The Material thickness and mounting plate Technical Analysis

By:
Matthew Baker

Off–Road Bumper Team

Instructor: Carson Pete

Mechanical Engineering design I
– April 30, 2023

Introduction

The Off-road bumper team was tasked with designing and creating three bumpers for their clients Carson Pete, and David Bui. Dr. Pete will be receiving a Front and rear bumper for his Chevy 3500HD. Mr. Bui will receive a front bumper for his Jeep liberty. These bumpers are to be significantly stronger than the factor bumpers. Other requirements for these bumpers are that they keep their factory lines and functionality, support a Winch of the customers choosing, support light pods/light bar, and have an engravement for Dr. Pete front bumper.

The function of this analysis is to understand and answer the Engineering requirements of yield strength and Modulus of toughness. Which came from are customer requirements of durability and strength. This analysis will cover the material choice, the thickness of that material, and lastly the mounting frame for the Jeep Liberty. The starting assumption to begin this analysis is the team will be using $\frac{3}{16}$ inch steel for the exterior plating and $\frac{1}{4}$ inch steel for the Winch mounting plate. This assumption was made for the bench marking showed far and away that the majority of bumpers use this thickness. By the end of this analysis the team will answer the following questions of why $\frac{3}{16}$ and $\frac{1}{4}$ inch steel is the correct thickness for their use, as well as how the team plans to mount their bumper to Mr. Bui Jeep ensuring they keep the customer requirements of Strength and Durability.

This will be achieved by first studying the material properties to determine what the best material for the cost of that material. Once a material is selected a to study further the analysis of the thickness will be conducted through several calculation to see what is required to withstand the force generated from an impact at 45mph allowing for a high threshold that the bumper can withstand. The Last question this analysis plans to answer is how the team will Mount their bumper to Mr. Bui Jeep since the current bumper is currently held on through a series of plastic clips. Which is insufficient for the bumper design that the team will be attaching to Mr. Bui Jeep Liberty.

Bumper/Winch Mounting Plate Material

An evaluation of different types of steel was performed to determine the appropriate option to consider based on cost vs durability. This was done by studying the Yield Strength, Ultimate strength, and modulus of elasticity. These properties were chosen because they outline a material ability to deform without being damaged and then as it starts to deform plasticly tell failure.

Variables

- Yield strength = σ_y
- Ultimate strength = UTS
- Modulus of elasticity = λ

The following variables are defined through a materials ability to withstand stress and strain. Thus, the following variables are specific points and regions on a stress strain curve. Each Variable can be defined by an equation to find where on that curve you are for a given material based on the stress and strain involved in the system at work. Yield stress can be calculated from the following equation.

$$\sigma_y = \frac{Force\ at\ Yield}{Orignal\ area-sectional\ area} \quad (1)$$

$$UTS = \frac{Ultimate\ Force}{Orignal\ area-sectional\ area} \quad (2)$$

$$\lambda = \frac{Stress}{strain} \quad (3)$$

These variables have an agreed upon value for a given material. Thus, for this part of the analysis going over the yield strength and ultimate strength and then determine the best material that fits the need for strength.

The defined force for this analysis is ~100kPa. Based on the force generated by Dr. Pete's truck moving at approximately 35mph. Based on this the team chose to use steel. However, there are several different types of steel which all should have the necessary strength. The following choices are as follows that will have the strength needs to fulfil our customer requirements.

Table 1: Material Properties

Material	λ	UTS	σy	cost
	Gpa	Mpa		
Steel, Structural ASTM-A36	200	400	250	cheapest
Steel, High Strength Alloy ASTM A-514		760	690	mid
Steel, stainless AISI 302	180	860	502	most

From strictly a material property standpoint, the high strength steel would withstand the most damage and allow the customer the most protection. However, once cost and the expected force are accounted for the cheaper structural steel is more than appropriate for this application.

Bumper Plate Thickness

Now with a material of A36 structural steel chosen to be what are bumpers are created from the next part of this analysis is to determine the thickness for both the bumper plates and the mounting plate. This will be accomplished by setting the appropriate safety factor for each material and using a solid works simulation to see how the material will deform based on the stress, strain, and displacement. The bench marking has set the standard thickness for an off-road bumper at 3/16" for the bumper plates.

