Bearcat Baja Frame/Ergonomics

Senior Design Proposal submitted to the
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Bachelor of Science

in Mechanical Engineering Technology

by

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Nicholas Plataniotis
Doug Rife
2019-20 Bearcat Baja Team

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Abstract

The objective of Baja SAE is to design and build a single seated, all terrain, sporting vehicle that can compete with similar products that are being produced today. All vehicles must use the same 10 horsepower Briggs and Stratton engine to keep the competition fair and encourage unique design to other components of the vehicle. These vehicles will be tested at one or more competitions out of three available located throughout the United States. They will be judged based off of performance in dynamic and static events. Dynamic events include rock climb, towing, acceleration, maneuverability, and endurance courses. Static events include design, sales, and cost presentations. Based on performance in these events teams will be scored and winners can be determined for each event as well as an overall winner of the competition. The goal of the 2019-20 Bearcat Baja team is to get entered into these at least one of these competitions and to build a car that will perform well at them.

Problem Statement

There have been many changes to the Baja SAE rulebook since the last time the Bearcat Baja team took a Baja car to competition. Due to this, this year's Baja team has decided to build a new Baja car for the 2020 competition. The 2019-20 Bearcat Baja team has divided up the responsibilities for building the car into several different sections. These sections are frame/ergonomics, suspension, drivetrain, brakes, wiring/electronics, and project management/steering. This report will mainly focus on the frame and ergonomics section of the vehicle.

A major factor in having a successful Baja car starts at the frame. This is where the rest of the components are mounted and also where a large part of the vehicles overall weight will come from. The best Baja cars at competition are typically smaller and lightweight, so the objective of frame/ergonomic design would be to minimize the size and weight while still being able to fit a driver ranging from 5' to over 6' tall. The frame lead will also need to work closely with all of the other project sections to ensure that there is enough space for their components and that everything can be easily mounted to the frame.

Research

Background of the Problem

The Baja SAE competition includes schools from all over the country where students compete to create the best all-terrain, single seat sporting vehicle. The competition started in 1976 at the University of South Carolina. The idea of the competition was to make a vehicle that would compete with the one-man all-terrain vehicles that were being manufactured and put out on the market. The University of Cincinnati competed that first year and has made common appearances ever since. [1]

The cars are put through multiple tests for acceleration, maneuverability, and endurance. They must also pass a tech inspection before the competition to make sure they comply with all of the SAE standards. Many of these standards have changed over the years, most notably is that all cars will require 4WD or AWD by the 2020 competition. It will not be required for the 2019 competition, but bonus points will be awarded to teams that do have it.

When it comes to the frame/ergonomics the goal is to have a small and lightweight design that accounts for all the other components and will be able to fit someone that is shorter as well as someone that is tall. There are two different types of frame that are used in Baja cars, front braced and rear braced. Both frame designs are made up of primary and secondary roll cage members that have standards set by the Baja SAE rulebook. These two different frame designs can be seen pictured below.

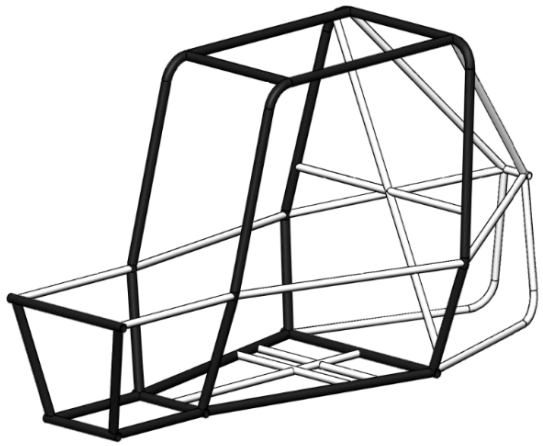


Figure 1: Baja SAE Rear Braced Frame [1]

Figure 2: Penn State Univ. 2019 Baja Car [2]

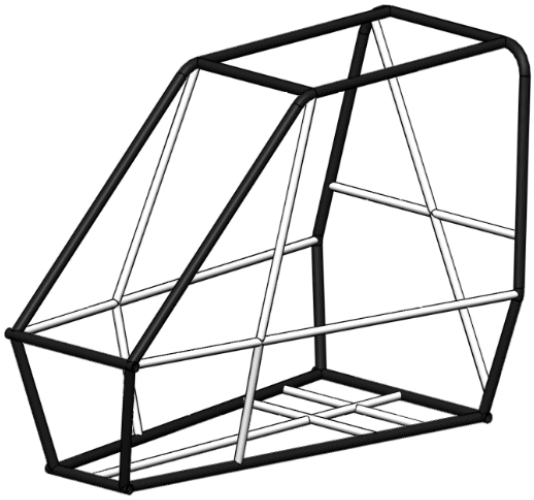


Figure 3: Baja SAE Front Braced Frame [1]

Figure 4: Univ. of Waterloo 2012 Baja Car [3]

State of the Art

Currently UC has 3 cars for the competition: one from last year's senior design team that is in great shape, one from a few years back that is functional and registered but needs improvement, and another from a few years back that is in very rough shape and is not currently functional. I looked at the past seniors' projects from 2019, 2018, 2017, 2016, and 2014 (The 2015 team did not do much with the frame).

