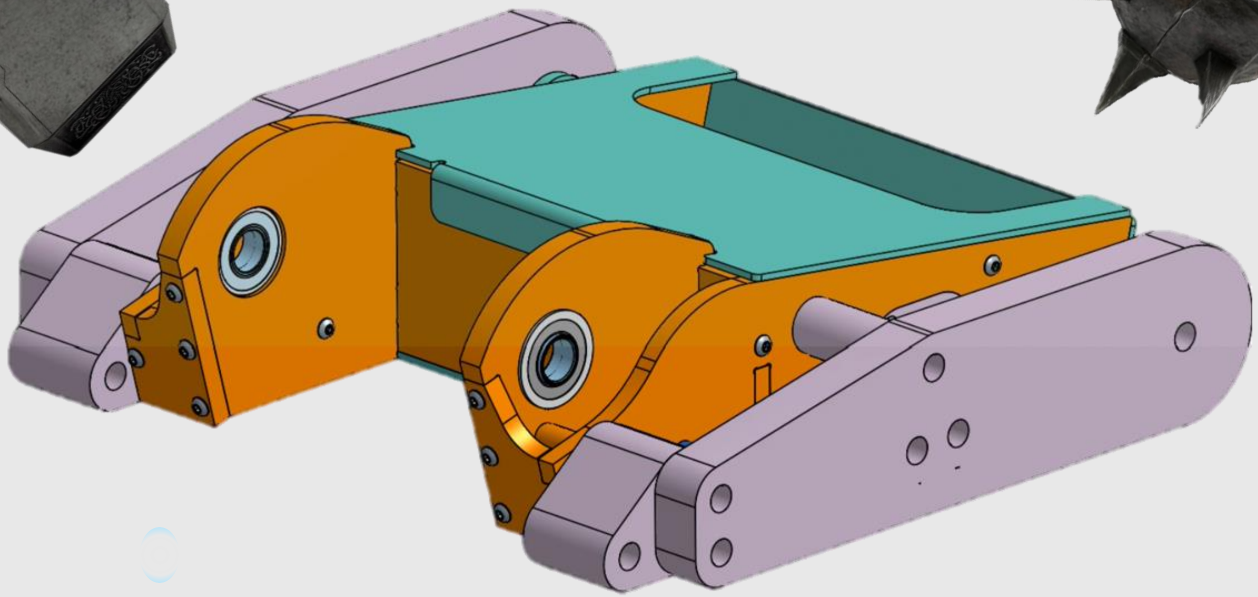
BATTLE BOT IMPACT ANALYSIS



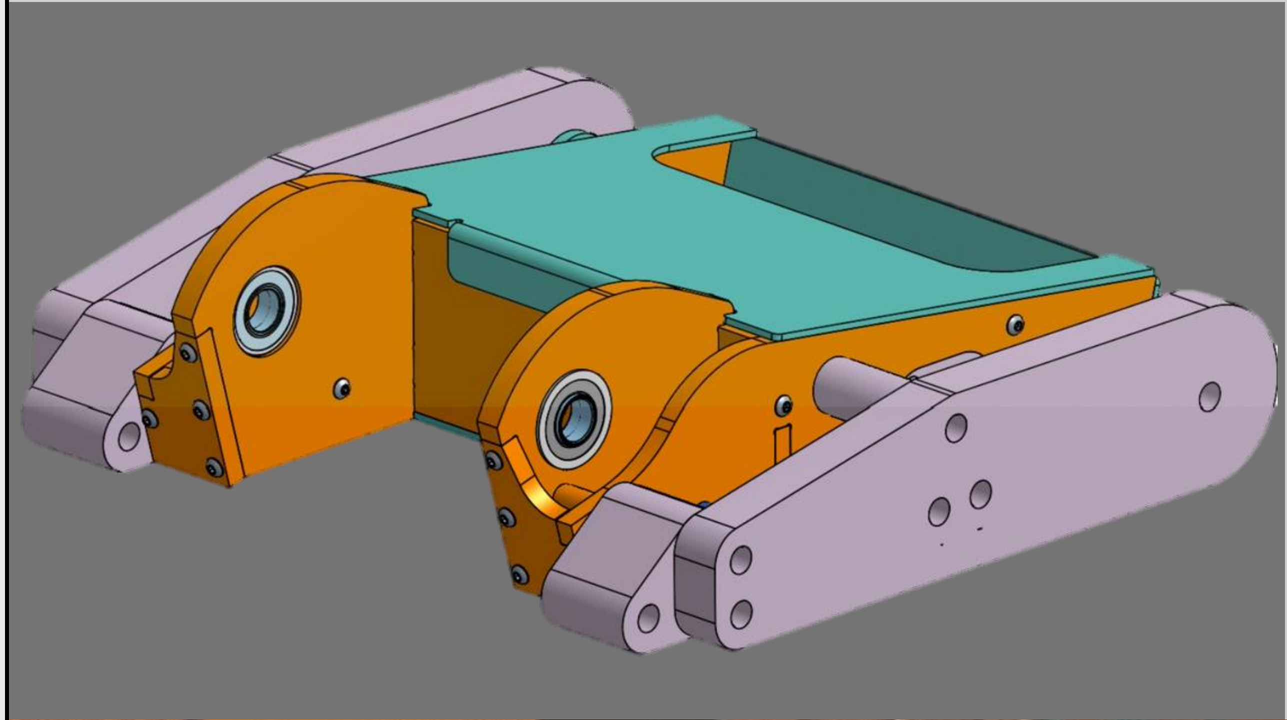
Joshua Ernst, Josh Martin, Terrence San Gabriel, Chase Thorenson

The Problem

- The Battle Bot will be attacked with a variety of weapons in competition

- Competitions impose robot weight limits

- We must balance weight with structural integrity to survive impacts



Analysis

- Simulating the landing impact on the outer plate of the battle bot should it be thrown in the air

- Simulating impacts on the outer plate of the battle bot by an axe

- Using ANSYS geometry optimization to reduce the overall weight of the machine

- For each analysis, Aluminum Alloy NL is used for the side plate having a yield stress of 276 MPa

Free Fall Analysis

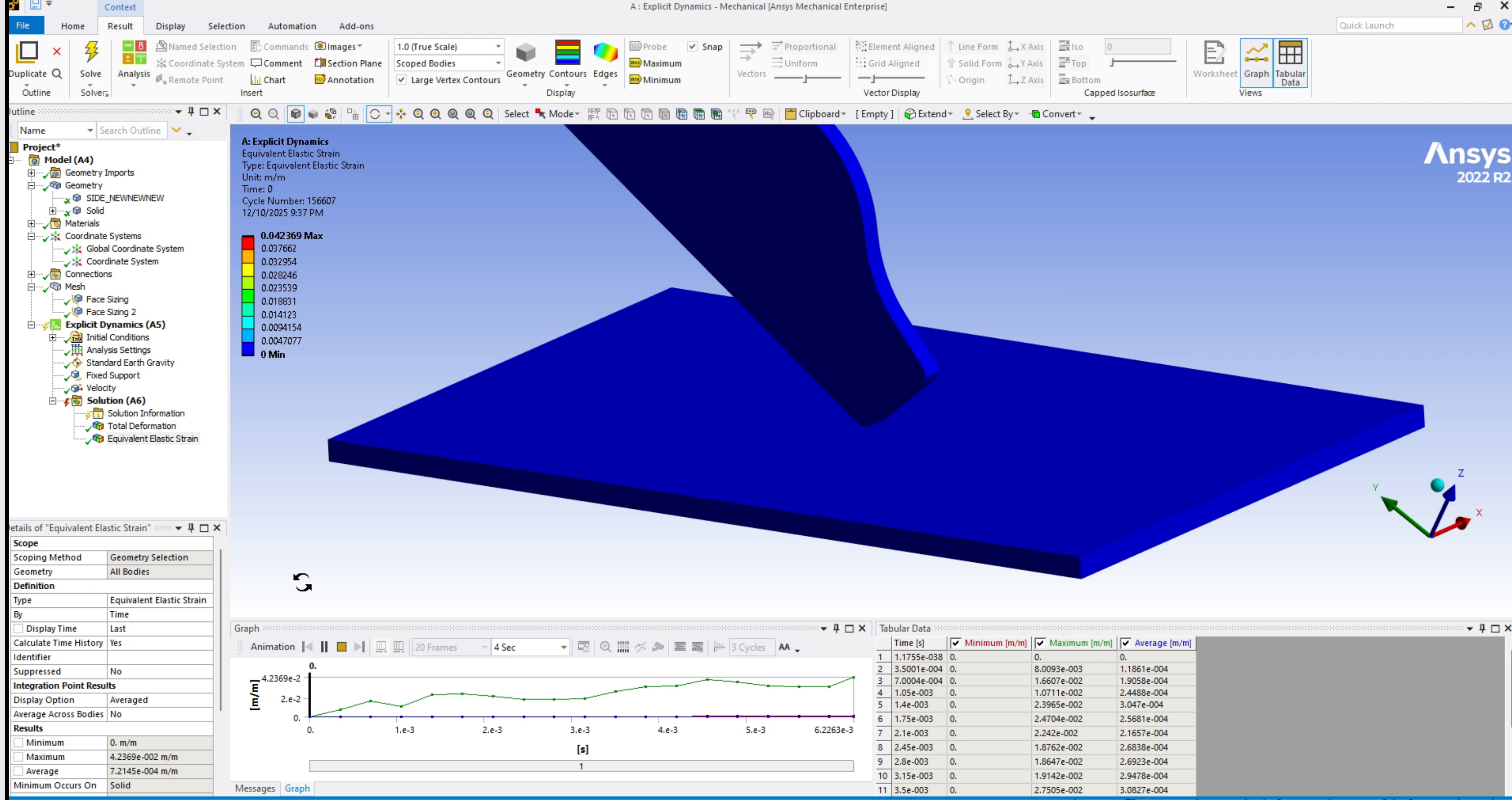
Analyzed the max stress experienced by the side plate post fall.

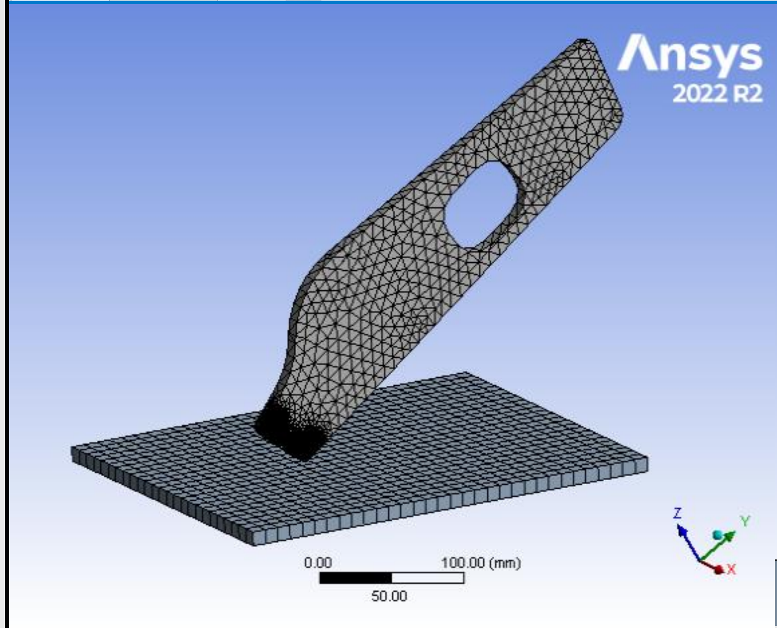
Initial Conditions

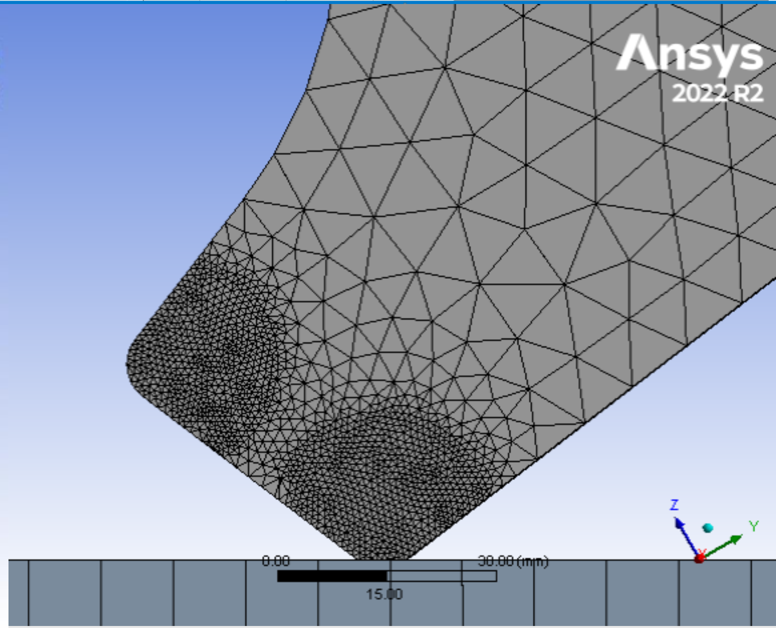
- Assumed 20 inch free fall
- Impact speed of 10.4 ft/s
- Landing on a rigid concrete pad

