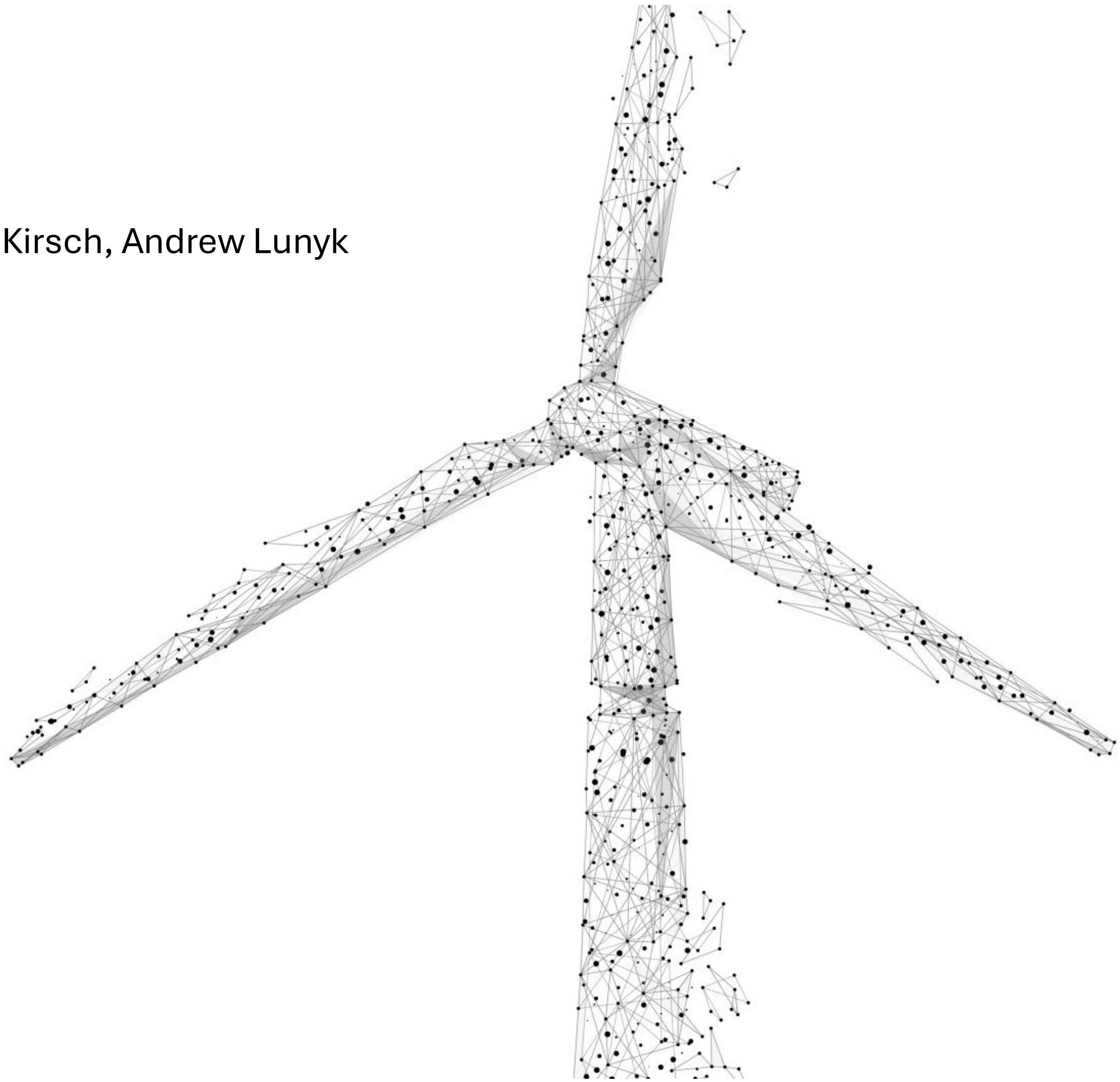
CAE Midterm Project
Wind Turbine Design

Myisha Hassan, Joseph Sutton, Spencer Kirsch, Andrew Lunyk



Design Goals

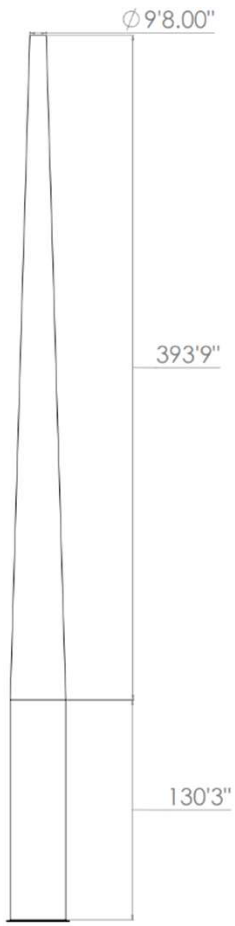
Category	Constraint
Equivalent Stress*	< 23.6 KSI
Normal Deflection	< 12.6 in
Extreme Deflection	< 17.0 in
Buckling	FS of > 8
Natural Frequency	> 12 RPM

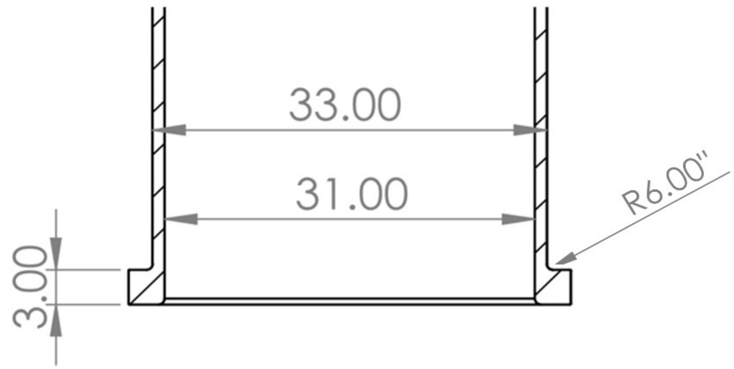
*Considering Safety Factor and
Fatigue of Infinite Cycles

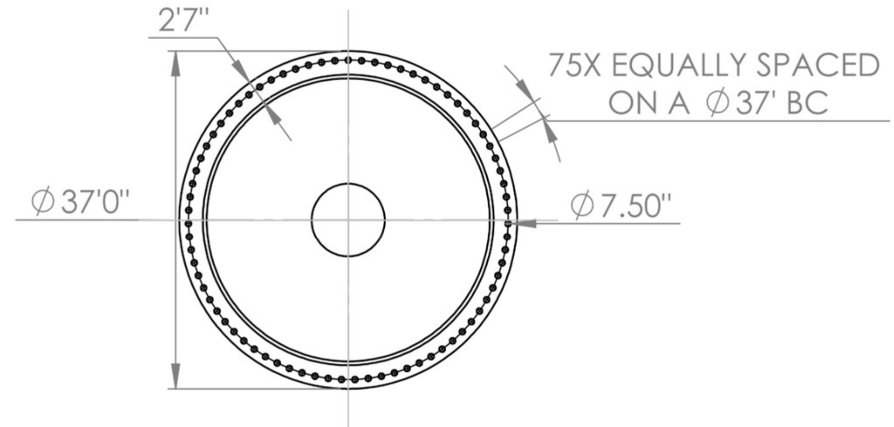
Tower Design Methodology

- ‘Straight Cylinder’ tower for hand calcs and initial simulations.
- ‘Fully Tapered’ tower : No substantial volume or mass savings
- Final ‘Hybrid Cylinder-Tapered’ design:
  - A hollow cylinder for the first quarter of the tower’s height
    - Base is stronger to withstand loads
  - Steeper tapered section for the remaining three-quarters
    - Lower volume compared fully tapered design to base region to save on material costs

Final Design





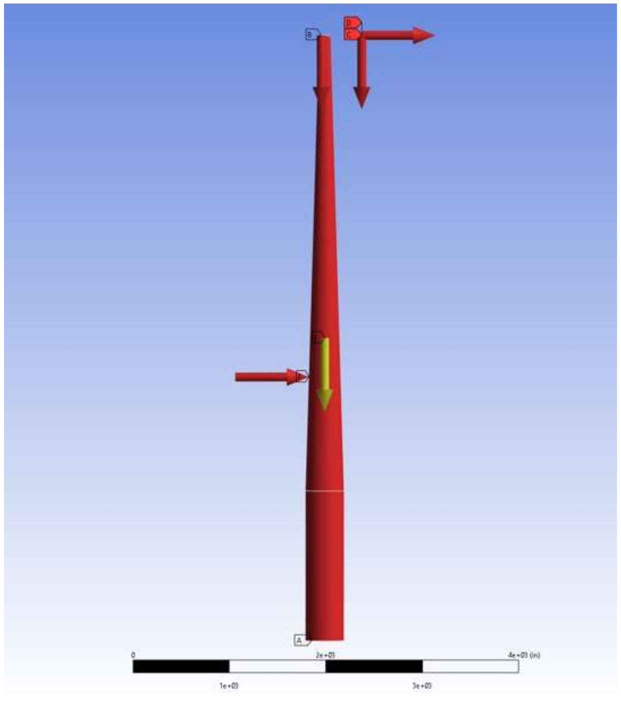


	Hybrid Cylinder-Tapered Tower
Top Outer Diameter [ft]	9.3
Base Outer Diameter [ft]	33
Tower Wall Thickness [ft]	2
Baseplate Outer Diameter [ft]	37
Baseplate Thickness [ft]	3
Footprint [ft^2]	4300
Cross-Sectional Area [ft^2]	12731

