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ME 424
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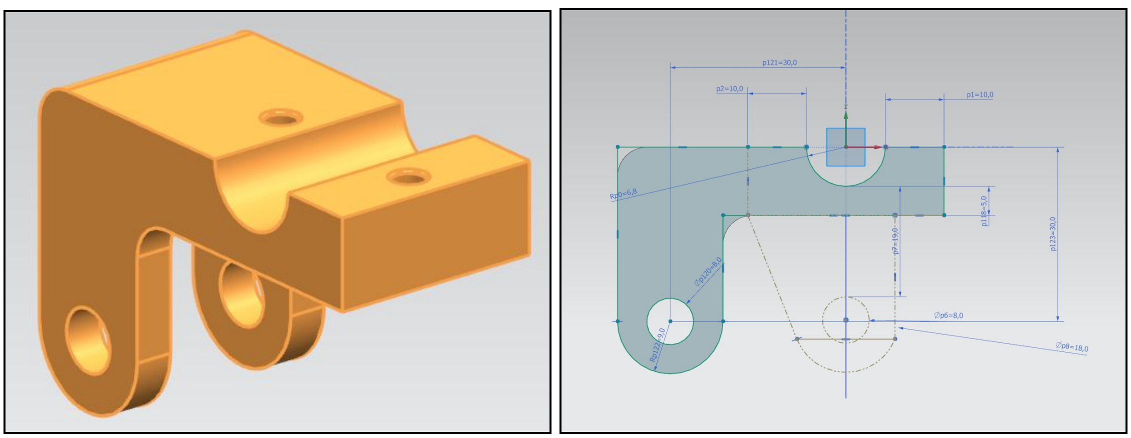
GFR Shifting Clevis FEA Report

Goal:

The focus of this analysis is a shifting clevis for GFR (Global Formula Racing). This part is a bracket that provides an attachment for the pneumatic cylinder that actuates the shifting lever on the KTM 450 SX-F engine on the Formula SAE competition car. The goal of this analysis is to reduce the weight of the bracket while maintaining or improving the rigidity and strength. The constraints are that all modifications have to be capable of being performed on lathes and mills in the OSU machine shop.

Model Description:



Figures 1: Geometry and Dimensions of Shifting Clevis.

The shifting clevis clamps onto an engine mount tube and rotational and translational movement is resisted by friction from that clamping force. The pneumatic cylinder attaches with a bolt at the two holes in the clevis leg and can only push and pull perpendicular to the legs. Due to the loading of a force perpendicular to the beam, stress due to bending is most prevalent throughout the part. Also, a stress concentration will most likely be located at the fillet located where the clevis legs meet the main body of the part that can be seen in figure 2.

From visual inspection of the model, a majority of the material is located in the top portion, while the legs have much less material to resist the same force. Since this part hasn't failed in the past, the legs must be sufficiently strong and rigid. This means that the top portion is most likely overbuilt, and will be the first focus for weight reduction.