Frist is to establish the factor of safety that will be used for both the bumper plates. The set value including a factor of safety was set at 150kPa. This value was chosen because it will significantly increase the strength that the bumper will be able to withstand. This was also chosen for in the event that Dr. Pete was to get into an accident it's important to ensure his safety seeing how the bumpers have the potential to be first point of contact they need to be able to withstand the force being applied to them. Needing to achieve a total force of 150kPa the factor of safety was assessed to be 1.5.

Now with the factor of safety for the bumper plates was set to be able to with stand 150kPa the testing of are components to prove and show why the $\frac{3}{16}$" for the bumper plates and the $\frac{1}{4}$" for the winch plate. In this analysis the winch mounting plate and the front bumper plate were taken from our current design of Dr. Pete's front bumper to see how the 150kPa force would act on them to understand if that was the appropriate thickness. The bumper plate will analysis and show the appropriate thickness for the external shell of the bumper. What is most likely to come into contact with foreign object.

To start the analysis the first step is to set the material as the chosen A36 steel. Solidworks has material properties loaded into it so that it can accurately generate what will happen to the material. Once the material is set the following set is to set the fixtures meaning how the front bumper will be held in place. Since we are welding the bumper all the edges will be fixed in place allowing for no movement of the plate meaning that there are no reaction forces that can be ignored. Once the fixtures are set the next step is to add the 200kPa force to the front plate of the bumper.

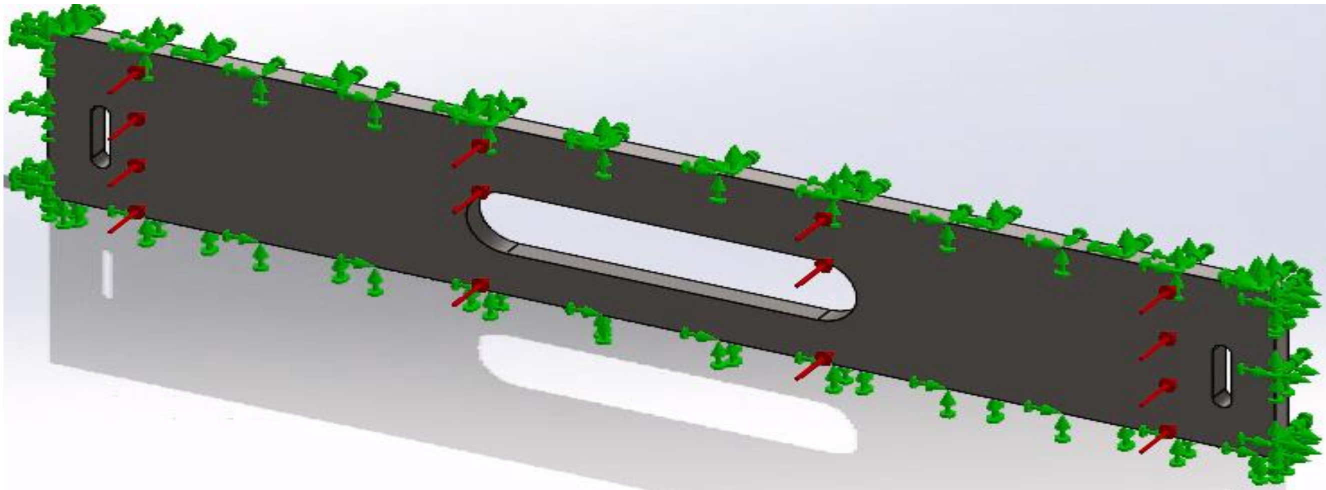

Figure 1: Front Bumper Plate with fixture and force vectors

The final step needed to set the simulation is to create a mesh grid that will show how the force is displaced through the front bumper plate. Once the mesh grid is set the simulation can run calculating the stress, strain, and displacement through the front bumper plate. The first calculation that was done is the stress through the front bumper plate. As shown below.

