effective Density = 0.0000000E+000				

Meso Scale Results

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

Section 3- Macro-scale analysis of the Airfoil using Abaqus CAE with the Abaqus SwiftComp GUI and SwiftComp 2.1.

Step 3.1. Set sketch plane for customized SG -> Create planar shell -> Select the plane and vertical axis -> Sketch the cross section shown from the baseline coordinates.



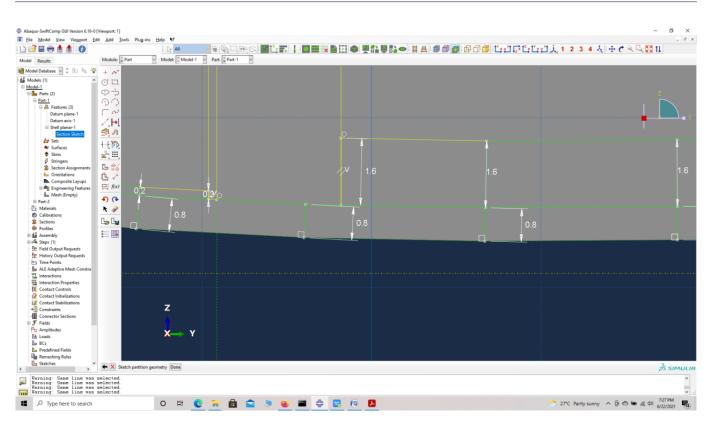
Airfoil shell

X Coordinate	Y Coordinate	X Coordinate	Y Coordinate
1.00000000	0.00000000		
0.99619582	0.00017047	0.00001249	-0.00046881
0.98515158	0.00100213	0.00023032	-0.00191488
0.96764209	0.00285474	0.00079945	-0.00329201
0.94421447	0.00556001	0.00170287	-0.00470585
0.91510964	0.00906779	0.00354717	-0.00688469
0.88074158	0.01357364	0.00592084	-0.00912202
0.84177999	0.01916802	0.01810144	-0.01720842
0.79894110	0.02580144	0.03471169	-0.02488211
0.75297076	0.03334313	0.05589286	-0.03226730
0.70461763	0.04158593	0.08132751	-0.03908459
0.65461515	0.05026338	0.11073805	-0.04503763
0.60366461	0.05906756	0.14391397	-0.04986836
0.55242353	0.06766426	0.18067874	-0.05338180
0.50149950	0.07571157	0.22089879	-0.05551392
0.45144530	0.08287416	0.26433734	-0.05636585
0.40276150	0.08882939	0.31062190	-0.05605816
		0.35933893	-0.05472399
0.35589801	0.09329359	0.40999990 0.46204424	-0.05254383 -0.04969990
0.31131449	0.09592864	0.51483073	-0.04637175
0.26917194	0.09626763	0.56767889	-0.04264894
0.22927064	0.09424396	0.61998250	-0.03859653
0.19167283	0.09023579	0.67114514	-0.03433153
0.15672257	0.08451656	0.72054815	-0.02996944
0.12469599	0.07727756	0.76758733	-0.02560890
0.09585870	0.06875796	0.81168064	-0.02134397
0.07046974	0.05918984	0.85227225	-0.01726049
0.04874337	0.04880096	0.88883823	-0.01343567
0.03081405	0.03786904	0.92088961	-0.00993849
0.01681379	0.02676332	0.94797259	-0.00679919
0.00687971	0.01592385	0.96977487	-0.00402321
0.00143518	0.00647946	0.98607009	-0.00180118
0.00053606	0.00370956	0.99640466	-0.00044469
0.00006572	0.00112514	1.00000000	0.00000000