Analysis

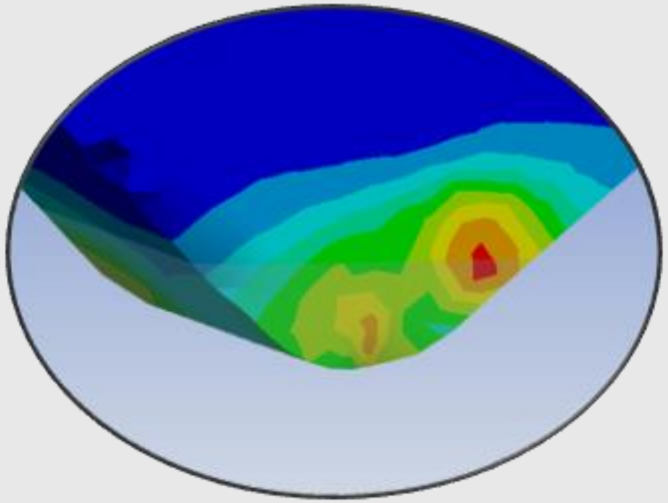
- Used higher density elements in areas of interest
- 0.85 mm element size near the impact site
- 10 mm element size for the rest
- 1.2 ms analysis time

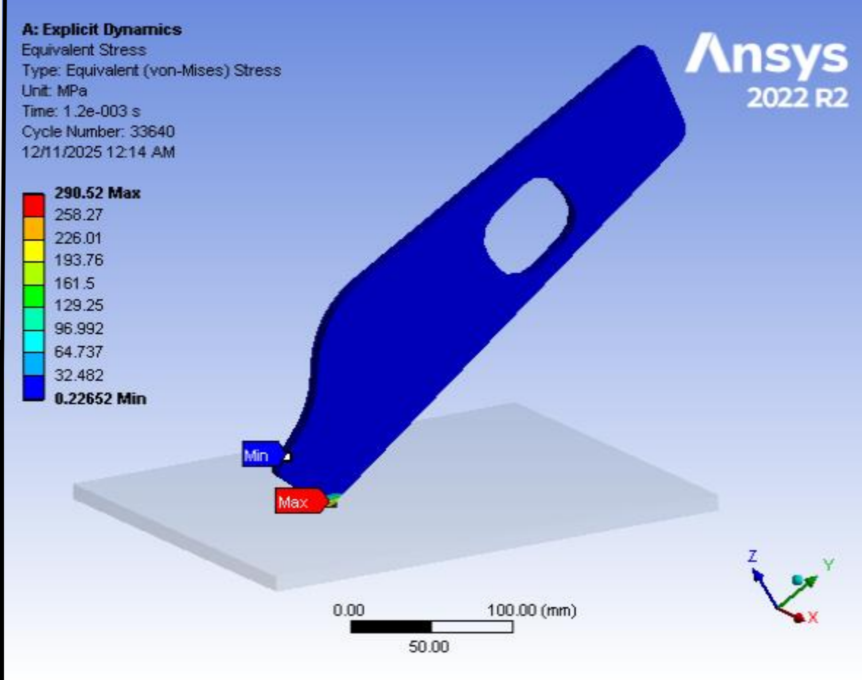






Free Fall Analysis Results



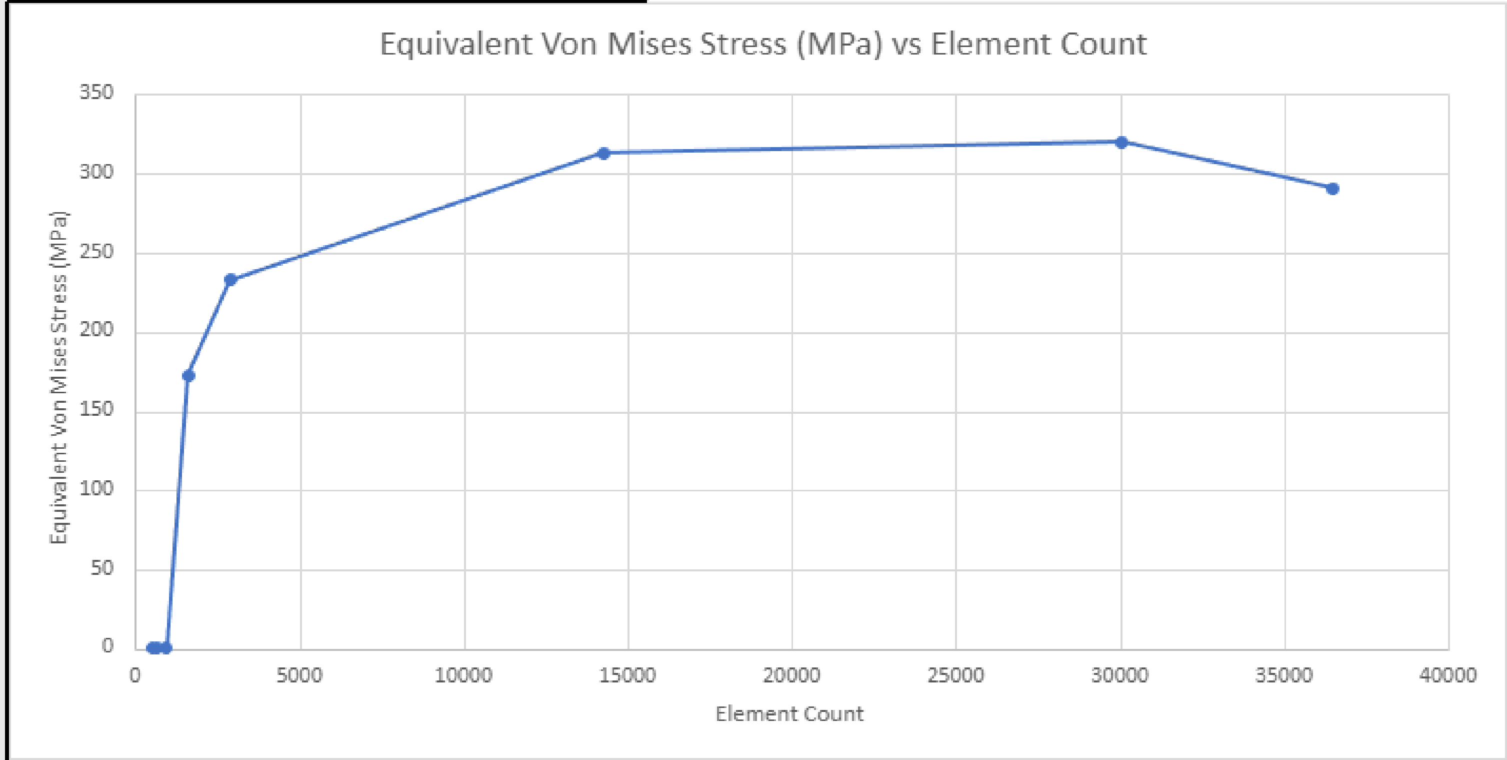


Results

- Convergent Equivalent Von Mises Stress of 290.5 MPa
- Convergence of values near higher element sizes
- Down to 2.2% error in results

The convergence of the graph shows that no singularities were present on the model.

Finer meshing impractical due to the time required to simulate explicit dynamics.



Axe Impact Analysis

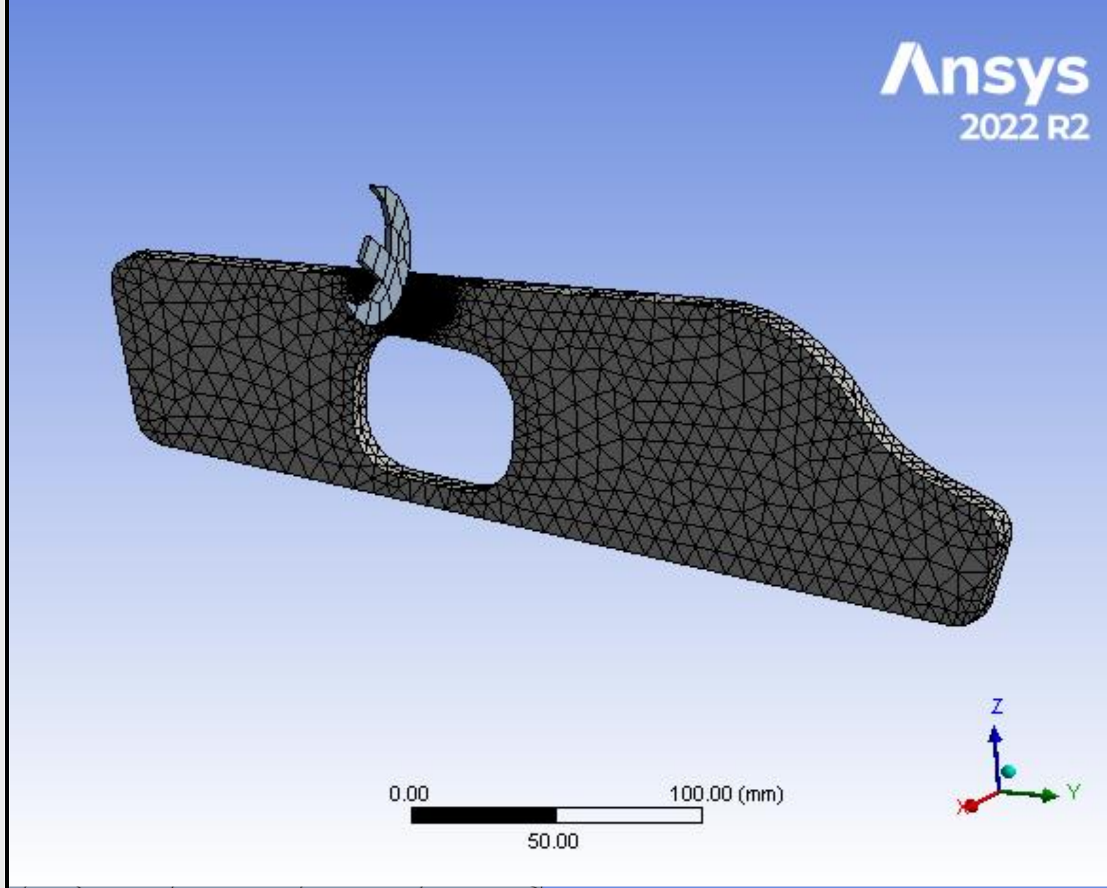
Analyzed the max stress experienced by the side plate when struck by an axe

