MEEG-304:MACHINE DESIGN II
TEAM 23-6

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Executive Summary

The project required a new design of a roll cage for a Maverick for use in the King of the Hammers race that still met all of the specifications of the race. In order to accomplish this, several models were made in SolidWorks and Finite Element Analysis (FEA) was performed in several different scenarios to see if the designs could withstand a 70 MPH collision. After conducting analysis, we were able to determine out of the models we made which would deflect the least. The side deflection for the chosen design was 0.064 meters, 0.17 meters from the top, and 0.053 meters from the front. This met the desired performance in terms of deflection. We prototyped our original concept, and made adjustments to the solid model afterwords to better reflect the direction we need to go in.

Introduction

Project Scope

To modify or design a roll cage to withstand a front, rear, or side impact collision at 80 mph in the lightest, strongest design without injuring the driver.

Performance Requirements

This cage is designed for the "King of the Hammers" race. Therefore, the cage cannot deform to a point in which it is within 3 inches from the driver, it must have a minimum of 1.5 inches diameter, and 0.12 inches wall thickness for the roll cage. AISI 1020 Steel CR satisfies the minimum material requirements for the "King of the Hammers" competition. For the design, the team aimed to minimize the amount of deflection to the roll cage and Finite Element Analysis (FEA) is the perfect tool to analyze the impact forces for deflection and yield strength. The standard used to evaluate the final prototype's functionality are generally as follows: three forces are applied to test: Frontal impact force, side impact force, and top impact force. Through calculation, we determined a 70 MPH impact force would correspond to a 134,000N load on the cage's bars. The cage must be able to withstand a force of 134 kN which would be applied to the front bar, side, and the top of the cage without deflection reaching within 3 inches of the driver. If the car were to flip over, or run head first into a tree, or get sideswiped, we need to make sure our design would be able to withstand these types of impact and not kill the driver.

Design Process

The first step in the design process is to gather information, but since we were already given a problem from our sponsor, we did not need to conduct much background research to justify this project. As a group, we brainstormed some rough concepts for the design of the roll cage and benchmarked against existing roll cages used in the "King of Hammers" race. We developed a few designs to choose between. We made a decision for our original design choice. Then we started to model the design in SolidWorks and get information about stress and deformation that the cage would experience under loading. Our initial results indicated that the side impact may be problematic for deflection. We then made two more iterations on the initial design in hopes of correcting for this large deflection, as well as creating a design concept that was aesthetically pleasing to the consumer. We created a prototype of the original design choice using PVC piping instead of the chosen material. Some testing was done with the prototype, but our design validation mainly comes from the analysis run on SolidWorks. Prototyping the next iteration is important in continuing the design process, and would contribute to completing the process for this design.

Concept Development

In order to get an idea for how to develop our concepts, we first needed to see the Maverick car and obtain general measurements of the car and the mounting points. We also researched the specifications of existing six point roll cages used in the King of the Hammers race, and found that they are all mostly the same. Once we got the correct measurements, we started to create some SolidWorks models of different roll cages. We also talked to our customer, Carl Jarvis, to gain more insight into the exact specifications of what the design needs and to what he wants in the cage, like aesthetics and other features such as a GoPro mount. With these features in mind, other concepts were developed that fit within his wants and constraints (see **Figure 1, 2,** and **3**). Aside from just the roll cage, we also considered adding a mounting box on the floor to provide a flat base for mounting the plates. That would require us to cut out an existing member that serves no apparent structural purpose.