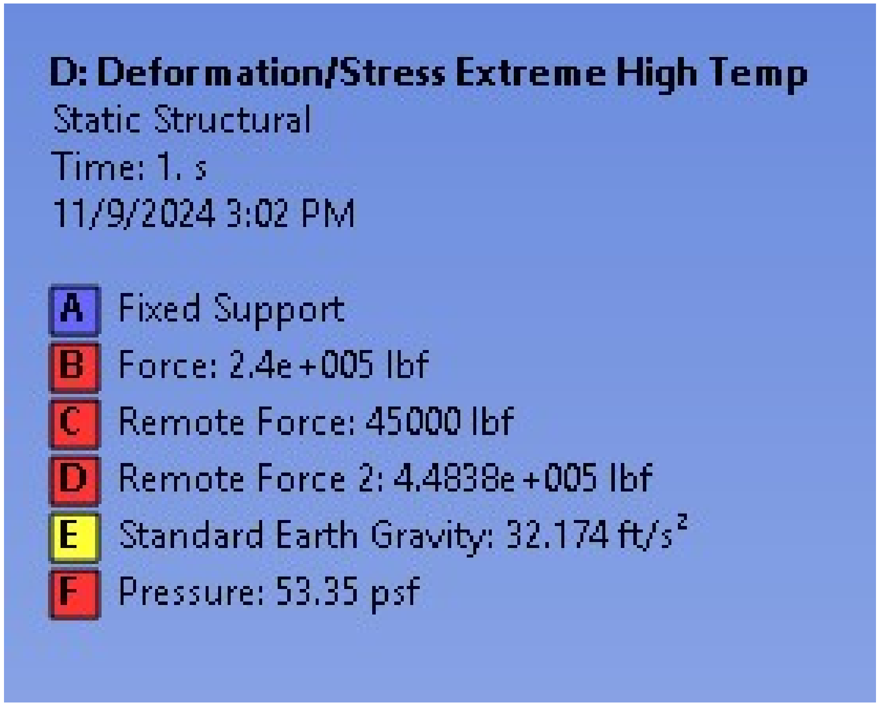
Tower Loading and Constraints (Normal)

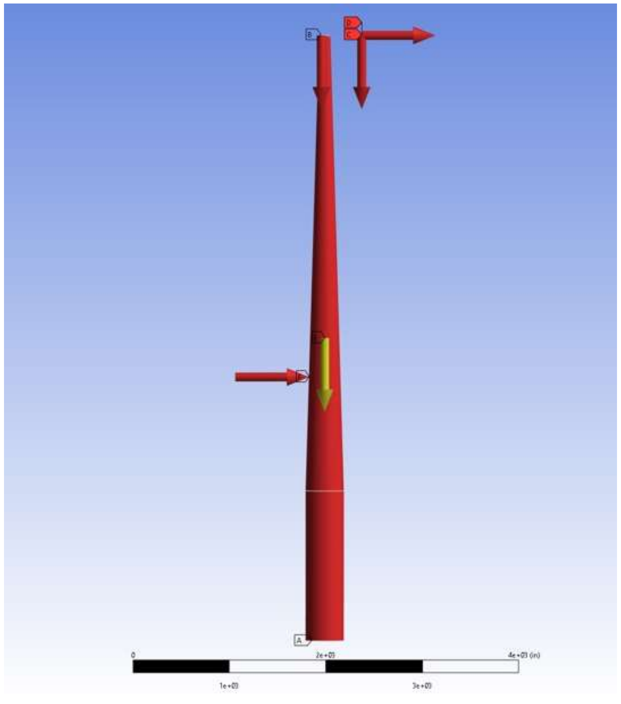
I: Copy of Deformation/Stress Normal Ambient
Static Structural
Time: 1. s
11/9/2024 4:40 PM

- **A** Fixed Support
- **B** Force: 2.4e+005 lbf
- **C** Remote Force: 45000 lbf
- **D** Remote Force 2: 1.2056e+005 lbf
- **E** Standard Earth Gravity: 386.09 in/s^2
- **F** Pressure: 9.9583e-002 psi



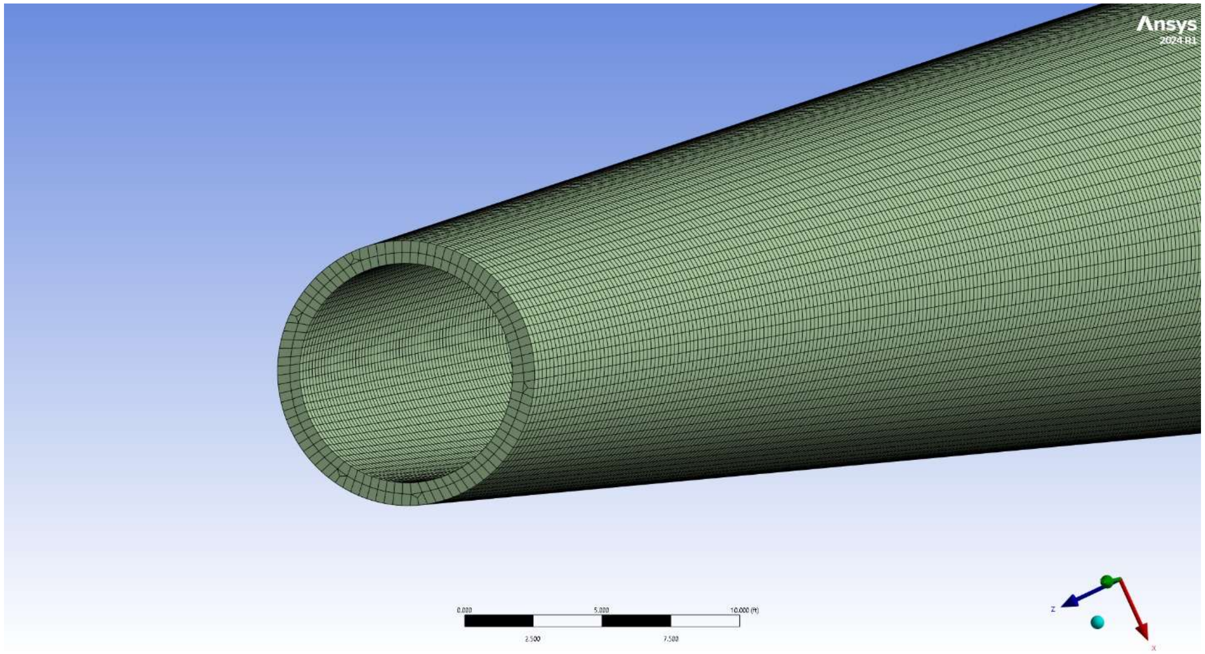
Tower Loading and Constraints (Extreme)