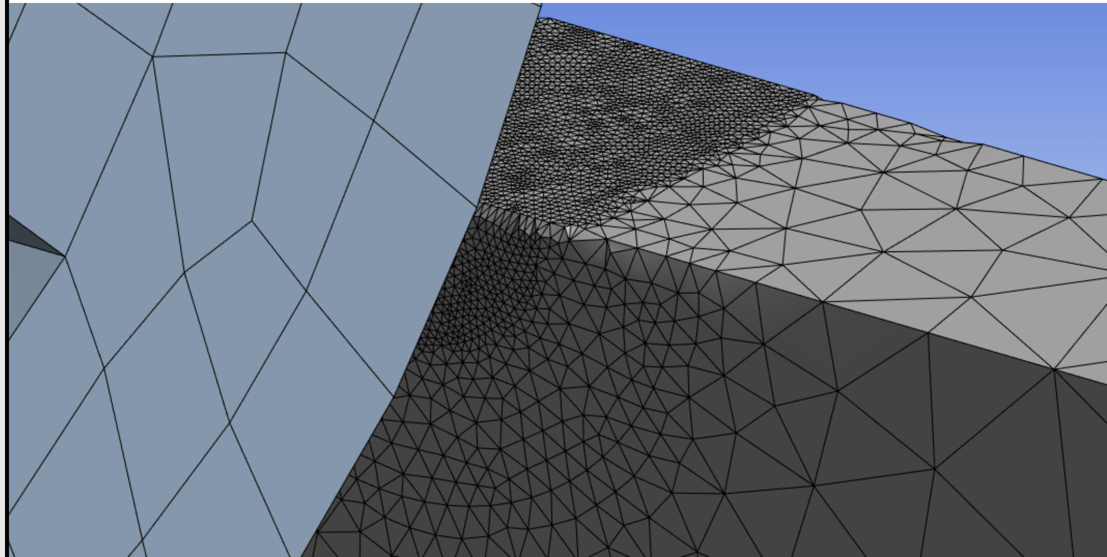
Initial Conditions

- Axe edge 2 mm thick
- Axe tip speed of 100 mph
- Axe is carbon steel and considered rigid

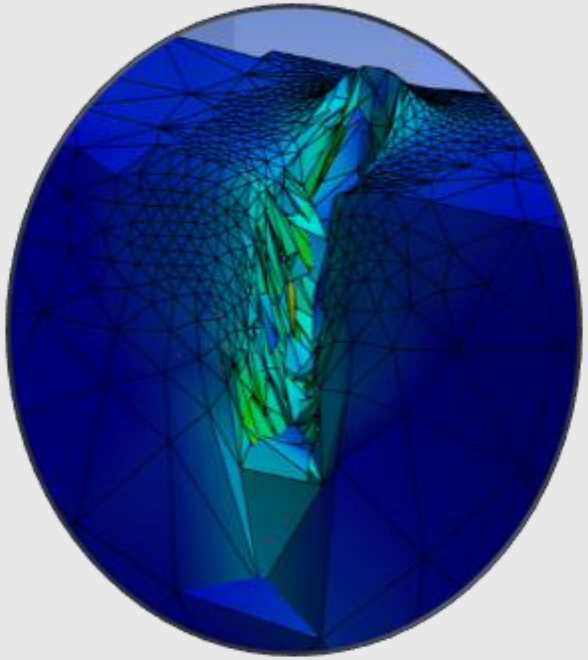
Analysis

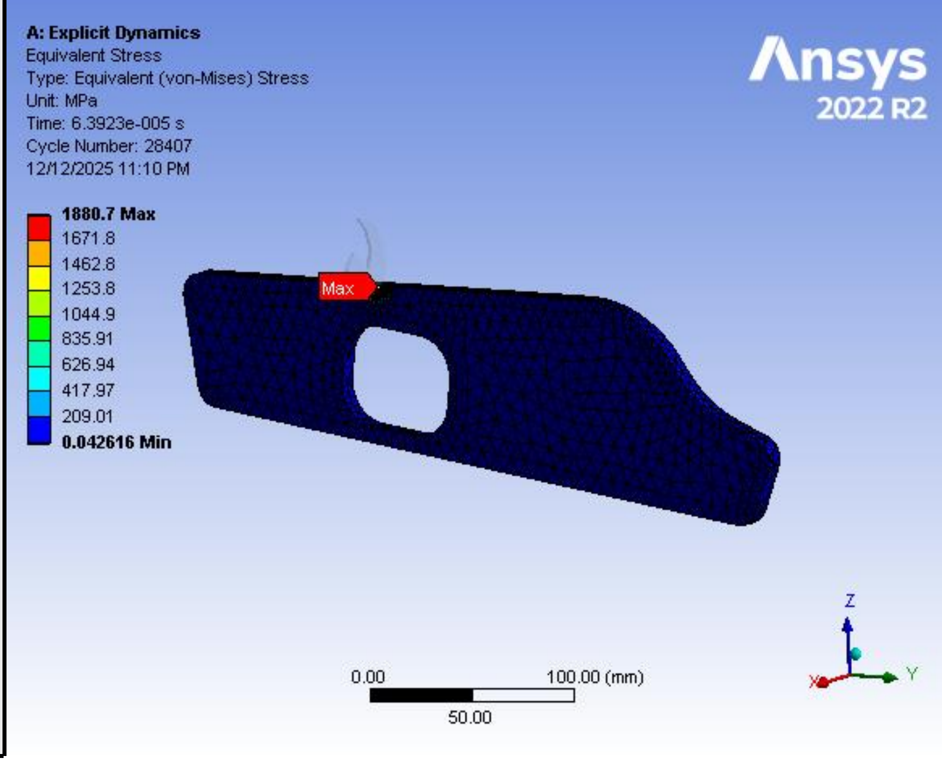
- Used higher density elements in areas of interest
- 0.2 mm element size near the point of contact
- 10 mm element size for the rest of the piece
- 0.3 ms analysis time





Axe Impact Analysis Results

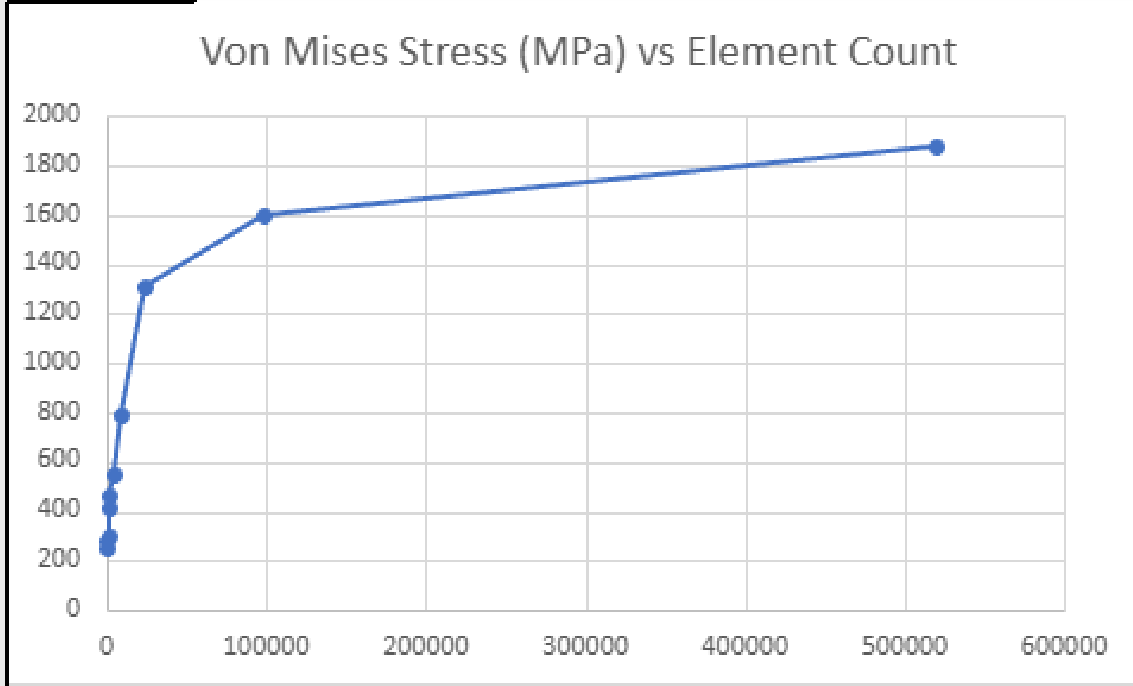




Results

- Maximum simulated Equivalent Von Mises Stress of 1881 MPa
- Even with the finer mesh, results continued skyrocketing

As the axe had a fine edge and rigid body, the elements on the side plate experienced increasing compression

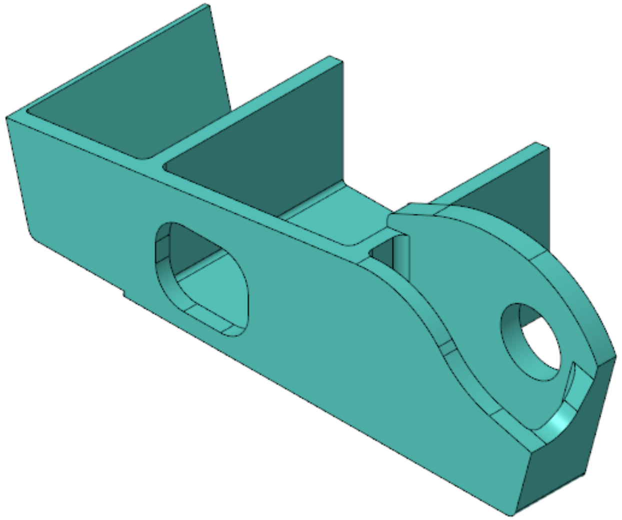


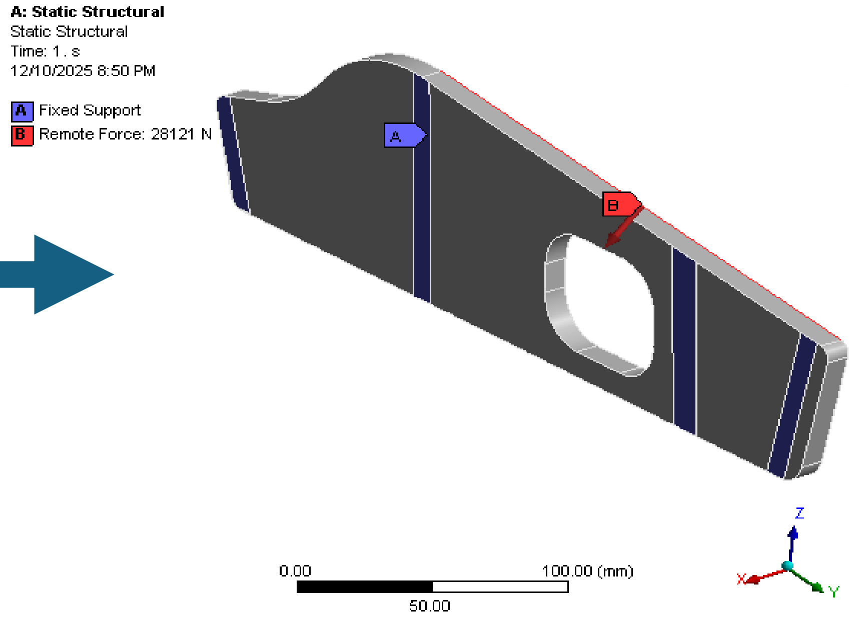
The compression led to singularities within the simulation, and a continually increasing stress due to the creation of singularities.

