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Simplified Composite Airplane Fuselage

A Design Study with Stiffeners

ME I6700 Composite Materials

Fall 2016

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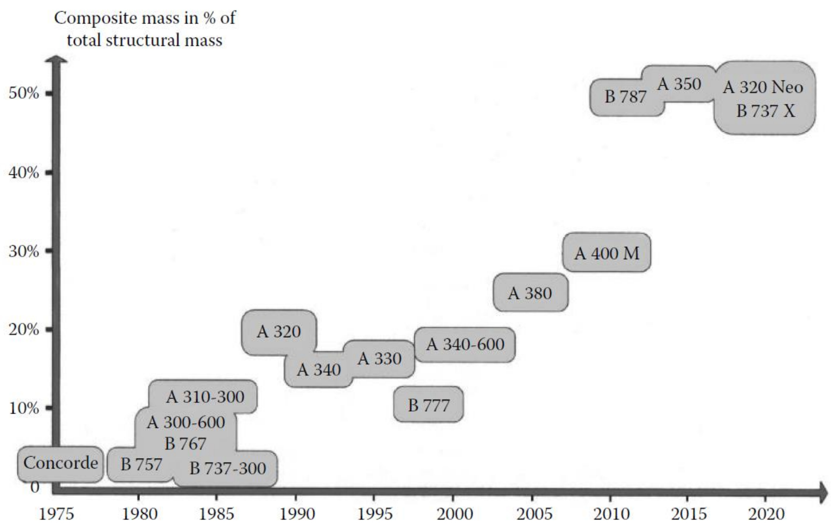
➢ Introduction:

The use of composite laminates provides an enormous advantage as compared to bulk isotropic materials when stiffness to weight ratio must be maximized. Composite materials are becoming more important in the construction of aerospace structures. Aircraft parts made from composite materials, such as fairings, spoilers, and flight controls, were developed during the 1960s for their weight savings over aluminum parts. New generation large aircraft are designed with all composite fuselage and wing structures, and the repair of these advanced composite materials requires an in-depth knowledge of composite structures, materials, and tooling. The primary advantages of composite materials are their high strength, relatively low weight, and corrosion resistance.



Laminated Structures Composite materials consist of a combination of materials that are mixed together to achieve specific structural properties. The individual materials do not dissolve or merge completely in the composite, but they act together as one. Normally, the components can be physically identified as they interface with one another. The properties of the composite material is superior to the properties of the individual materials from which it is constructed. An advanced composite material is made of a fibrous material embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness.

An airplane fuselage can be simplified and modeled as an eccentrically stiffened circular cylindrical shell. The circumferential stiffeners, also known as ring stiffeners or frames, could be on the outside of the shell unless not permitted for aerodynamic or hydrodynamic reasons. The axial stiffeners are the one that are place on the inside of the shell. They are also known as longerons or spars.

➢ Problem Statement:

A simplified shape of an airplane fuselage consists of a composite shell and many radial stiffeners as shown in figure 1.

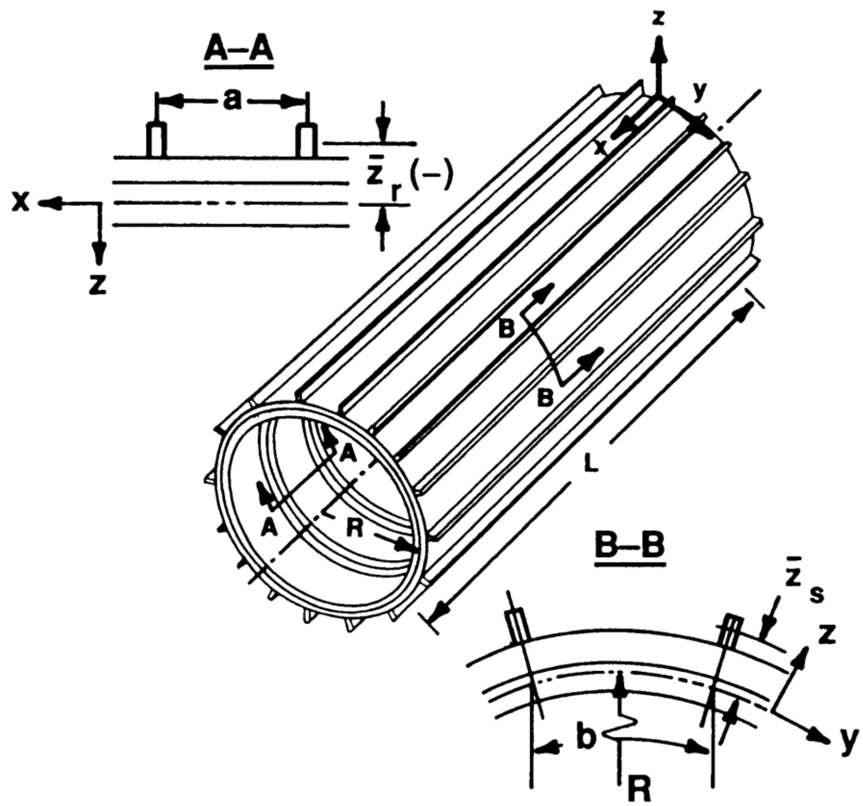


Fig. 1 Stiffened Circular Cylindrical Shell

- The shell has five layers of composites (60/-60/90/-60/60) and is 40 feet long.
- The inner diameter of the fuselage is 10 feet.
- The fuselage is pressurized and is subjected to a bending and torsion loads.
- The fuselage is subjected to 10 psi internal pressure and 20,000 pound distributed load on the outer surface of the top half of the shell.
- Assume one side of the fuselage is fixed and the free end is subjected to 10,000 ft-lb torque.

➢ Design Constrains:

Design the materials, dimensions and number of stiffeners such that the structure does not deflect more than 5 inches vertically at the free end and does not rotate more than 5 degrees at the free end.

The modeling and finite element analysis of the stiffened shell will be done in Solidworks and Ansys Finite Element Analysis Software to find out optimum design.

➢ **Material:**

Properties in Material Co-ordinate	E_1	E_2	E_3	ν_{12}	ν_{23}	ν_{13}	G_{12}	G_{23}	G_{13}
Properties in Global Co-ordinate	E_x	E_y	E_z	ν_{xy}	ν_{yz}	ν_{xz}	G_{xy}	G_{yz}	G_{xz}

Geometry to be modeled as Material co-ordinate 1, 2 and 3 aligning with X, Y and Z co-ordinates. Therefore,

Properties in Global Co-ordinate	E_x	E_y	E_z	ν_{xy}	ν_{yz}	ν_{xz}	G_{xy}	G_{yz}	G_{xz}
Values	45GPa	16GPa	1 Pa	0.27	0	0	4GPa	1 Pa	1 Pa

Table 1. Material Properties of Lamina in Principal Direction

Outline of Schematic C2, D2, E2, F2, G2: Engineering Data

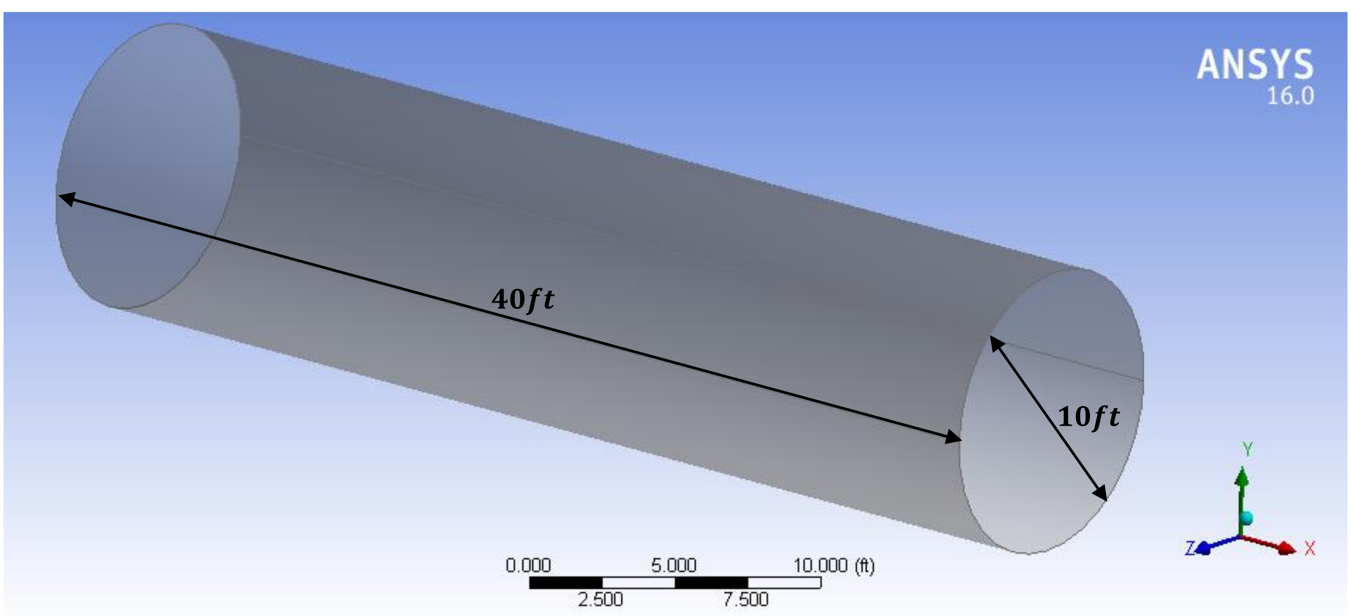
	A	B	C	D
1	Contents of Engineering Data		Source	Description
2	Material			
3	Epoxy_EGlass_UD		C:\Pro	
4	lamina		C:\Use	
*	Click here to add a new material			

Properties of Outline Row 4: lamina

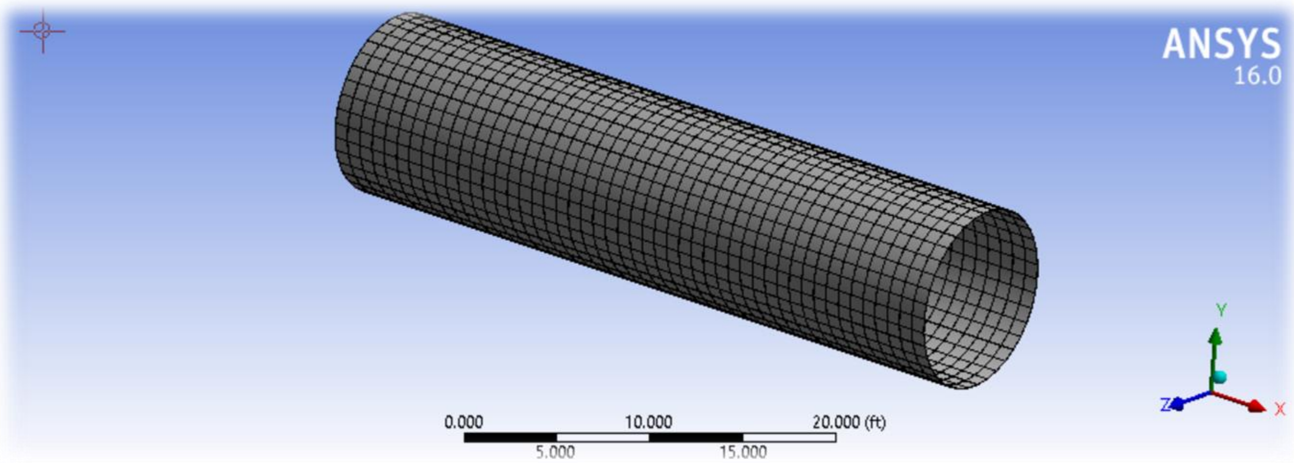
	A	B	C	D	E
1	Property	Value	Unit		
2	Orthotropic Elasticity				
3	Young's Modulus X direction	45000	MPa		
4	Young's Modulus Y direction	16000	MPa		
5	Young's Modulus Z direction	1	Pa		
6	Poisson's Ratio XY	0.27			
7	Poisson's Ratio YZ	0			
8	Poisson's Ratio XZ	0			
9	Shear Modulus XY	4000	MPa		
10	Shear Modulus YZ	1	Pa		
11	Shear Modulus XZ	1	Pa		