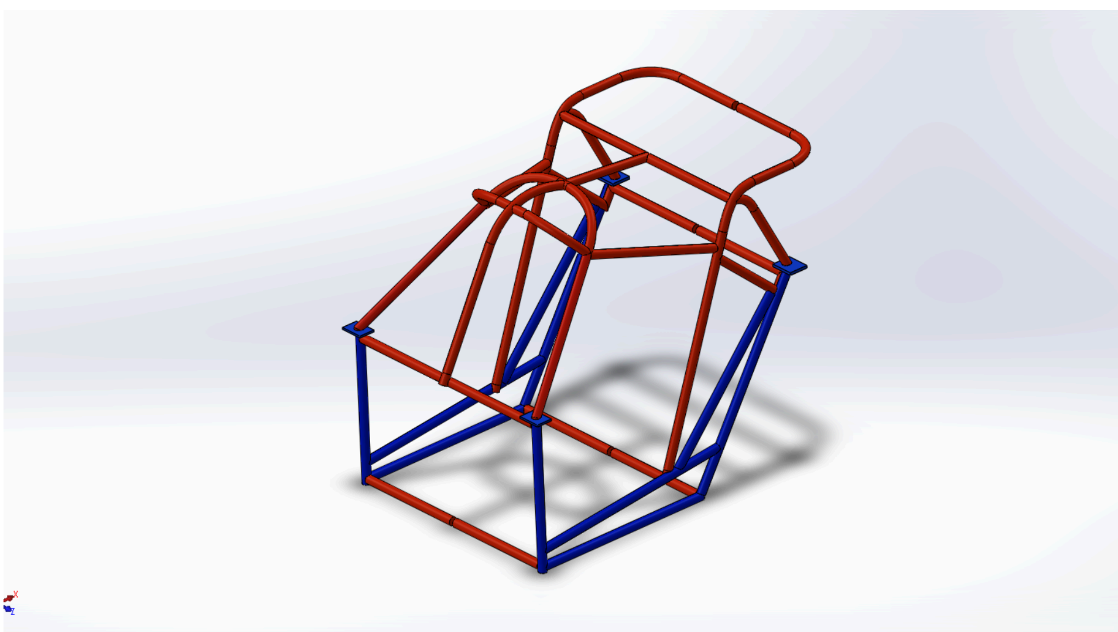

Figure 1: Initial concept

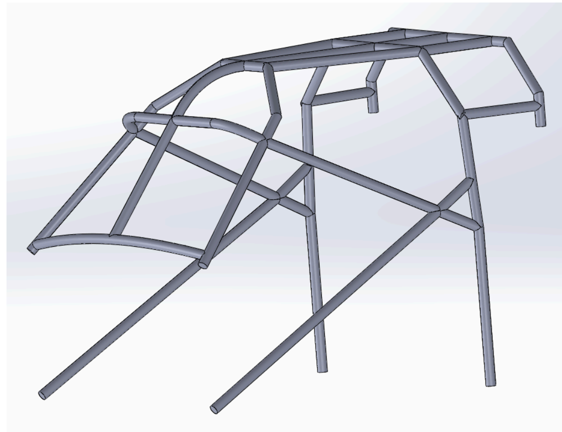

Figure 2: Second design concept

Figure 3: Third design concept

Concept Selection

We used several criteria for our selection of a design concept. The main metric to design for was the safety of the driver, therefore we wanted the design that maintained the well-being of the driver best, as well as was as light and strong as possible. Our initial design (Figure 1**)**, though it may have fit the project scope, after review with our customer in our first Knowledge Brief, it was neither aesthetically-pleasing nor ergonomic enough for his use. Knowing this concept was out of favor of our target audience, we decided to choose between our second and third design concepts. The second design concept (Figure 2) had several complications as well. Through our Finite Element Analyses of our design concepts, we were able to determine which concepts led to the least amount of deflection and were therefore safest to the driver. In our second design concept, deflection values reached upwards of 22cm, which posed a danger to the potential customers, therefore we further optimized our concept and came up with design concept 3, our selected design concept. The third design concept was acceptable to our customer (however, our even more “optimized” final design (shown in Figure 5) was preferred over this) as well as safer as it had significantly lower deflections. Its highest deflection value was 6.4 cm of side deflection, which was within our design metric. For these reasons, we chose to move forward with our third design concept into the further analysis and prototyping stages.

Detailed Design Analysis

With the selected design, finite element analyses were performed on the roll cage. We applied 134 kilonewtons to the front, side, and top of the cage to replicate real life impacts that may occur during the King of the Hammers race. Instead of making the force a concentrated point force, we distributed the force over a series of bars. This made the simulated impact more realistic. While performing the analysis in SolidWorks, we ran into a little problem in that there were no real specification as to where to apply the load, which resulted in several displacements ranging from acceptable, to definitely killing the driver. We remedied this problem by applying the load over as much area as possible, while still limiting the deflection to about three inches. We deemed that this would be the worst case scenario. There were initially problems with running our FEA analysis. The model had slight imperfections in the front bar and in the back of the center bar. These imperfections in the model gave us errors when trying to mesh and run static studies. Once this was rectified, we were able to move forward with analysis of the design. After meshing the model and running the simulation, we found that our design had a maximum deflection of 6.4 centimeters from a side impact, as seen in Figure 4, 17 centimeters on a top impact, and 5.3 centimeters on a front impact. There is such a large amount of deflection on the top of the cage because when the analysis was performed, we applied 134kN to every bar which would have meant that a constant force of that magnitude would happen at all of those locations, which is completely infeasible. Aside from that, the design holds well for a front and top load. However, the side impact had a concerning amount of deflection, which may endanger the driver. Adapting to these results, we made a second model that limited side deflection.

