25-650: Applied FEA
Assignment 4
Ryan Nagle
Due: 2/28/2024

Overall Objective

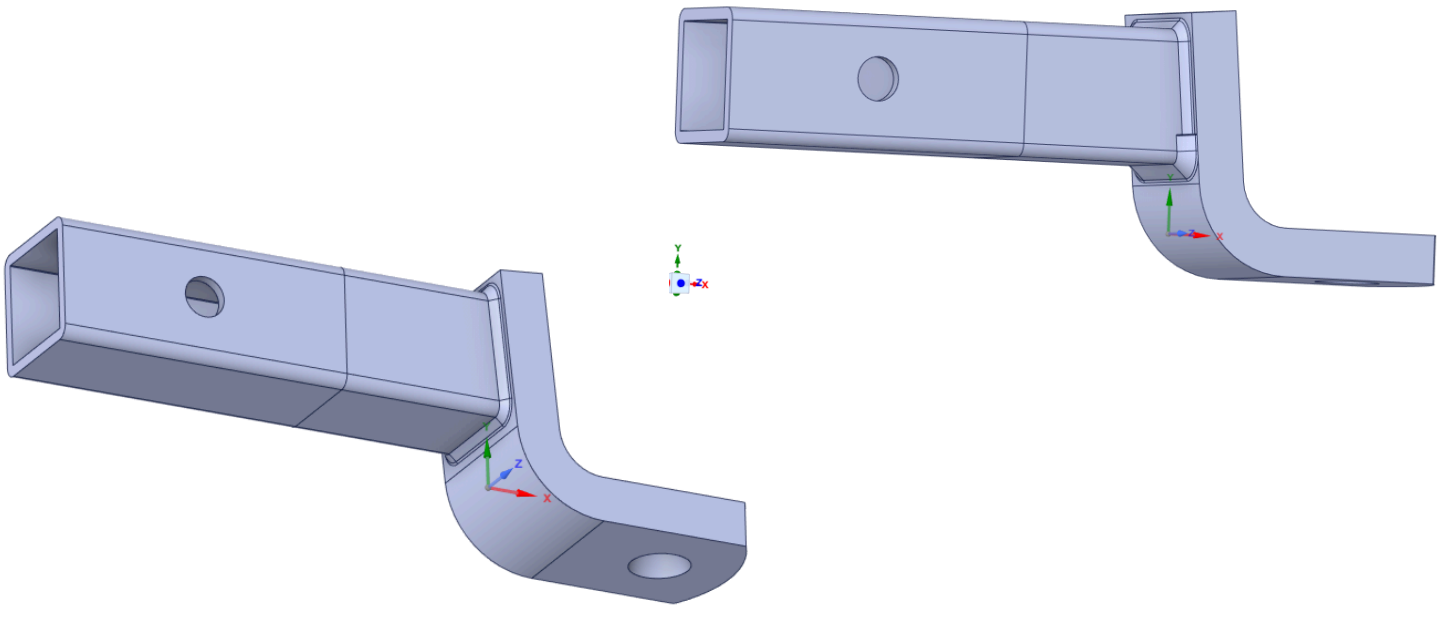
The goal was to perform a fatigue analysis of a trailer hitch. There were 3 sub goals: A, perform a stress analysis on the 4 base load cases and converge the results to an accuracy of 5%; B, perform a fatigue analysis for the 4 configurations and identify any load cases not meeting the design requirement; C, propose design modifications that will result in an improved fatigue safety factor as compared the results in Part B.

Assumptions

For all situations below, it is assumed that the 4 outer faces of the hitch are constrained in the normal direction (frictionless support) and the 2 holes in the rectangular section are constrained radially (cylindrical support). The load is assumed to be uniformly distributed about the inner face of the trailer hitch hole.

Geometry

For Part A/B (left), the hitch was created in SpaceClaim.
For Part B (right), material was added to the bottom section where the rectangular portion originates.
The resulting geometries are shown below:

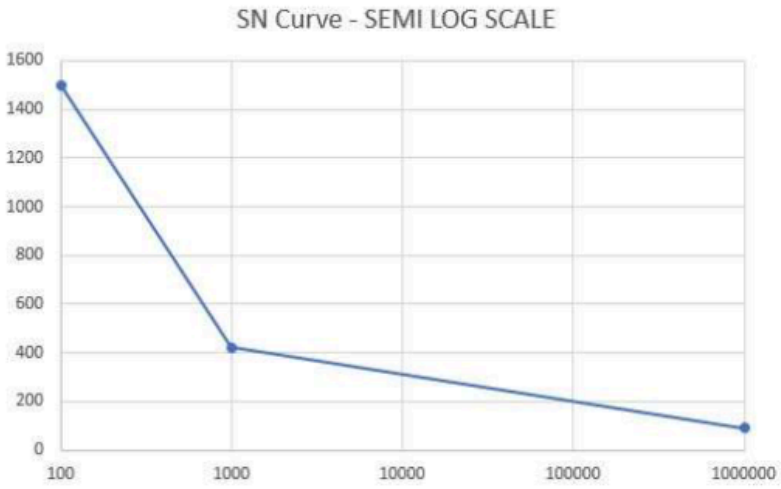


Material Data

The hitch is made of a custom material:

- E = 200 GPa
- Nu = .3
- Density = 7850 kg/m^3
- Ultimate Strength = 460 MPa
- Stress Life Fatigue Properties using Semi log scale (life is log, stress amplitude is linear)

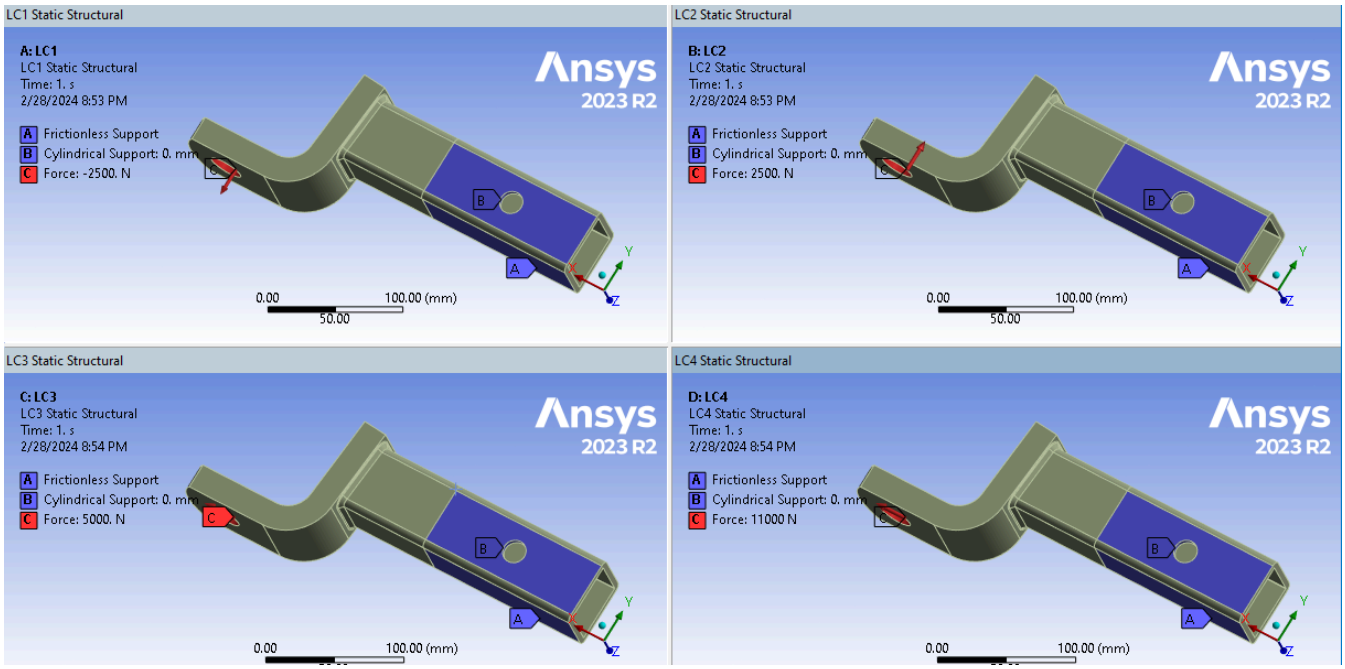
cycles	stress amplitude (Mpa)
100	1500
1000	420
1.00E+06	90



Boundary Conditions

For both Part A, B and C, the following conditions were used:

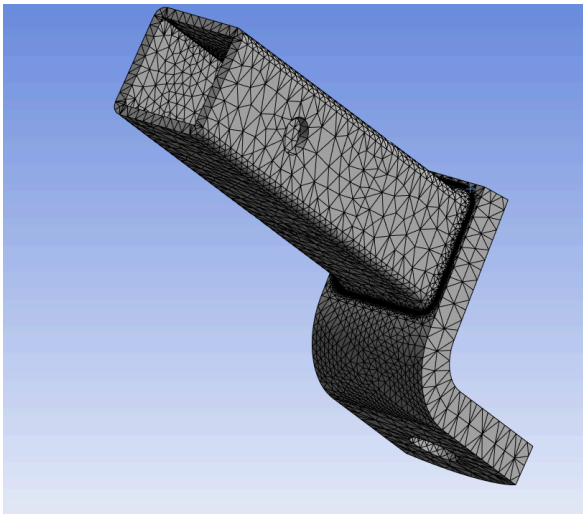
- Frictionless support along 4 faces of the rectangular portion
- Cylindrical support constrained only in the radial direction along the 2 holes
- Force along the inner surface of the trailer hitch hole:
  - LC1: 2500N in the positive y-direction, LC2: 2500N in the negative y-direction, LC3: 5000N in the positive x-direction, LC4: 11000N in the positive x-direction