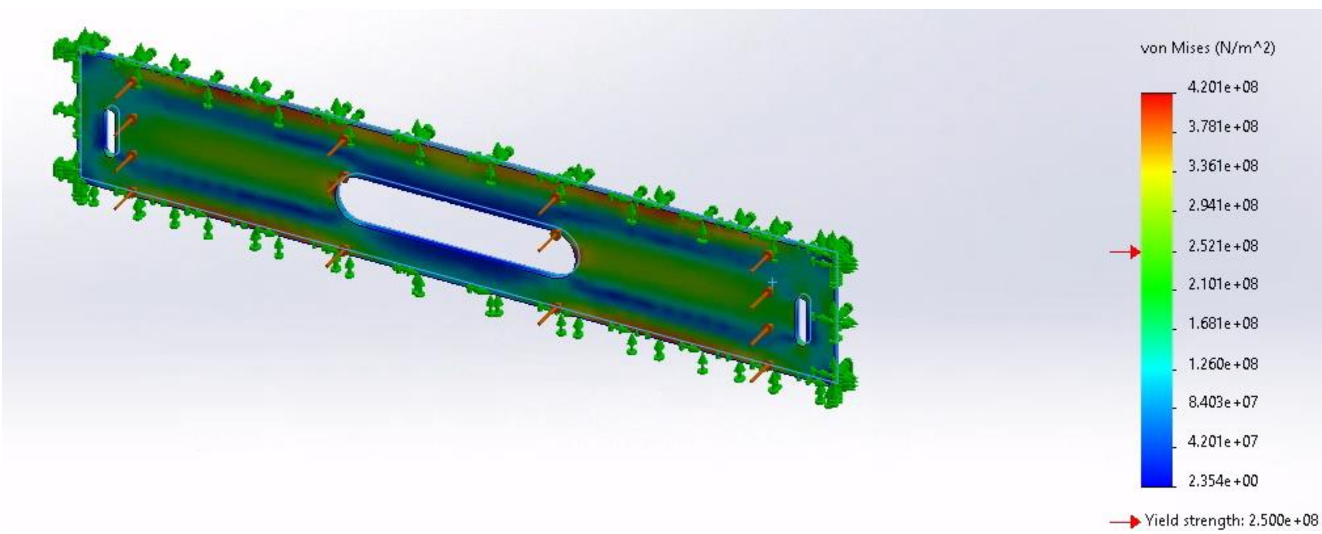

Figure 2: Front Bumper Plate $\frac{3}{16}$" stress analysis

As shown in figure 3 we are still within our yield strength of 250MPa for most of the model there are some resigns toward the outer edges next to the reactionary forces. Seeing how the max force applied is slightly higher than UTS which provides some concern which is mitigated by since the reactionary force are true to the model since in this simulation is ignoring the remainder of the of the model which would be more forgiving allowing for a reduction around the edges of this model proving that this is the appropriate thickness based on are factor of safety. For any stronger you are spending significantly more money and any thinner you start to fail the integrate of the plate upon the impact of 200kPa which was set by the factor of safety.

The next analysis that was performed for the front bumper plate was the strain and displacement analysis. This is the calculation of how much the material will deform after the force is applied.