Side Plate Analysis After Axe Impact

Model Simplification:

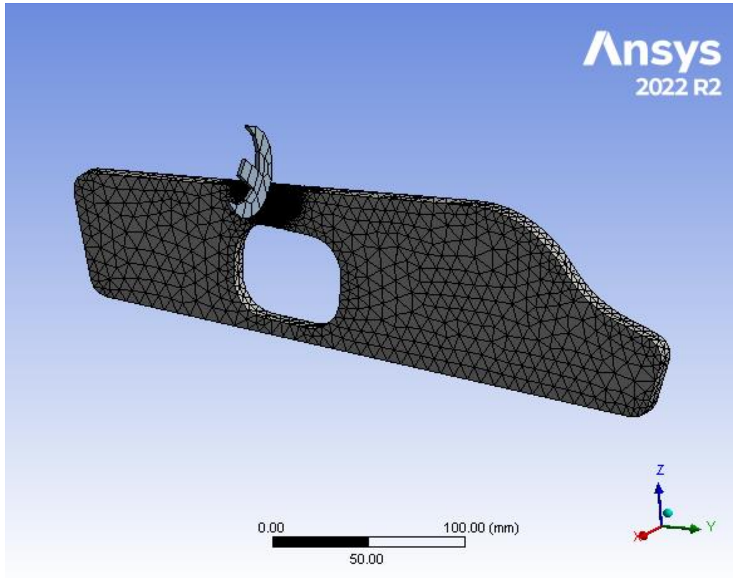
- Initial model presented many areas where singularities could occur
- When initially completing analysis, little to no stress appeared in the other members
- Only 6061 Aluminum was tested



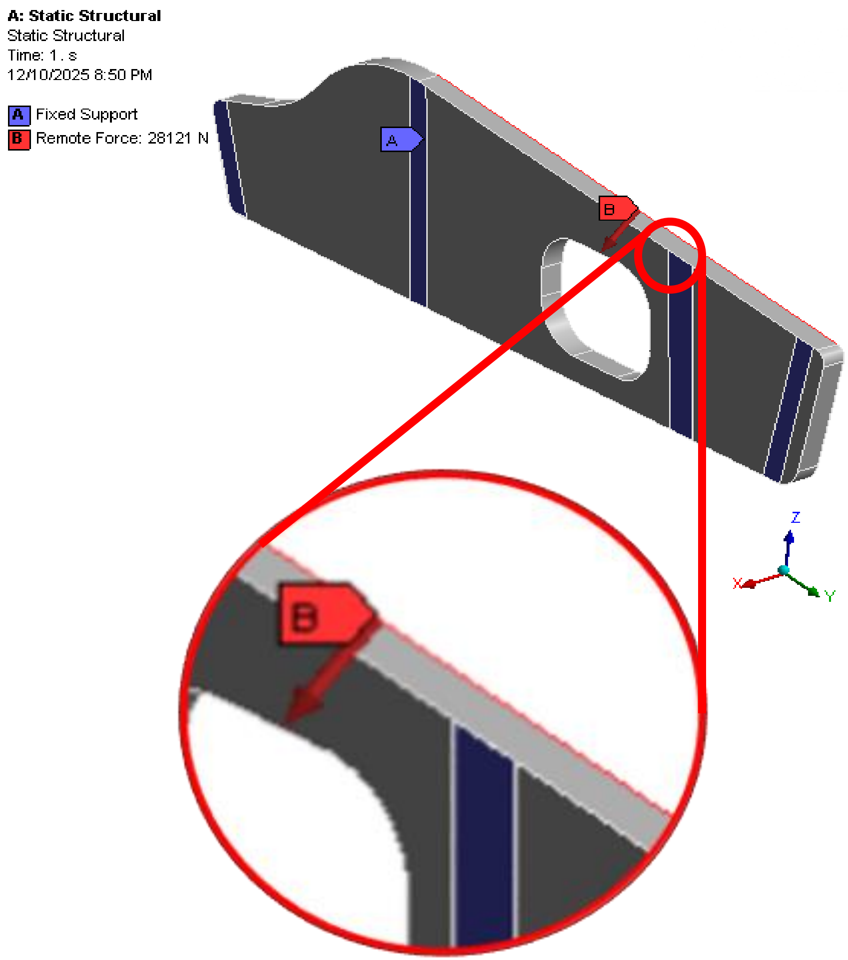


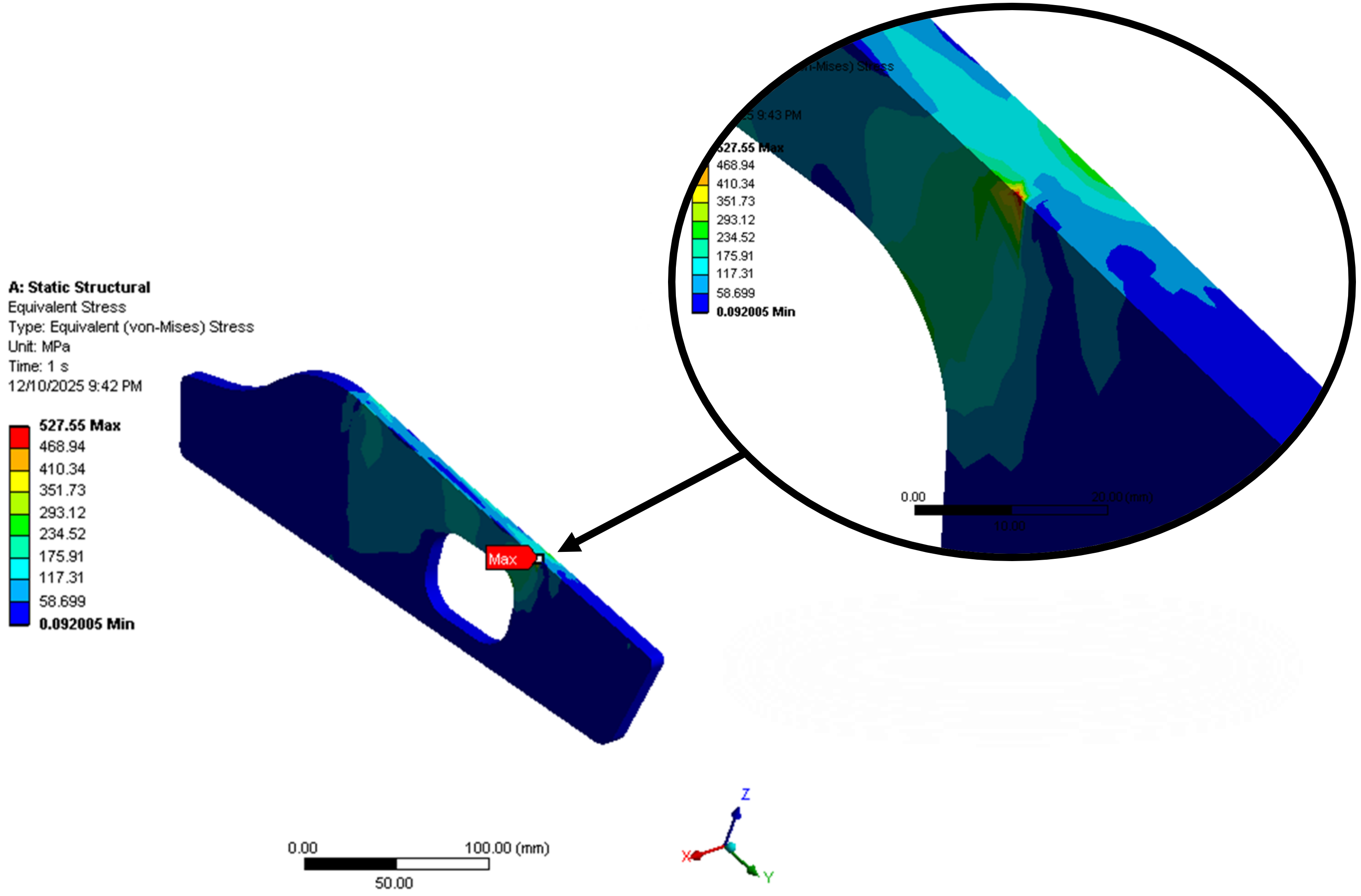
Force Calculation:

- 5000 Joules of energy at impact, 7 inch axe blade moment arm
- Force = Work/Distance -> 5000/(7/39.37) = 28,121.43 N
- Assuming 45° impact: Force in X and Z is 19,884.85 N
- Remote load applied at point where material between hole and impact is minimal.



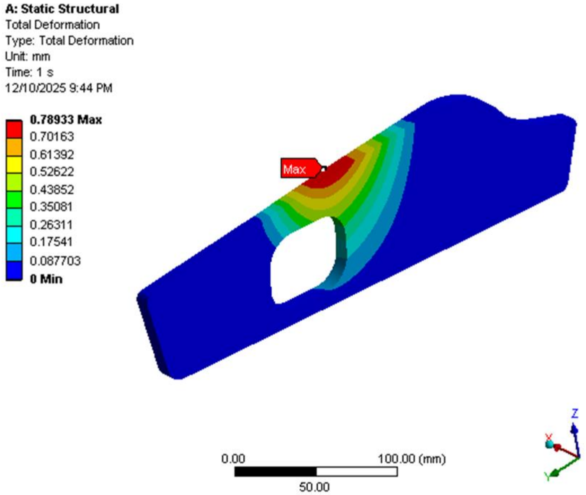
Singularities – Static Structural





Simulation Results – Static Structural

Elastic Al 6061:

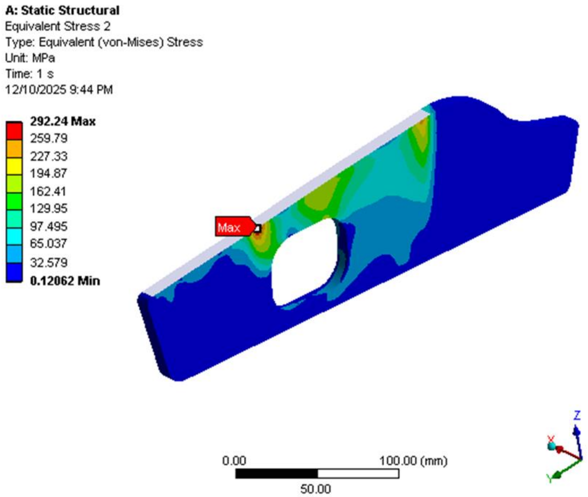


Max Deflection:
- 0.789 mm

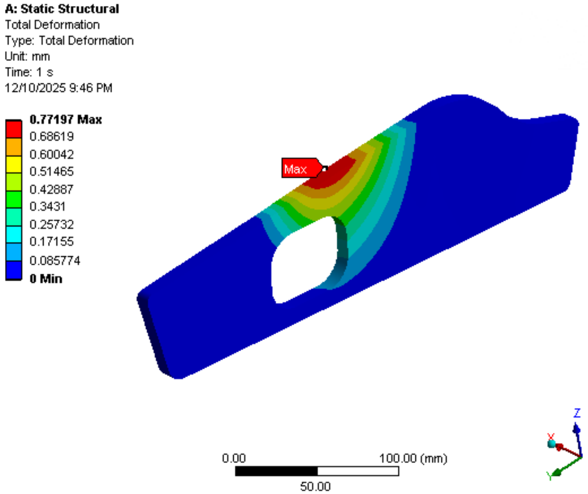
Max Von Mises Stress:
- 292.24 MPa

Singularity Stress:

Mesh Size (mm)	Stress (MPa)
10.00	487.58
7.50	303.18
5.00	393.49
4.00	401.28
3.00	417.73
1.75	527.55
1.00	664.99



Nonlinear Al 6061:

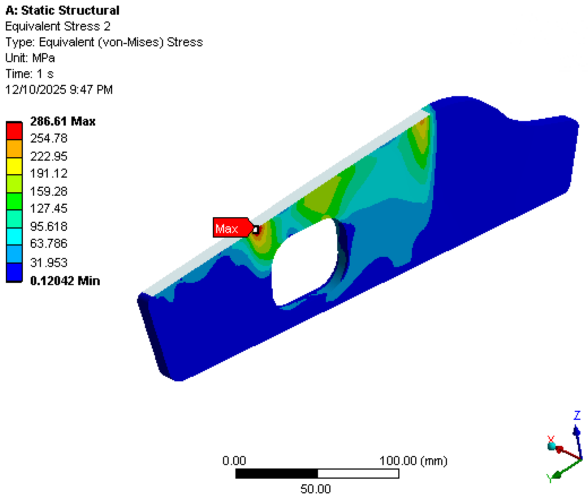


Max Deflection:
- 0.772 mm

Max Von Mises Stress:
- 286.61 MPa

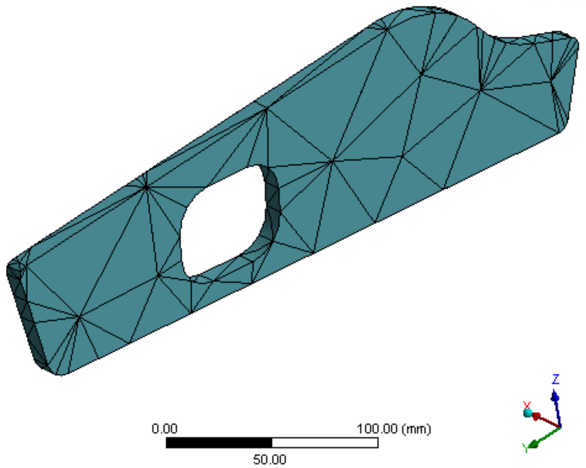
Singularity Stress:

Mesh Size (mm)	Stress (MPa)
10.00	286.13
7.50	273.43
5.00	307.8
4.00	334.09
3.00	309.41
1.75	293.16
1.00	294.87

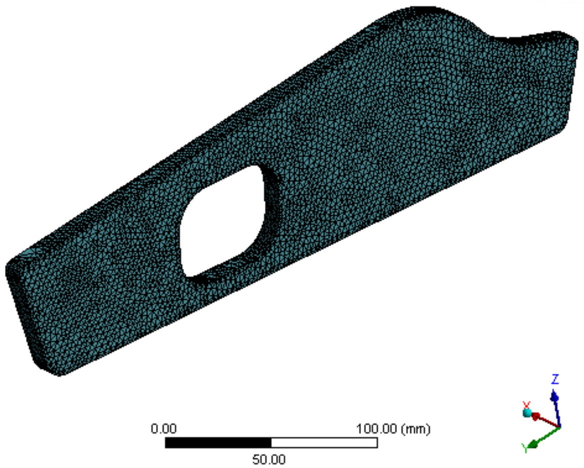


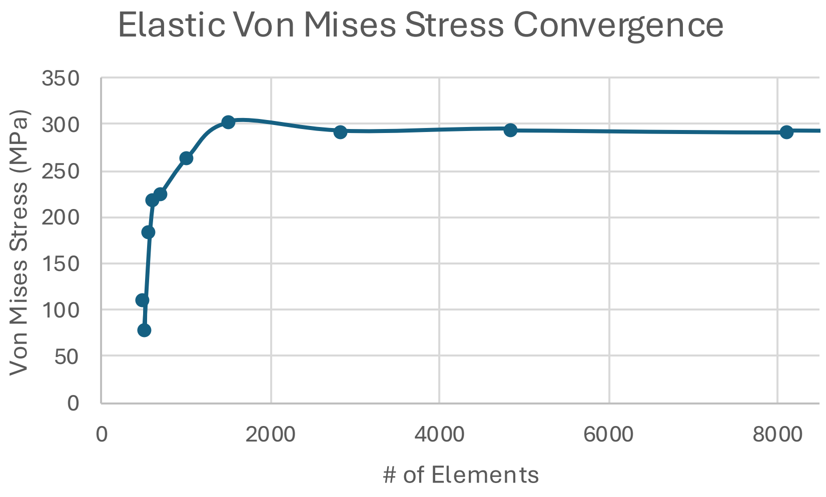
Convergence Study – Von Mises Stress

Initial Mesh:
- 100 mm
- # of elements: 496

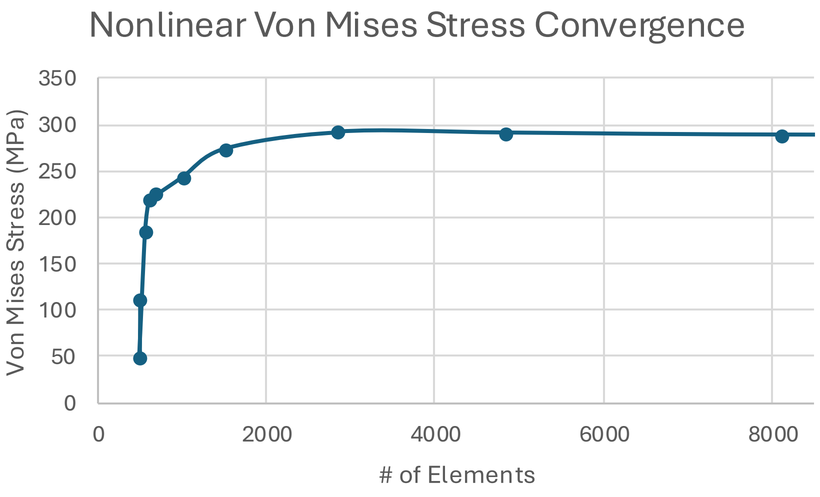


Final Mesh:
- 1.75 mm
- # of elements: 23,542





Error:
- At 1.75 mm: e = 0.14%



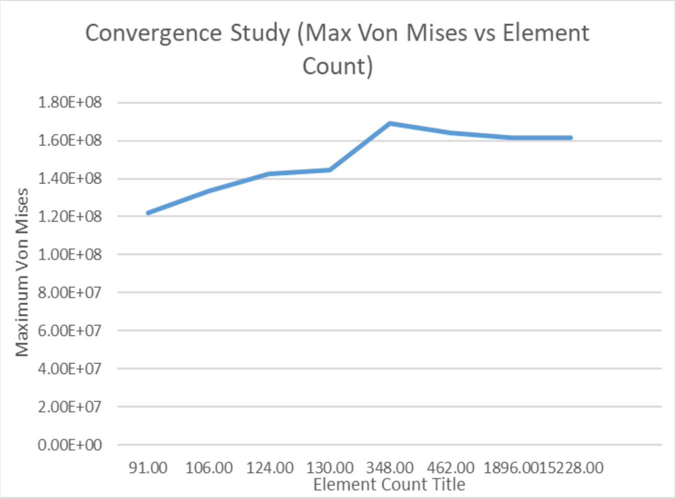
Error:
- At 1.75 mm: e = 0.63%

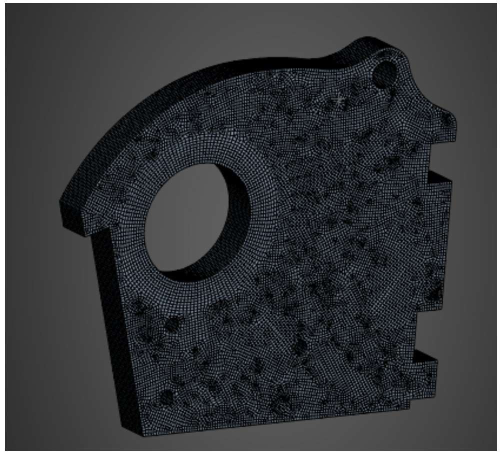
Topology Optimization

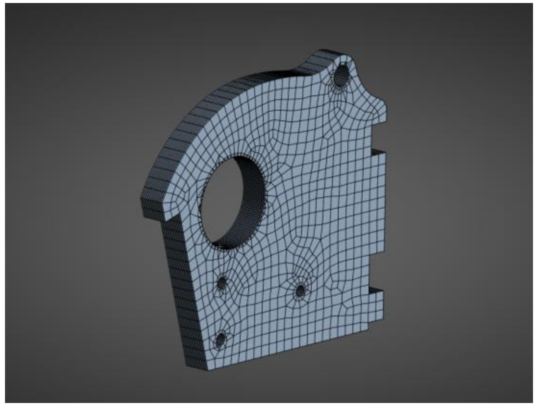
- Easier to analyze single components
- In this case, we are interested in minimizing the front weapon mount
- Updated model was imported with holes modelled
- Note that new model has no chamfers on the tabs and the reliefs are eliminated

