2019 University of Cincinnati SAE Baja® Body & Safety

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

Through this report, it takes an in-depth look at the 2019 SAE Baja body and safety. Our mission this year was to build a car that stuck to a tight budget and surpassed all those of prior years. This report outlines a few of the major concerns and reasons the body is such an important part of achieving this goal. The body is one of the few pieces responsible for keeping the driver safe and protected from outside objects. Looking at previous projects and issues that have come up from materials and designs in past years. Then going an extra step to ensure this year's car met all the needs that we felt just for our Baja.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

I am working alongside a group of my peers to compete in the SAE Baja challenge. Following specific rules and regulations in hopes of competing in an organized event with other schools and teams alike. My main responsibility for this competition is to focus on the body and safety for the Baja. In order to make sure our vehicle meets all required SAE specs, and pass the rigorous test that will be done in order to ensure the designs are acceptable. For this year's competition we have decided to start with a clean slate, we are going to build an SAE Baja car from the ground up. We have a great group of students very eager to put their skills out there and build the best Baja the university has seen yet.

The main thing on that list of tests is to make sure the body itself is non-puncturable. Meaning a sharp or blunt object that may come in contact with the outer shell will not penetrate through and potentially harm the driver. Continuing with the body testing's, the areas around the drivers' feet and legs must also be full enclosed. To check that this meets the requirements, a dowel rod of a specific size, will be used to try and fit in any seams or holes.

To meet these requirements, I will be examining what our school did in previous events and communicating with organization leaders to ensure we follow the correct rules and requirements. I will also be taking in past designs and working to make our vehicle far superior than any in years' past.

The rest of our Baja vehicle will be worked on and collaborated with the rest of the team to ensure the best vehicle in years past.

BACKGROUND

This section will take an in depth look at one of the University of Cincinnati's ongoing team activities, the SAE Baja team. The University is now in its 5^{th} year of participation in the Baja event. This vehicle is pretty much an off-roading dream. It contains a small but powerful 10 horsepower engine. Although it doesn't sound like much, but equipped with the right drive train and suspension components, it is the perfect combination for any off-roading challenge. Each year a student led organization oversees designing, building and facilitating the Baja team. For the Baja team, there are several regional competitions available for the students to participate and represent their schools in. There are four main areas the teams will be evaluated in based on their performance upon entering in the SAE Baja competition. Prior to competing in these events, the teams and cars must undergo a rigorous series of technical inspections. The main inspection that I am focusing on is the body and cockpit areas. Below is a section of the rules stating where the critical areas of the body and cockpit will be evaluated.

B.8.5 - Body Panels

The cockpit must be protected with body panels that completely cover the area between the LFS and the SIM. No gaps can exist that are larger than 6.35 mm (0.25 in) and will be checked with a 6.35 mm (0.25 in dowel rod). These panels must be made of puncture resistant material, including: plastic, fiberglass, metal, or similar material. They must be designed to prevent debris and foreign object intrusion into the driver compartment. The panels must be mounted securely to the frame using sound engineering practices (cable ties or hook-and-loop fastening is not acceptable).

Note: Quick disconnect or easily accessible fasteners for body panels are recommended, and facilitate a faster technical inspection process.

Figure 2: How Body Is Tested. (1)

The previous cars that have been built by the university have lacked in strength and quality. The current body panels do not seem like they would hold up too much of an impact from a blunt or sharp object, which can really pose as a safety hazard for the driver and team. The current design also uses a loosely connected mounting technique which allows the body to flop and bow in and out, resulting in gaps that will not pass the mandated SAE inspection. The second issue with the loosely mounted body is that when in race mode, dirt and debris will be ricocheting off of the Baja. Anywhere there is a gap, is an opportunity for dirt and debris to enter the drivers' area and potentially come in contact with the driver.