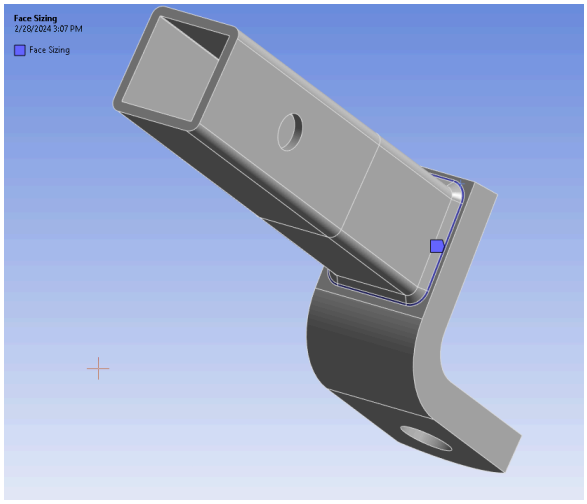


Mesh and Solution Setup

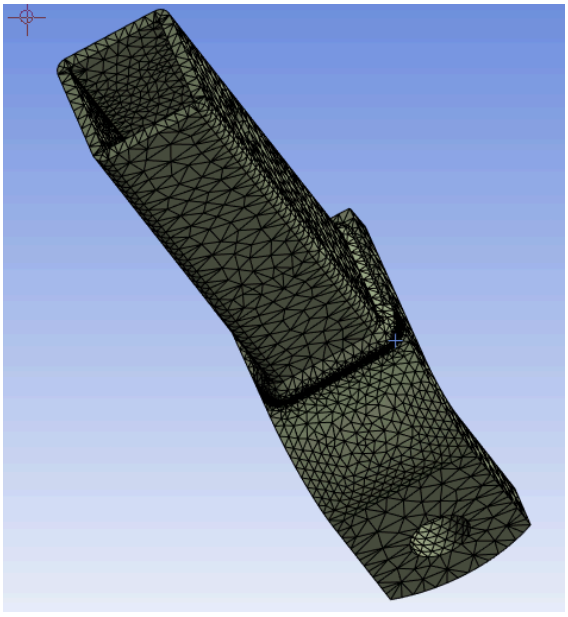
For Part A and B in load condition 1, three meshes were generated with element sizes of 5mm with 1mm along the face shown, 5mm with 0.5mm, and 5mm with 0.2mm. There were less than 5% observed differences between results as shown below, thereby indicating that the mesh is converged. 5mm with 0.2mm shown below. Similar results were observed for all 4 load conditions and similar peak stress locations were observed.

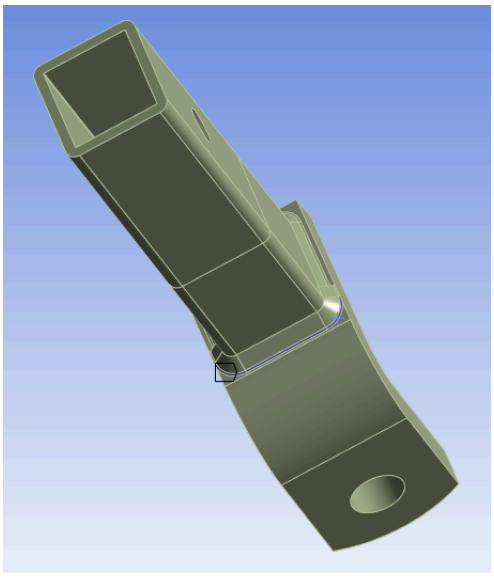
	Nodes	Elements	Equivalent Stress (MPa)	
			Minimum	Maximum
Solution 1: 02/28/2024 03:10 PM	35,427	19,778	6.66e-002	88.953
Solution 2: 02/28/2024 03:10 PM	52,802	30,562	7.0069e-002	100.66
Solution 3: 02/28/2024 03:11 PM	136,298	81,180	7.2045e-002	101.79





For Part C, two meshes were generated with element sizes of 5mm with 0.2mm along the faces (shown below) and 5mm with 0.5mm. There were small observed differences between results as shown below, thereby indicating that the mesh is converged. 5mm with 0.2mm shown below.





	Nodes	Elements	Equivalent Stress (MPa)	
			Minimum	Maximum
Solution 1: 02/28/2024 10:08 PM	66,200	38,560	7.0496e-002	98.665
Solution 2: 02/28/2024 10:12 PM	38,667	21,842	6.6111e-002	100.58

For all load cases, Goodman mean stress correction and signed Von-Mises Stress Components were used to ensure conservative calculations of peak stress and to account for compression vs tensile loading.

Results

**NOTE: plots included in appendix at the end of this report

Result Case	Peak Stress (MPa)	Life	Damage	Safety Factor	Fatigue Equivalent Alternating Stress (MPa)
Load Case 1	101.8	1e6	N/A	1.77	50.9
Load Case 2	101.8	1e6	N/A	1.48	57.2
Load Case 3	109.3	4.2e5	0.24	1.38	109.3
Load Case 4	240.4	1.2e4	0.41	1.34	240.4

Part A:

An artificial stress singularity was found in the rectangular section with the 5mm global mesh. As expected, once the mesh was refined, peak stress was located at the curved fillet where the rectangular section meets the curved plate. The stress concentration locations were the same across all four load configurations which means that one convergence study should be sufficient to determine if the mesh is converged for this particular situation.