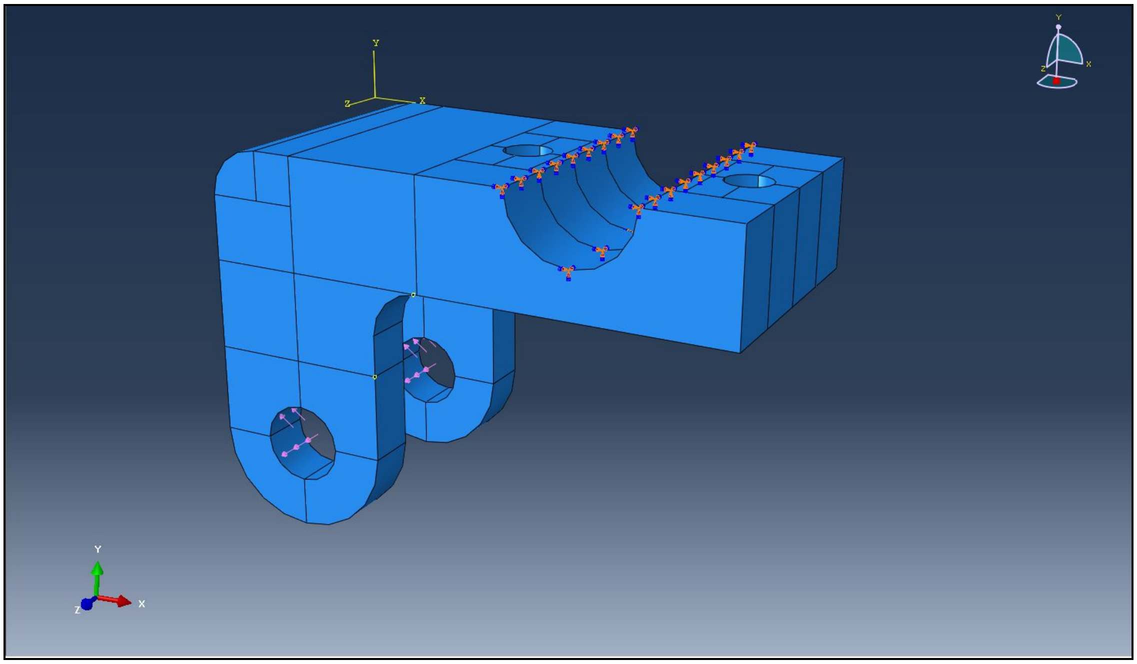


Figure 2: Loading and Boundary Conditions

The expected loading from the pneumatic cylinder was measured as 476 N, rounded to 500 N, and it will be modeled as being distributed equally over two bolts holes with radii of 4 mm and equal thicknesses of 5 mm each.

Eq 1. $Area = (((2 * pi * 4mm) * 1/2\ bolt\ hole) * 5mm)\ *\ 2\ holes\ \ =\ 0.000125664\ m^2$

Eq 2. $Distributed\ Force\ as\ a\ Pressure\ =\ F/Area\ =\ 500\ N\ /\ 0.000125664\ m^2 =$ ***3.98 MPa***

Even though the force of 500 N has already been rounded up from 476 N, the distributed force was rounded from 3.98 MPa to 4.00 MPa for a conservative result.

Predicted Results:

The lower bound of deflection can be calculated by assuming the the part doesn't have the channel or pinholes removed yet.

Eq. 3 $\delta = \frac{FL}{EA}$ $(Change\ in\ length\ due\ to\ axial\ loading)$

Eq. 4 $\delta = \frac{FL^3}{EI}$ $(Deflection\ due\ to\ bending)$

The deflection in the X-direction is the axial strain plus the bending moment of the leg. The deflection in the Y-direction is due to the bending in body.

Eq. 5 $\delta_x = \frac{FL}{EA} + \frac{FL^3}{EI}$

Eq. 6 $\delta_y = FL^3/EI_{body}$

	Body	Legs	Total	Magnitude
X Deflection	1.21E-06	1.77E-05	1.89E-05	**2.20E-05**
Y Deflection	1.12E-05	0	1.12E-05	

Table 1: A table of the lower bound of predicted maximum deflections.

Discretization:

This model is a continuous, elastic, ductile material with a blocky shape. Most edges are rounded, but will be modeled as square edges to simplify the meshing. Hex shaped elements are preferred, and will be used if possible. Partitioning will be performed first, to allow using hexahedral elements, and secondly to improve the quality of the mesh. The model will start by using quadratic, reduced integration C3D20R elements to accurately model elements in bending. After convergence is analysed, a mesh with C3D20 elements will be used to compare to the original results.

A convergence analysis will be performed on the original model. Each iteration will use a fine mesh, but will not be studied for convergence. The final iteration that reaches the goal weight reduction and stiffness will be analysed for convergence for an accurate comparison between the original and final.