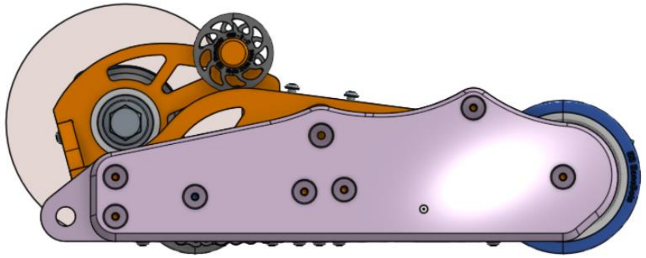
- Convergence Study

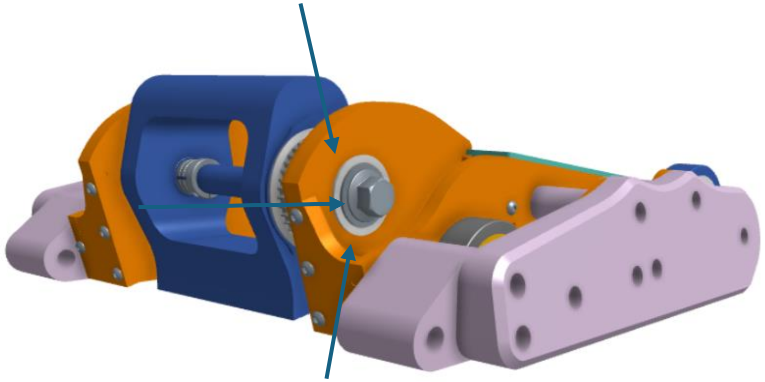
  1mm mesh size ~ 0.14% error

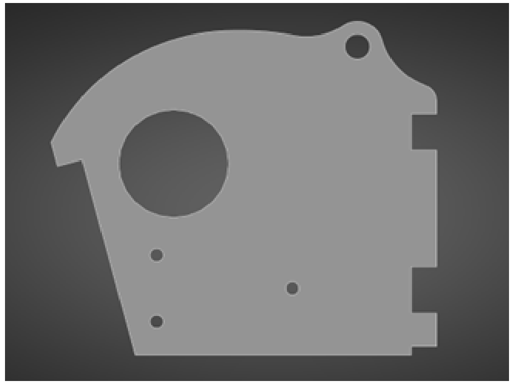








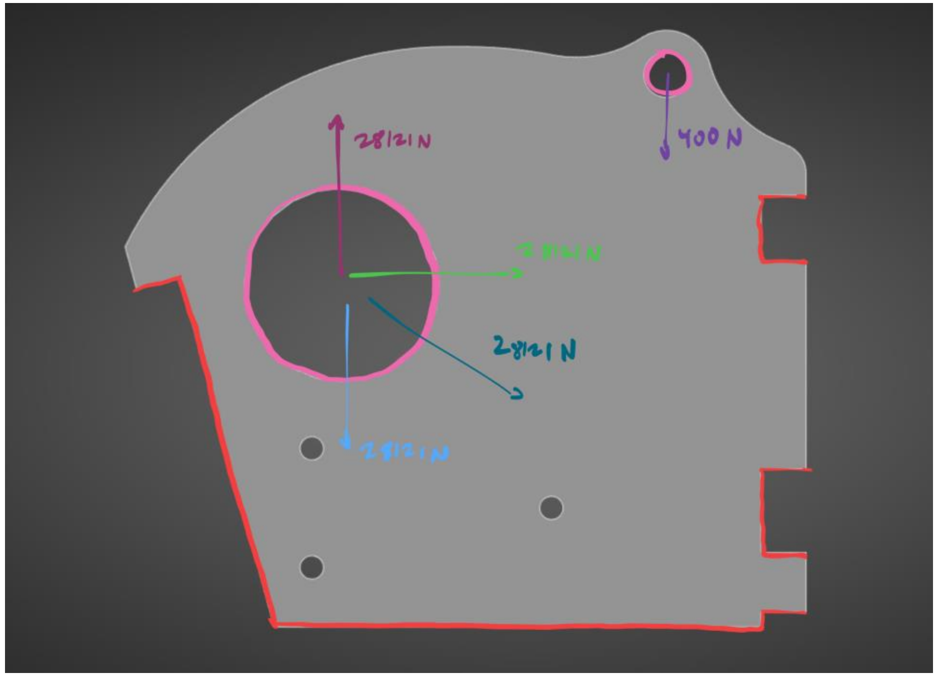




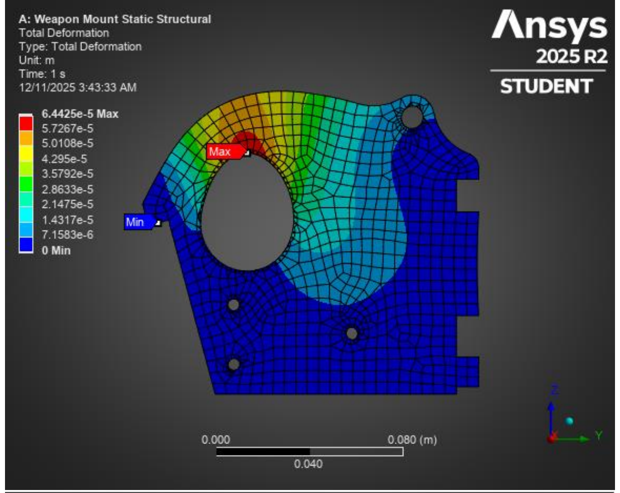
Topology Optimization

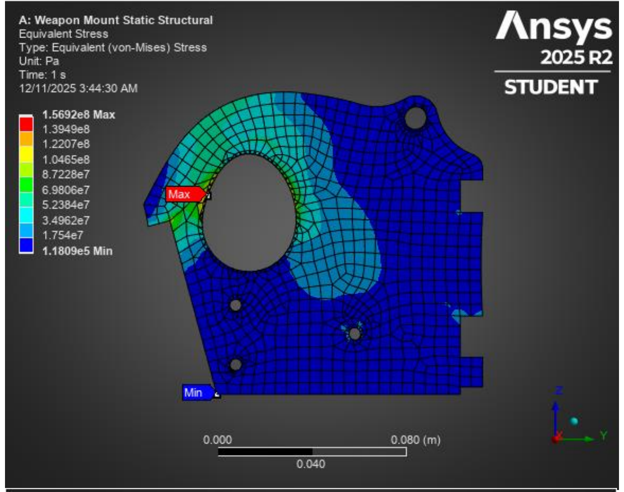
- 3 different load cases

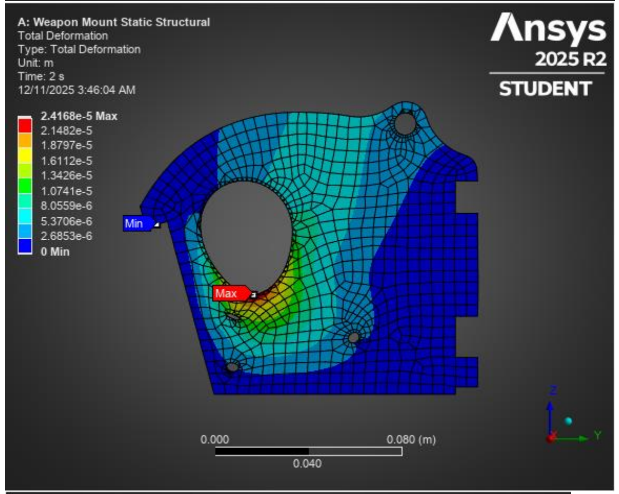
Step Controls	
Number Of Steps	3.
Current Step Number	3.
Step End Time	3. s
Auto Time Stepping	Program Controlled

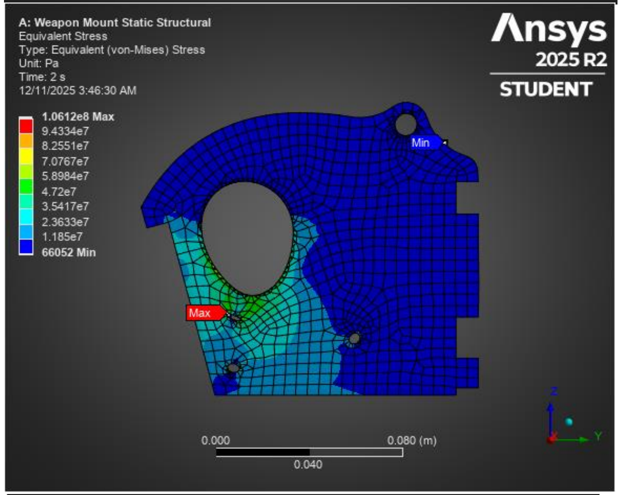


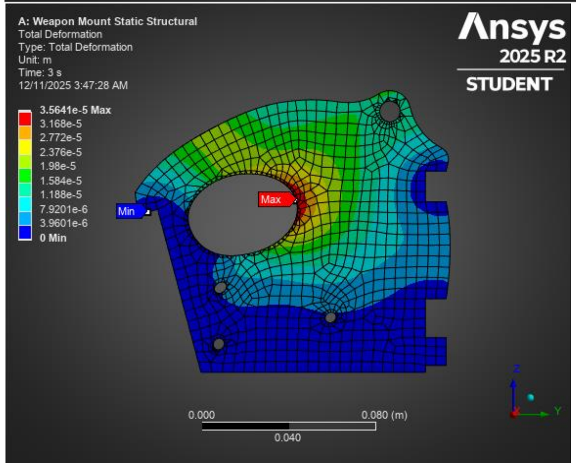
Optimize for 50% mass reduction

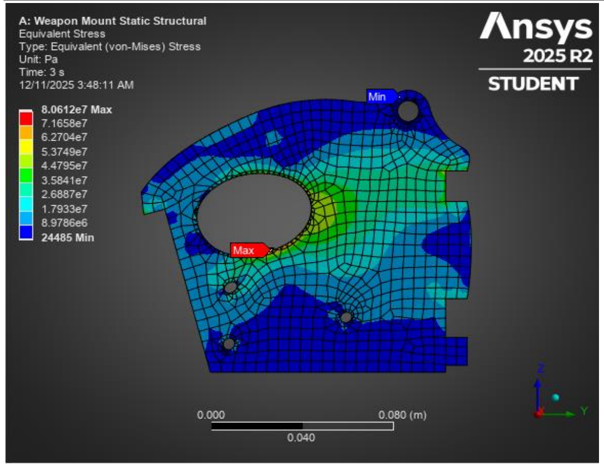








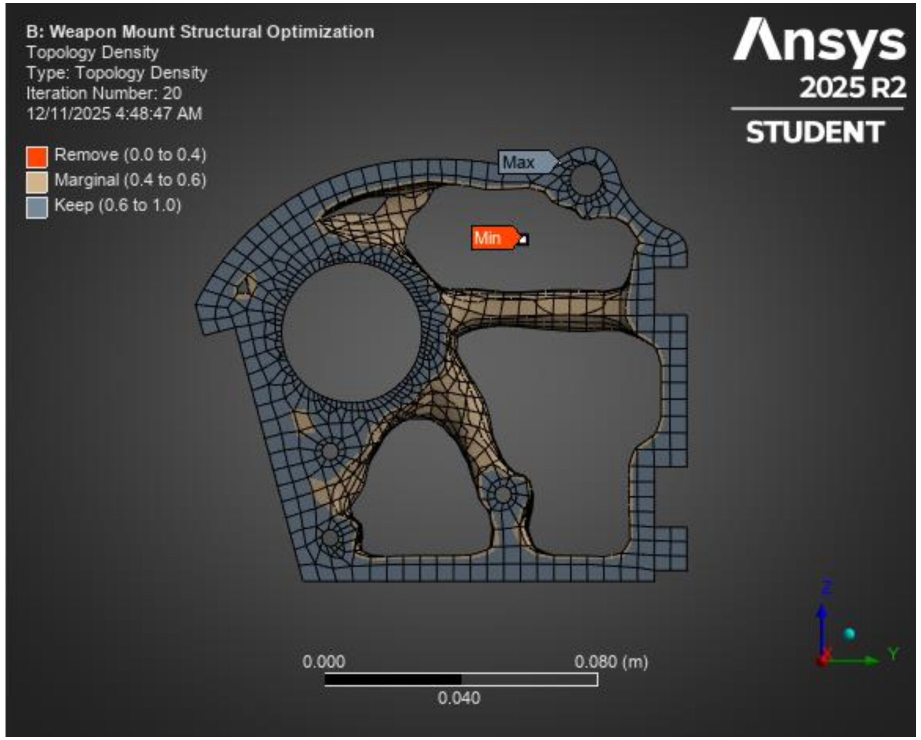


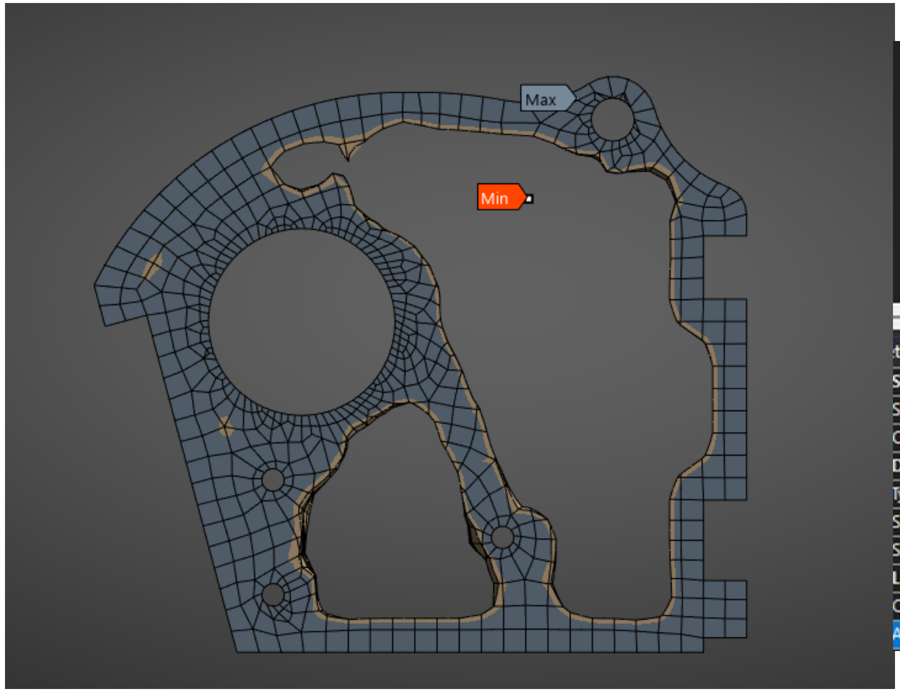


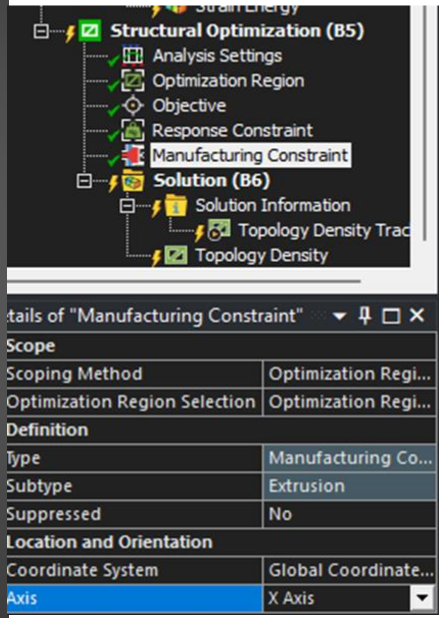
Topology Optimization

- 1st attempt
- Takes into account the Y and the Z directions, but not the diagonal
- The bunny ear at the top that allows the robot to be maneuvered while upside down not considered
- Stems are not manufacturable

- 2nd attempt
- Bunny ears given 400N 'bearing load'
- Manufacturing constraint added