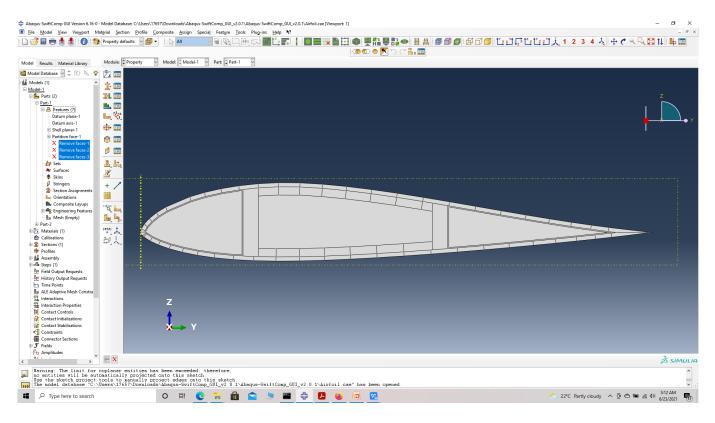
Baseline coordinates

Step 3.2. Partition the part as shown to obtain the final cross-section

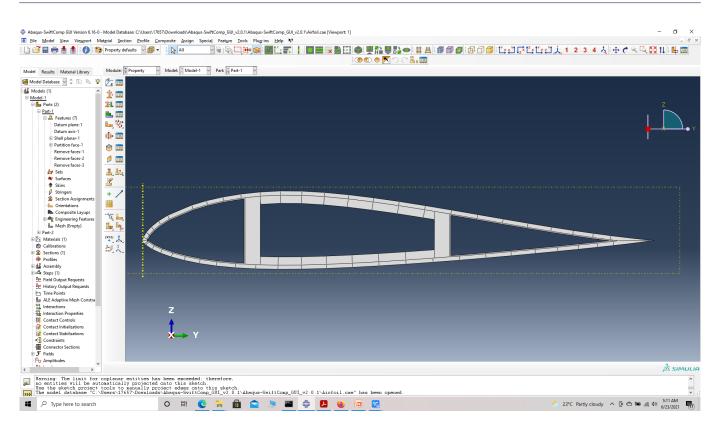
ELASTIC ANALYSIS OF AN AIRFOIL WITH UNIFORM CROSS-SECTION USING ABAQUS SWIFTCOMP GUI



Airfoil shell partition dimensions



Airfoil shell partition



Airfoil Crosssection

Step 3.3. Enter the material properties for the model. First we need to choose the material properties from the results of the computed effective elastic properties in the previous part. Then 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. Within the Materials section of Abaqus CAE, we create a material called "Material-1" and add the corresponding properties. We can also import the homogenized properties from the toolbar.

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

Abaqus's

Constitutive relations

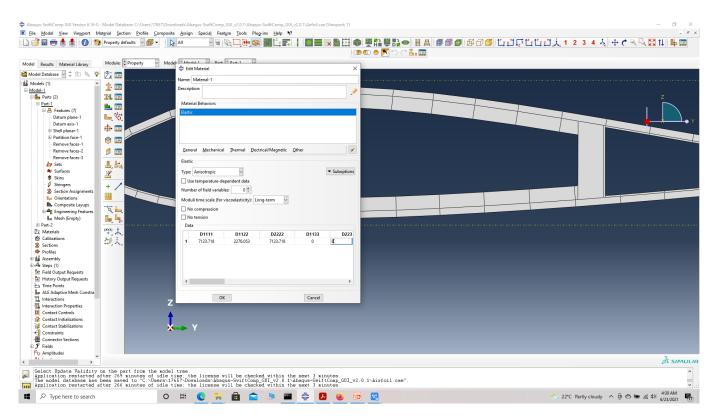
(σ_{11})	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	$\left(\varepsilon_{11}\right)$
σ_{22}	c_{12}	c_{22}	c_{23}	c_{24}	c_{25}	c_{26}	ε_{22}
σ_{33}	c_{13}	c_{23}	c_{33}	c_{34}	c_{35}	c_{36}	$\left \begin{array}{c}\varepsilon_{33}\\2\varepsilon_{23}\\2\varepsilon_{13}\\\end{array}\right\rangle$
$\left\{ \begin{array}{c} \sigma_{33} \\ \sigma_{23} \end{array} \right\} =$	c_{14}	c_{24}	c_{34}	c_{44}	c_{45}	c_{46}	$2\varepsilon_{23}$
σ_{13}	c_{15}	c_{25}	C_{35}	c_{45}	c_{55}	c_{56}	$2\varepsilon_{13}$
σ_{12}	c_{16}	c_{26}	c_{36}	c_{46}	c_{56}	c_{66}	$2\varepsilon_{12}$