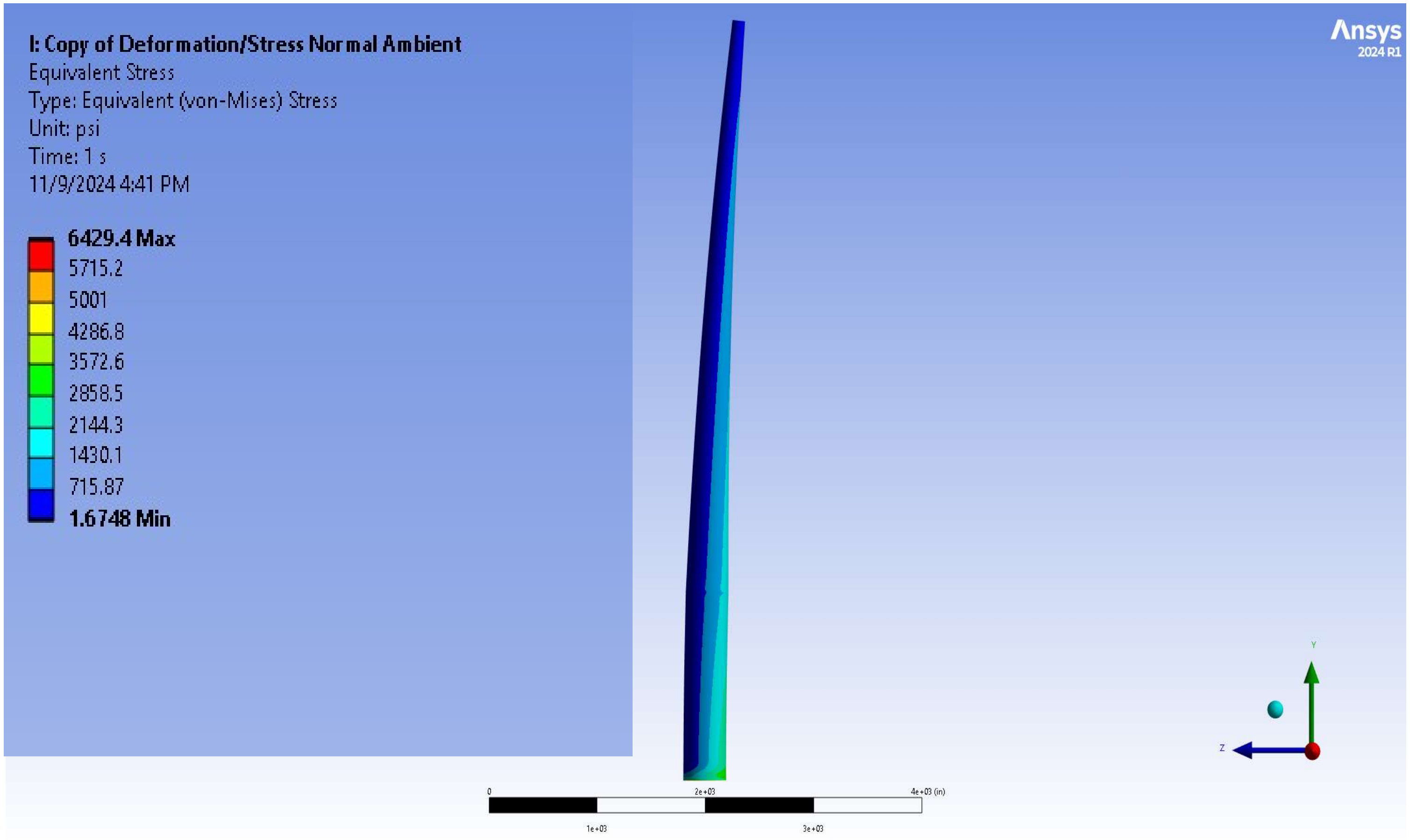


Tower Meshing Methodology

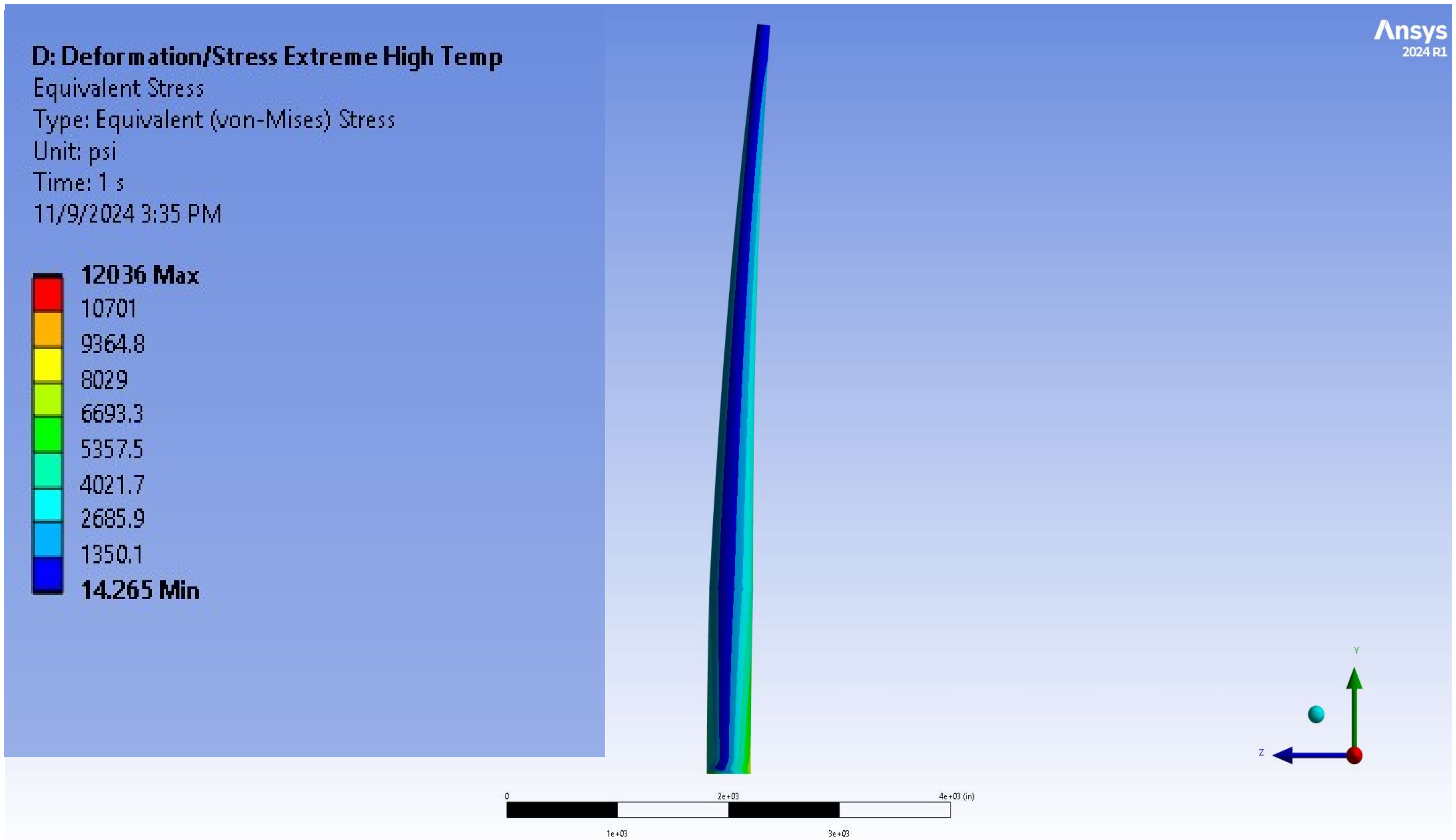
- Multizone Hexa/Prism
- Mesh ½ foot element size
- Deemed sufficient via meshing analysis



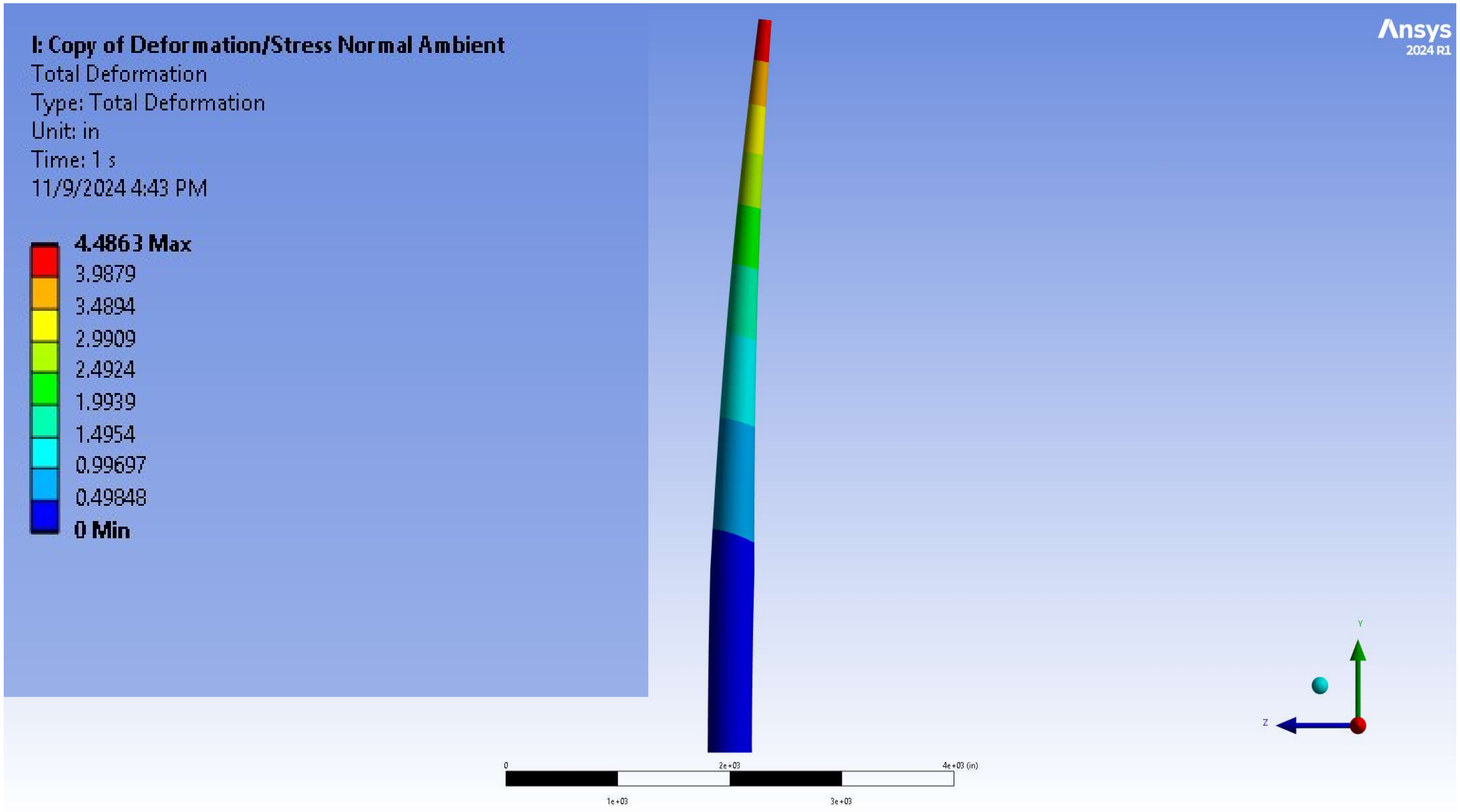
Tower: Von Mises Stress Normal Wind Conditions and Ambient Temperature (62.5 °F)