Part B:

None of the fatigue cases fail to meet the design life requirements. The hitch passes all the loading conditions with FOS > 1. Within the peak stress area, LC1 is in compression while LC2 is in tension. Tensile loading results in a greater chance of fatigue failure even if the loads are identical (like in LC1 vs LC2).

Part C:

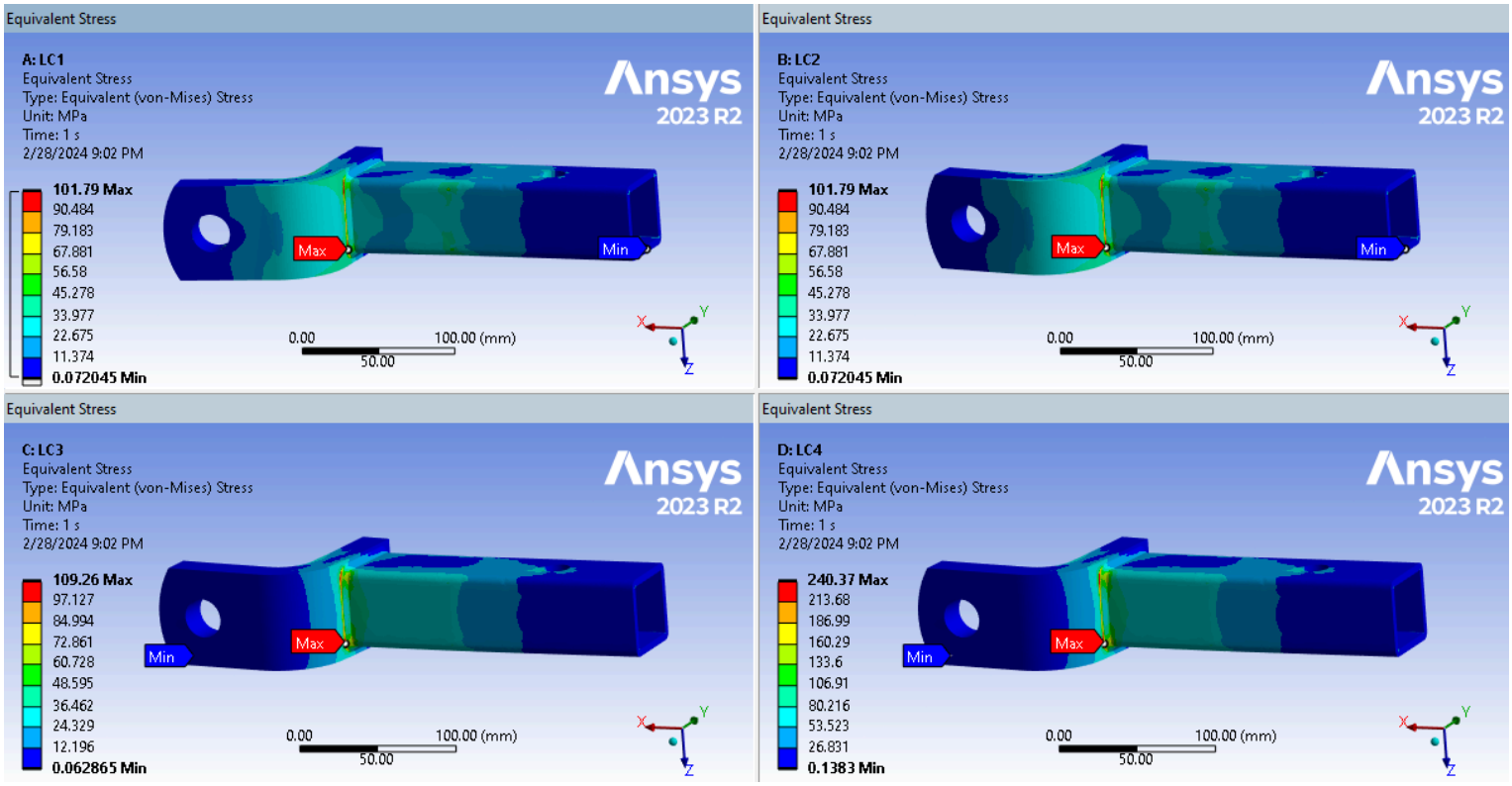
Part C Result Case	Old Safety Factor	New Safety Factor
Load Case 1	1.77	1.8
Load Case 2	1.48	1.53
Load Case 3	1.38	1.57
Load Case 4	1.34	1.39