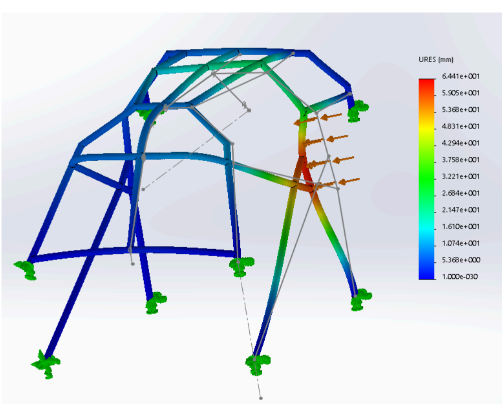

Figure 4: FEA of a side impact for initial design

In our redesign, the geometry of the side was changed to limit the amount of curvature and simplify the connections, all to help reduce the deflection, as seen in Figure 5. More straight bars were used which would make prototyping simpler and adding gussets to the side greatly reduced the side deflection, as seen in figure 6. Adding the gussets and straight bars to the sides reduced the deflection down to only six centimeters and the top deflection was lowered to only 7 centimeters. The front displacement did increase to about nine centimeters. However, we determined that this was negligible since there is substantial space between the front bar and the driver. Also, the front of the car would take the force of the impact instead of that bracer. Another optimization of the redesign is that it also used less material the our original selected concept.

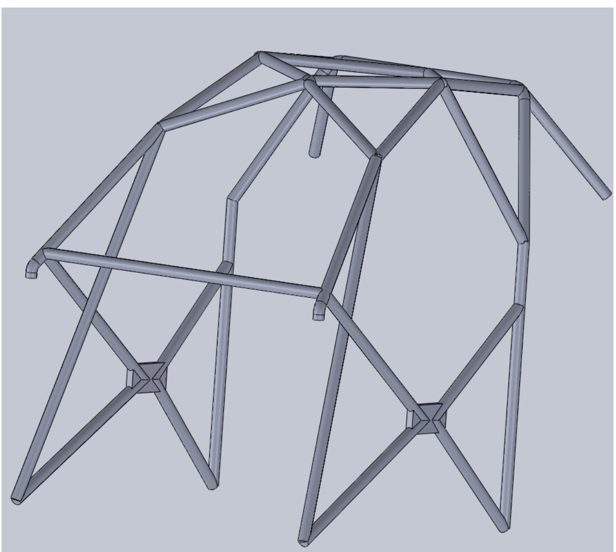

Figure 5: Model of redesign

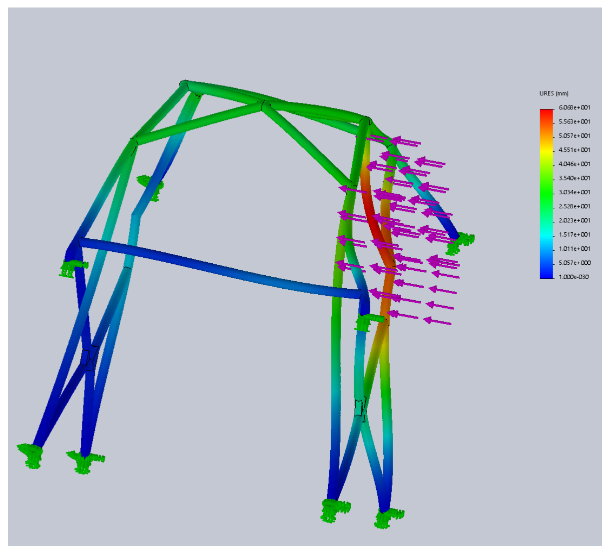

Figure 6: FEA of side impact for redesign

Prototype Development

We were not able to completely complete the prototype of our original design choice. This was due to a few reasons. Since our design had curves, we had to determine an effective way of modifying the PVC pipe so that it could bend. We were able to make cuts into the PVC that allowed for desired bending. Another issue we had with prototyping was making secure connections between the individual pipes that we had previously cut for length. We did not have access to duct tape, and instead relied on hot glue and scotch tape. This meant that the connections were much weaker than we would have liked, and gave us difficulty when trying to assemble the prototype on the mock up for the mounting points. This led to us adding extra support in the form of wooden "plates" at the two main connections on the top of the cage. Although we were not able to completely assemble the cage, we were able to finish a basic framework of our original design (Figure 7). This helped us determine whether or not our design would be able to be successfully mounted to the Maverick. Our prototype did rest to the mounting points, however they were not completely centered (Figure 8). This is most likely due to how we connected the individual pipes. Our model smoothly connected every bar, and when cutting, we cut for length, not taking this into account. If we properly notched our PVC, this likely would not have occured. If given more time, we would have been able to troubleshoot these problems and develop a more practical prototype.