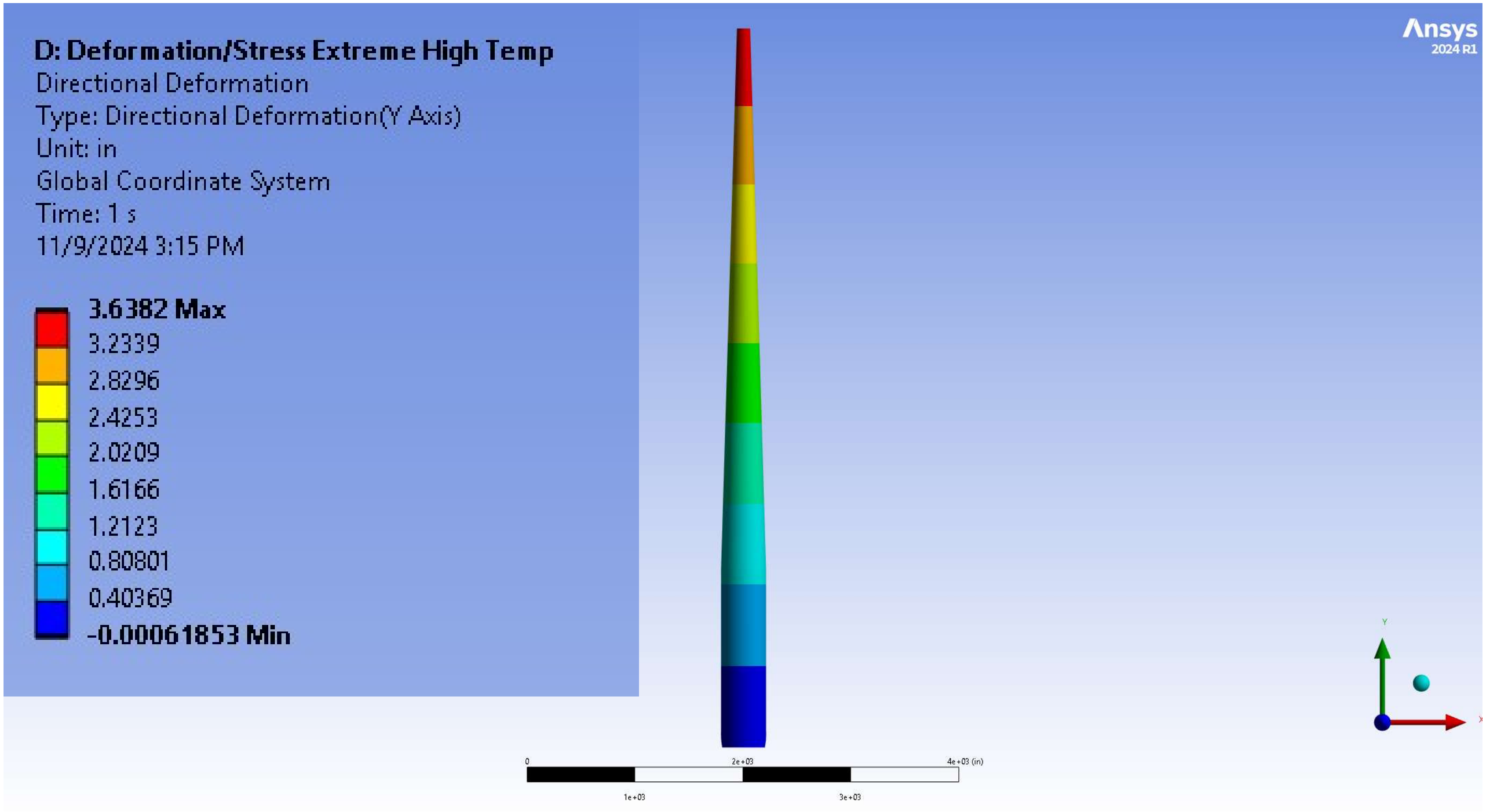
Tower: Von Mises Stress Extreme Wind Conditions and Ambient Temperature (62.5 °F)



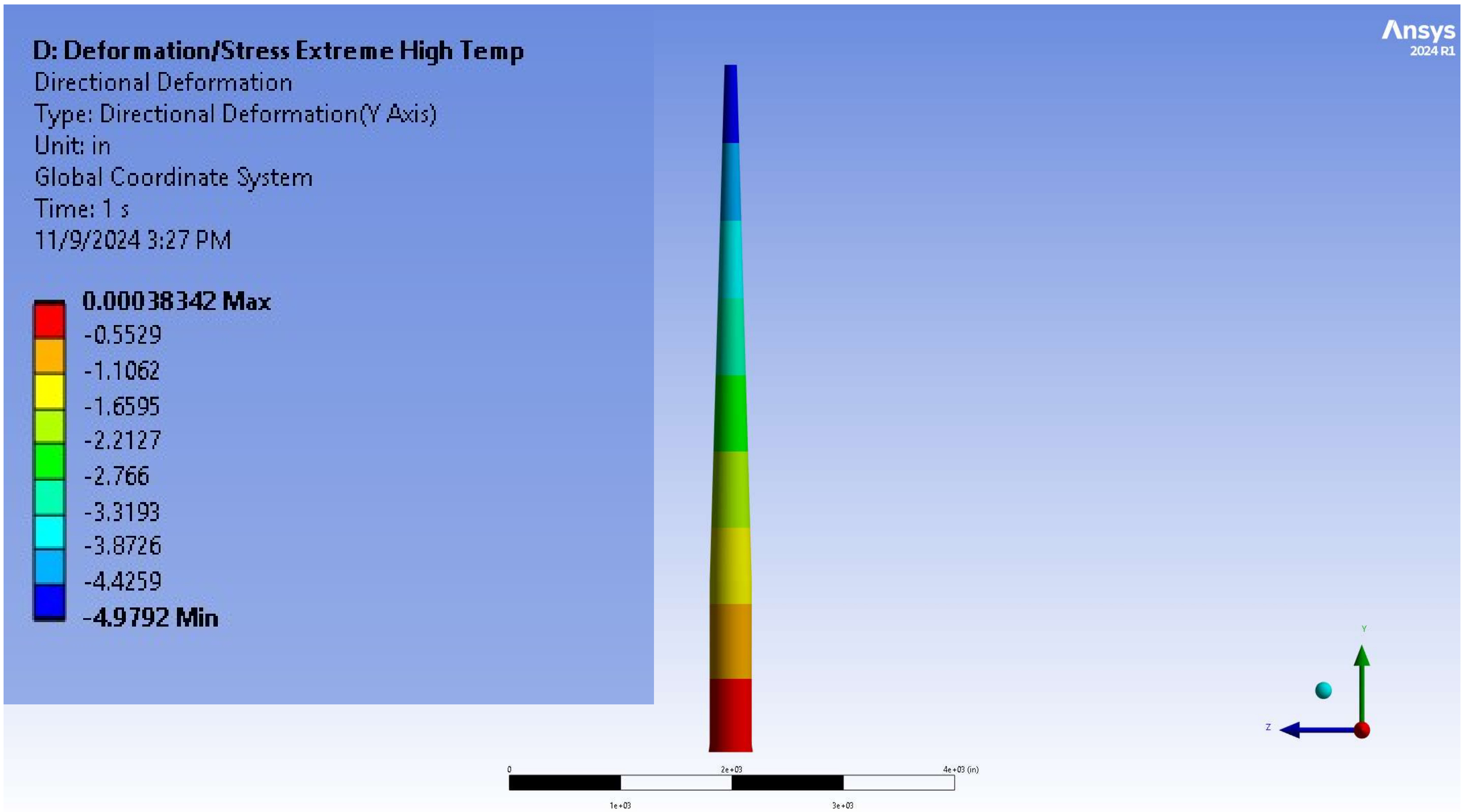
Tower: Deflection Under Normal Wind Conditions and Ambient Temperature (62.5 °F)