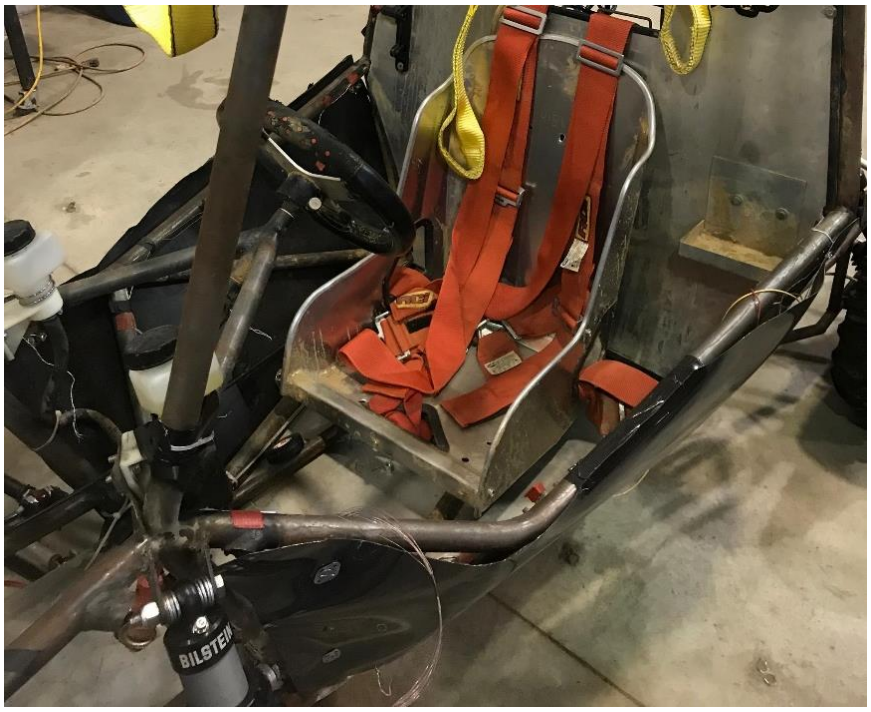

Figure 2. The University of Cincinnati 2018 SAE Baja

Looking at the very bottom of this picture, there is a visible issue with the body on this years' current car. Right where the cage bar is bent the body has a rather large gap. This gap is neither acceptable with SAE rules and regulations, nor is it acceptable with the current students. This area along with many others could be a failure in the body and cockpit as a whole and allow unwanted objects to reach the driver.

RESEARCH

SCOPE OF THE PROBLEM

The problem I am addressing on this year Baja car is the body and body panels. This is a major portion of the car because it contributes to the safety of the driver. The body panels must keep harmful objects from entering the drivers compartment and potentially harming the driver. In past years the body has been made of a thin plastic that has been left torn and warped, now failing any test the SAE competition would evaluate it on as far as body panels.

CURRENT STATE OF THE ART

When building the new body for the SAE Baja, there are many things to take into consideration; driver size, ease of exit, material, durability, weight, cost, function, and presentation. There are many materials allowed to construct the Baja body, the first being plastic. Plastic is okay as far as weight and cost goes, but when it comes down to the other areas it surely lacks. The two best materials when it comes to building a body for something of this application is either carbon fiber, or aluminum. These two materials are going to be the strongest options to withstand the harsh conditions of off-roading. With that being said, carbon fiber still has its disadvantages, "if puncture occurs on one fiber, the strength of the entire length of the fiber would be compromised (2)." This is the major worry with carbon fiber applications on an off-road vehicle.