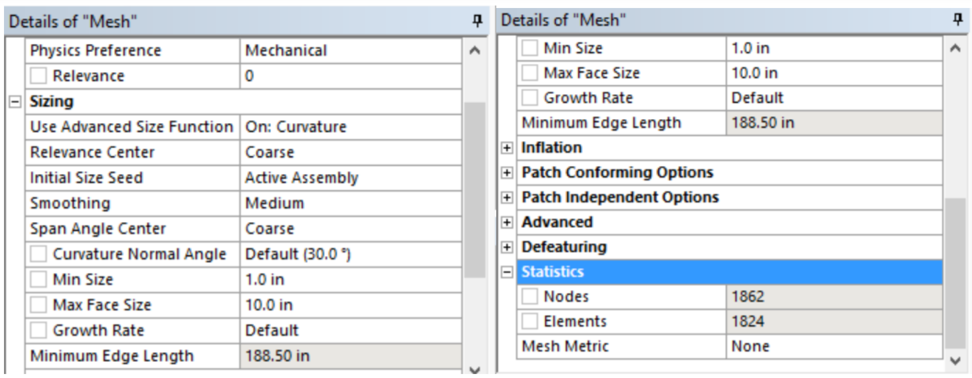
➢ **Solid Modeling:**

Simplified Geometry:



➢ Mesh:





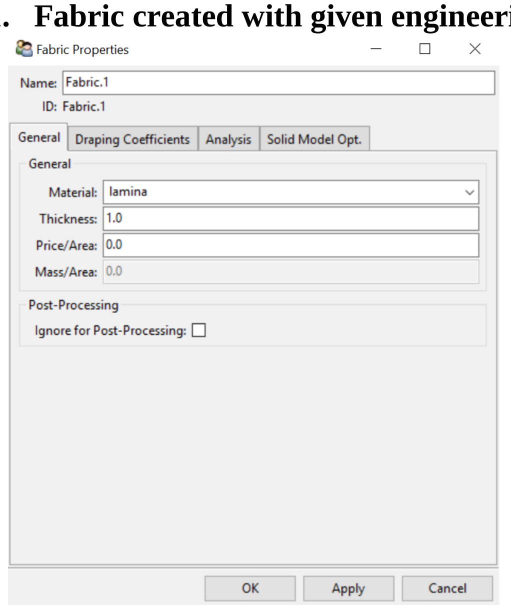
➢ Laminate Modeling:

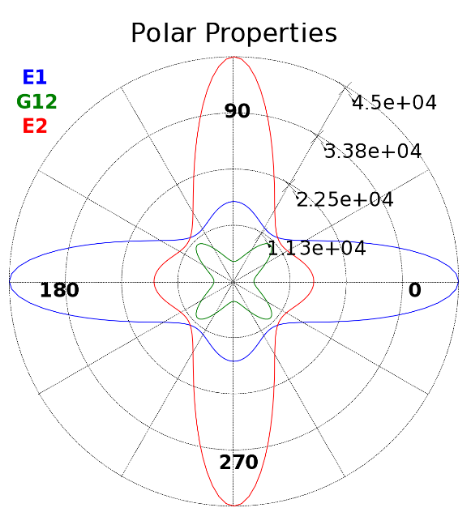
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Orientation	60º	-60º	90º	-60º	60º
Thickness	1 mm	1 mm	1 mm	1 mm	1 mm

Laminated Composite for Cylindrical Shell

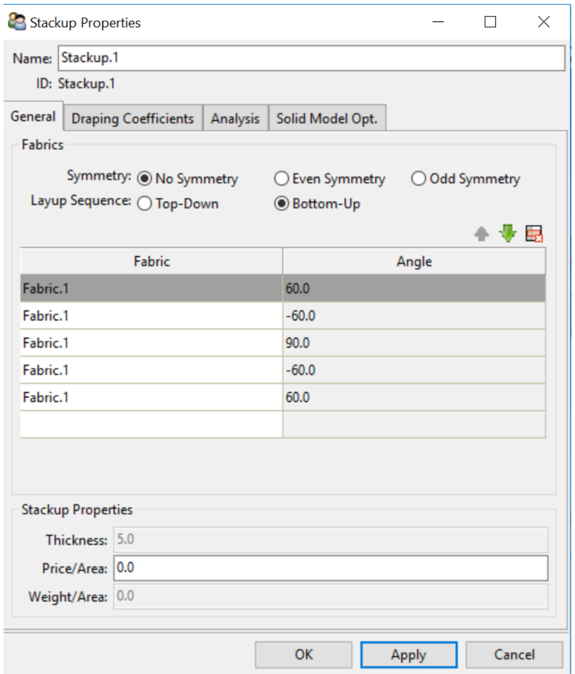
COMPOSITE PRE-ANALYSIS IN ANSYS ACP-PRE:

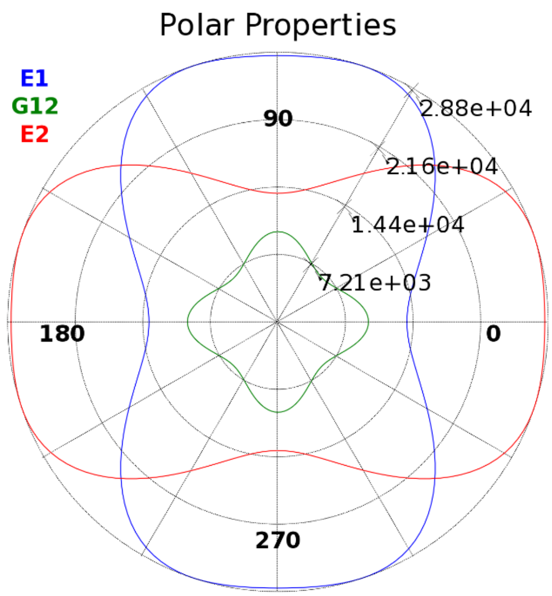
1. **Fabric created with given engineering constant of material with 1mm thickness.**