Figure 7 (Left): Front view during prototyping

Figure 8 (Right): Back view during prototyping

Testing and Validation

Most of our testing and validation came in the form of FEA on our solid models developed in SolidWorks. We thought this was the most accurate way to understand how our designs would interact with forces being applied to it as opposed to testing on the prototype. Also considering we did not completely finish the prototype, we could not run any meaningful tests with forces on it. Through FEA, we were able to validate our redesigned roll cage changes. The purpose of the redesign was to limit the side deflection and lower the center of gravity of the cage. We were successful in these endeavors, as shown in the FEA analysis and solid model (Figure 6, Appendix C). Prototyping our design was also a great way to validate whether or not the model satisfied the measurements. Once the main body was assembled, we mounted the cage to the frame and found the the mounting points were slightly off centered and two of our columns were too long to fit on the frame. We realized that we had not taken into account that the cutting would take off a substantial amount of material and that our manufacturing methods when cutting the pipes were very crude. Even though each pipe was off by a miniscule amount, the change in the size of the cage was too great to properly fit onto the frame. The inconsistencies compounded upon each other, which threw off the whole design.

Conclusion

After running FEA of our models, and prototyping our original design choice, we were able to come to some conclusions. Our redesigned model showed clear improvements over the original chosen concept. The deflection from the side, which was the most concerning from our analysis, was smaller in the redesign. The redesign also used less material, which cut down weight and cost from the previous iteration (Appendix A). We also think that the redesign was more aesthetically-pleasing, which although is not a performance requirement, it is an important factor to consider. With all of these factors considered, we can confidently conclude that the redesigned model was superior to the original design choice. If the timeline for this project was elongated, we would continue to prototype and test based on this redesigned model.

Recommended Next Steps

To continue the design process, we would prototype the redesigned model out of PVC to check for how it interacts with the mounting points. Assuming that the new model mounts properly, we rigorously test this prototype along with more FEA analysis to see if there are any problem areas. Gusseting also needs to be added to the prototype, which would help secure the connections. If all of this is successful, we would move forward to assemble our design using the material we chose, AISI 1020 CR Steel.

Appendix A

1. **Bill of Materials**

Material	Quantity	Weight	Price
AISI1020 CR Steel Pipe	993.4” (83’)	142 lbs	$233.23
Total:			$233.23

Table 1: Bill for original design choice

Material	Quantity	Weight	Price
AISI 1020 CR Steel Pipe	859.6” (72’)	121 lbs	$202.32
Total:			$202.32

Table 2: Bill for redesigned roll cage

Assumed Additional Cost for Gusseting: $77.48 (4 12”x12” 13 Gauge Sheets)

Appendix B: Metrics

Metric	**Desired Value**	**Metric Met**
Deflection	Greater than 3 in of clearance between cage and driver	**Y**
Diameter of Pipe	1.5 in, 0.12 in wall thickness	**Y**
Material Requirements	1020 Steel	**Y**

Appendix C: FEA of Redesign

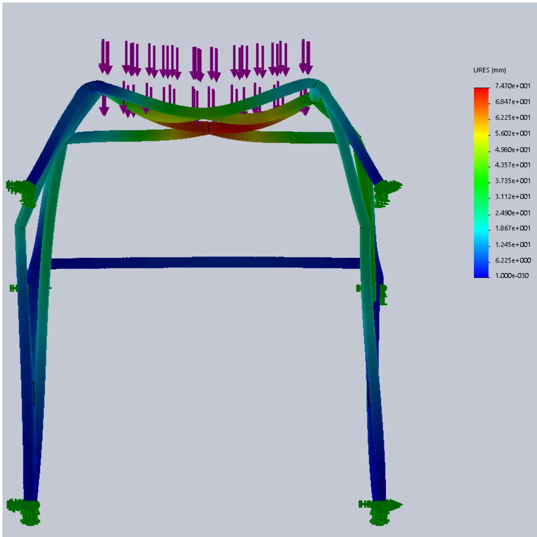

Figure 11: FEA of top loading for redesign

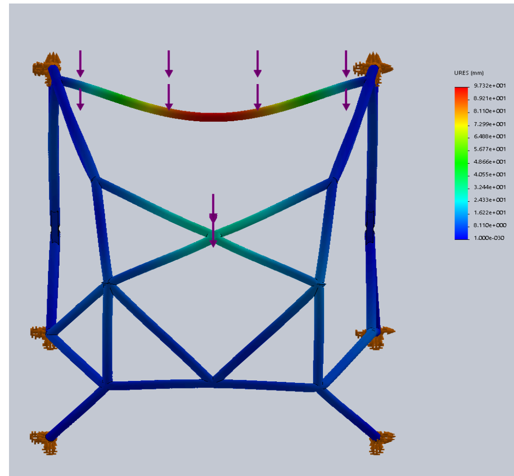

Figure 12: FEA of front loading for redesign

Appendix D: Project Plan

	Weeks 1-3	Weeks 4-6	Weeks 7-9	Weeks 10-12	Weeks 13-15
Design Concepts					
Model Concepts					
Run Analysis					
Prototype					