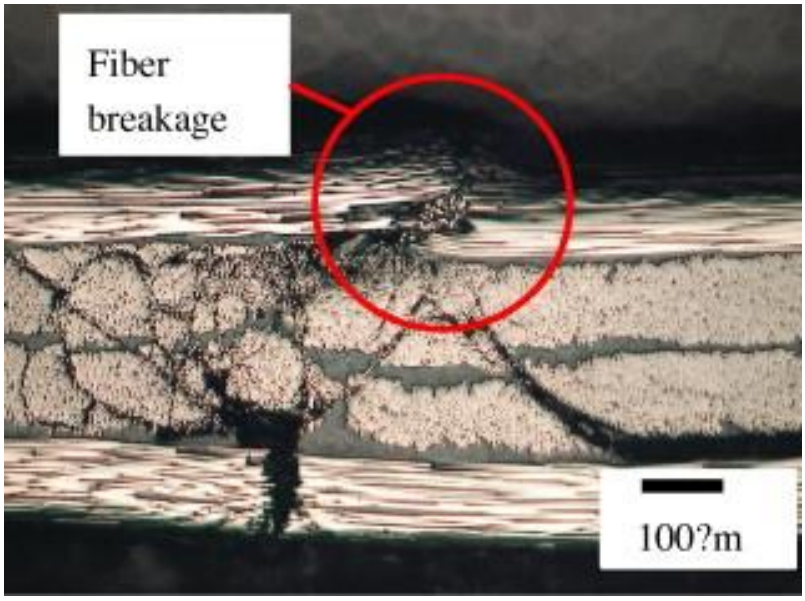

Figure 3 Damage to Carbon Fiber Sheets, Rapidly Spreads to Many Other Fibers. (2)

As you can see in Figure 3, once damage has been sustained to a single thread of carbon fiber, it almost completely disintegrates and completely separates. With the Baja event partaking on an off-road course with jumps, ruts, flying rocks and other competitors, the likely hood of having a large enough object damage a carbon fiber component is very likely.

Figure 4. University of Waterloos' Previous Baja. (3)

The University of Waterloo has made a very well-built Baja, pictured above. When examining the body components, it is very easy to see how well they have been constructed and thought out. It is made of a strong lightweight aluminum material. This material is a very

smart choice as it is very durable and will hold up to just about anything. Even when the aluminum panels are damaged they simply dent or scratch, and punctures rarely occur. The weight saved with choosing aluminum versus most plastics or steels is quite noticeable, not to mention the money that can be saved using aluminum compared to a carbon fiber. This along with many other deciding factors are what make an aluminum material superior to others when it comes to off-roading.

END USER

The end user of this Baja is not only the students and faculty, but potentially the mass market. We are working as a team to produce what we think is the best possible SAE Baja out there. Upon completion, we will take our Baja and compete in an open competition against other universities in hopes of being the best there. A trophy isn't the only thing we are competing for, but in this competition, we are competing against other schools for the chance to have our design accepted for manufacture by a fictitious firm.

From what the teams have been putting out in past years, we want to be able to take the things they've done well and the areas that could be improved on, and build off of that. We want to build a slick, ergonomically fit machine that upon first glance you think, "man I would love to own that". The final product needs to be something that anyone can drive and be well protected in, and something that everyone wants to drive.

Throughout this process we will be working as a team to bring together the numerous assets that we each hold as individuals to build one car that is safe, reliable, and competitive. More importantly, we are coming together to build a Baja that we are all proud to be a part of and to represent the University of Cincinnati.

CONCLUSIONS AND SUMMARY OF RESEARCH

From the research gathered, the most efficient solution would have to be aluminum. The thin plastic that forms to the roll cage will just not be strong enough. Yes, the plastic is cheap and lightweight, but with the little force required to puncture the plastic and potentially enter the drivers' area, it is not the most viable material to use. The carbon fiber option could potentially have a purpose for body panels. However, in the off-road world it does not seem to have the durability to withstand the abuse and harsh environments likely to be experienced in this competition.

CUSTOMER FEATURES

Customer Features	Weighted Importance
Accelerates Quickly	0.10
Maneuvers Easily	0.10
Meets Safety Specifications	0.15
Drives Over Large Obstacles	0.10
Climbs Steep Grade	0.05
Low Maintenance	0.05
Cost Efficient	0.10
Brakes Quickly	0.10
Ergonomical	0.10
Light Weight	0.15

PRODUCT OBJECTIVES

RANK	1	2	3	4	5
Lightweight					
Acceleration					
Ease of Use					
Cost Effective					
Speed					
Ergonomics					
Durable					
Safety					