0.) Original Part

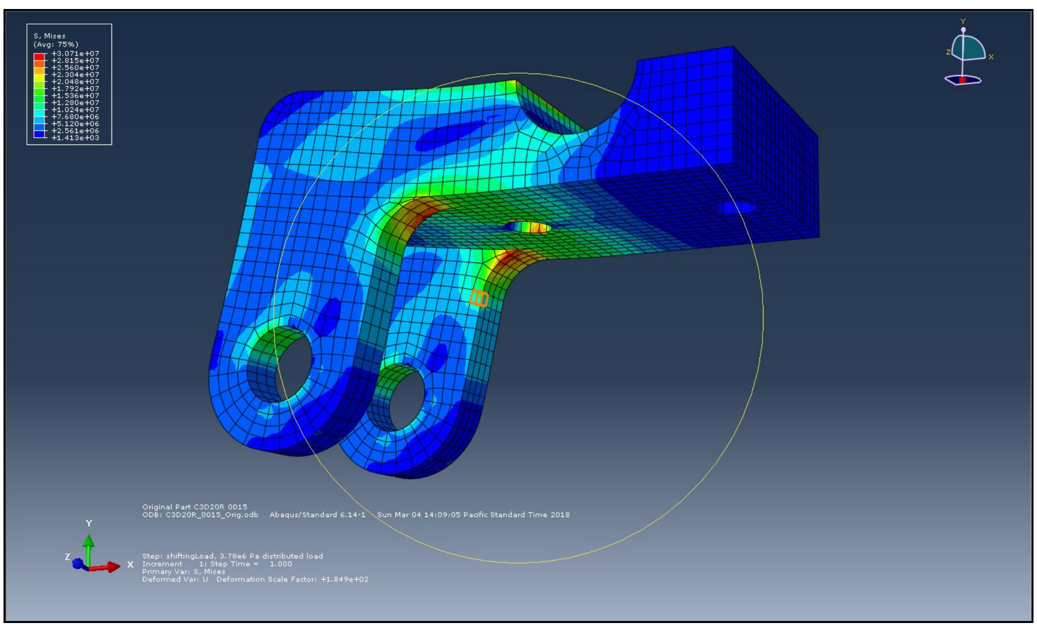


Figure 3: FEA of the original part

Analysis of the original part was analysed for convergence. A baseline magnitude of deflection of 3.279E-05 meters and maximum Von Mises stress of 3.071E07 Pa was set from the converged model to be used for comparison later.

Stress concentrations appeared at the fillet between the legs and the body, and at the edge of the semi-circular channel on the top of the body. Material removal and reinforcement would take these areas into account, as well as the over built areas showing low stress.

1.) Modification 1

For the first modification, a square block of material was removed from the body part of the clevis, and two holes were drilled in the far right portion of the block showing the lowest stresses overal.

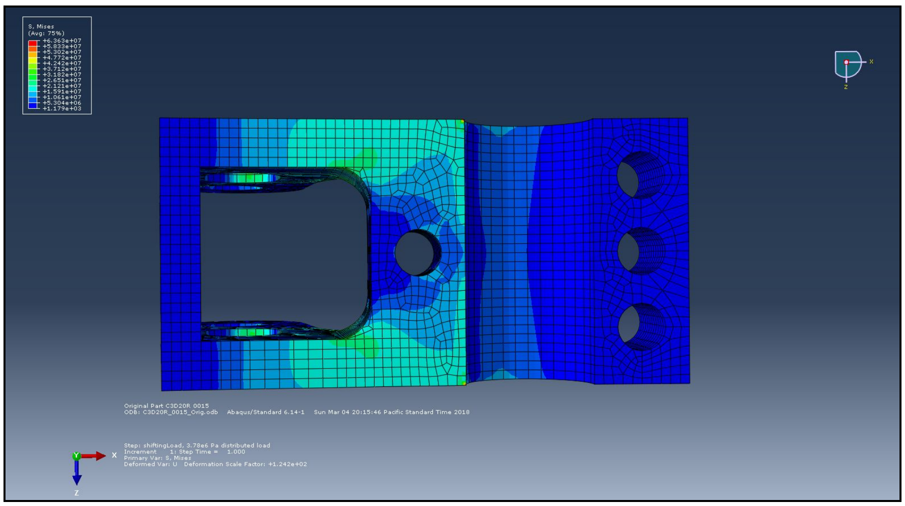


Figure 4: Top view of material removal modifications.