Constitutive relations

σ11 C11 C12 C13 C16 C15 C14 211 σ22 C12 C22 C23 C25 **ε22** C26 C24 C13 C23 σ33 C33 C36 C35 C34 833 = C16 C26 C36 C66 C56 C46 2812 σ12 C25 C35 C56 C55 C15 C45 2813 σ13 σ23 C14 C24 C34 C46 C45 C44 2823

SwiftComp's

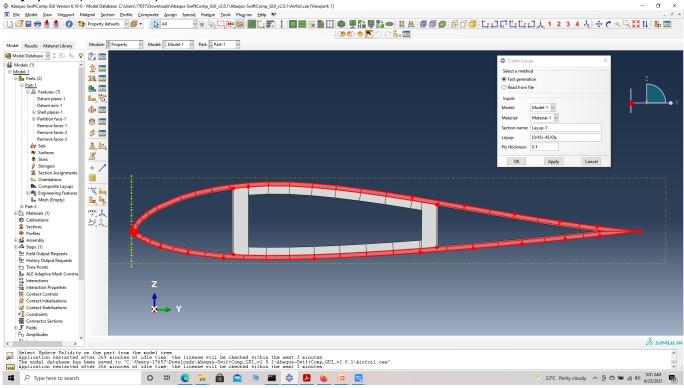
output Constitutive relations converted into Abaqus's input Constitutive relations



Importing Material properties

SwiftComp's

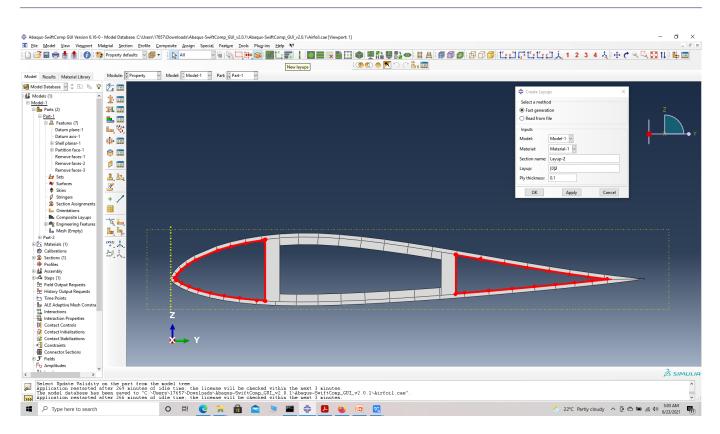
Step 3.4. Now go to New Layups and add the material, section name, Layup and thickness to create the required layup. This is repeated five time since we have multiple layups. We will use plies of orientation 0,45 and -45 with a individual ply thickness of 0.1 mm for all laminates of the Airfoil. We will also have to portion the web as shown in part-1 model tree -> partition face->edit section sketch -> make appropriate changes -> Feature -> Regenerate.