Table 5: Product Objectives

1 – Low Importance **5 – High Importance**

QUALITY FUNCTION DEPLOYMENT

			Engineering Requirements (units)													Customer Satisfaction Rating (0.00 - 1.00)			
	Customer Requirements	Importance wt.	Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)	CP	A	B	C
			1	2	3	4	5	6	7	8	9	10	11	12	13	14				
1	Accelerates Quickly	0.10	9									9		9	3		1	0.6	1	1
2	Maneuvers Easily	0.10		9		1				1		3				3	1	0.7	1	1
3	Meets Safety Specifications	0.15			9				3	1	1		1				0	0.8	1	1
4	Drives Over Large Obstacles	0.10				9	3						3	3		1	1	0.6	1	1
5	Climbs Steep Grade	0.05	3					9				1		9	1		0	0.7	1	1
6	Low Maintenance	0.05							9								1	0.5	1	1
7	Cost Efficient	0.10							9			3					1	0.5	1	1
8	Brakes Quickly	0.10			1					9		3					1	0.8	1	1
9	Ergonomical	0.10									9						1	0.7	1	1
10	Light Weight	0.15	3		1			3	9	3		9	3	3	3	3	1	0.7	1	1
	Total Importance	1.00																		
	Engineering requirement importance		1.5	0.9	1.6	1	0.3	0.5	3.2	1.2	1.1	3.2	0.9	2.1	0.8	0.9				
	Performance Current Product		2	1	1	2	3	2	3	3	3	4	2	3	3	2				
	competitor A		3	2	4	3	3	3	2	4	4	3	3	3	3	3				
	competitor B		2	2	3	3	2	2	3	4	3	4	3	2	3	3				
	competitor C		1	1	4	2	2	1	3	4	1	4	4	2	2	2				
	New Product Targets		4.5	4	5	3.5	4	4	3.5	4	4.5	4	5	4.5	3.5	4				

Interaction Matrix

Engineering Requirements		Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees)	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Acceleration 0-20 (mph^2)	1		-3	-3	-9	-9	3	1	-9	-9	3	-9	9	3	-1
Turning Radius (ft)	2			-3	-3	-3	-9	-1	-9	-9	-9	-9	-1	-1	1
Factory of Safety (SF)	3				-3	-3	1	9	3	1	1	3	-3	1	-3
Ground Clearance (in)	4					9	1	1	-3	-9	3	3	-9	-9	3
Wheel Travel (in)	5						1	3	-3	-9	3	9	-3	-3	9
45 Degree Incline (Degrees)	6							1	-9	-9	3	-3	9	3	1
Materials Cost ($)	7								3	-3	9	3	3	3	3
Braking Distance (ft)	8									-9	9	-9	-3	9	3
Leg Room (in)	9										-9	-9	-9	-9	-9
Weight (lbs)	10											3	3	9	1
Sustains Drop (ft)	11												-9	-9	9
Torque (lbf)	12													3	3
Speed (mph)	13														1
Stiffness (lbs/in)	14														

DESIGN

Design alternatives and selection

- Flexible Plastic
  - Loose construction, easy to puncture, unappealing.
- Carbon Fiber
  - Lightweight, strong, expensive, hazardous.
- High Strength Aluminum
  - Strong, lightweight, cheap, easy to work repairable.

With this concept there are three different variations. Since the Baja is so restricted with rules surrounding is cage and chassis this is a basic design but will have the option of being either lightweight aluminum, carbon fiber, or sheet plastic.

Selection

High Strength Aluminum – Final Choice
- Familiar with material
- Lightweight and High strength

- Aluminum sheet metal is the main component used in the racing industry as well.
  - Easy to form
  - Easy to repair or replace
  - Cost effective
  - Handles the wear and tear
- 6061 Ultimate Tensile Strength
  - 18000 Psi
  - Total Weight: <25 lbs