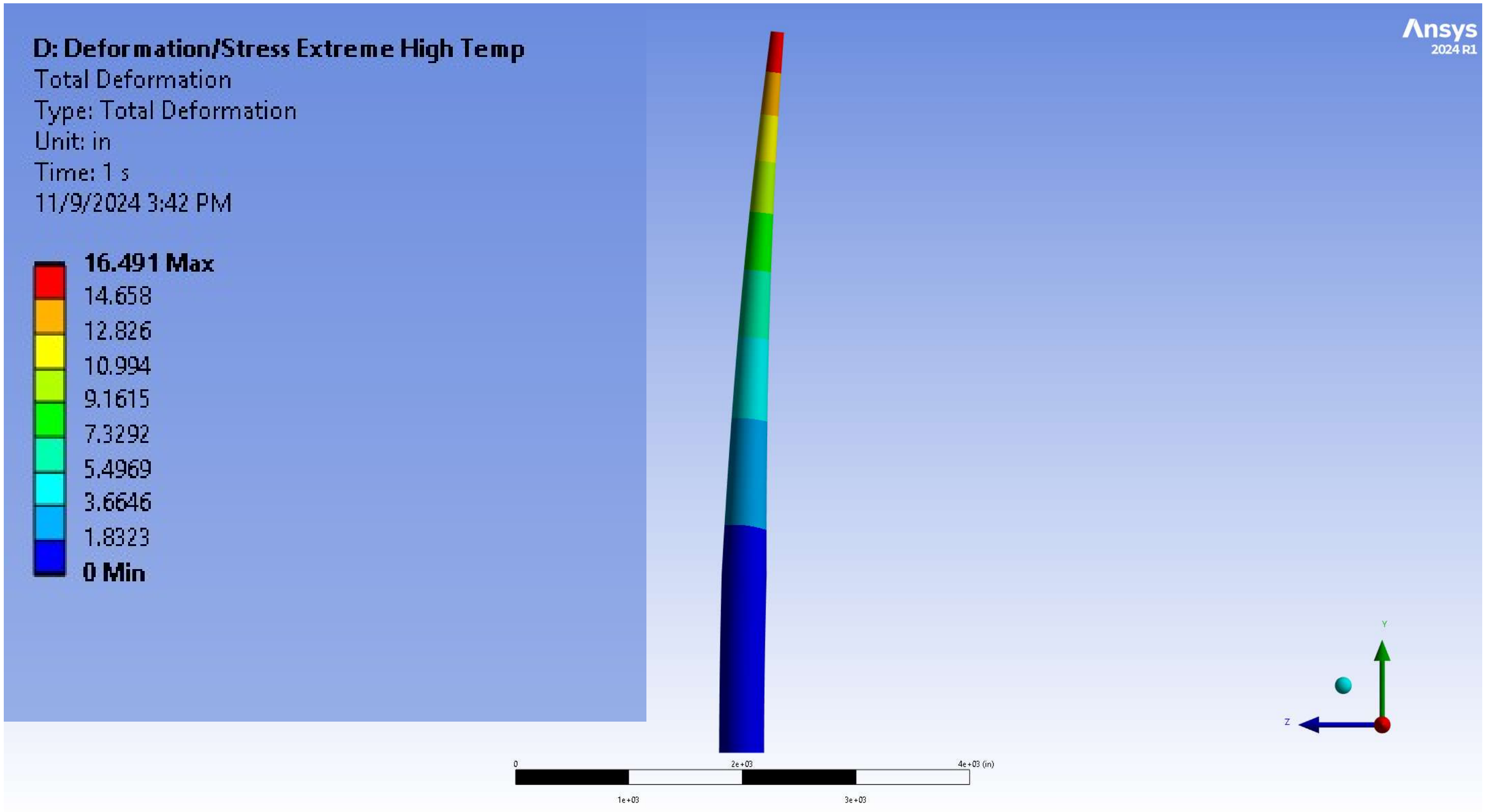
Tower: Height Change Due to 135 °F Ambient Temperature



Tower: Height Change Due to -10 °F Ambient Temperature



Tower: Deflection Under Extreme Wind Conditions and Ambient Temperature (62.5 °F)



Vibrational Performance

Tabular Data

	Mode	Frequency [Hz]
1	1.	0.53409
2	2.	0.5341
3	3.	1.9694
4	4.	1.9694
5	5.	4.6033
6	6.	4.6033

Conversion Factor: 1Hz = 60 RPM

First Mode: $0.534\ Hz\ * \frac{60RPM}{1\ Hz} = 32.04\ RPM$

Buckling Resilience

Tabular Data

	Mode	Load Multiplier
1	1.	94.933
2	2.	95.697

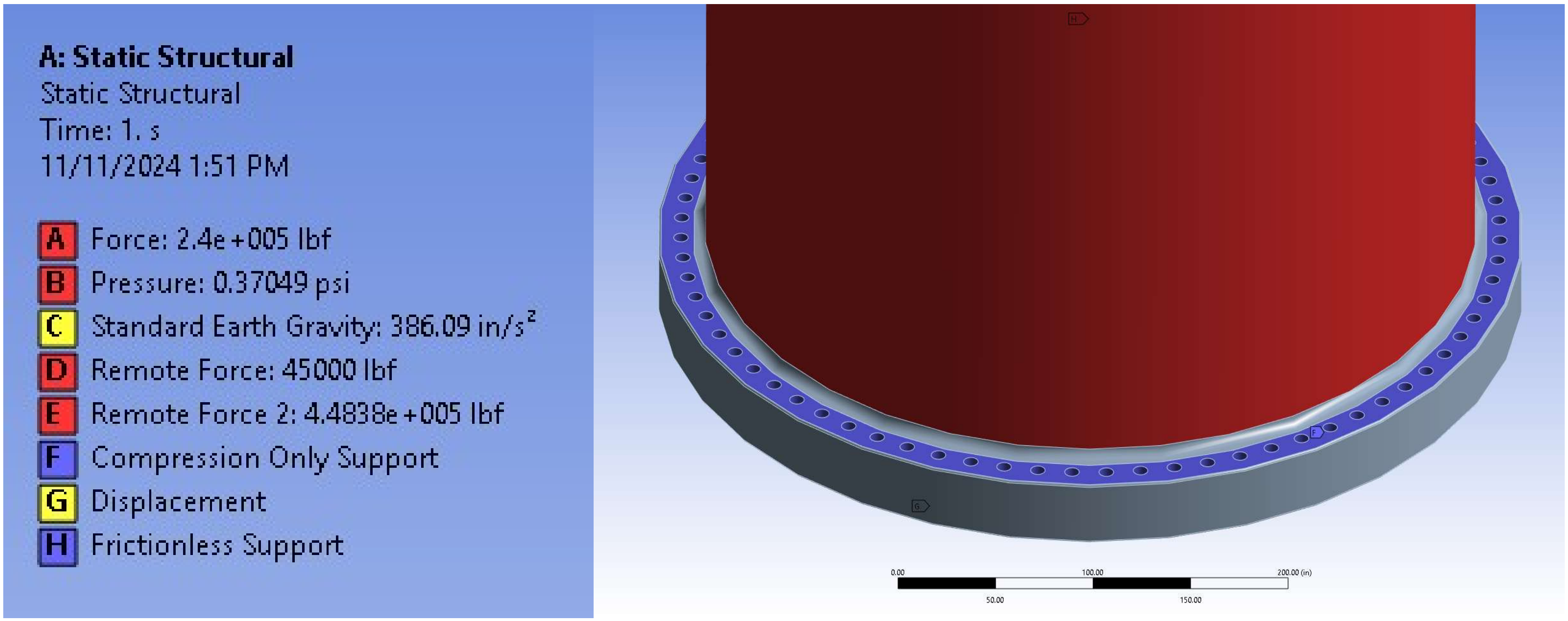
Tower Design Results Comparison

	Design Constraints		Hand Calculation		FEA Simulation	
			Straight Cylinder		Hybrid Cylinder-Tapered	
Weather Condition	Normal	Extreme	Normal	Extreme	Normal	Extreme
Max Deflection [in]	< 12.6	< 17.0	**3.7**	**13.6**	**4.5**	**16.5**
Max Tower Stress [ksi]	< 23.7	< 23.7	**2.0**	**7.2**	**6.4**	**12.0**
Buckling Load Failure Multiplier	> 8		**31**		**95**	
Natural Frequency: 2 blades [rpm]	> 12		**21**		**32**	
Thermal Effects: Tower Height Change for -10°F [in]	-		**-4.4**		**-5.0**	
Thermal Effects: Tower Height Change for 135°F [in]	-		**4.4**		**3.6**	