Layup 1 - (0/45/-45/0)s

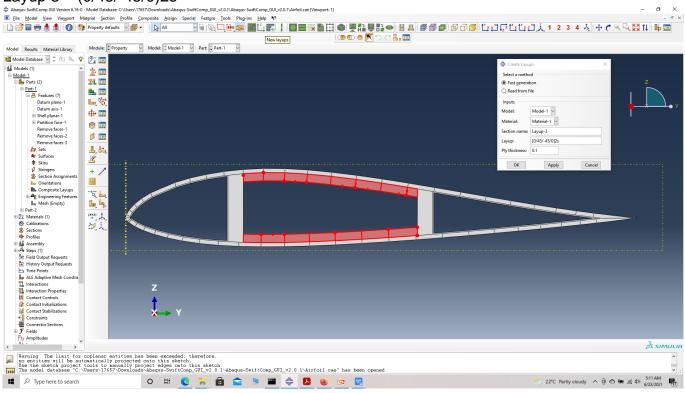
Layup-1

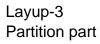
Layup 2 - (0)2

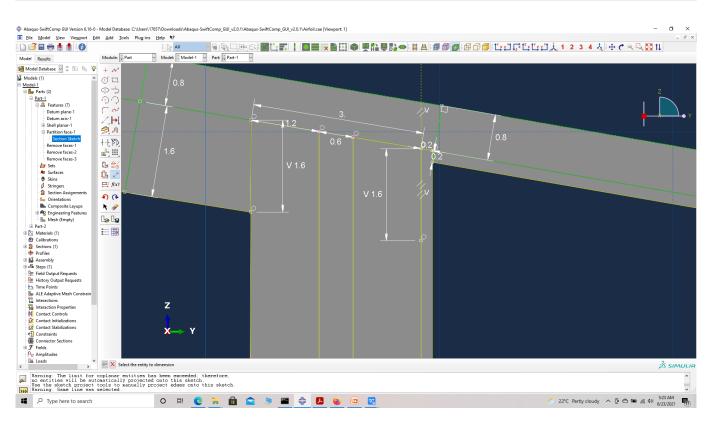


Layup-2

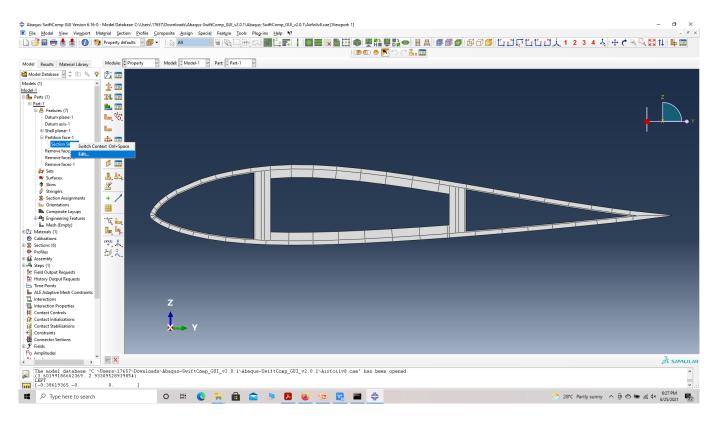
Layup 3 - (0/45/-45/0)2s



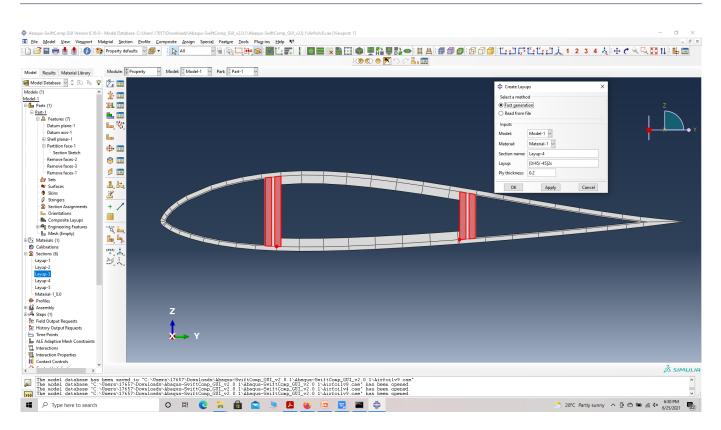




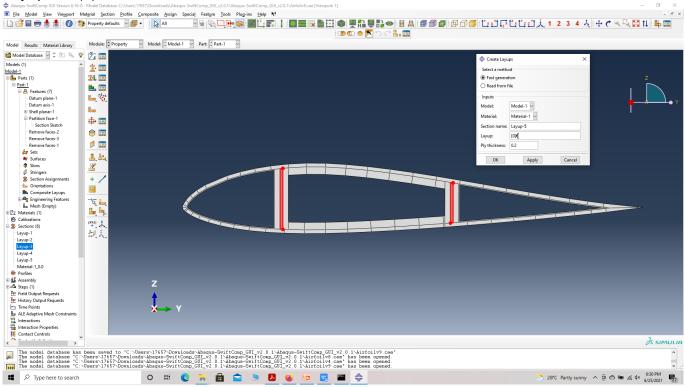
edit partition