Drawings

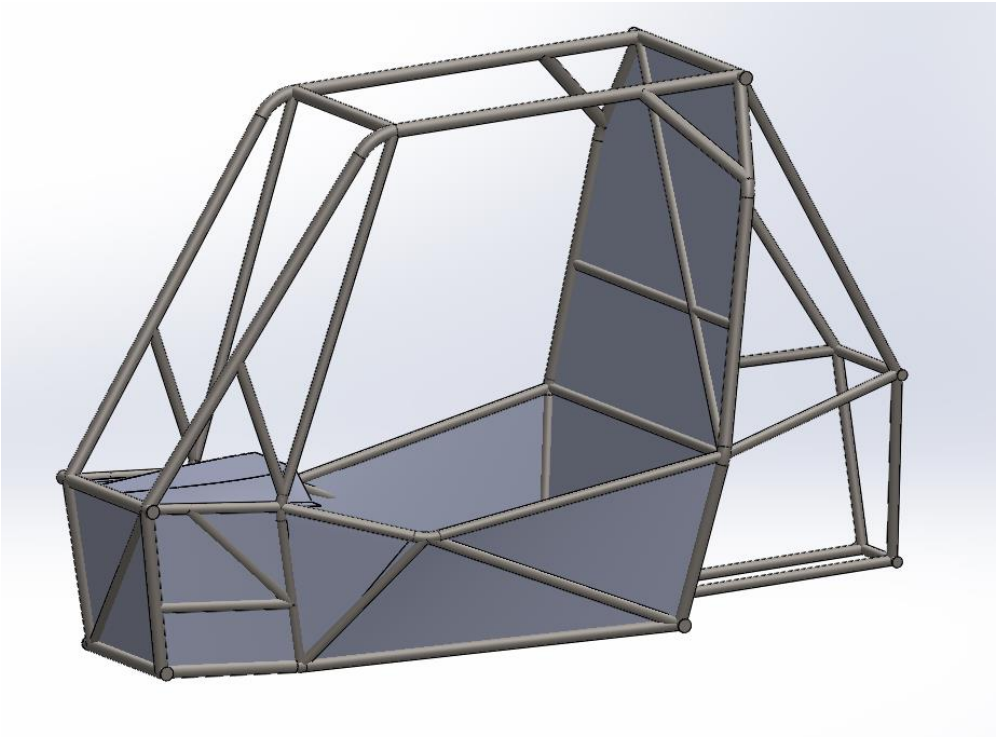

Figure 5: First Look at 2019 Body Design.

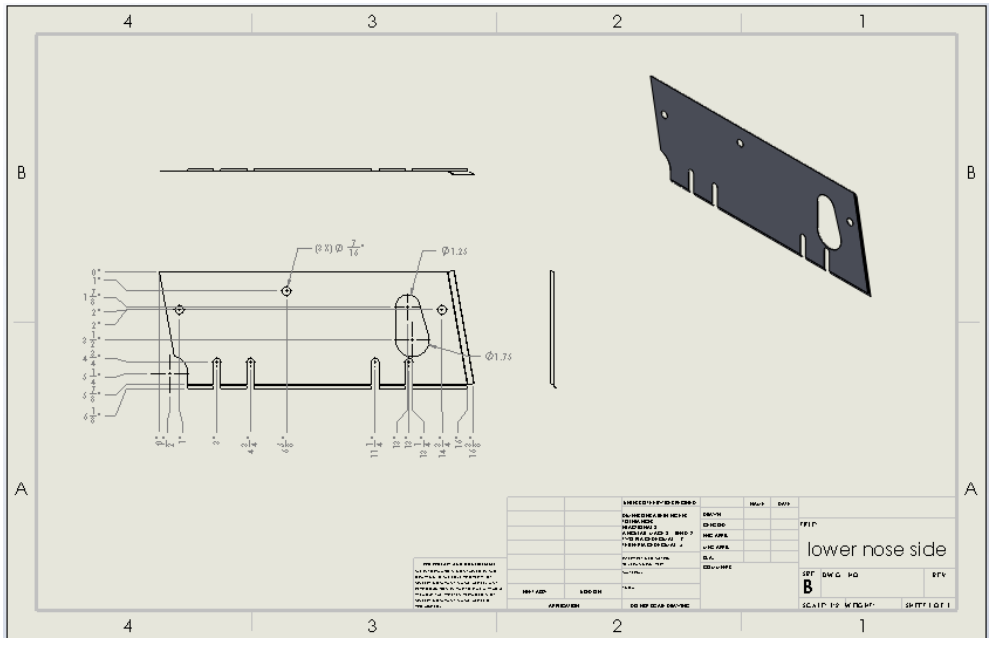

Figure 6: Lower Nose Side Drawing.