Thermal Consideration: Baseplate

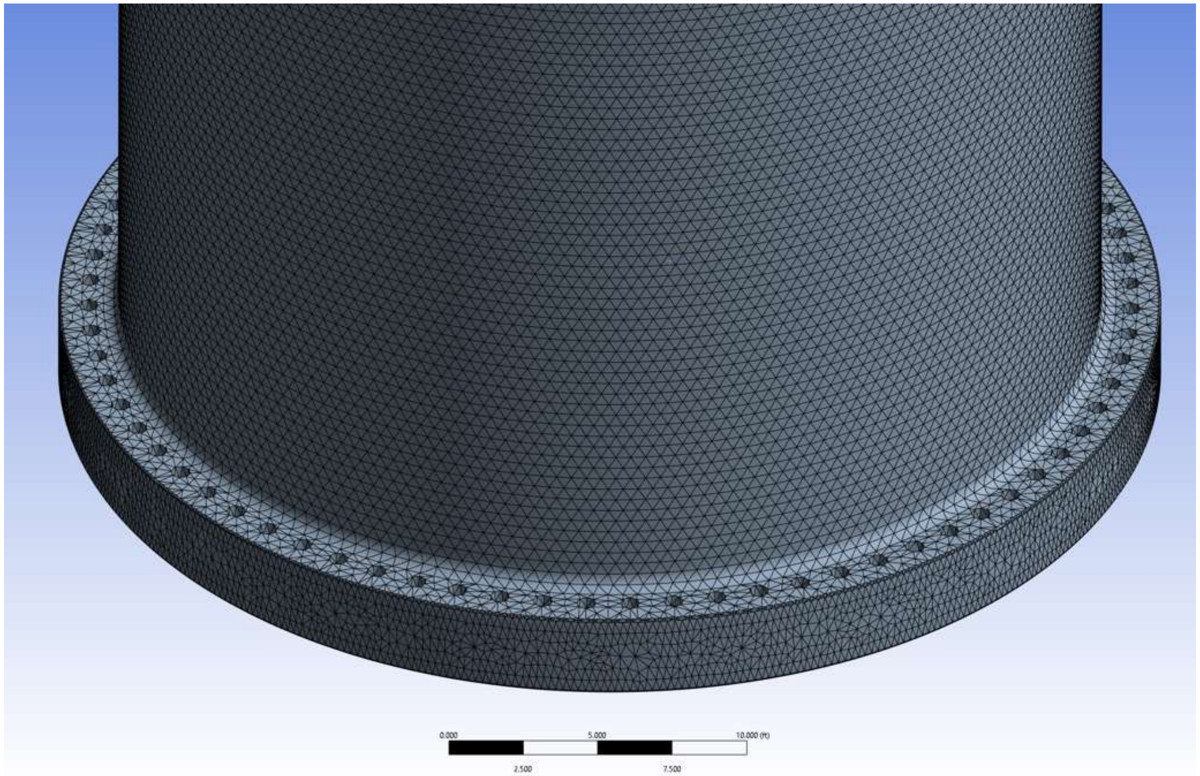
- Tolerancing bolt holes → Greatest ΔR due to Δ°F was 0.3 inches.
- Flange containing 75 bolts: B7M bolts (7in diameter) manufactured by Lightning Bolt Supply
- Maximum deformation in radius around the holes is minimum tolerancing used for the bolt holes
- Bolt holes modeled with 7.6 in diameter

Flange Loading and Constraints (Extreme)



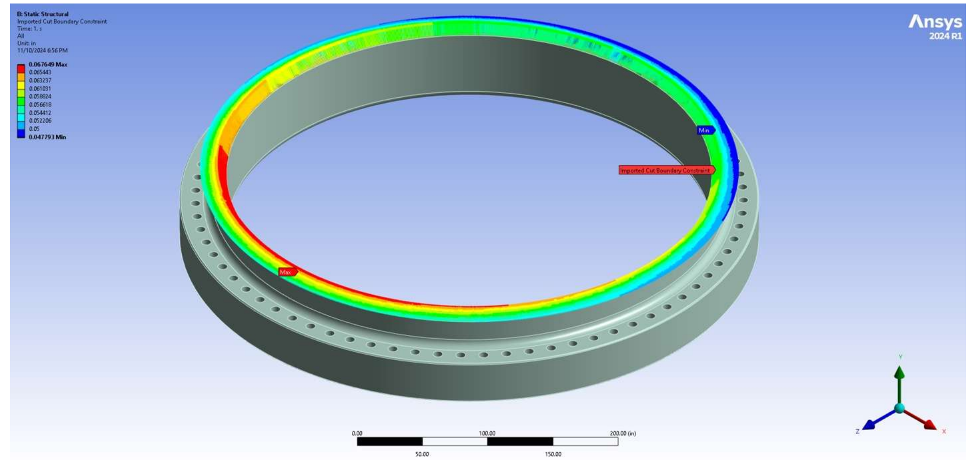
Single Body Meshing Methodology

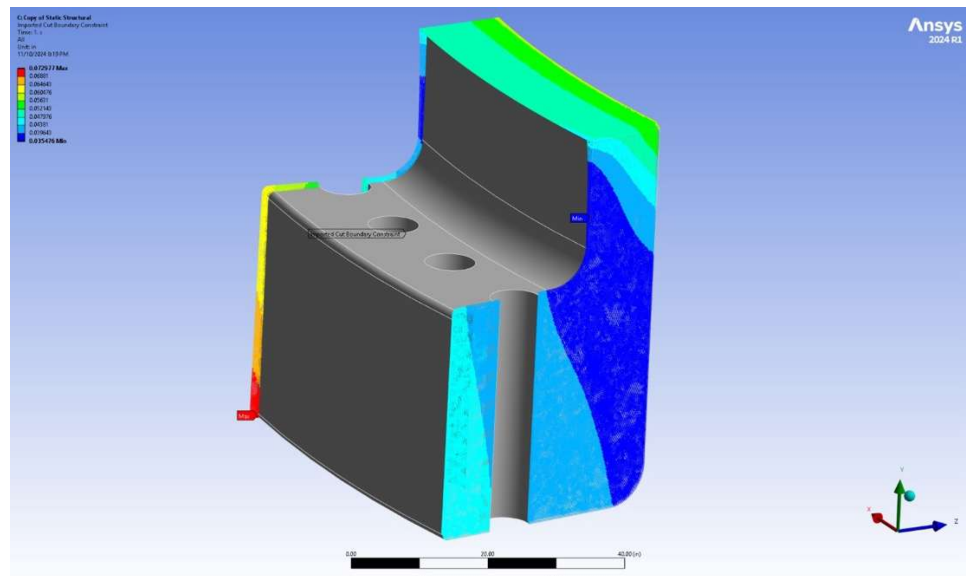
- Tetrahedral mesh
- 1/2-foot element size
- Hole elements are coarse



Sub-modeling Methodology

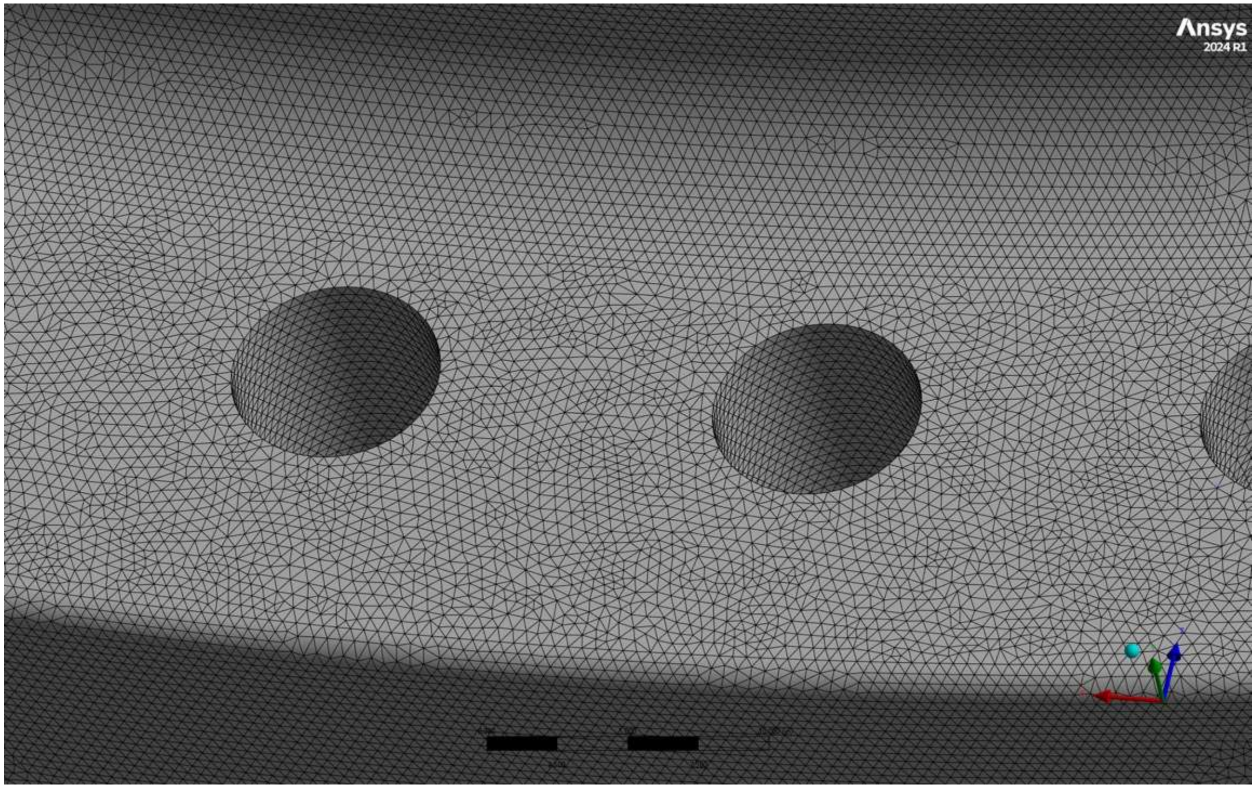
- To accurately portray the bolt holes, we needed a finer mesh than we would have memory for across the whole tower
- We therefore split up the geometries in Design Modeler and meshed them separately
- We then applied a cut boundary constraint on the connecting edge of the flange
- This allowed us apply the reaction forces from our tower model to our finer flange model