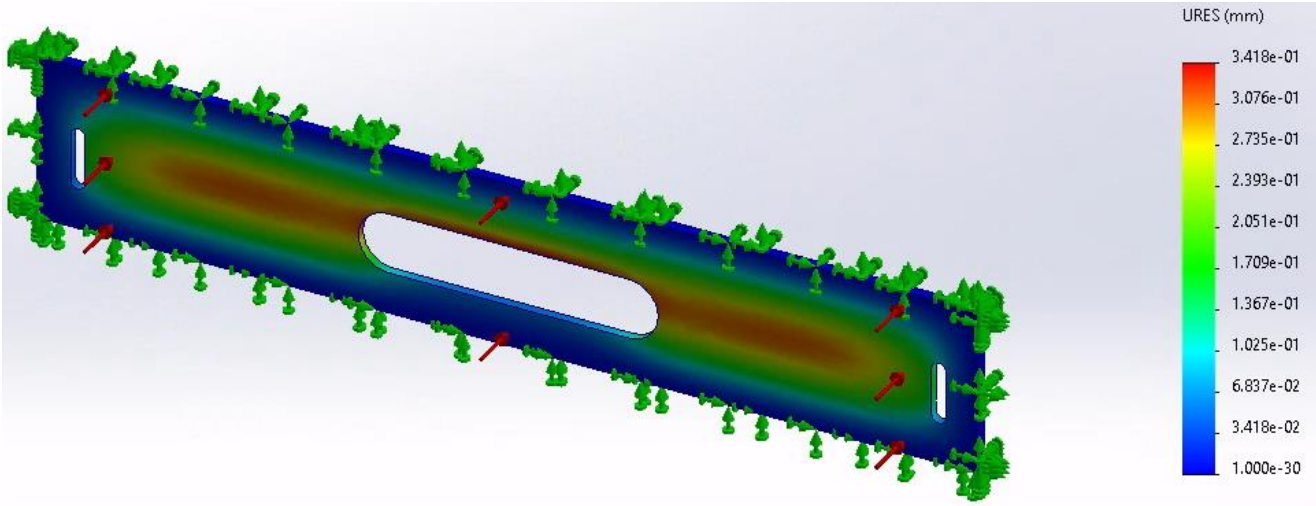

Figure 3: Front Bumper Plate $\frac{3}{16}$" displacement analysis

This figure shows that towards the middle we will see some deflection. However, the maximum deflection is 0.342mm which is next to nothing and as shown in figure three the welds will fail before the material starts to have significant displacement. This analysis also confirms that $\frac{3}{16}$" steel is the correct thickness for this application. Similarly, to the stress if there is little to no deflection at $\frac{3}{16}$" there will be even less at $\frac{1}{4}$" and if a thinner material was chosen there would be some significant displacement in mm.

Winch Mounting Thickness

For the mounting the factor of safety was set for the plate to withstand force of 200kPa for Dr. Pete's, which is a 15,000 lb. winch which generates approximately 100kPa. Meaning our factor safety will be 2. This was done for this is the frame of our bumper and in addition to that there is potential to generate significantly more force than that of the winches rating. An additional safety factor was added since this is a part of the bumper frame that it was set to be $\frac{1}{4}$" to withstand the reactionary forces that will be applied to it from all the exterior bumper plates.

Like the front bumper plate simulation, the first step is to obtain the part and set the fixtures and force vectors.