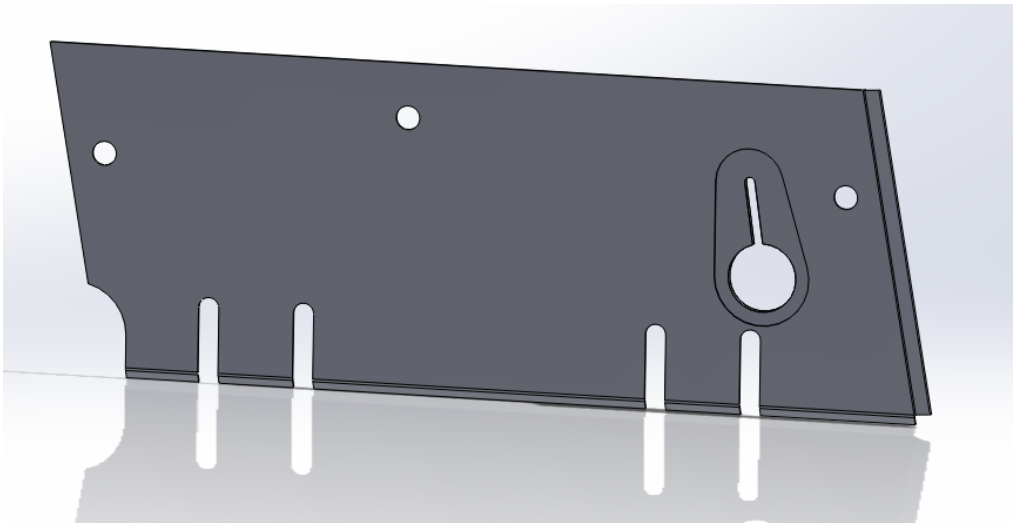

Figure 7: Completed Model of, Lower Nose Side with Rubber Insert Behind Panel.

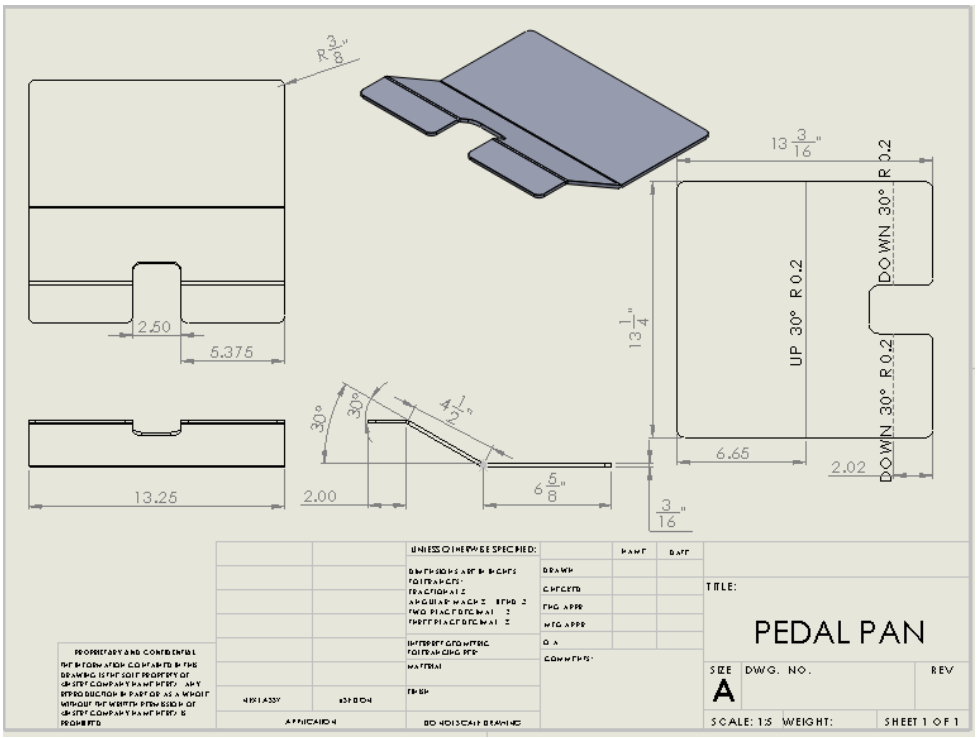

Figure 8: Pedal Pan Drawing.