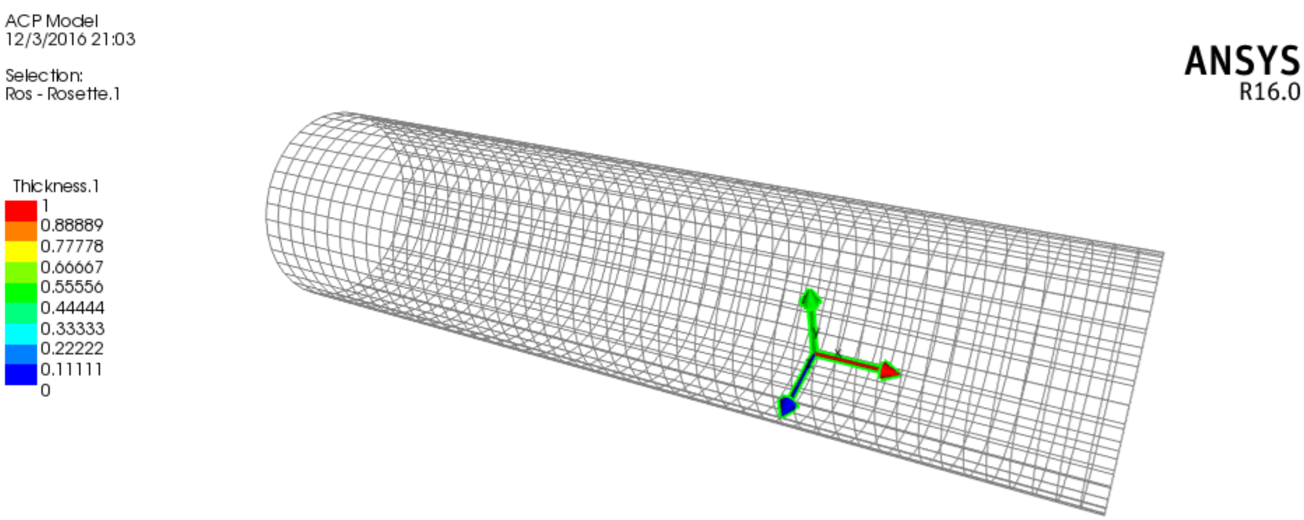


2. Laminate stack created with five layer [60/-60/90/-60/60]

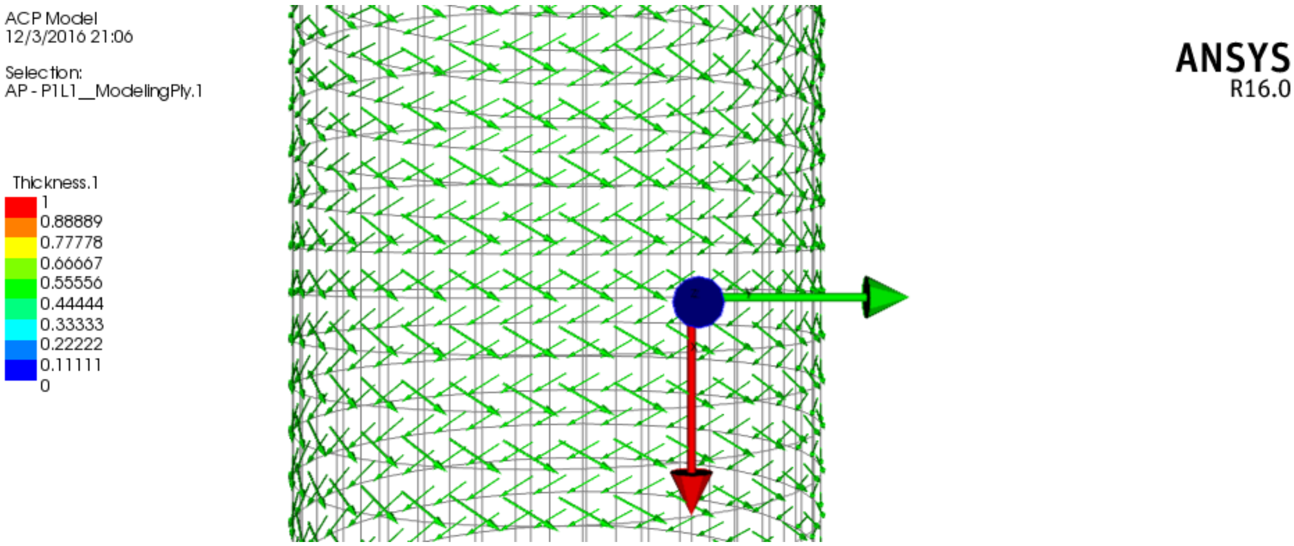


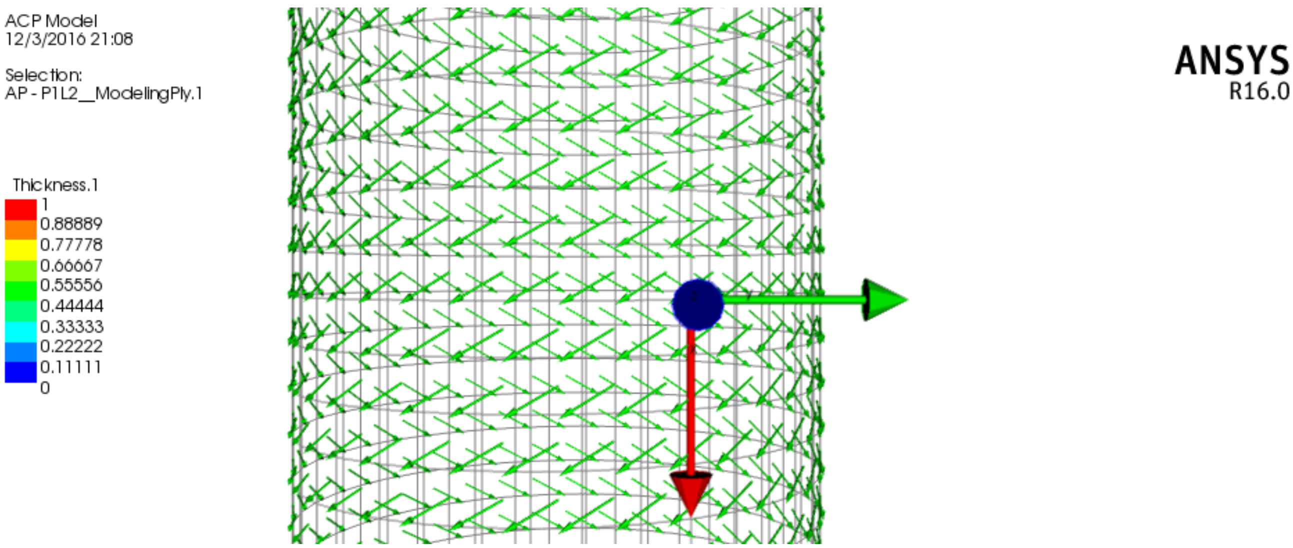


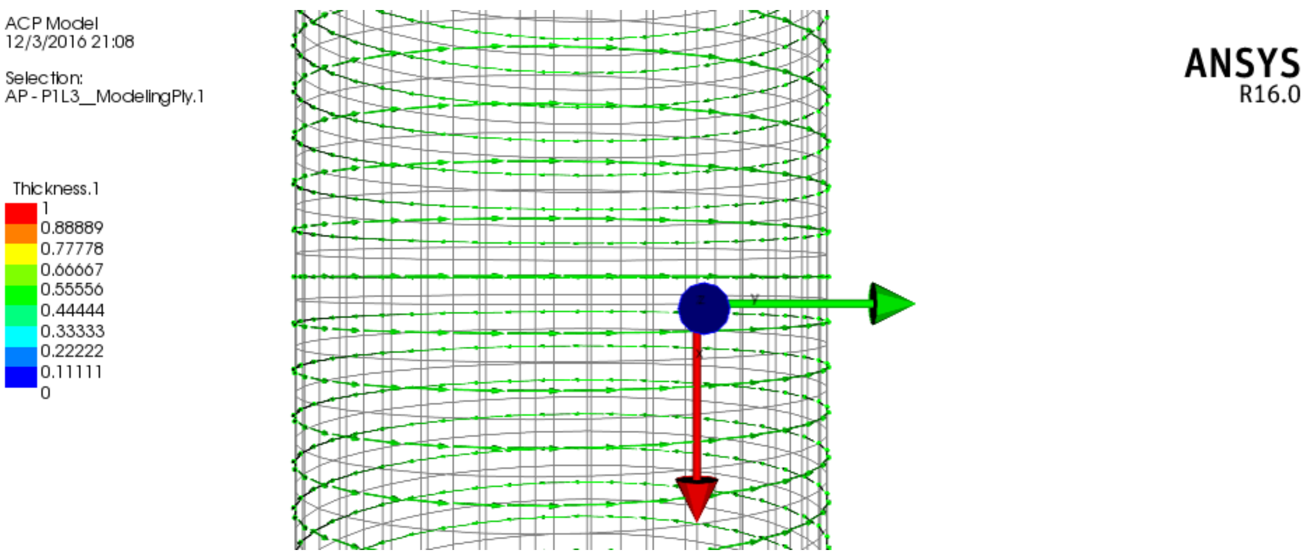
3. Fiber co-ordinate created

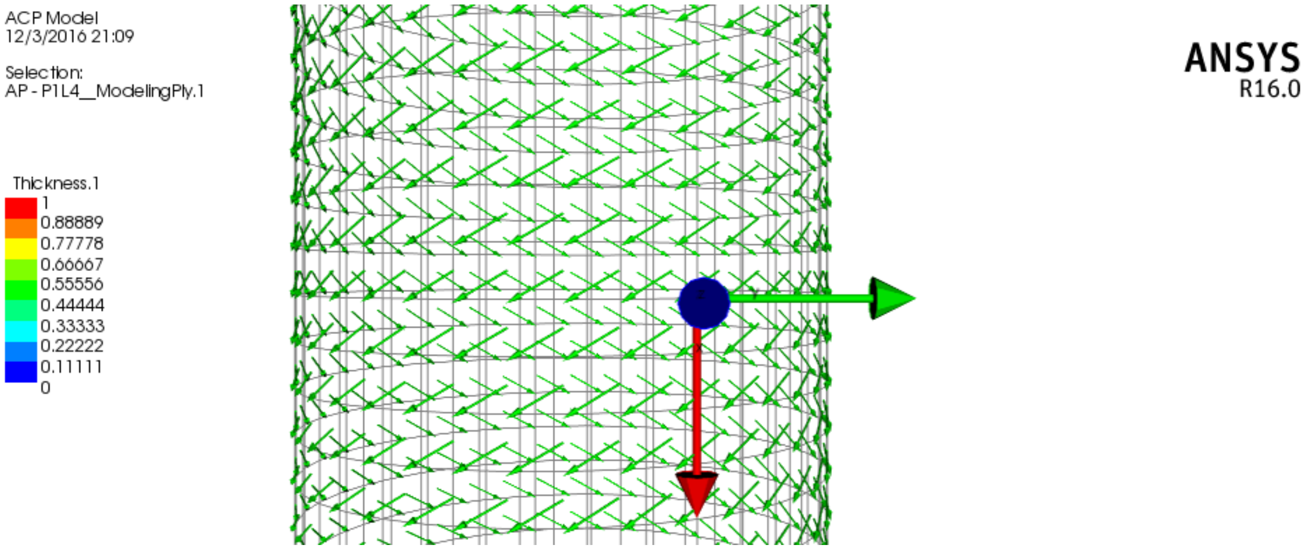


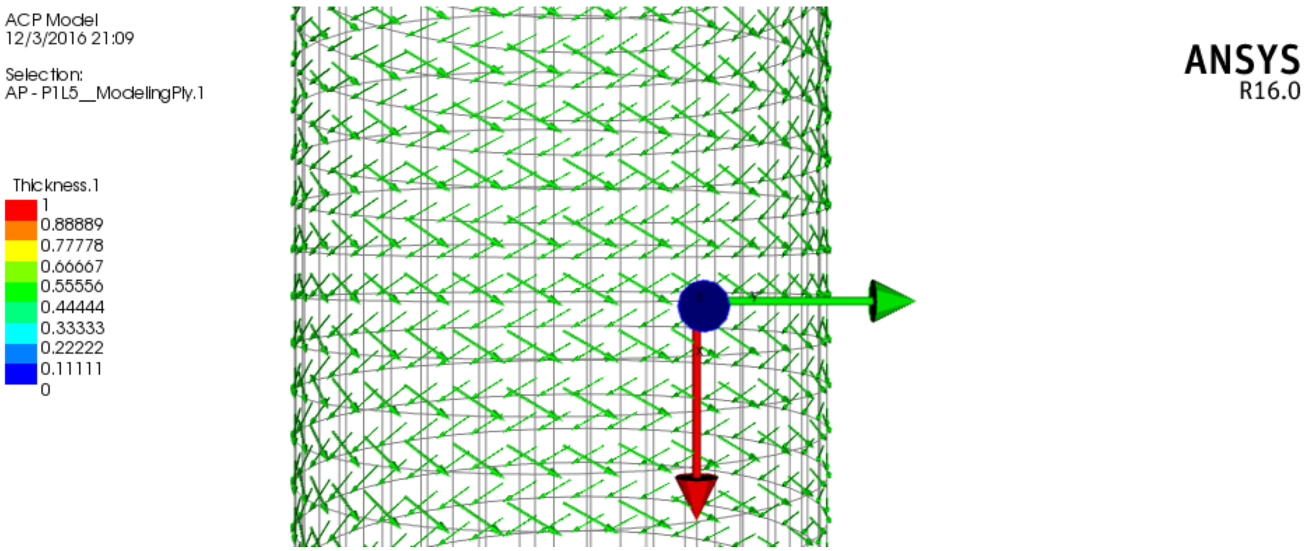
4. Ply Direction



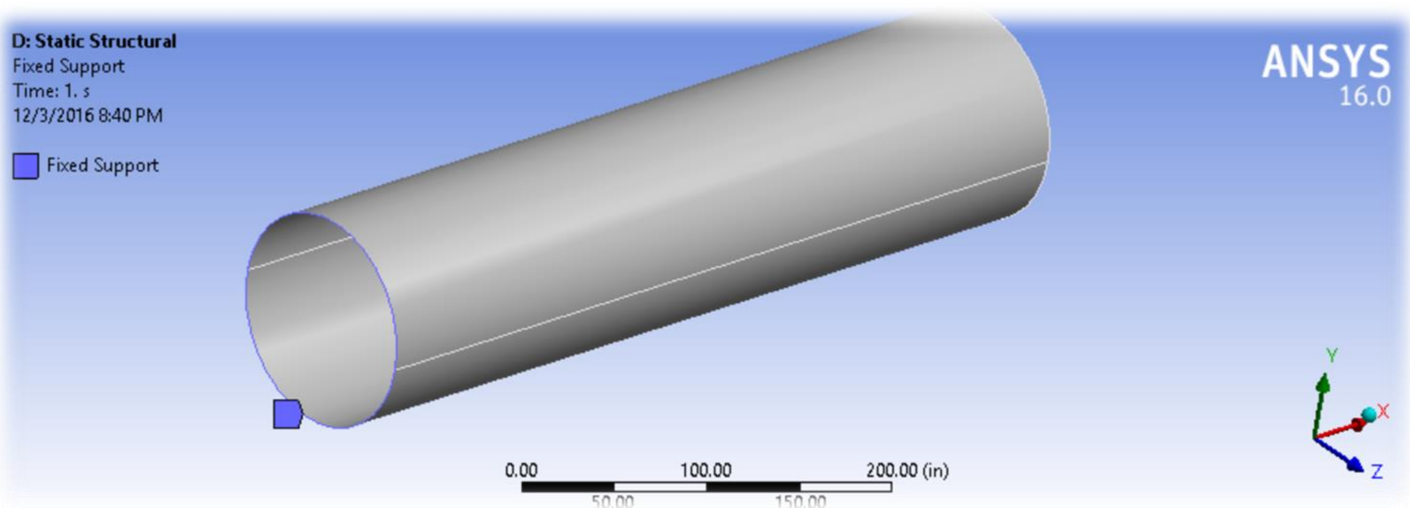


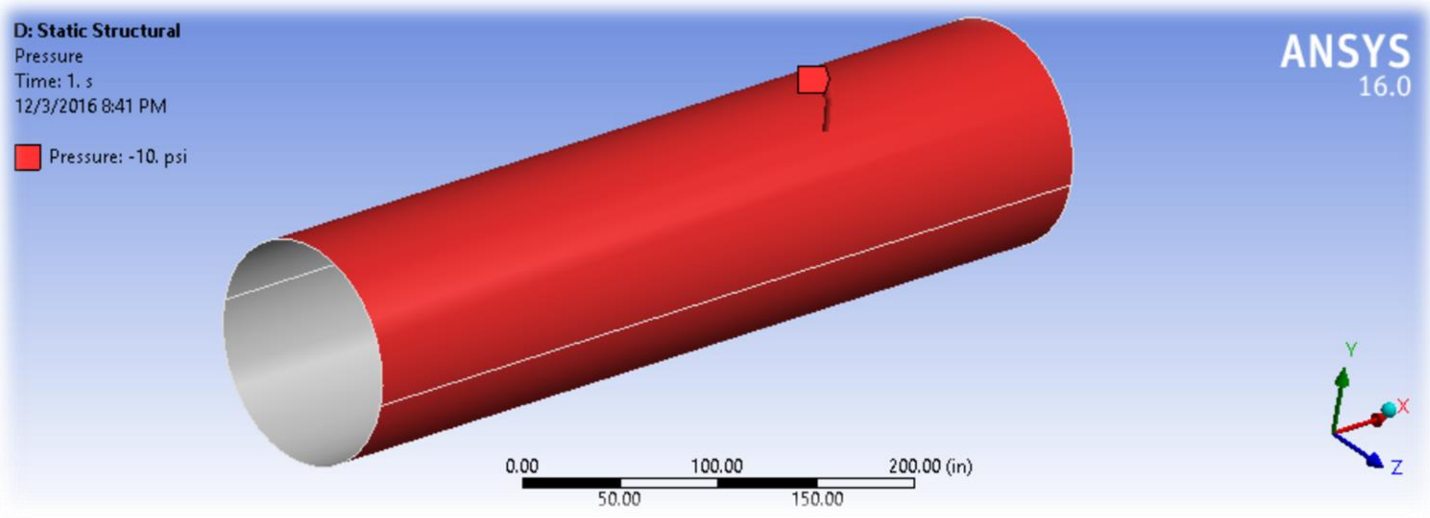


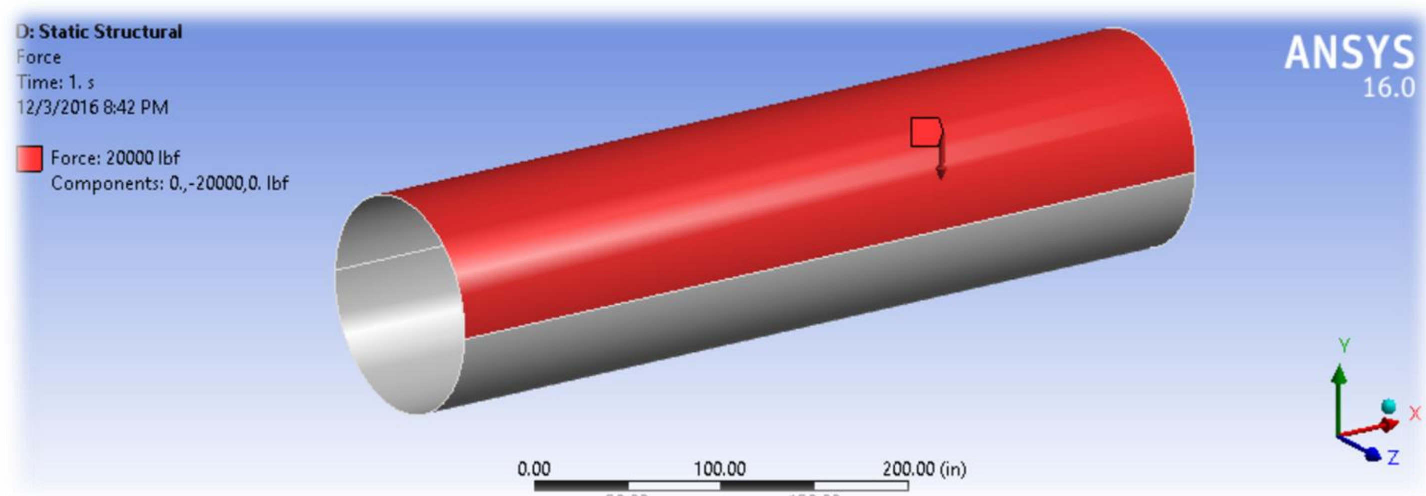


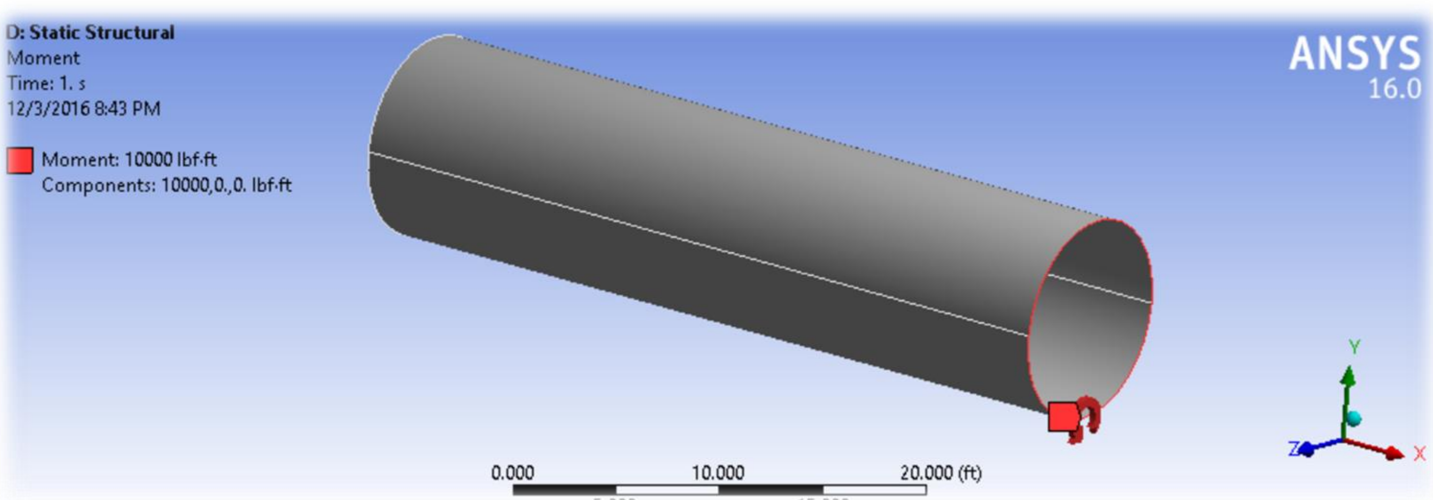


- **Boundary Condition**