New partition Layup 4 – (0/45/-45)2s

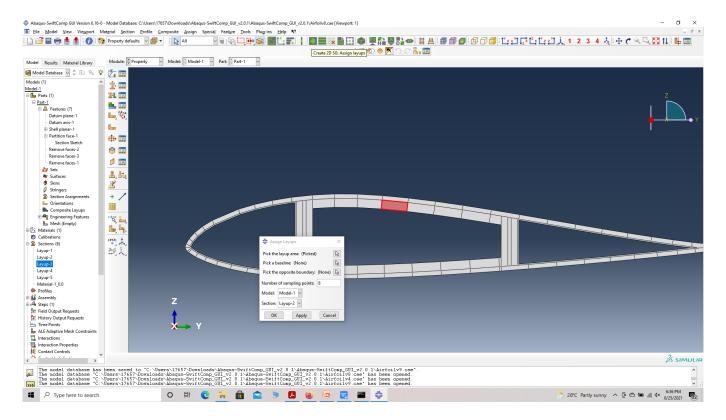


Layup-4 Layup 5 – (0)6

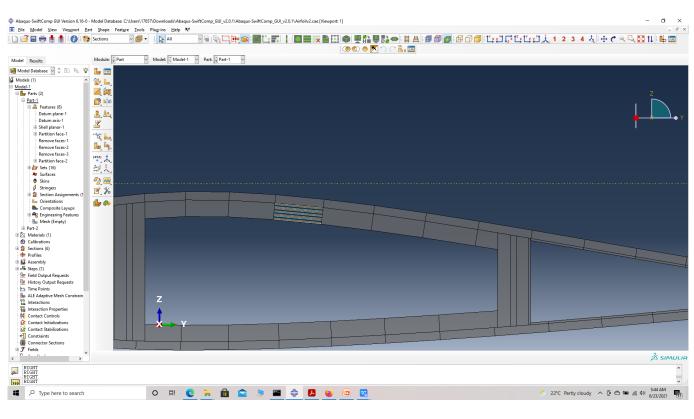


Layup-5

' # 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 section as shown and then hit Ok. Do this for all sections. Since we have reduced the model, we will consider the outer lines as base lines