Conclusion

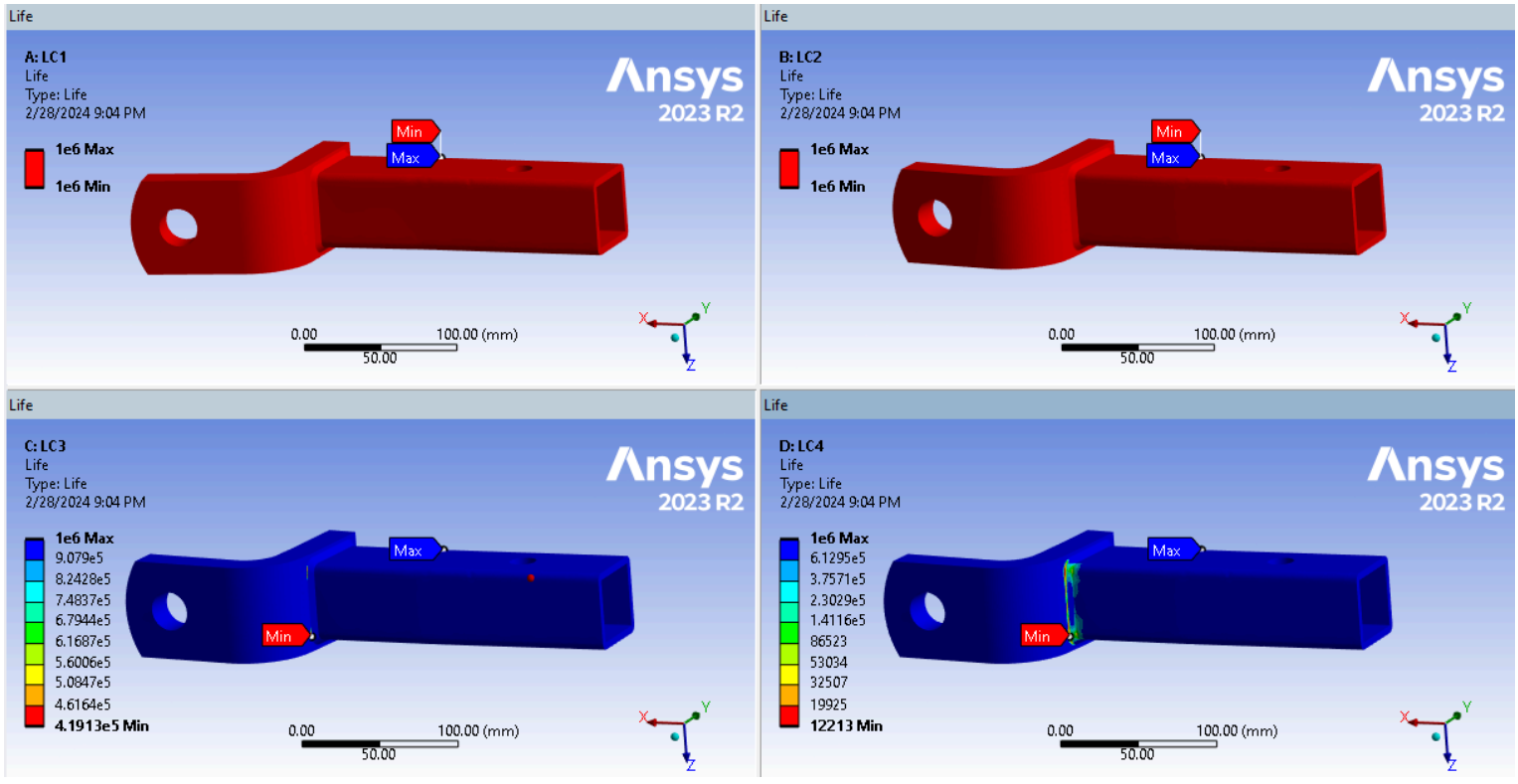
Overall, the results of the simulations make sense given the conditions used. It makes sense that the max stress would be located at the curved fillet junction of the rectangular portion of the hitch. The fatigue failure results also make sense given how tensile vs compressive loads affect how failure will occur.

Appendix

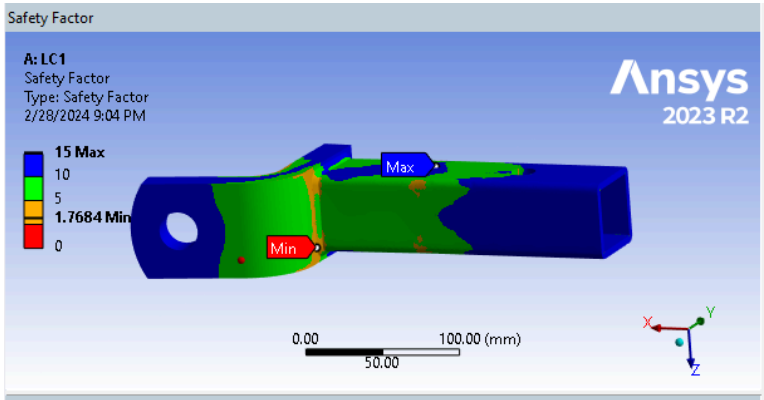
Part A:

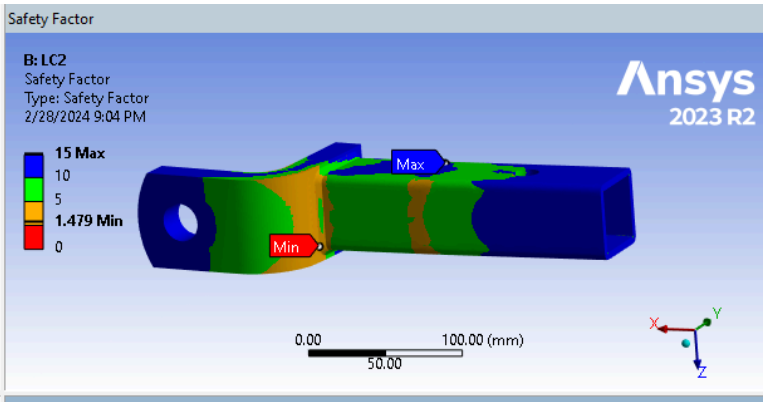


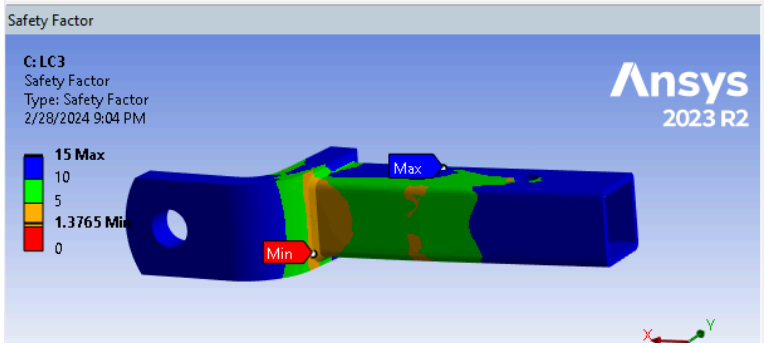
Part B:

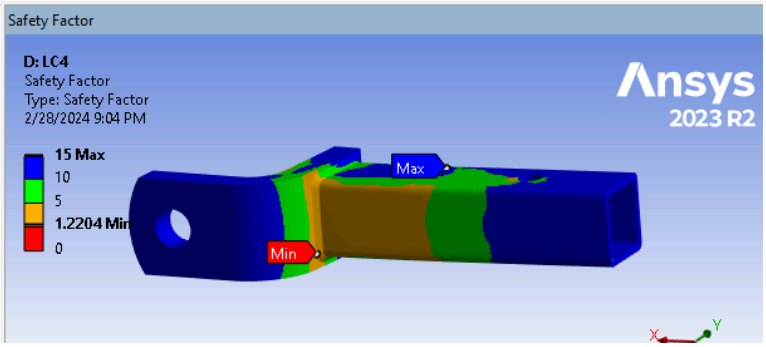


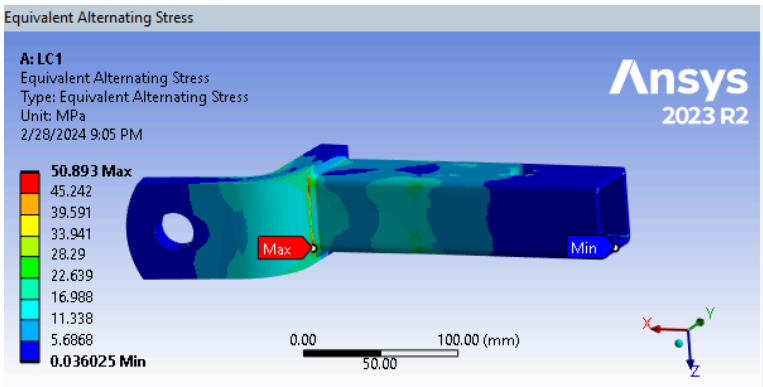
Ryan Nagle 24-650 HW4 2/28/2024

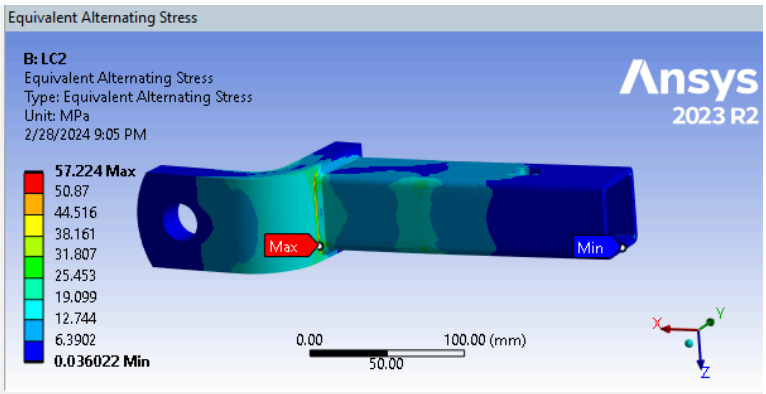


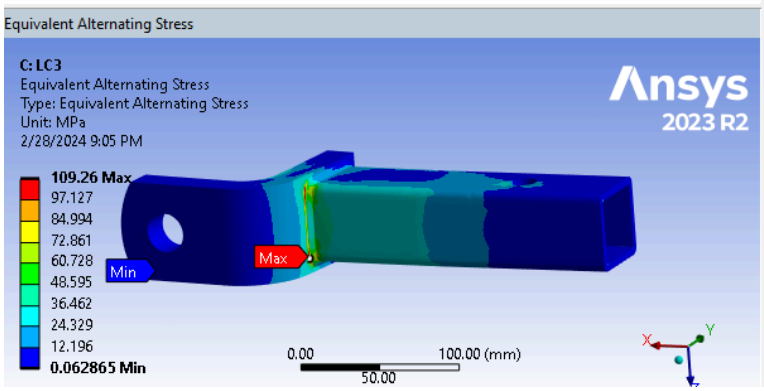


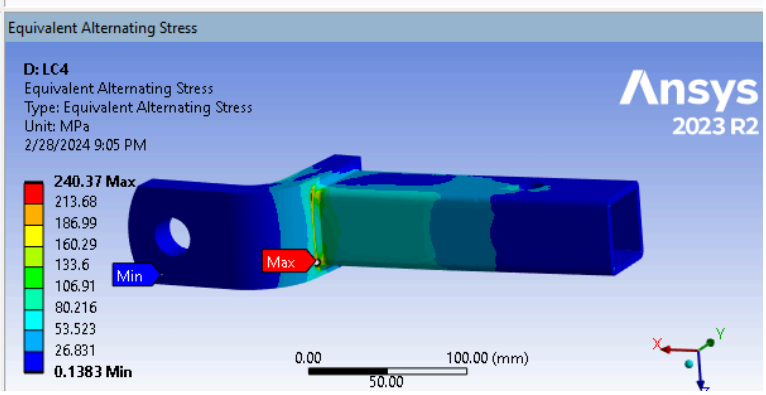


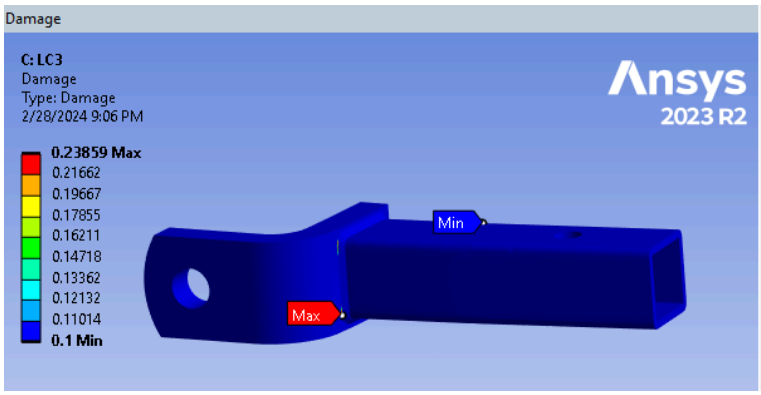


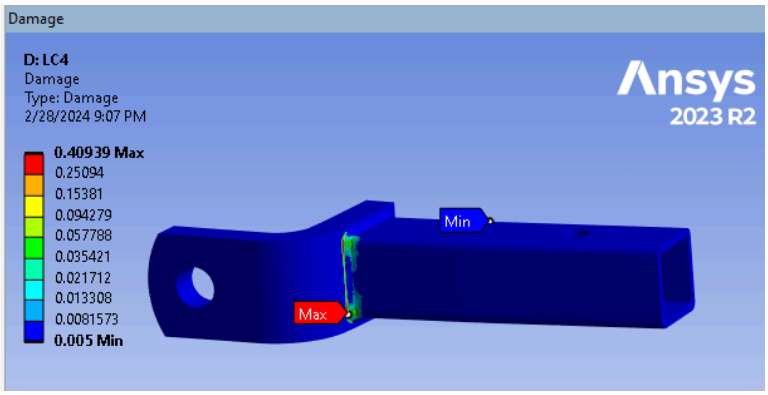




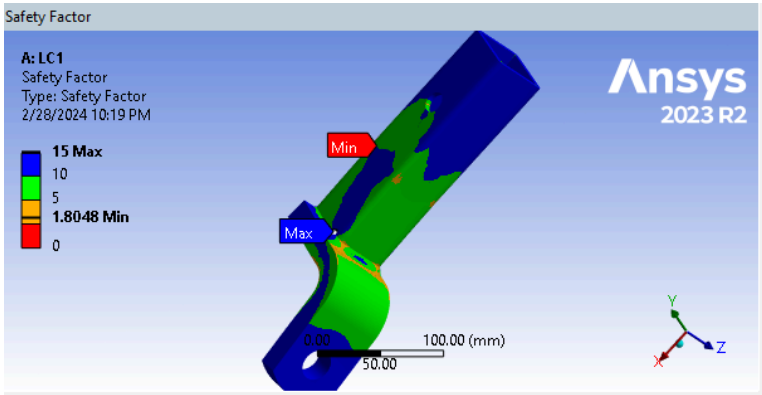


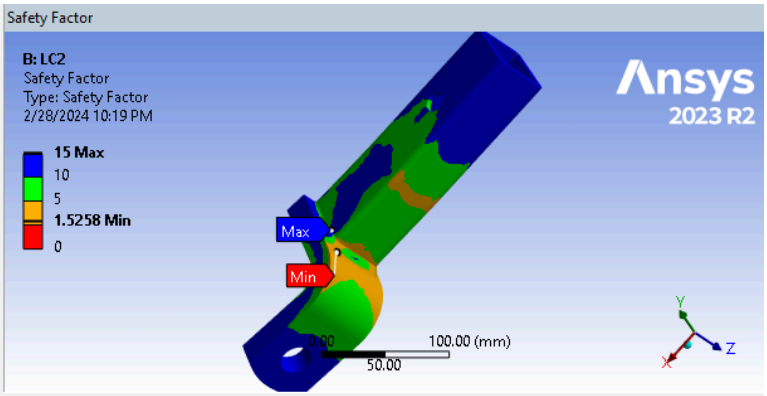


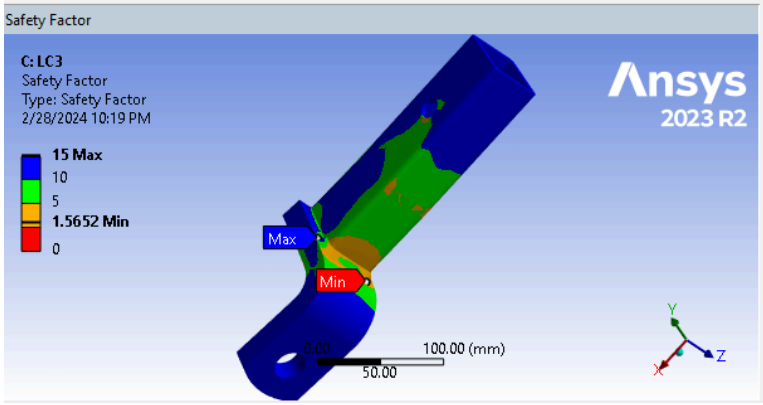

Damage
C: LC3
Damage
Type: Damage
2/28/2024 9:06 PM
0.23859 Max
0.21662
0.19667
0.17855
0.16211
0.14718
0.13362
0.12132
0.11014
0.1 Min
Min
Max
Ansys
2023 R2

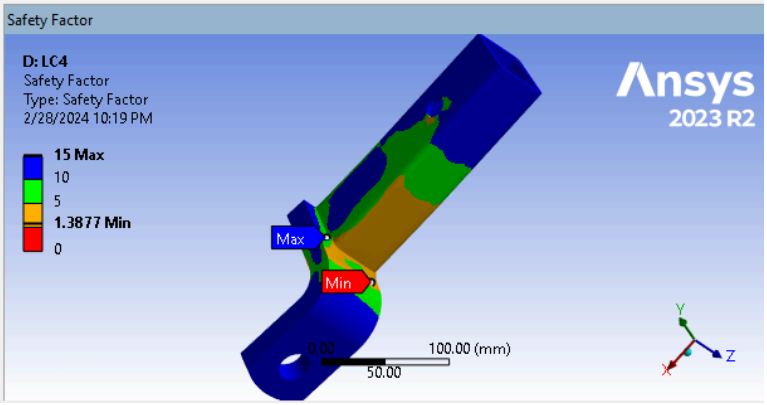

Damage
D: LC4
Damage
Type: Damage
2/28/2024 9:07 PM
0.40939 Max
0.25094
0.15381
0.094279
0.057788
0.035421
0.021712
0.013308
0.0081573
0.005 Min
Min
Max
Ansys
2023 R2

Part C:


Safety Factor
A: LC1
Safety Factor
Type: Safety Factor
2/28/2024 10:19 PM
15 Max
10
5
1.8048 Min
0
Min
Max
0.00
50.00
100.00 (mm)
Y
Z
X
Ansys
2023 R2


Safety Factor
B: LC2
Safety Factor
Type: Safety Factor
2/28/2024 10:19 PM
15 Max
10
5
1.5258 Min
0
Max
Min
0.00
50.00
100.00 (mm)
Y
Z
X
Ansys
2023 R2


Safety Factor
C: LC3
Safety Factor
Type: Safety Factor
2/28/2024 10:19 PM
15 Max
10
5
1.5652 Min
0
Max
Min
0.00
50.00
100.00 (mm)
Y
Z
X
Ansys
2023 R2


Safety Factor
D: LC4
Safety Factor
Type: Safety Factor
2/28/2024 10:19 PM
15 Max
10
5
1.3877 Min
0
Max
Min
0.00
50.00
100.00 (mm)
Y
Z
X
Ansys
2023 R2

Ryan Nagle	24-650	HW4	2/28/2024