D: Static Structural
Pressure
Time: 1. s
12/3/2016 8:41 PM
Pressure: -10. psi
ANSYS
16.0
0.00
100.00
200.00 (in)
50.00
150.00
Y
X
Z


D: Static Structural
Force
Time: 1. s
12/3/2016 8:42 PM
Force: 20000 lbf
Components: 0.,-20000,0. lbf
ANSYS
16.0
0.00
100.00
200.00 (in)
Y
X
Z


D: Static Structural
Moment
Time: 1. s
12/3/2016 8:43 PM
Moment: 10000 lbf·ft
Components: 10000,0.,0. lbf·ft
ANSYS
16.0
0.000
10.000
20.000 (ft)
Y
Z
X

- **Simulation Results:**

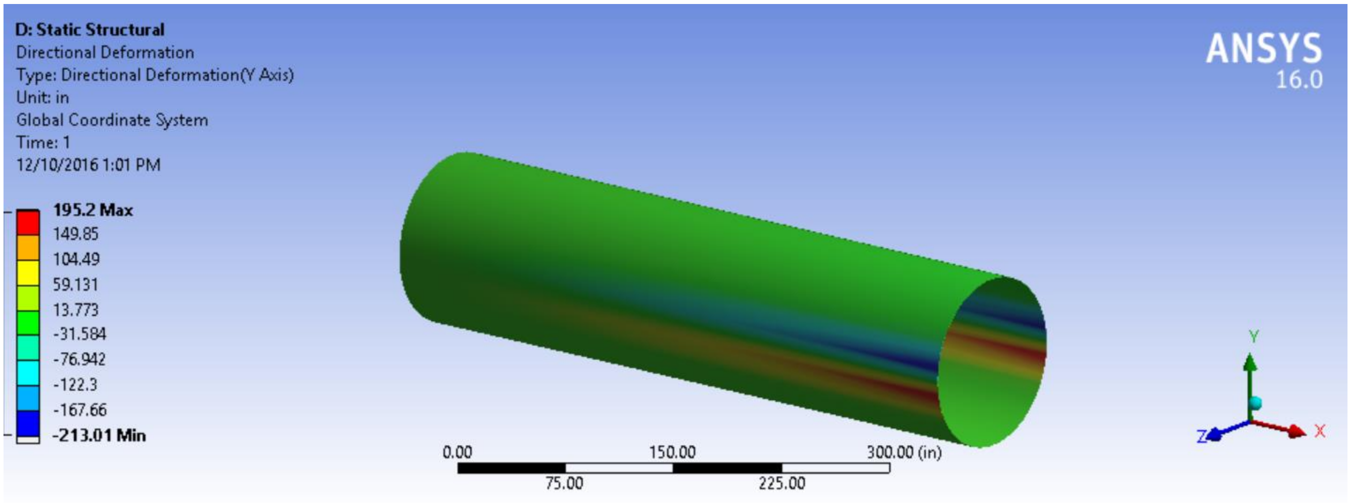


Figure: Vertical displacement at free end.