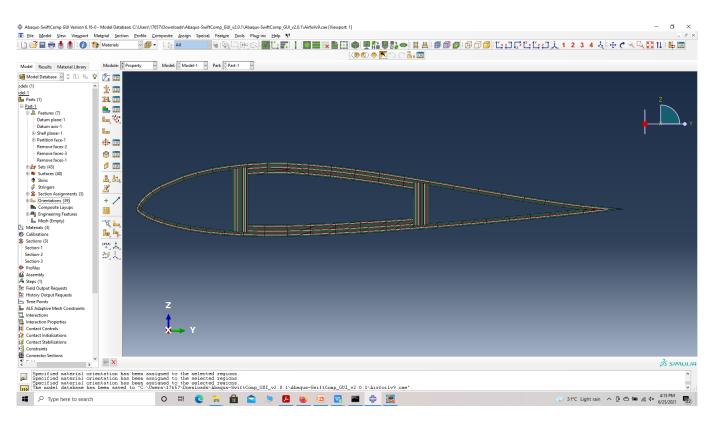


Assign Layups



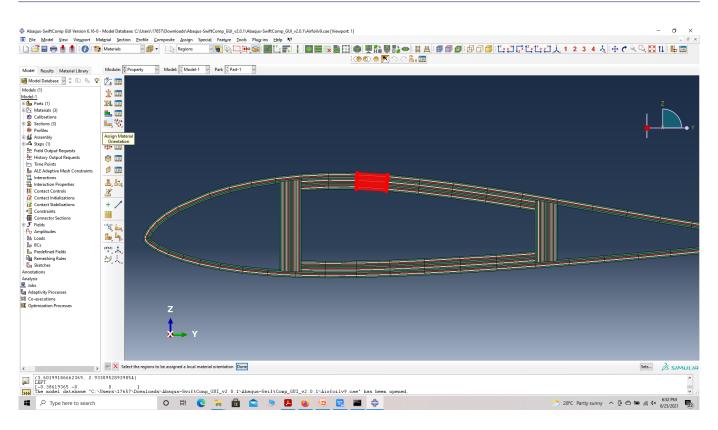
Assign Layups

Step 3.6. We can also partition the part and assign materials manually, which is another time consuming option. Since the add layup feature uses regenerate option each time a new layup is assigned, the limited computational resources of the free student edition of abaqus will direct this tutorial to use the manual partition method with half the plies, ie the ply thickness is increased to 0.2 mm. So the final part with the layups assigned will resemble the figure below.

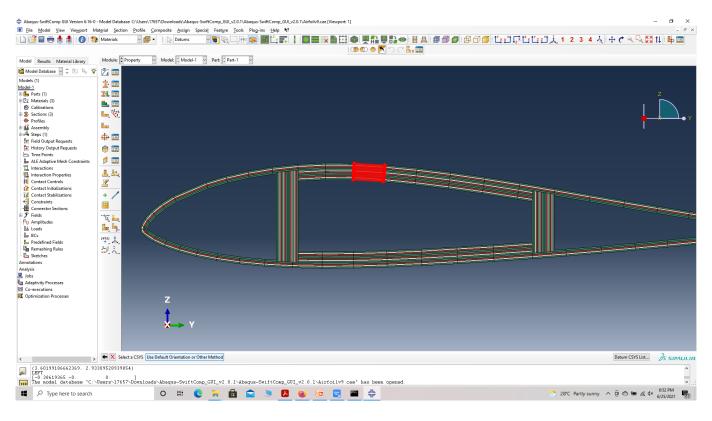


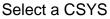
Assign Layups

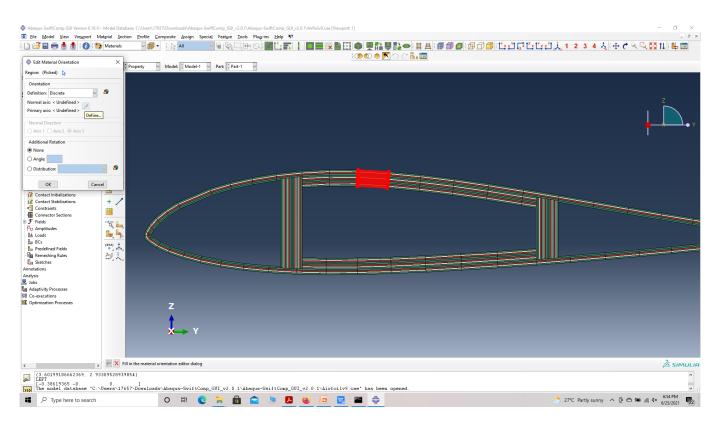
[•] # Step 3.7. Now we assign the material orientation for the part. Go to Assign material orientation -> select the sections of the part with the same orientation -> Done -> Select a CSYS (use default orientation or other method) -> Definition (Discrete) -> Define -> Primary axis orientation -> choose 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.