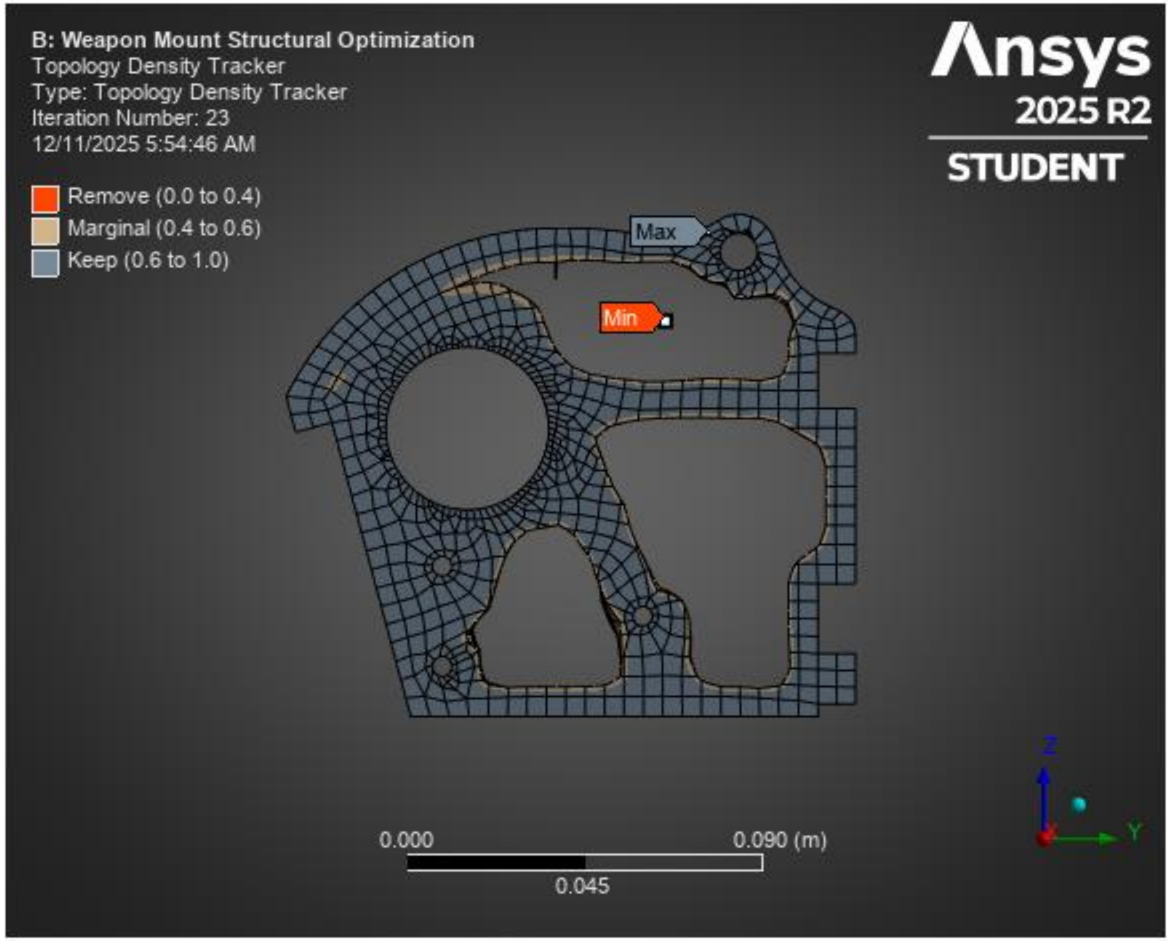




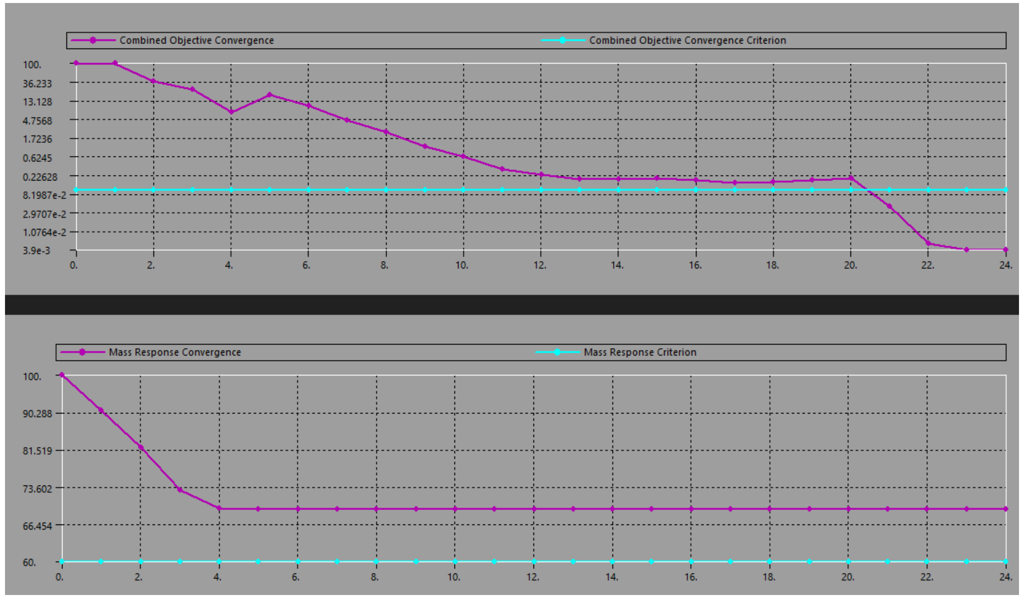


Topology Optimization

- 3rd attempt

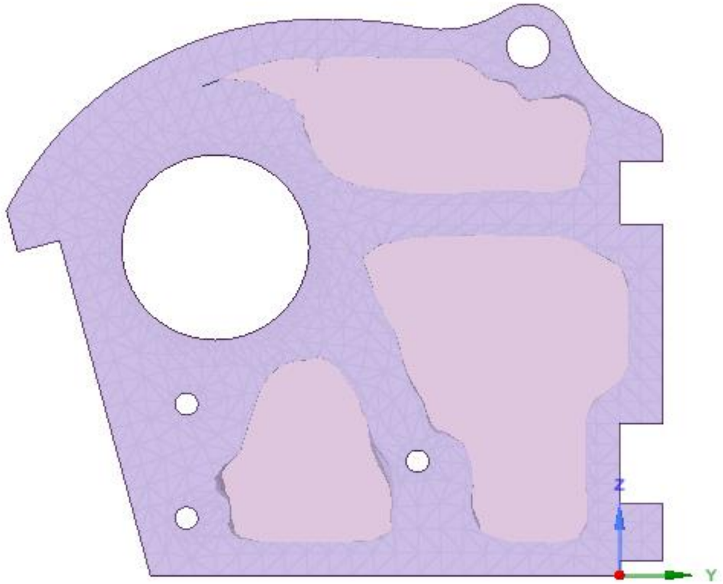


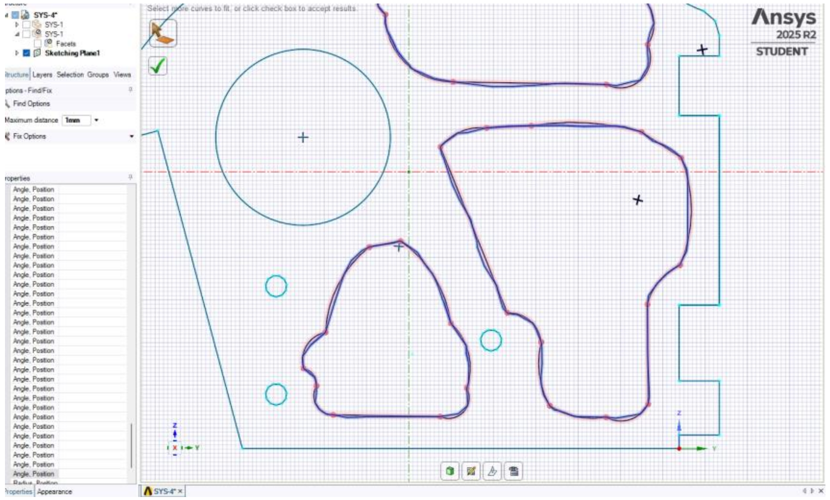
- From previous optimization, the horizontal bar was marginal.
- With newly added material due to manufacturing constraint, it was removed.
- From experience, this is not ideal. The bearing mount should be supported radially.
- All bearing loads were doubled
- Switched to 60% mass reduction goal