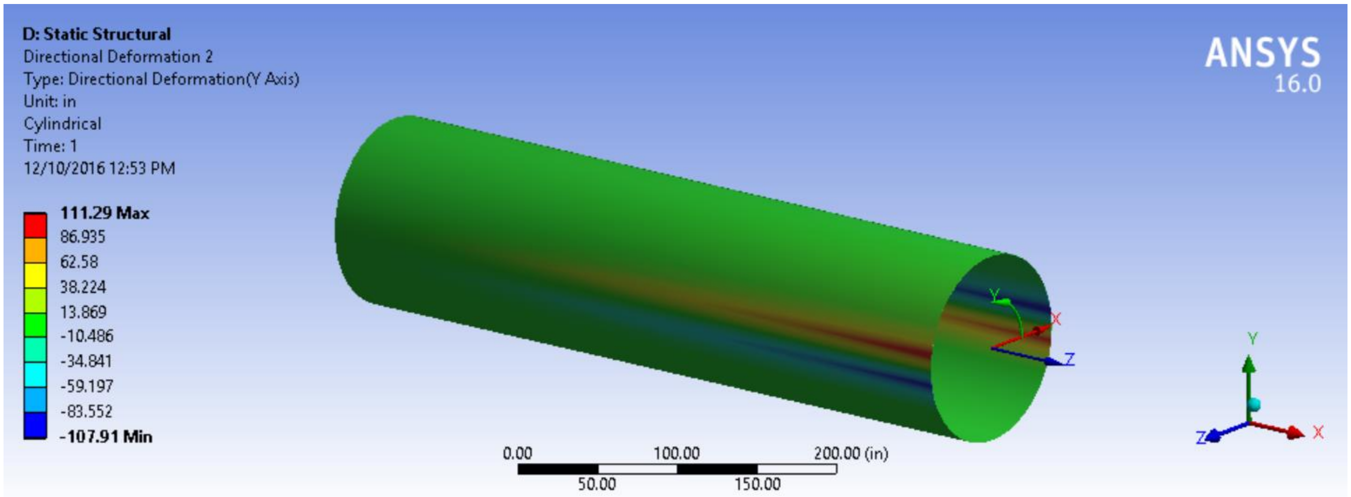
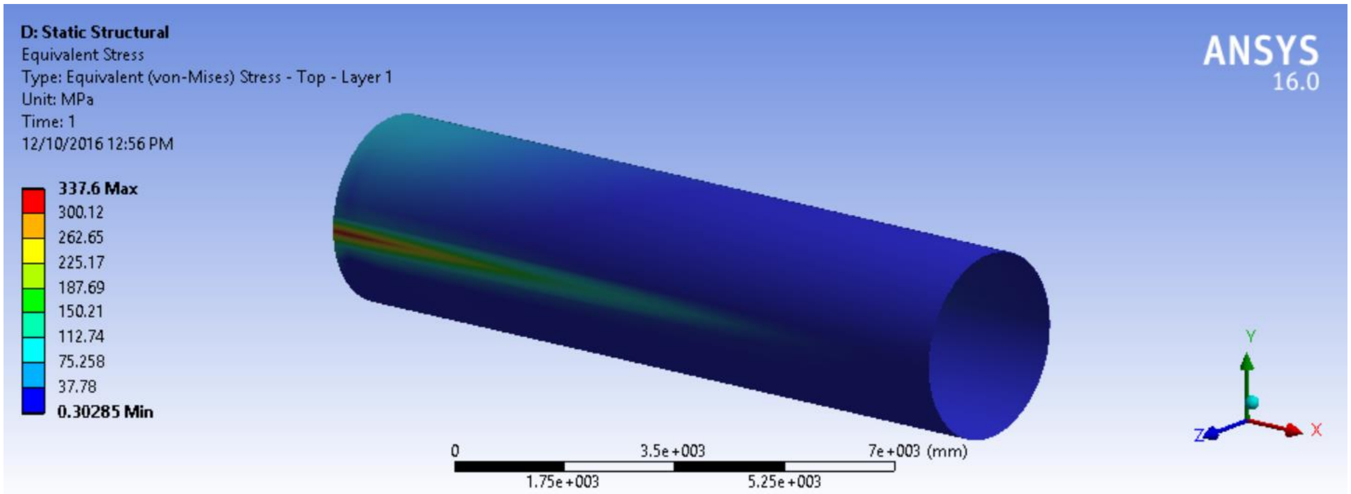
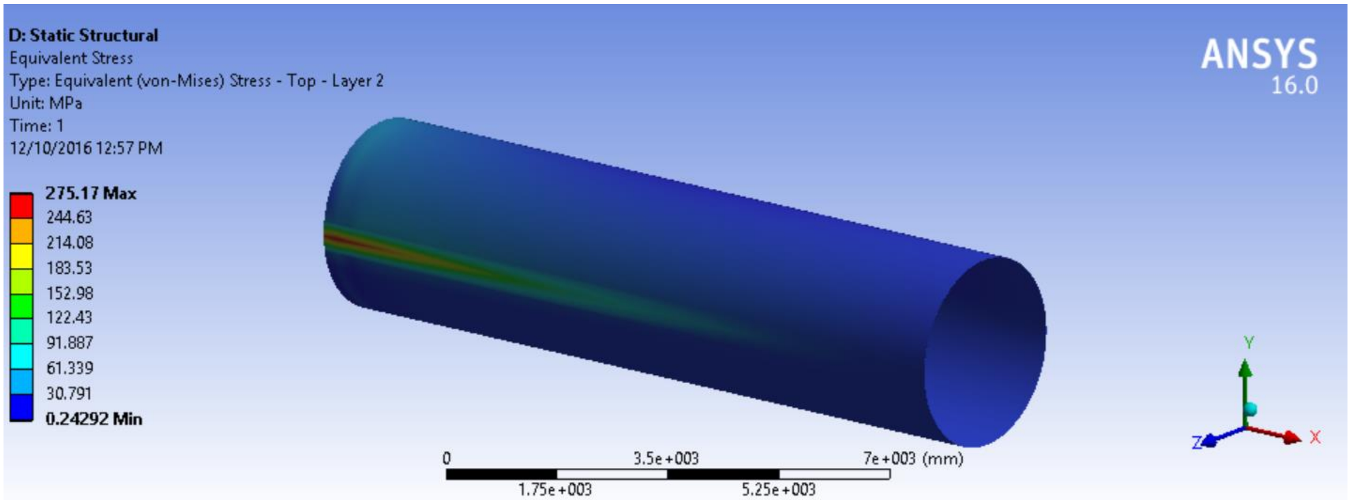
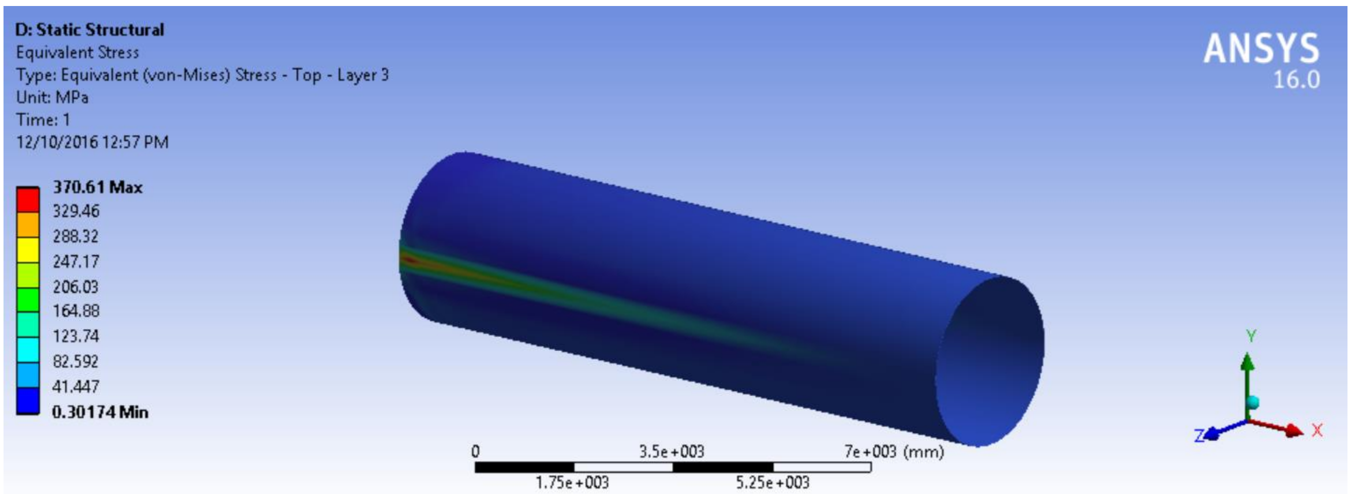
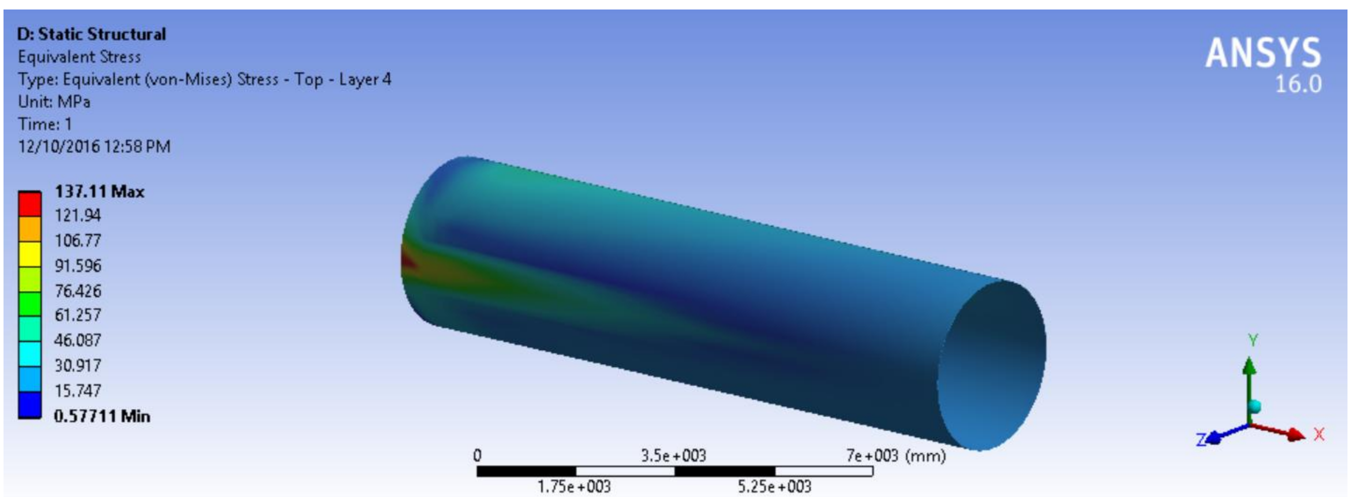


Figure: Angular displacement at free end.




D: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top - Layer 2
Unit: MPa
Time: 1
12/10/2016 12:57 PM
275.17 Max
244.63
214.08
183.53
152.98
122.43
91.887
61.339
30.791
0.24292 Min
ANSYS
16.0
0
3.5e+003
7e+003 (mm)
1.75e+003
5.25e+003
Y
Z
X


D: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top - Layer 3
Unit: MPa
Time: 1
12/10/2016 12:57 PM
370.61 Max
329.46
288.32
247.17
206.03
164.88
123.74
82.592
41.447
0.30174 Min
ANSYS
16.0
0
3.5e+003
7e+003 (mm)
1.75e+003
5.25e+003
Y
Z
X


D: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top - Layer 4
Unit: MPa
Time: 1
12/10/2016 12:58 PM
137.11 Max
121.94
106.77
91.596
76.426
61.257
46.087
30.917
15.747
0.57711 Min
ANSYS
16.0
0
3.5e+003
7e+003 (mm)
1.75e+003
5.25e+003
Y
Z
X