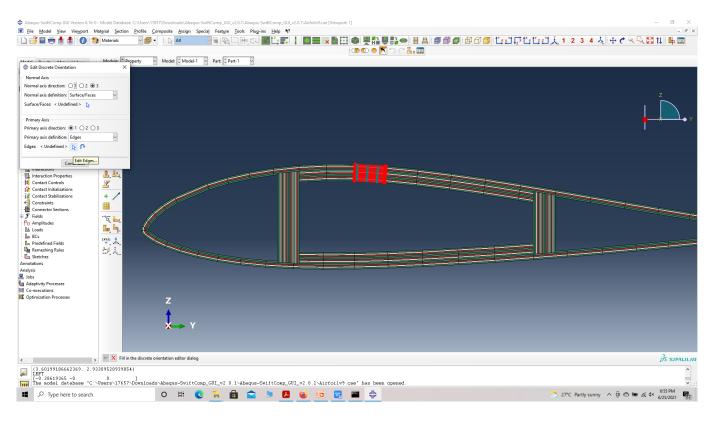
Assign material orientation







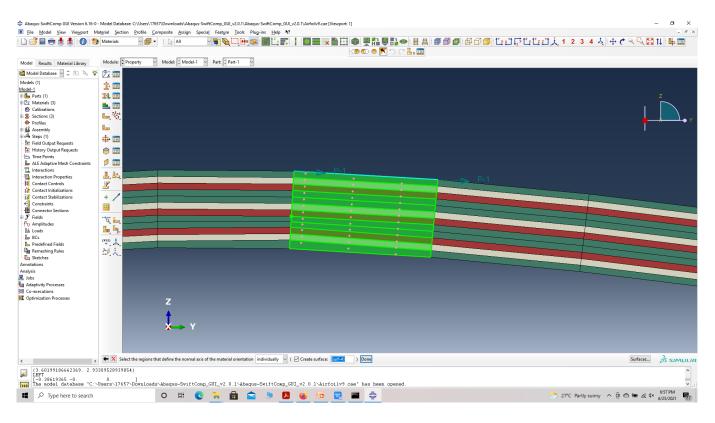
Define orientation



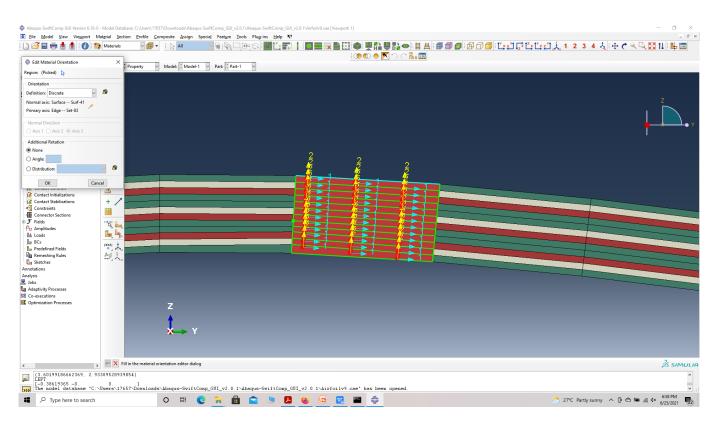
edit edges

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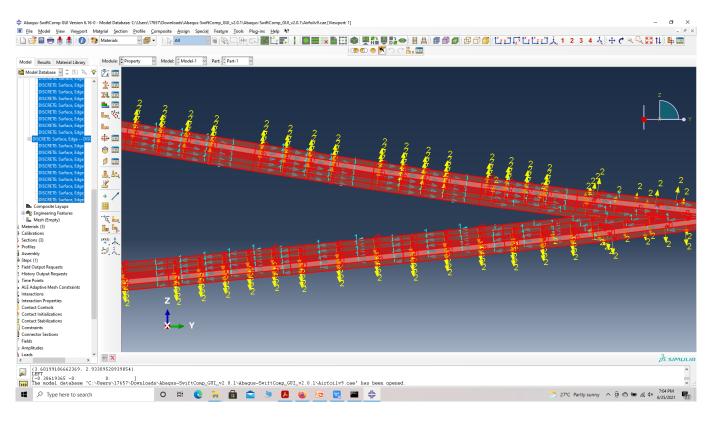
flip edges to clockwise orientation