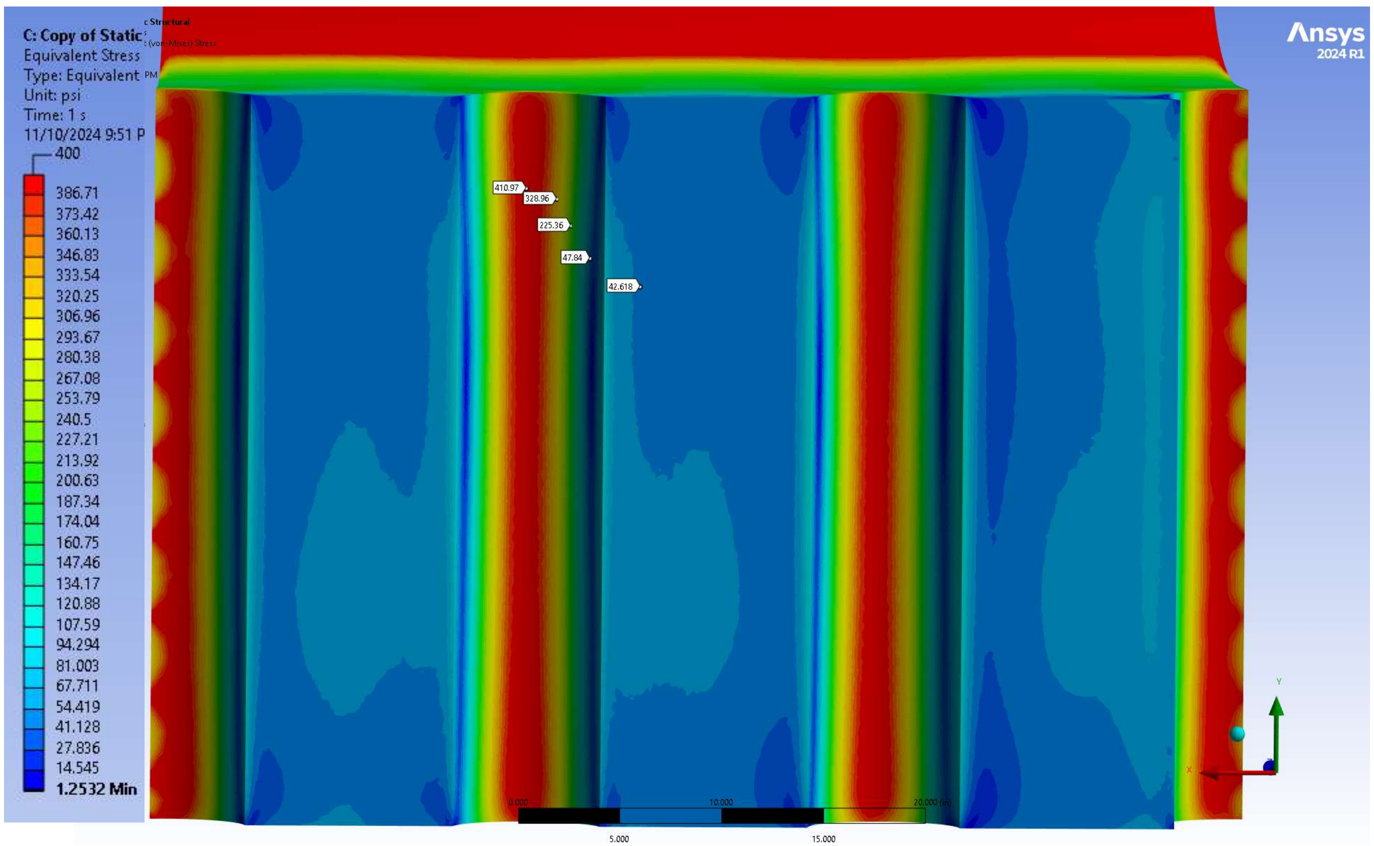


Flange Meshing Methodology

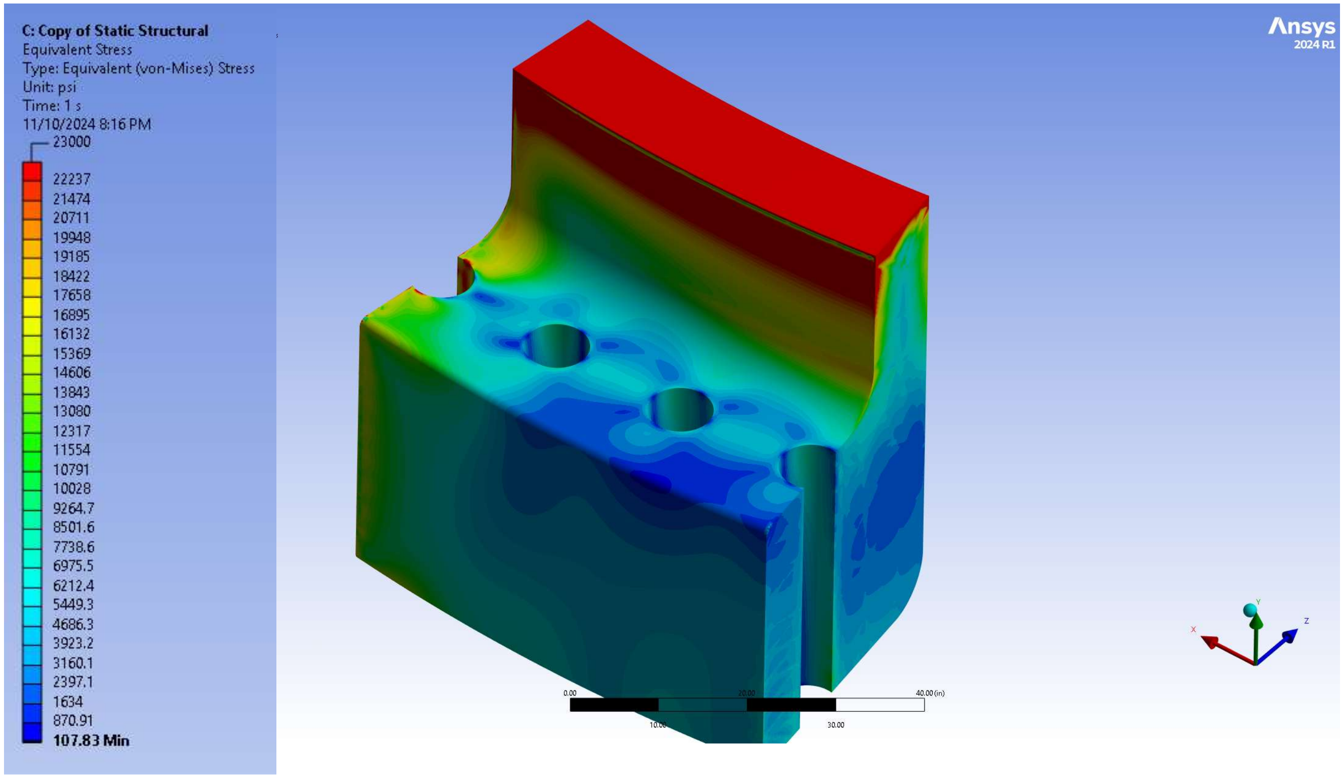
- Tetrahedral mesh
- 1/2-foot element size
- Deemed sufficient via meshing analysis