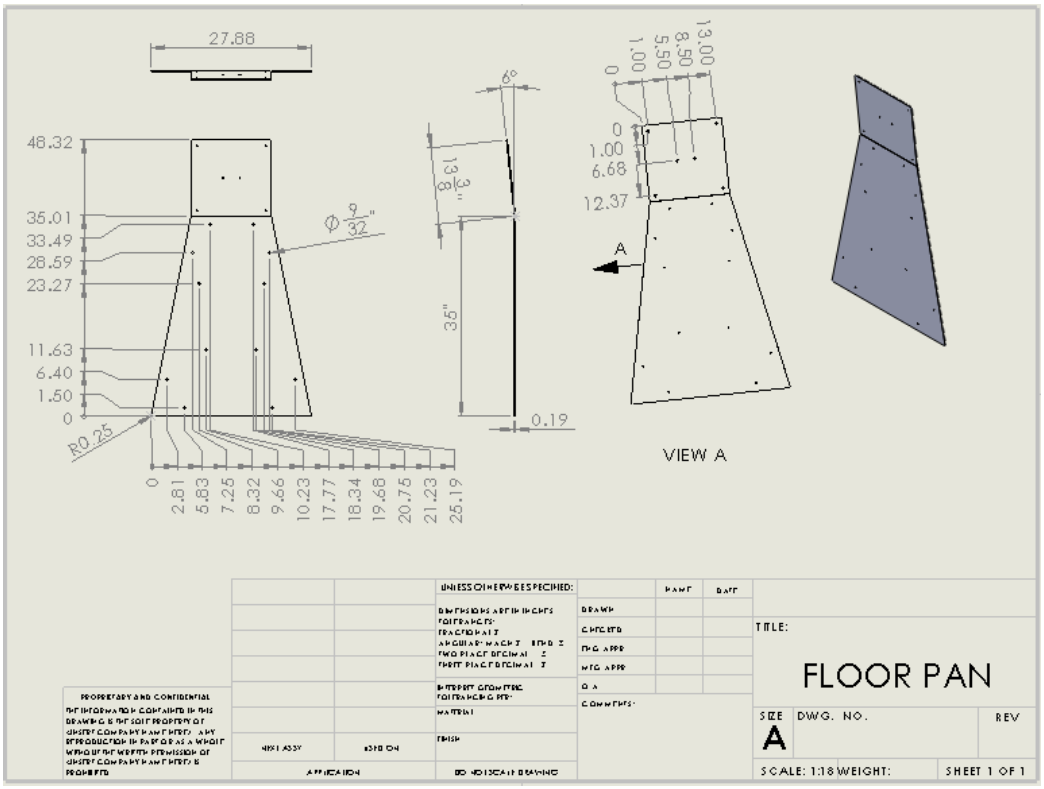

Figure 9: Floor Pan Drawing.

Loading Conditions

6061 Aluminum Sheet

- For this particular part I have viewed it as if we made contact with a stick at a high angle side impact.
  - ½" round Red Oak stick
  - Impact force of 4.5 lbf being hit directly on a ½" diameter location
  - The door will only deflect .05 inches (1.27 mm). Less than 1/16"

S = 5.1 Fy
M = 1626.6 Fy
RF = (.48/sin(10)) = 2.8 lbf ➔3 lbf
Going with a design factor of 1.5
798 = 5.1FY + 1626.6FY
S= FY/(π*.25^2)
M = (FY*20*.25 / ((π*.25^4)/4))
Allowable deflection = L/400 L = 940 mm
940 / 400 = 2.35 mm
Calculated deflection = 1.27 mm

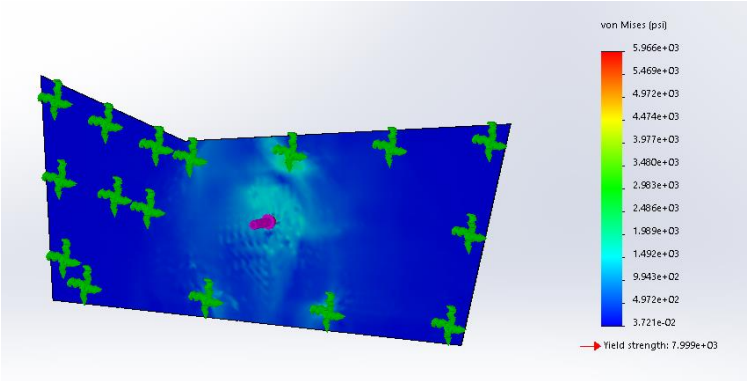

Figure 10: Side Impact from 1/2" Diameter Stick.