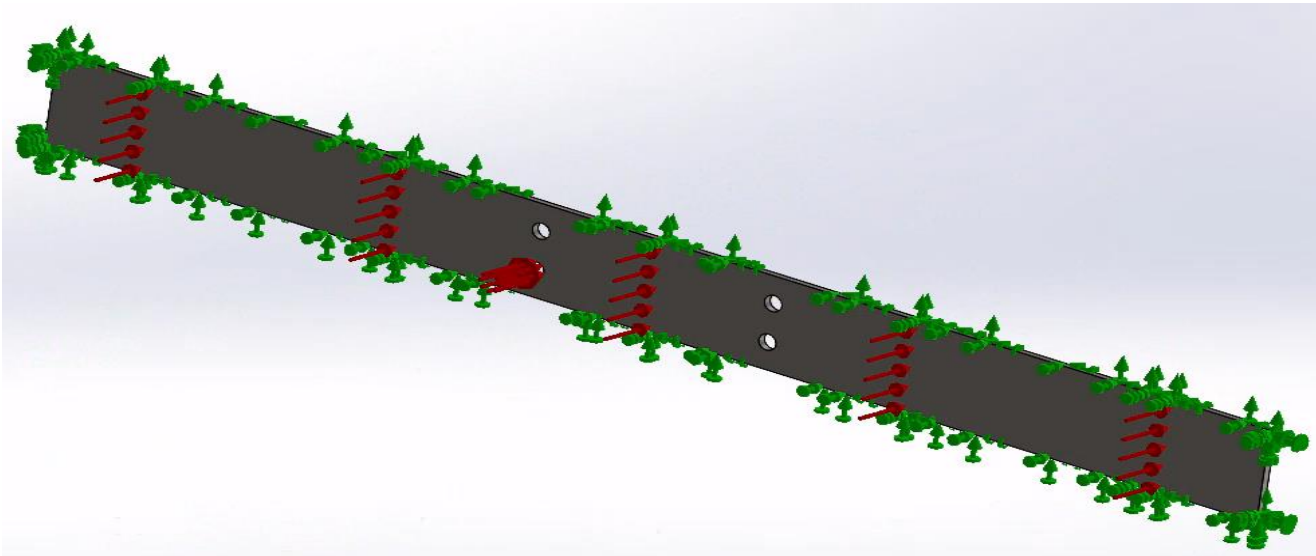

Figure 4: Mounting Plate $\frac{1}{4}$" fixture and force vectors

Similar to the last simulation this will be welded into place meaning that all reactionary forces need to be accounted for since it will not be able to move. The force vector spans the length of the mounting plate since the winch will be bolted the plate helping to apply the force equally through the mounting starting from the holes and distributing it outward.

For the stress and displacement analysis of the mounting plate there needs to be little to no displacement and there needs to be room to spare in the stress analysis in the event that Dr. Pete uses e a series of pulleys to double his winching power.

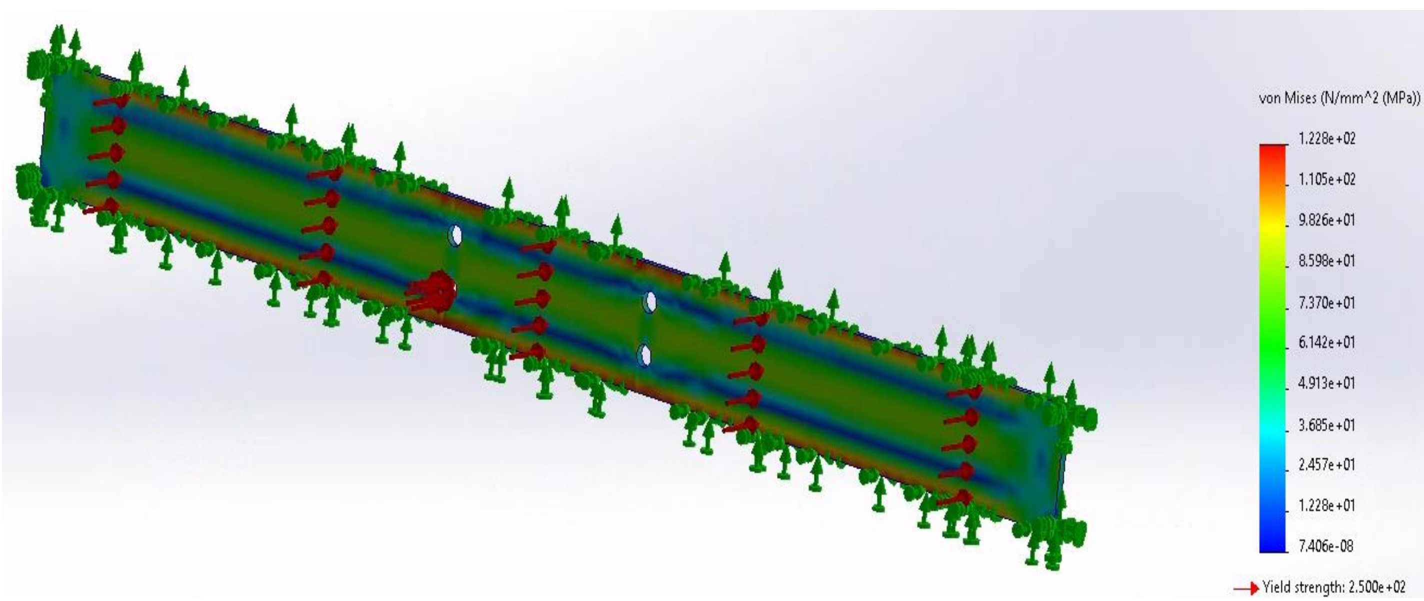

Figure 5: Mounting plate $\frac{1}{4}$" thickness stress analysis

Figure 5 shows that the $\frac{1}{4}$" Thickness is more than appropriate for the applied use it might even be over kill but seeing how this is apart of the frame for are bumper we wanted to ensure that there would be no failures due to the materials. This assumption is made for the yielding strength doesn't even appear in figure 5 since the yielding strength is 250MPa and max force generated in this simulation is 122.8MPa well below the yielding point. The displacement analysis painted a similar picture to that of the stress analysis which is be expected due to the nature of our choice to pick $\frac{1}{4}$" steel.