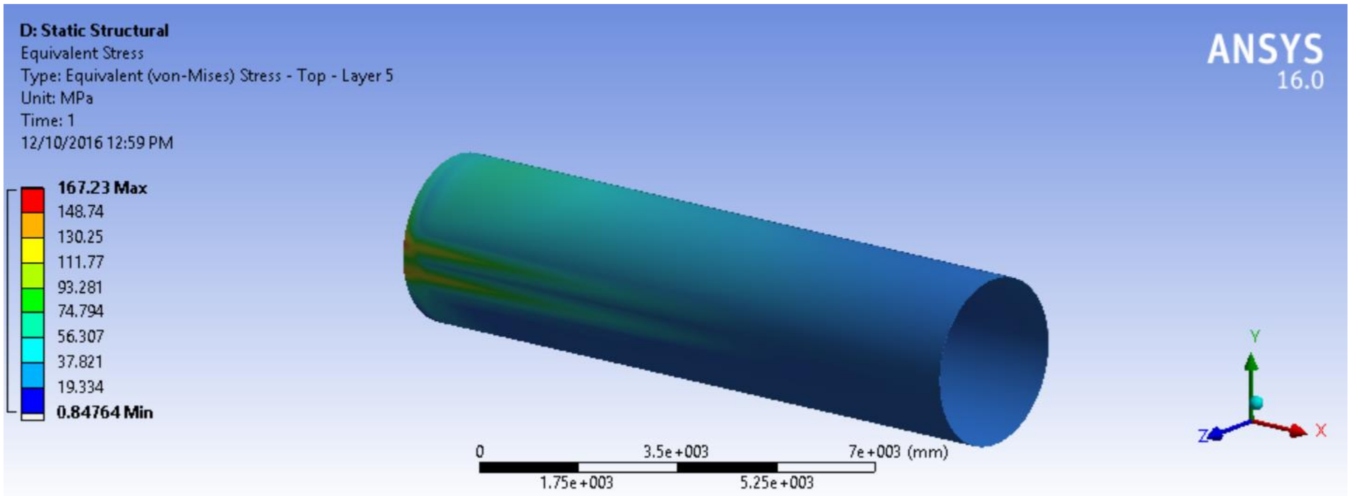
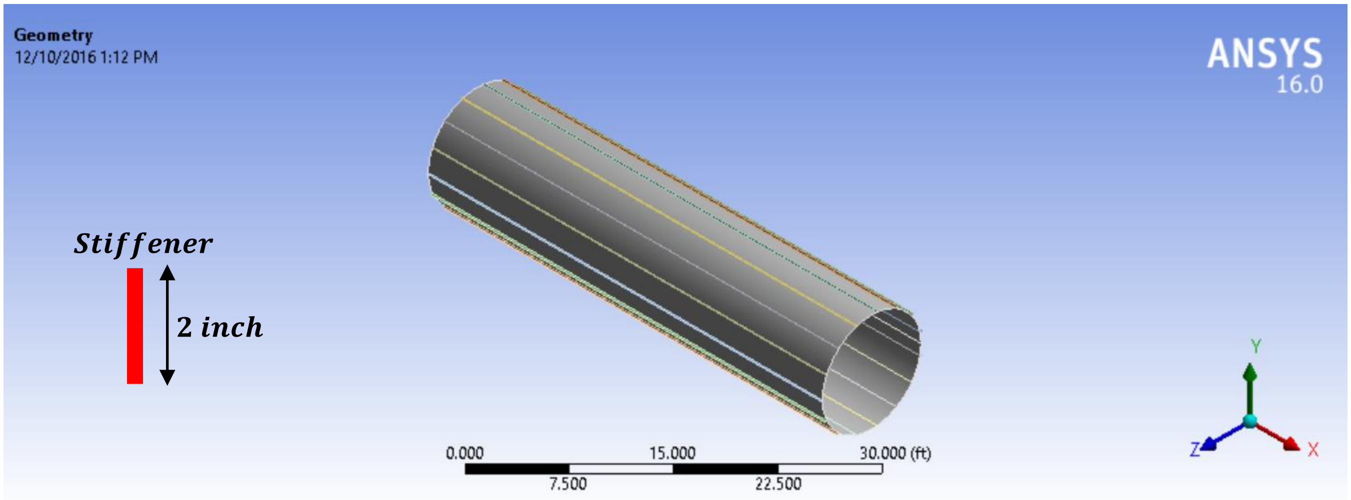
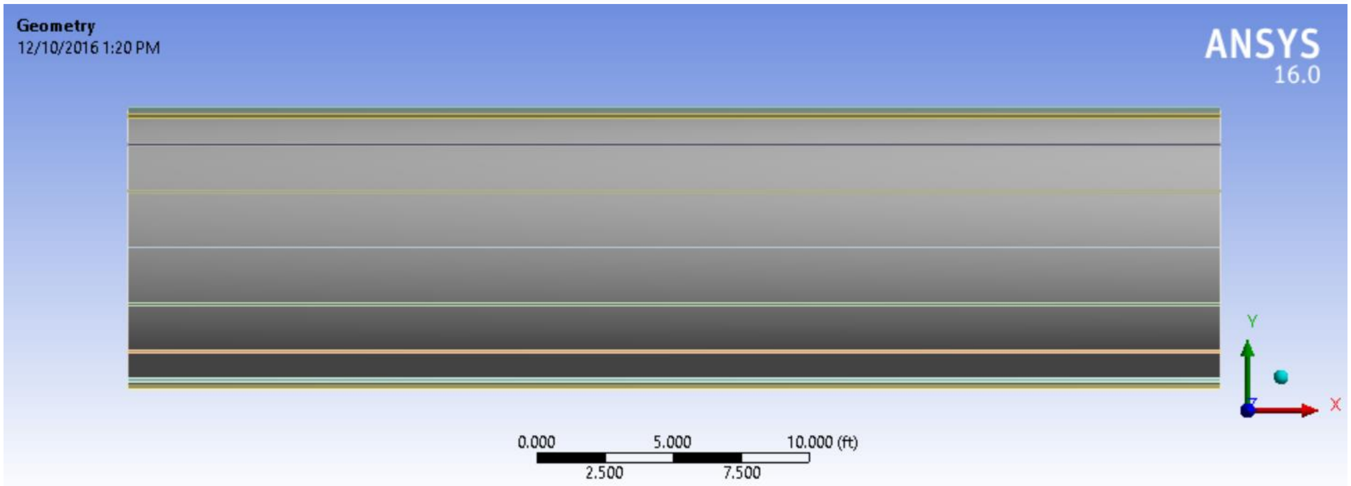


Figure: Von-Mises Stress at top of all 5 layers

The observed maximum vertical displacement is 213 inch and maximum angular displacement is 111 inch. These are large displacement and model has failed totally.

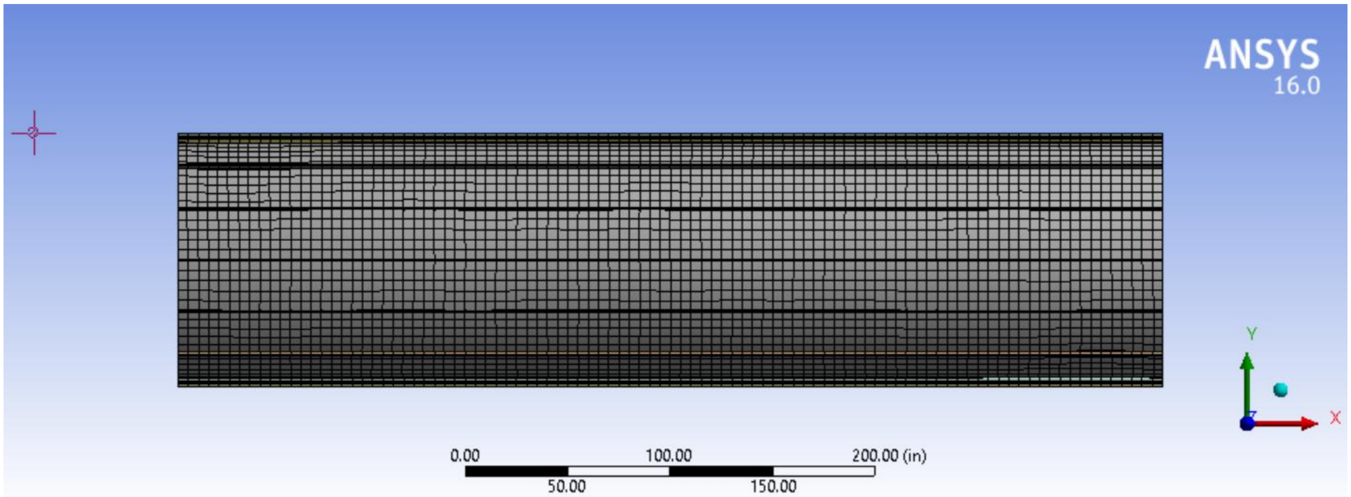
- **Laminate Re-modeling with axial stiffeners**





15 of 40 ft. long axial stiffeners added

➢ Mesh:



Sizing	
Use Advanced Size Function	On: Curvature
Use Fixed Size Function For Sheets	No
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Curvature Normal Angle	Default (30.0 °)
Min Size	1.0 in
Max Face Size	5.0 in
Max Size	5.0 in
Growth Rate	Default
Minimum Edge Length	0.1250 in

Statistics	
Nodes	21292
Elements	8448
Mesh Metric	None

➢ Laminate Modeling:

Fuselage

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Orientation	60^o	-60^o	90^o	-60^o	60^o
Thickness	2 mm	2 mm	2 mm	2 mm	2 mm

lamina > Orthotropic Elasticity

Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
45000	16000	1.e-006	0.27	0	0	4000	1.e-006	1.e-006

Stiffener

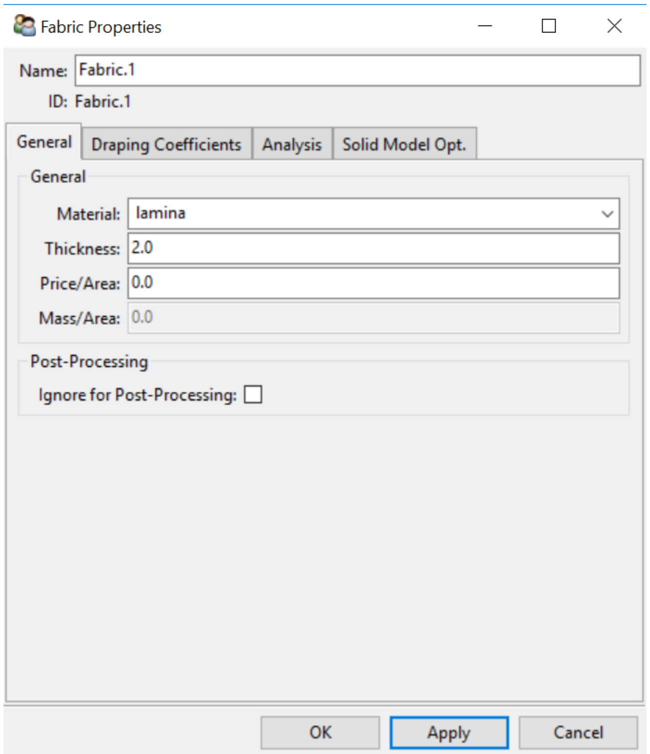
	Layer 1	Layer 2
Orientation	-45^o	45^o
Thickness	5 mm	5 mm

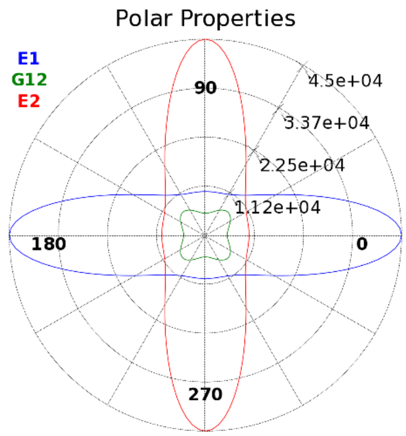
Epoxy_EGlass_UD > Orthotropic Elasticity

Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
45000	10000	10000	0.3	0.4	0.3	5000	3846.1	5000