choose surfaces

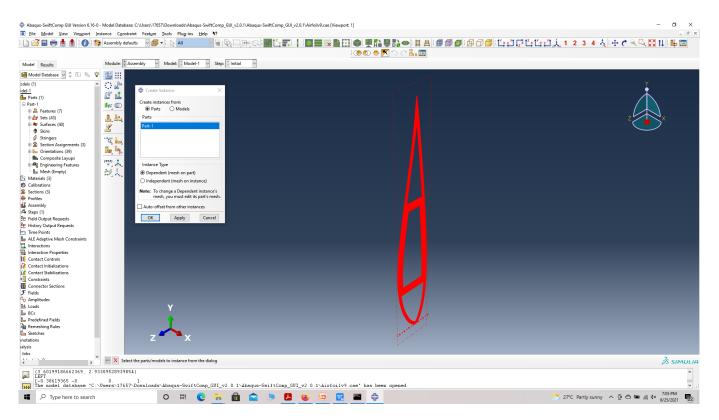


Orientation



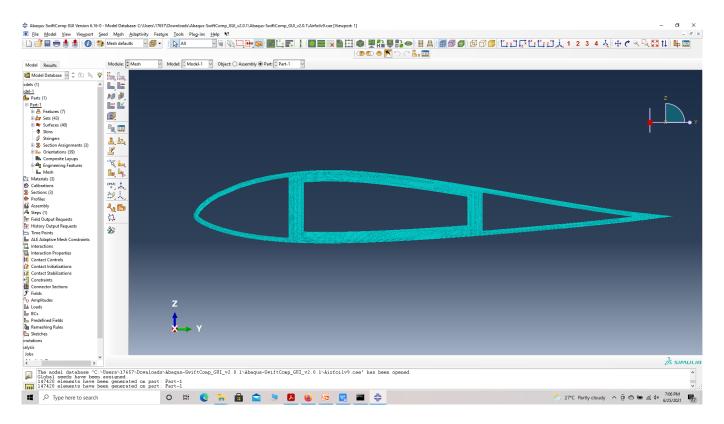
Part Orientation

' # Step 3.8. Now go to Assemble, create the part instance with dependent mesh.



assembly

Step 3.9. In the Mesh section, Seed the Part and set approximate global mesh size, then Click 'Mesh Part'



Mesh

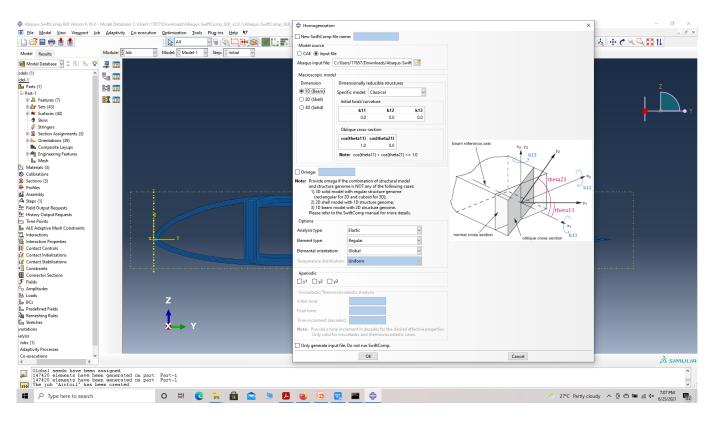
Step 3.10.Create a job and write its input file.

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ip file

Step 3.11.To the effective elastic properties. we click on Homogenization and select elastic in Analysis Type. Homogenize the part preferably as a beam using the Homogenization via input file option to get the final results.

ELASTIC ANALYSIS OF AN AIRFOIL WITH UNIFORM CROSS-SECTION USING ABAQUS SWIFTCOMP GUI



Homogenization

[desc="Material properties ")

References

Chen, H., Yu, W. & Capellaro, M. A critical assessment of computer tools for calculating composite wind turbine blade properties. Wind Energy, 13, 497-516, 2010.