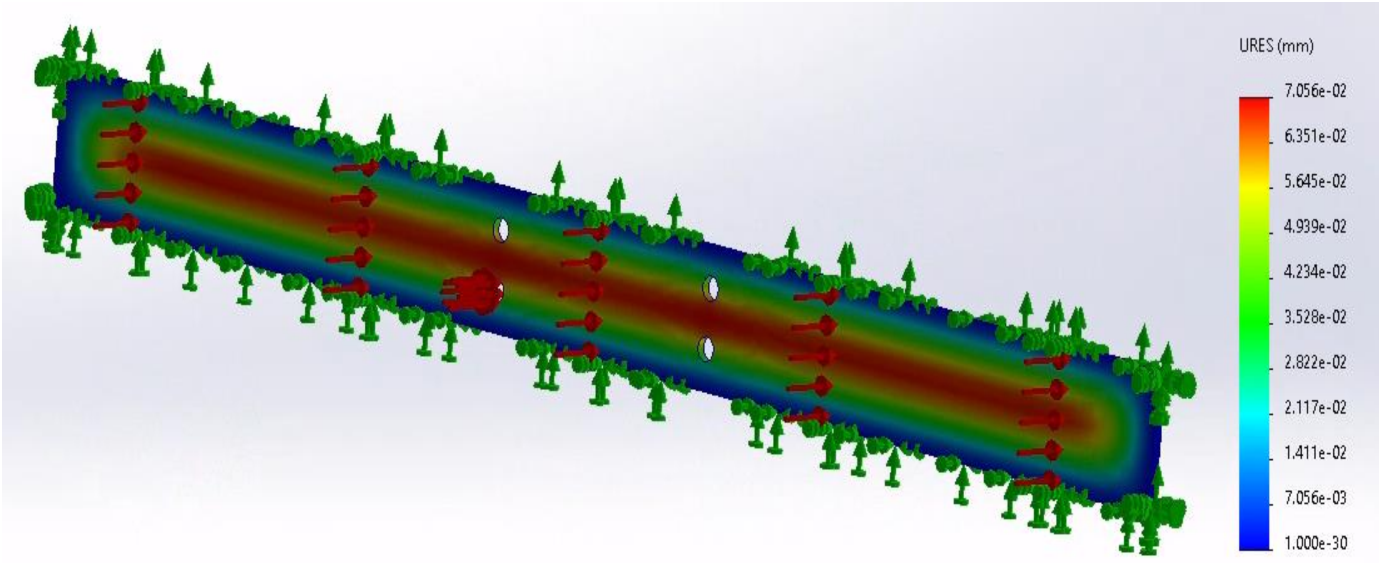

Figure 6: Mounting plate $\frac{1}{4}$" thickness displacement analysis

The max displacement at the 200kPa showed a 0.071mm displacement which is next to nothing. Showing that the $\frac{1}{4}$" thickness was more then adequate for the mounting plate. With both the stress and displacement analysis agreeing that $\frac{1}{4}$" is more then strong enough to withstand the force being applied to it.

Conclusions

With the following data collected my recommendation is to use $\frac{3}{16}$" A36 structural steel for are the exterior bumper plates and to use $\frac{1}{4}$" A36 structural steel for any mounting plate and frame components on both Dr. Pete's and Mr. Bui vehicles. The $\frac{3}{16}$" A36 steel is more than appropriate since it can withstand force well beyond what it should expect to see on a normal bases and in the event the limitation is tested it will fail at the welds or the bolts before the metal start to deform. As well as $\frac{1}{4}$" A36 steel is more than strong enough to support the bumper and the winch. Since the maximum force that the $\frac{1}{4}$" A36 steel would see is well below yielding point to where there is little to no risk that is will ever reach enough force to achieve it UTS and risk failure.