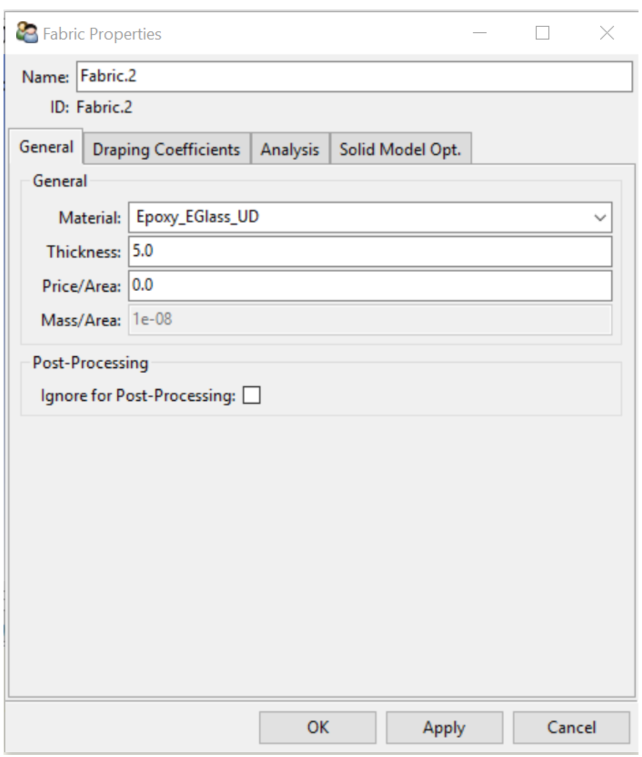
COMPOSITE PRE-ANALYSIS IN ANSYS ACP-PRE:

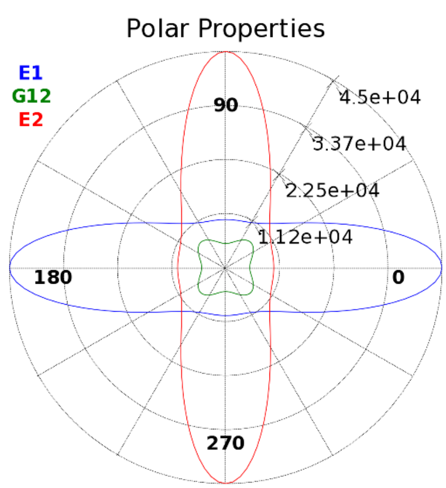
1. **Fabric created with given engineering constant of material with 2 mm thickness.**



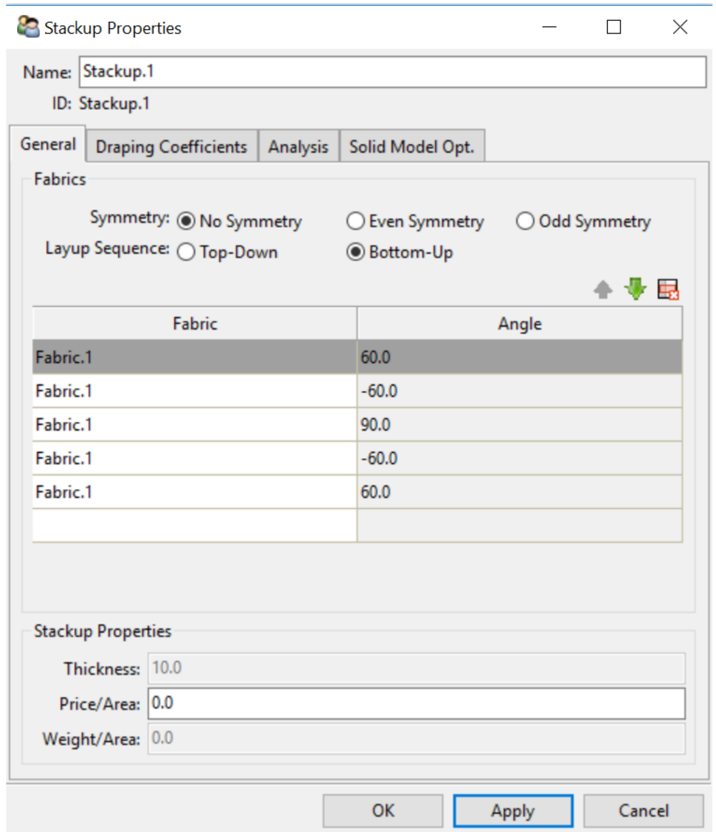


2. **Fabric created with Epoxy E-glass material with 5 mm thickness.**

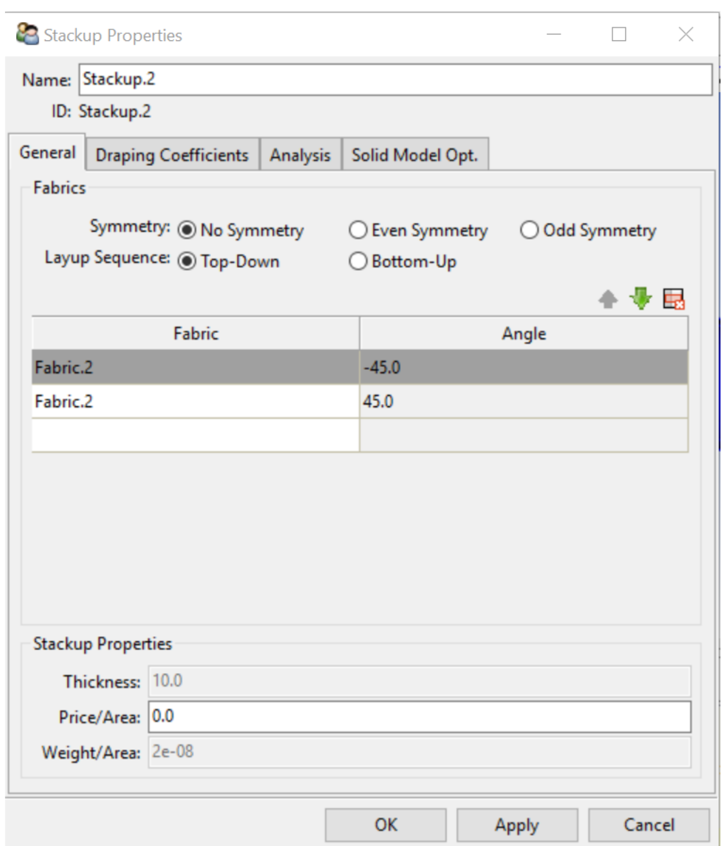




3. **Laminate stack created with five layer of lamina @ [60/-60/90/-60/60] orientation for fuselage shell.**



4. **Laminate stack created with two layer of Epoxy E-Glass @ [-45/45] orientation for stiffeners.**



➢ Re-design Simulation Results:

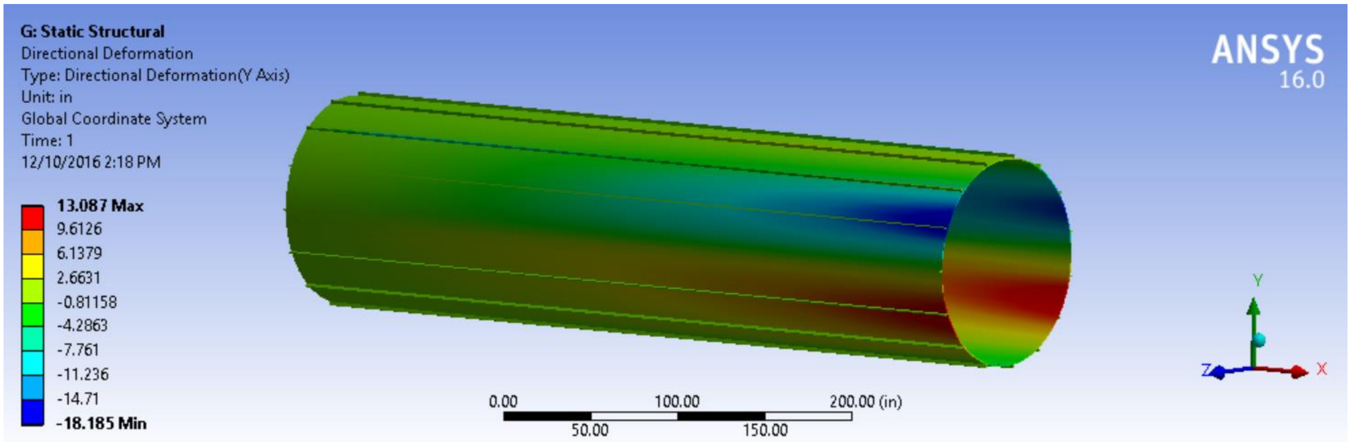


Figure: Vertical displacement at free end.