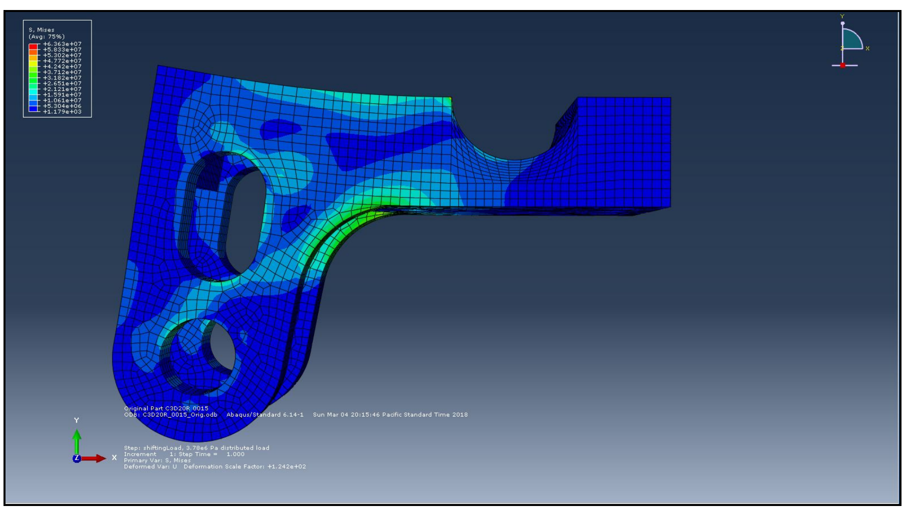


Figure 5: Side view of modification 1

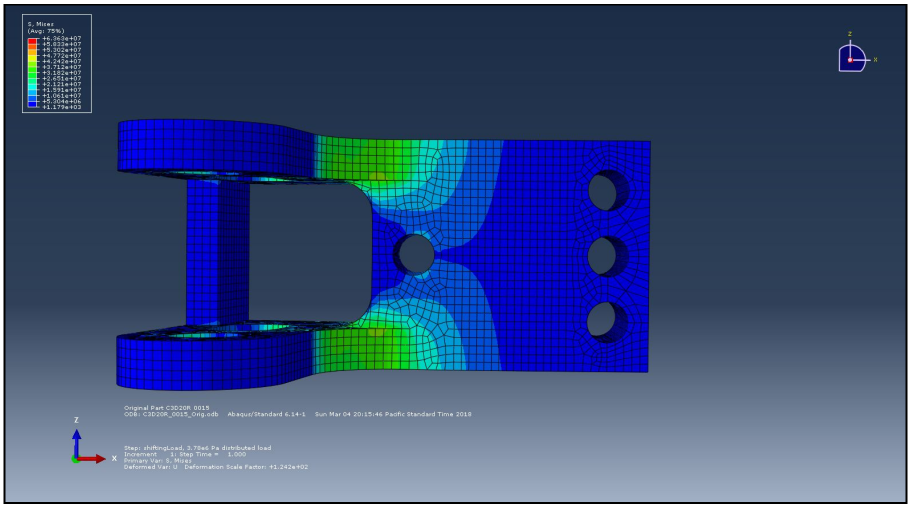


Figure 6: Bottom view of modification 1

Modification 1 was built over several iterations by removing material from one area at a time and analyzing the results. The modification was stopped once it approached 25% weight reduction. Unfortunately, this weight reduction resulted in almost 50% increase in the maximum deflection.