REFERENCES

[1] R. S. Figliola and D. E. Beasley, Theory and Design for Mechanical Measurements. Chichester: Wiley, 2006.
[2] “Young's modulus, tensile strength and yield strength values for some materials,” *Engineering ToolBox*. [Online]. Available: https://www.engineeringtoolbox.com/young-modulus-d_417.html. [Accessed: 29-Apr-2023].
[3] “07 08 09 10 Chevy Silverado 2500HD Rear Bumper Assembly Dents are presented OEM,” eBay. [Online]. Available: https://www.ebay.com/itm/363690869553. [Accessed: 26-Feb-2023].
[4] “Hot Roll Steel Sheet,” Midwest Steel & Aluminum. [Online]. Available: https://www.midweststeelsupply.com/store/hotrollsteelsheet. [Accessed: 26-Feb-2023].
[5] “07-18 JK pro series mid width front bumper rec winch MNT w/ bar & tabs 07-18 JK pro series mid width front bumper rec winch MNT w/ bar & tabs,” Icon Vehicle Dynamics. [Online]. Available: https://www.iconvehicledynamics.com/accessory/16074/Icon-Impact-Off-Road-Armor-07-18-JK-PRO-SERIES-MID-WIDTH-FRONT-BUMPER-REC-WINCH-MNT-W/-BAR-&-TABS?gclid=Cj0KCQiAo-yfBhD_ARIsANr56g4RNImCBa0GRwZWzdrHbwtP6CzTnYHMt_CTBaXdIphyfRrR58q2kywaAoZuEALw_wcB. [Accessed: 26-Feb-2023].

APPENDIX

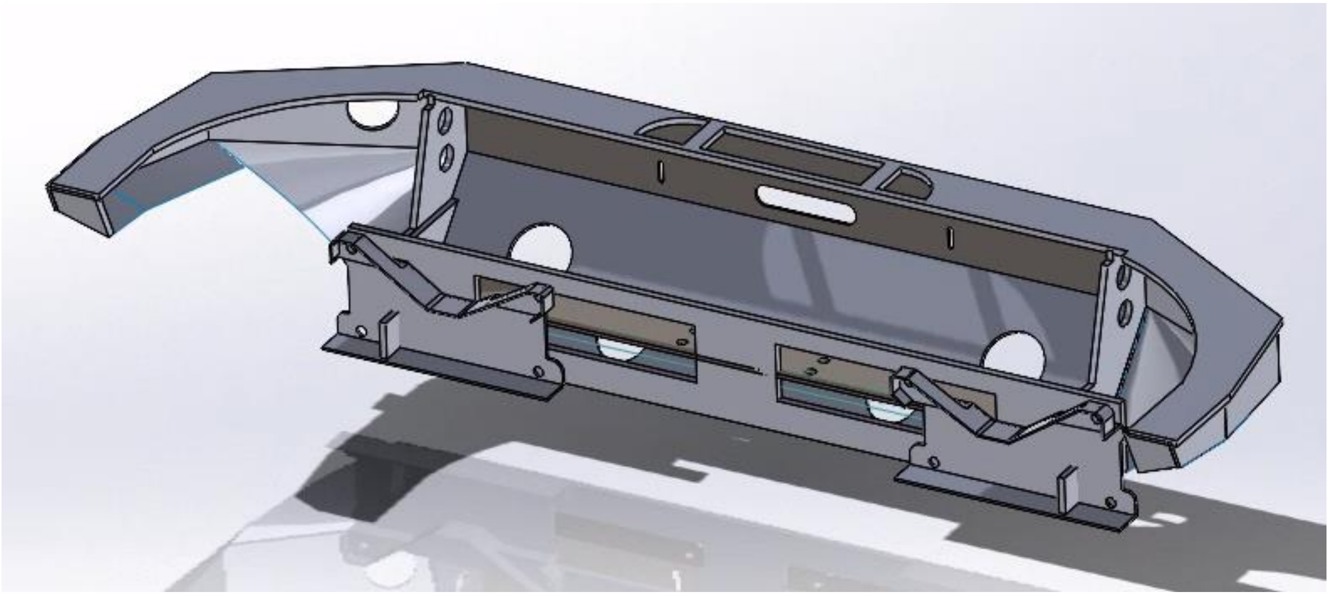

Figure 7: Dr. Pete’s Front Bumper assembly