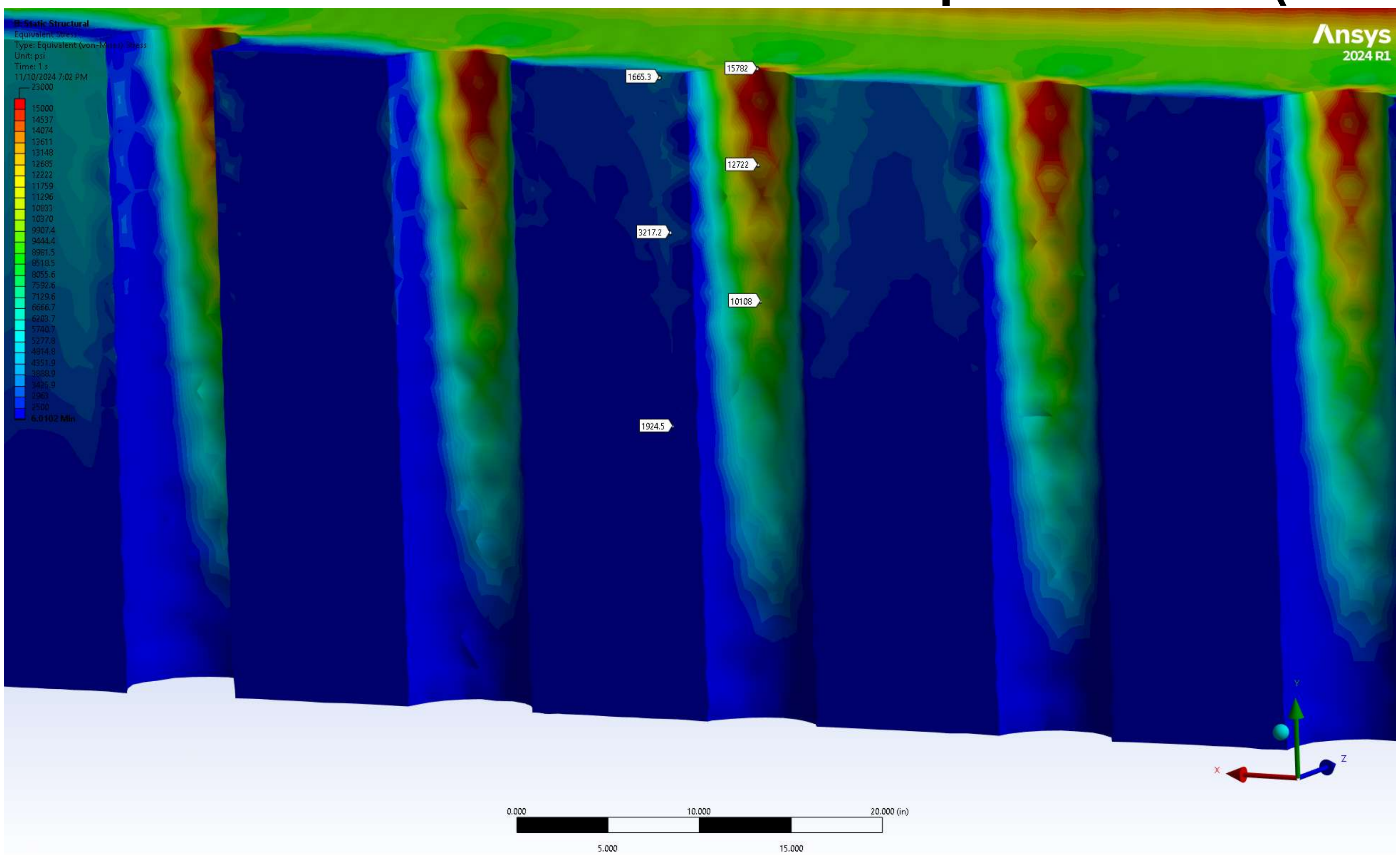
Flange: Von Mises Stress Extreme Wind Conditions and Ambient Temperature (-10 °F)



Flange: Von Mises Stress Extreme Wind Conditions and Ambient Temperature (62.5 °F)



Flange: Von Mises Stress Extreme Wind Conditions and Ambient Temperature (135 °F)

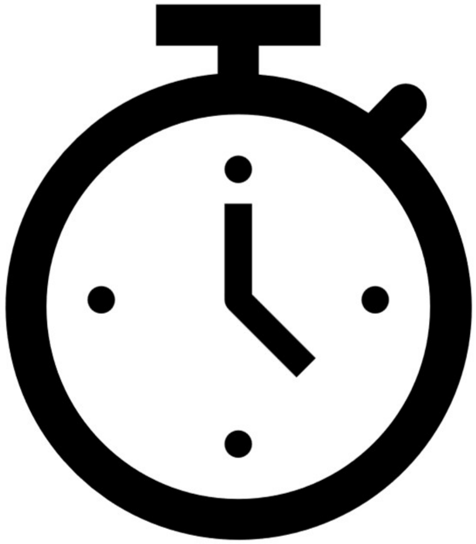


How the FEA affected our Design

- Although we were able to calculate parameters for a uniform section tower, the FEA enabled us to quickly characterize a tapered section that helped us save material
- The FEA also showed us unanticipated stress concentrations around our bolted flange which prompted us to redesign it.
- After the redesign, the FEA instilled us with confidence in the compliance of our final design.

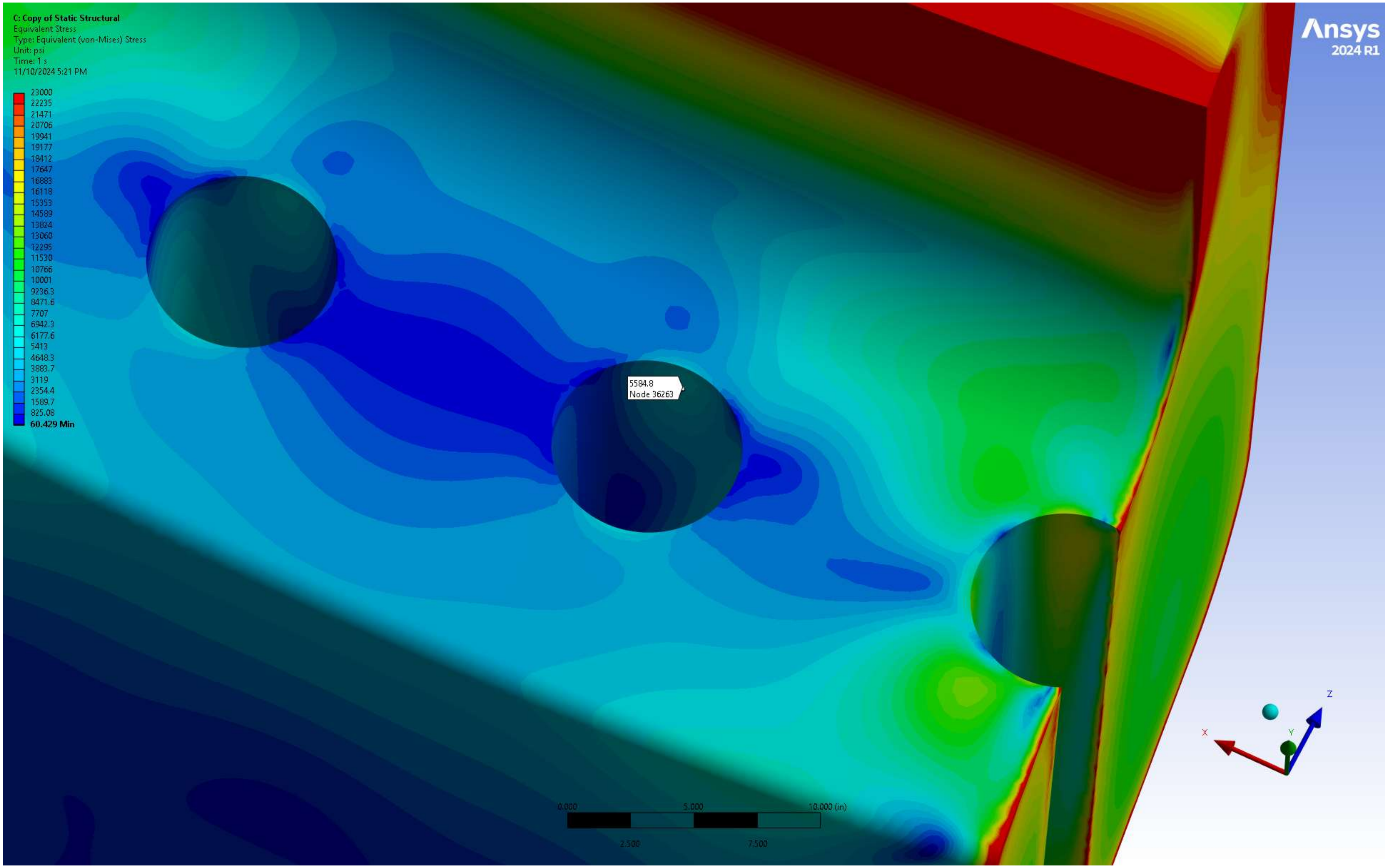
Time Estimate

About 160 hours



Thank You!

Questions?


C: Copy of Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: psi
Time: 1 s
11/10/2024 5:21 PM
23000
22235
21471
20706
19941
19177
18412
17647
16883
16118
15353
14589
13824
13060
12295
11530
10766
10001
9236.3
8471.6
7707
6942.3
6177.6
5413
4648.3
3883.7
3119
2354.4
1589.7
825.08
60.429 Min
Ansys
2024 R1
5584.8
Node 36263
0.000
5.000
10.000 (in)
2.500
7.500
X
Y
Z