From figures 4,5, and 6, there is still an uneven stress distribution throughout the part. The Von Mises Stress at the Fillet increased from 27.8 MPa to 38.2 MPa which is above the acceptable limit of 30 MPa. This failure was the reason for the changes made in the following modifications.

2.) Modification 2a

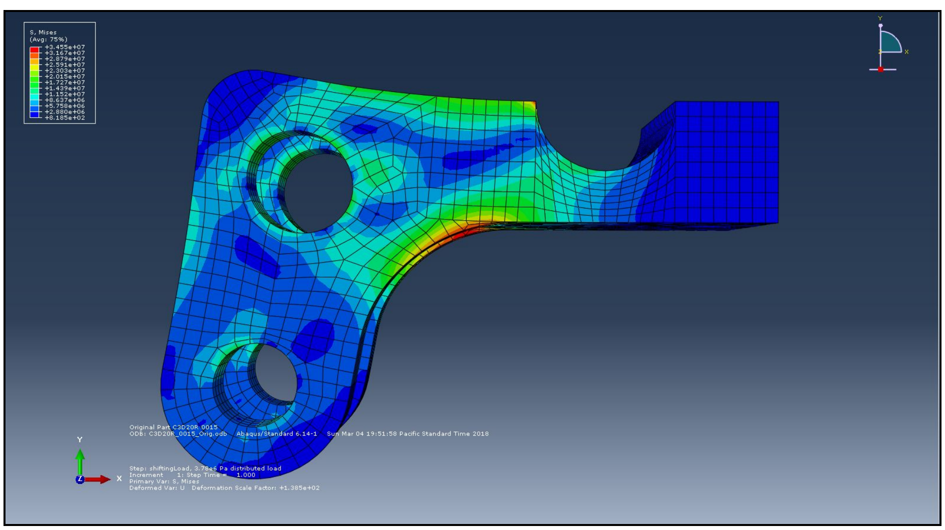


Figure 7: Side View of Modification 2a

Modification 2a was built by thickening each leg from 5mm to 6mm, increasing the overall thickness from 28mm to 30mm, and the radius of both fillets was increased from 5mm to 8mm.

Again, material was removed a piece at a time. Modification didn't meet the weight reduction goal, so modification 2b was made.