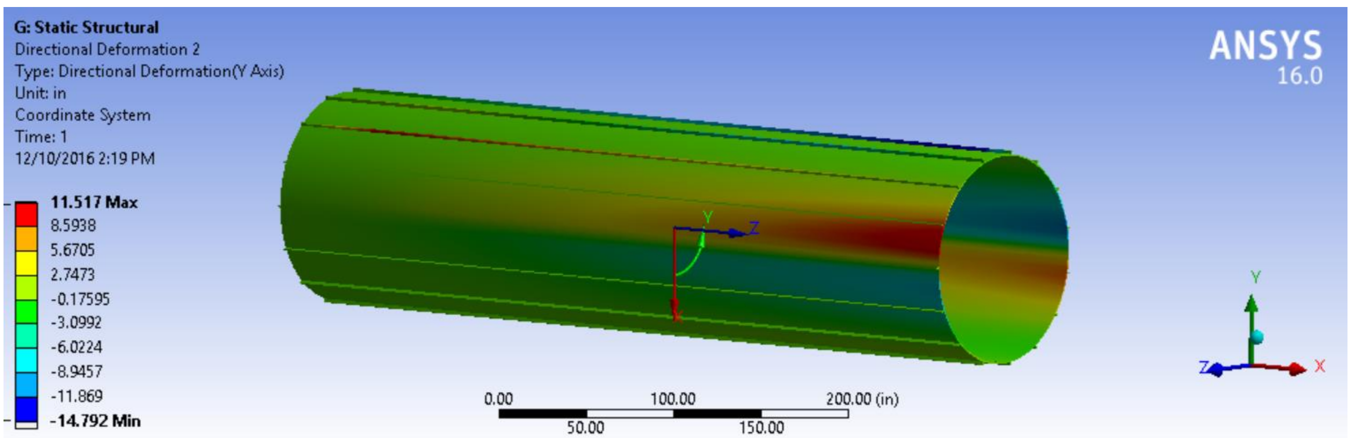
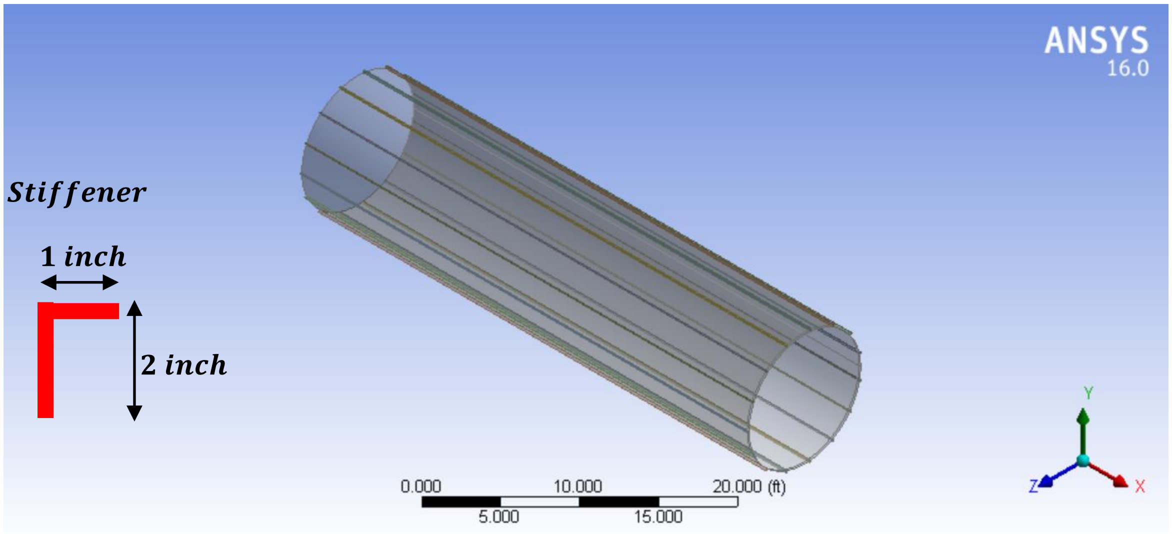
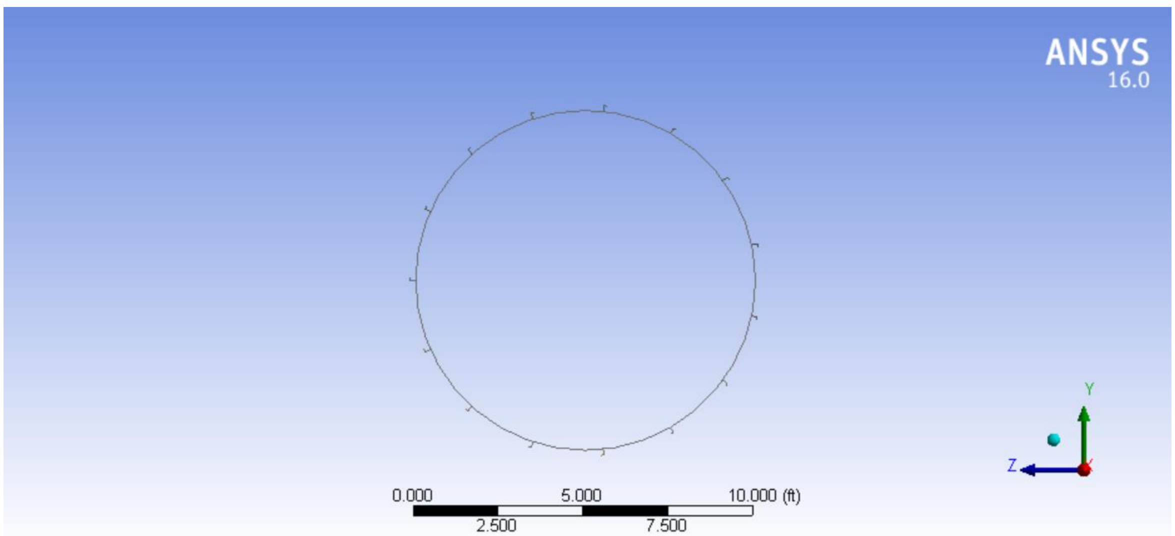


Figure: Angular displacement at free end.

For a re-designed model of the fuselage with 2 mm thick lamina making a stack ply laminate at [60/-60/90/-60/60] orientation with 15 X 5mm thick lamina making a stack ply laminate at [-45/45] orientation axial stiffeners made of Epoxy E-Glass, the observed maximum vertical displacement is significantly reduces **18.2 inch** and maximum angular displacement is **15 inch, i.e.** $\tan^{-1}\left(\frac{15}{12*5}\right) \sim 14.63\,°$.

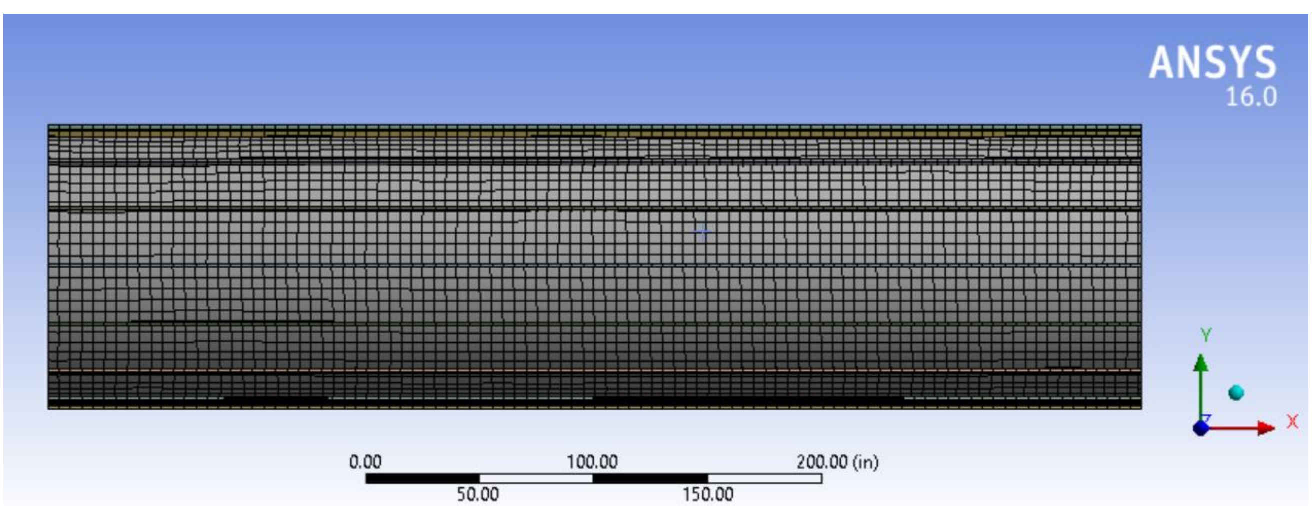
- **Laminate Re-modeling with L – shape axial stiffeners**





15 of 40 ft. long axial stiffeners added

- **Mesh:**



- **Re-design Simulation Results:**

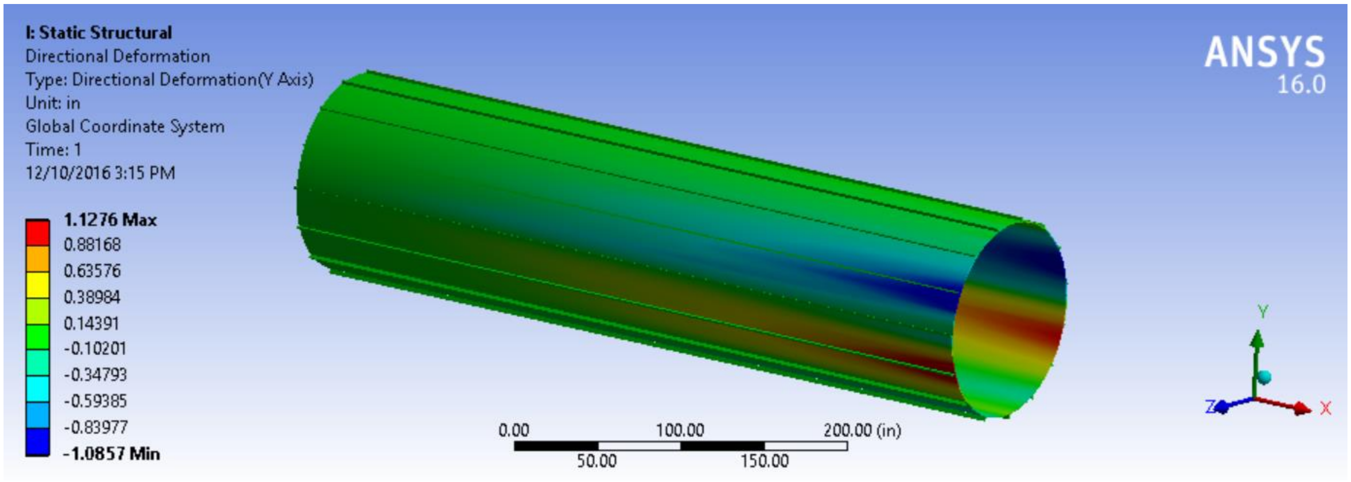


Figure: Vertical displacement at free end.

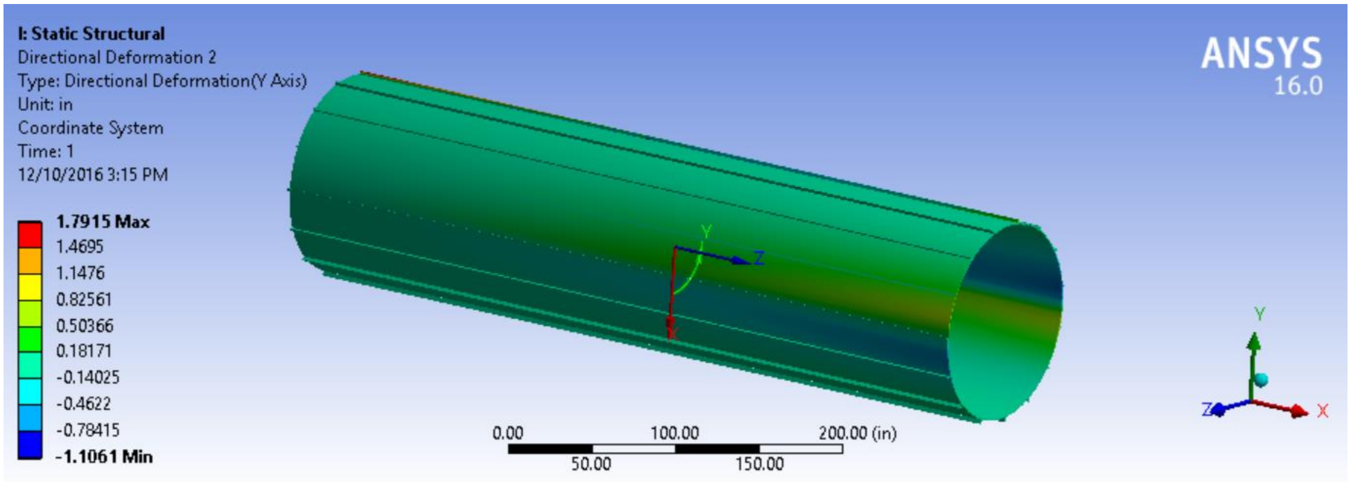


Figure: Angular displacement at free end.

For a re-designed model of the fuselage with 2 mm thick lamina making a stack ply laminate at [60/-60/90/-60/60] orientation with 15 X 5mm thick lamina making a stack ply laminate at [-45/45] orientation "L-shape" axial stiffeners made of Epoxy E-Glass , the observed maximum vertical displacement is significantly reduces **1.1 inch** and maximum angular displacement is **1.8 inch, i.e.** $\tan^{-1}\left(\frac{1.8}{12*5}\right) \sim 1.71\,°$.

It is important to notice that there is not a trivial solution for structure design when designing structure with laminated composite materials. However, the design and material selection will depend on factors that possess a greater significance to the entire design solution. Factor such as reducing weight, ease of manufacturing, or increasing weight to strength ratio are important factors to be consider when solving a design problem in composite. A simple structure can be modeled and using FEA solver such as Ansys, Abaqus or other commercially available FEA software we can accelerate design process before testing and validating by prototyping.