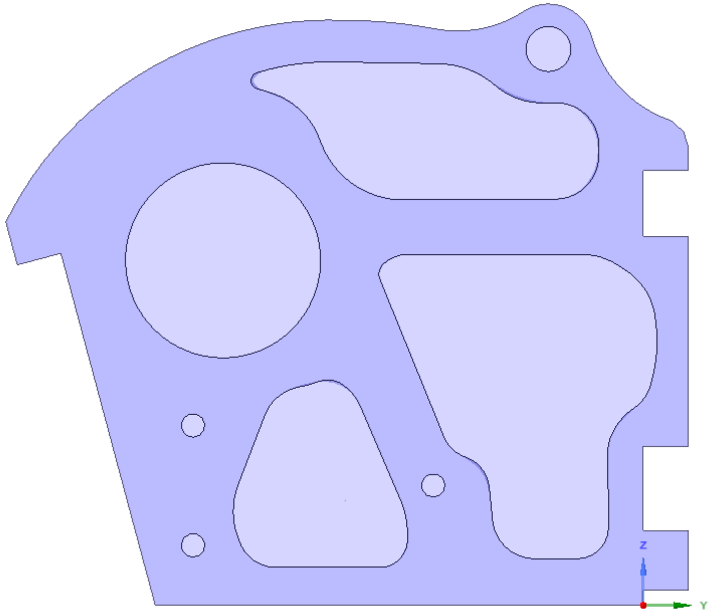
Topology Optimization

- Very rough edges



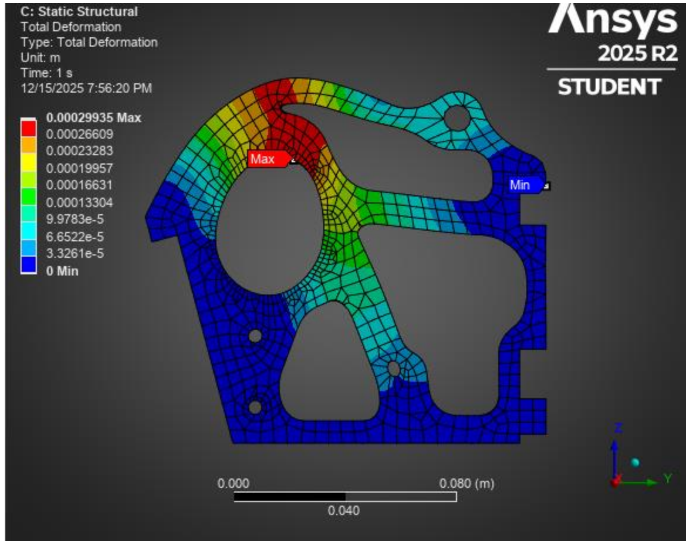


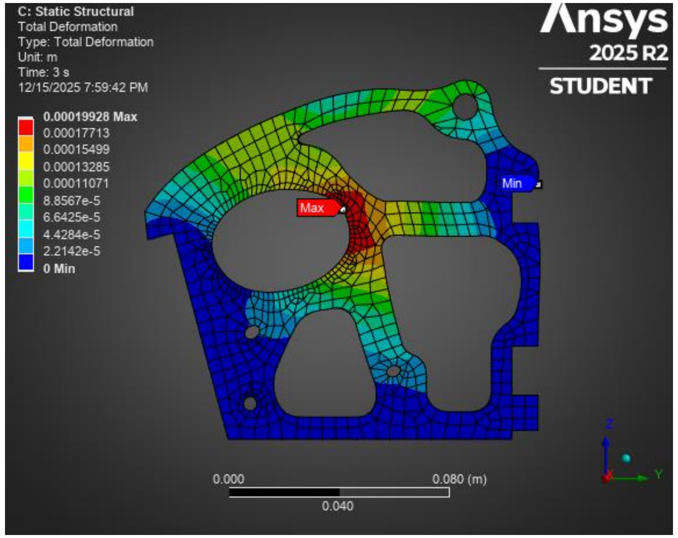
- Very *smooth* edges

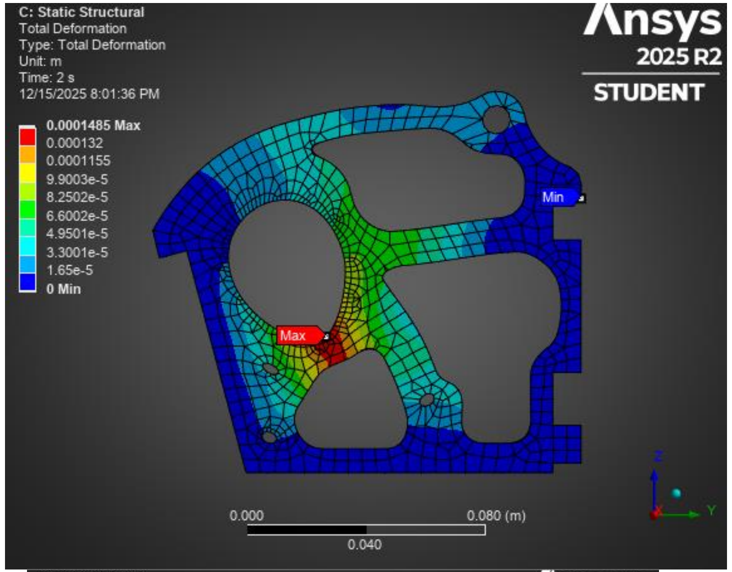


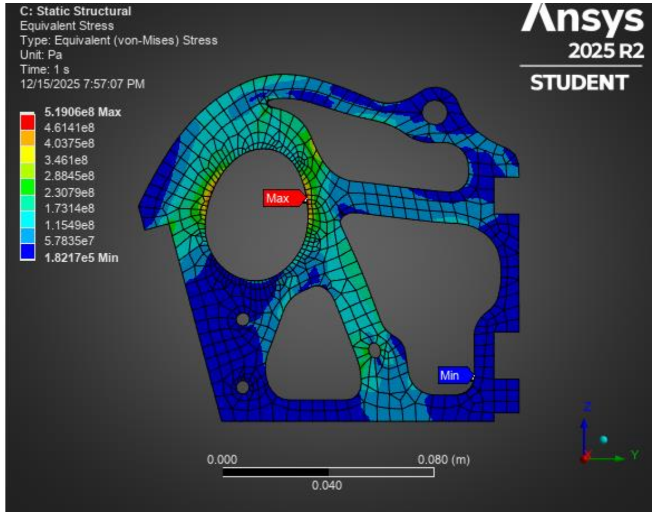
Topology Optimization

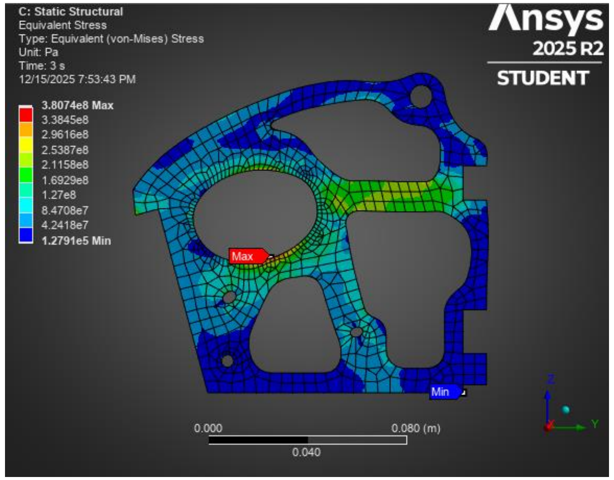
- With new topology, do the same analysis with the original load case (not doubled)

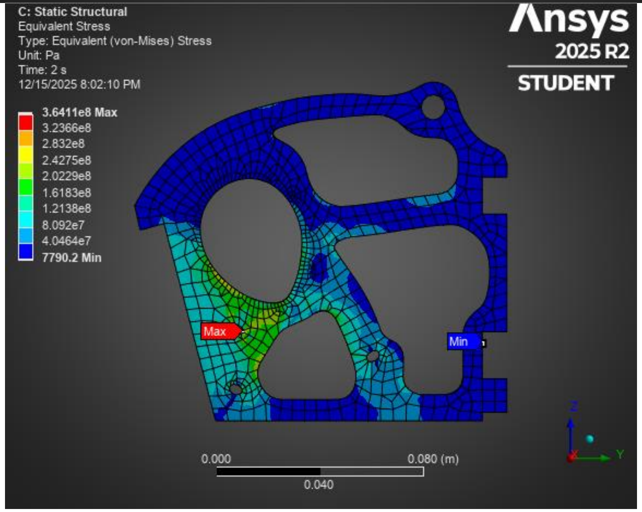








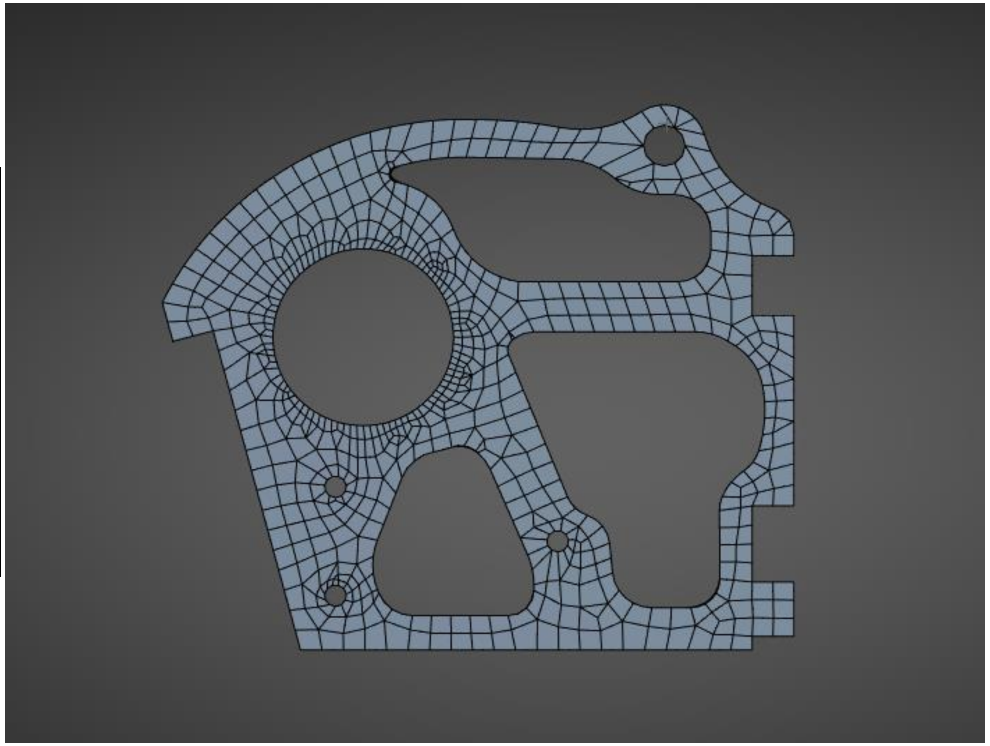




Topology Optimization

- New geometry
- FOS of 2 not satisfied, but none yield

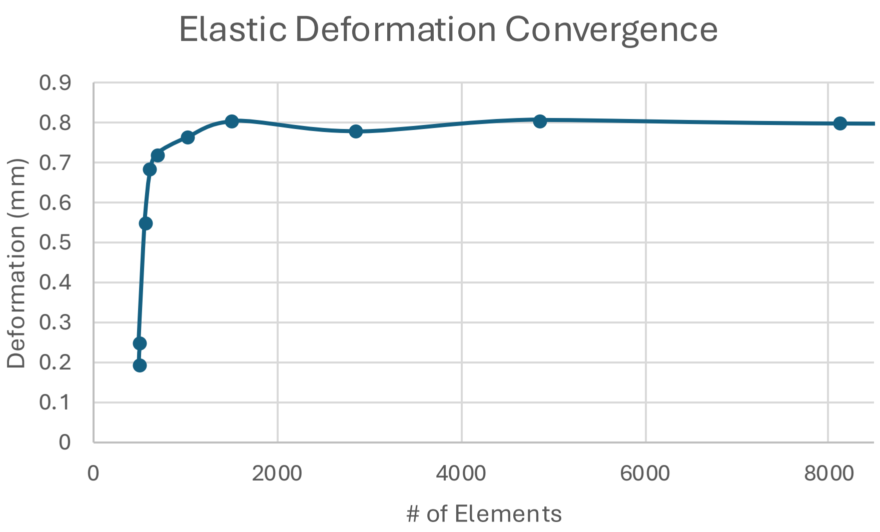
Load Case	Old		New	
	Max Deformation (m)	Max Von Mises (Pa)	Max Deformation (m)	Max Von Mises (Pa)
+Z	6.44e-5	1.52e8	1.49e-4	2.59e8
-Z	2.41e-5	9.41e7	7.42e-5	1.82e8
+Y	3.56e-5	7.98e7	9.96e-5	1.90e8
+Y, -Z	2.19e-5	5.67e7	8.25e-5	1.72e8
Bearing Load	1.73e-6	7.24e6	1.09e-5	1.75e7

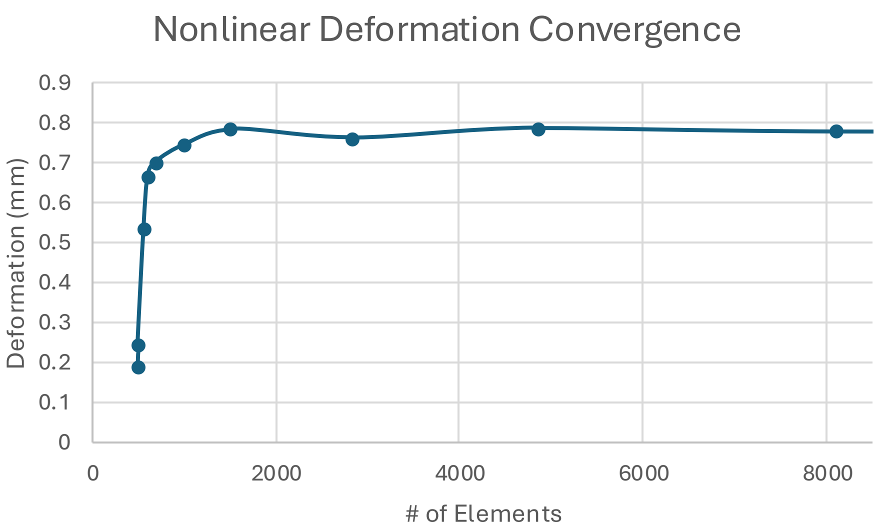


QUESTIONS

Appendix

Static Structural Deformation Convergence:





Mesh Size	# elements	Max deformation	Von Mises	
100	496	0.19551	111.64	
75	501	0.25211	79.359	
50	566	0.55154	184.53	
25	612	0.68644	219.25	
15	695	0.72368	225.35	
10	1017	0.76515	265.02	487.58
7.5	1511	0.80442	303.18	303.18
5	2845	0.78169	292.71	393.49
4	4854	0.80916	294.57	401.28
3	8111	0.79936	292.65	417.73
1.75	23542	0.78933	292.24	527.55
1	72939	0.80274	306.84	664.99

Mesh Size	# elements	Max deformation	Von Mises	
100	496	0.19011	111.64	
75	501	0.24515	49.359	
50	566	0.53631	184.53	
25	612	0.66749	219.25	
15	695	0.7037	225.35	
10	1017	0.74768	243.47	286.13
7.5	1511	0.78431	273.43	273.43
5	2845	0.7633	292.08	307.8
4	4854	0.78879	291.22	334.09
3	8111	0.78099	288.43	309.41
1.75	23542	0.77197	286.61	293.16
1	72939	0.78609	294.87	294.87