3.) Modification 2b

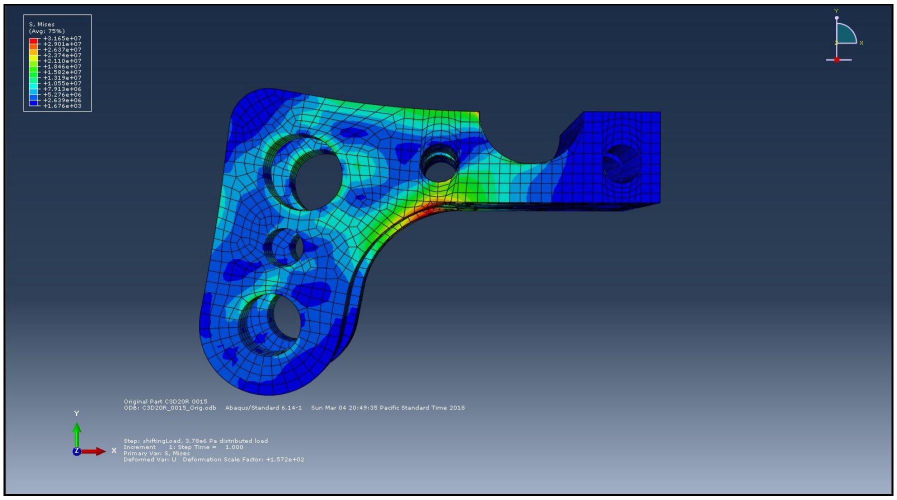


Figure 8: Side view of modification 2b

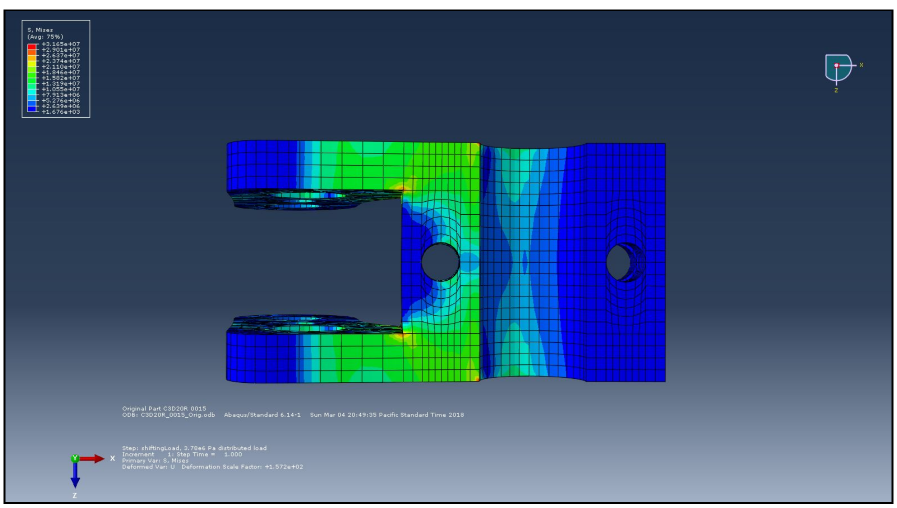


Figure 9: Top view of modification 2b

Modification 2b performs better due to its thicker legs and increase material at the fillet, while still having a weight reduction of 22.22%. The Von Mises stress at the fillet is 30.1 MPa is only 2.2 MPa greater than the 27.8 MPa found in the original part, and acceptably close to the limit of 30 MPa.

Results:

The final iteration of each modification is captured in table 2. Only the original part and final iteration were tested for convergence. The representative results that will be used for comparison are bolded in the table.

		Max Von Mises Stress [Pa]				Deflection [m]	Volume	Reduction
Iteration	# Element	Leg Hole	Top	Fillet	Max	Magnitude	[m^3]	[%]
Original							1.98E-05	0.00%
C3D20R	646	1.18E+07	1.20E+07	2.72E+07	3.182E+07	3.265E-05		
C3D20R	1746	1.26E+07	2.15E+07	2.71E+07	3.081E+07	3.275E-05		
C3D20R	3242	1.41E+07	2.17E+07	2.79E+07	3.101E+07	3.276E-05		
C3D20R	**6930**	**1.38E+07**	**2.27E+07**	**2.78E+07**	**3.071E+07**	**3.279E-05**		
C3D20	12472	1.35E+07	2.41E+07	2.60E+07	3.045E+07	3.279E-05		
Mod 1							1.49E-05	-24.75%
C3D20R	**19557**	**2.06E+07**	**2.40E+07**	**3.82E+07**	**6.363E+07**	**4.917E-05**		
Mod 2b							1.54E-05	-22.22%
C3D20R	2803	1.45E+07	1.75E+07	3.12E+07	3.304E+07	3.997E-05		
C3D20R	4528	1.41E+07	1.95E+07	3.11E+07	3.218E+07	4.000E-05		
C3D20R	8164	1.37E+07	2.08E+07	3.07E+07	3.165E+07	4.006E-05		
C3D20R	**16332**	**1.50E+07**	**2.22E+07**	**3.01E+07**	**3.535E+07**	**4.009E-05**		
C3D8R	16332	1.42E+07	1.87E+07	2.91E+07	2.938E+07	4.006E-05		

Table 2: Compiled results of each iteration.

The first modification is very close to the goal of 25% weight reduction, but the magnitude of deflection increases by 49.95%. While this is still a stiff part, the goal was to not change the stiffness if possible. The second modification was iterated over until the weight reduction was comparable to modification 1, but with higher stiffness. The magnitude of deflection of the second modification is 22.3% greater than the original. This second modification has an acceptable deflection with a weight reduction within 3% of the final goal of 25%.