Component Selection

Upon selecting hardware and components for this year's Baja, we wanted to keep everything as simple and easy as we could. For the body the main hardware consisted of dzus fasteners and threaded inserts. Both of these systems are used so that only one person is needed to operate and assemble any of the components. Primarily on the floor pan, in years past has required multiple people to assemble. With this selected hardware only one person and one tool will be required.

Figure 11: Threaded Inserts

Figure 12: Dzus Fasteners

Bill of Material

Item	QTY	Total Cost
6061 Black Aluminum	2	$170.00
Dzus Fasteners 50 pk	1	$125.99
Dzus Springs 50 pk	1	$38.99
Dzus Mount Plate 50 pk	1	$27.99
Countersunk Body Bolts 10 pk	2	$29.98
Threaded Inserts 10 pk	3	$68.97
Black Pop Rivets 3/16 250 pk	1	$23.99
Alum Pop Rivets 1/8 500 pk	1	$15.99
Rubber Sheets 12x12	4	$43.10
MISC / Safety	1	$100.00
TOTAL		$645.00

Table 2: Bill of Materials

PROJECT MANAGEMENT

BUDGET

Proposed

Category	Projected Cost ($)
Material	400
Tools	100
Hardware	100
Safety	300
Total	$900.00

Table 6: Proposed Budget

Actual

Category	Projected Cost ($)
Material	195
Tools	0
Hardware	350
Safety	100
Total	$645.00

Table 7: Actual Budget

SCHEDULE

Proposed

	Project Planning	Research	Design	Modeling	Material Ordering	Manufacturing	Testing
August							
September							
October							
November							
December							
January							
February							
March							
April							

Table 8: Proposed Schedule

Actual

	Project Planning	Research	Design	Modeling	Material Ordering	Manufacturing	Testing
August							
September							
October							
November							
December							
January							
February							
March							
April							

Table 9: Actual Schedule

CONCLUSIONS

Looking at the body as a whole, it is definitely an improvement over previous years. The aluminum does forfeit a little weight over the plastic of previous years, but what it gives up in weight we quickly gained back in strength and appearance. The rigidity of the aluminum has helped eliminate the tearing and warping of the body panels. The panel above mentioned in figure 7 was of main concern this year due to steering components binding on body panels in previous years. This new design has been a success through all testing's and events we have taken the car to thus far. A thorough pencil test of every single body panel and each one passed with ease. The new design has met my goal of being able to assemble and dis assemble with ease. Not only do the body panels look good and perform great, they have surpassed all my expectations of fit and finish on this year's car, only adding to the team's success.

PROJECT SUMMARY

Through the process of building this year's Baja body, there was a lot to take into consideration. One of the main focuses was ease of assembly. Each and every piece that went

into the body was laid out and made in the simplest way so that there was no order of operations when disassembling or assembling the car. Almost every piece is able to be removed without touching any other component, with acceptations to the shocks and seat this year. During fabrication all that was needed was a standard sheet metal brake and a pair of sheet metal scissors. The major complication with building the body was having the car and all my sheet metal working tools in two separate locations.

Figure 13. Finished Body

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2. **Akira Todoroki, Kazuhiro Yamada, Yoshihiro Mizutani, Yoshiro Suzuki, Ryosuke Matsuzaki.** *Composite Structures.* Tokyo : Elsevier, 2015.
3. **Engineering, Waterloo.** Baja SAE Team unveils 2012 vehicle. *Waterloo University - Engineering* . [Online] April 2012. [Cited: October 5, 2018.] https://uwaterloo.ca/engineering/news/baja-sae-team-unveils-2012-vehicle.

APPENDIX A

APPENDIX B


Valvoline
BILSTEIN
D&D
2019
MOBILGARD
MACHINTEX
BILSTEIN
CINCINNATI
Valvoline
D&D