2014 Team:

The 2014 team decided to use a rear braced design for the frame. Once a rough design was laid out, the team made changes in solidworks to adjust the frame to meet certain specifications in the rulebook. The left and right rear members of the frame were brought closer together for a narrower gap compared to previous years designs to allow more space for the rear suspension.

These members were also lengthened to allow the drivetrain to be mounted lower and therefore lower the center of gravity. The side members had a bend incorporated into them which was lower and more toward the nose of the car to allow for more leg room. Other members were designed based on rulebook standards and comfortability. All force calculations were done based on a target vehicle weight of 350lbs and a 250 lb. driver. [4]

2016 Team:

The 2015 team did not change much with the frame of the car, so it was not focused on in this report. The 2016 team decided to design a new frame that was based off the 2014 team's frame design. The three areas that they wanted to focus on were driver ergonomics, maintenance access, and weight reduction. In the rear braced frame design, there is a snub nose to the car where the pedals are placed and your feet rest. There was a small width to this part of the car that did not allow for much legroom around the driver's shins, so the team increased this clearance width in their design. Some unnecessary members were also removed to make egress easier and allow more adequate room for steering and front suspension. [5]

2017 Team:

The 2017 team focused mainly on testing and analysis to the frame of the 2014 and 2016 frame designs. The upper suspension mounting bolts were manufactured into load cells. These will calculate the axial, lateral, and vertical forces which can then be used to calculate the overall stress. 8 points were selected for the fixed geometry to do Finite Element Analysis (FEA). FEA estimations were able to show 12 unique areas where the most stress would occur, 6 symmetrically on the left and right sides of the car. [6]

2018 Team:

The 2018 team decided to use the 2016 teams frame and make changes to it to meet new specifications outlined in the rulebook. In the rulebook it says that the car should be adequate for the 95th percentile male which the current design at the time was not. They started by increasing the height to the primary members to meet clearance requirements. Since as much of the 2016 frame was being reused as possible, material selection matched what the 2016 team used. The other change that was made was to the mounting location of the seat. The four mounting points on the old car were on the backside of the car and were 1-2" above the under-seat member of the frame. These mounting points were removed, and the seat became mounted directly to the under-seat members to ensure that all clearance standards were met. [7]

2019 Team:

The 2019 team decided to build a completely new Baja car. In this team's frame design they wanted to focus on improving size for ergonomics and maximize driver safety. The design also went away from the rear braced design and to more of a front braced design. They put a good deal of focus into the welds of every joint on the car since some of the past welds were sloppy. With better welds there is more strength in these joints and driver safety is improved. They also lengthened the whole frame nearly 6 inches overall to all the driver to sit comfortably. [8]

Figure 5: UC 2014 Baja Car

Figure 6: UC 2016 Baja Car

Figure 7: UC 2019 Baja Car

End User

The end user for our teams Baja car will be us and future members of the UC Baja team. The design of the vehicle should be suited for a reliable, maintainable, ergonomic and economic production vehicle which serves a recreational use market, sized at approximately 4,000 units per year.

Summary of Research

This year's team wants to make a Baja car for UC that will be able to go to competition and be able to compete with some of the best Baja teams in the country. The team from last year made a great car that I think would sell a lot of units on the market, but wouldn't necessarily be the best in competition. Some points we would like to focus on this year are making a lightweight car, having a four-wheel drive capable powertrain, highly maneuverable car that is also easy to maintain. The frame design will have to take these points and everyone else's projects into consideration.

Quality Function Deployment

Customer Features

1. Comfortability
2. Features
3. Safety
4. User Friendly
5. Ease of Entry/Exit

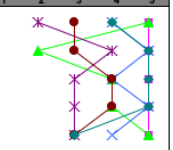
Engineering Characteristics

1. Material Selection
2. Design Selection
3. Design Quality
4. Material Cost

House of Quality

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Material Strength	Material Weight	Material Cost	Design Selection	Design Quality	Ergonomic Seating	Center of Gravity	Overall Length	Space for Engine, Pedals, Drivetrain
1	9	20.7	4.1	Comforablitily				▲	Θ	Θ	O	Θ	O
2	9	18.2	3.6	Features	O	Θ		▲	O	Θ		O	Θ
3	9	22.5	4.4	Safety	Θ	O		▲	Θ		O		
4	9	21.2	4.2	User Friendly			O			Θ			O
5	3	17.4	3.4	Ease of Entry/Exit				O		O		O	▲
6													
7													
8													
9													
10													
				Target or Limit Value	Tensile Strength (psi)	Pounds (lbs.)	Budget ($)	Front or Rear Braced	Meets Rulebook Standards	Body Angles (°)	Height (in.)	Length (in.)	Area (in^2)
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	4	2	5	7	6	9	10	8
				Max Relationship Value in Column	9	9	3	3	9	9	3	9	9
				Weight / Importance	256.8	231.2	63.6	113.6	443.5	593.4	129.6	293.4	307.0
				Relative Weight	10.6	9.5	2.6	4.7	18.2	24.4	5.3	12.1	12.6

Competitive Analysis (0=Worst, 5=Best)	Our Company	2019 Team	2018 Remodel	2016 Team	2014 Team	Razor/Polaris
	5	5	4	2	3	4
	5	2	5	4	3	5
	5	4	4	3	4	5
	5	4	5	3	4	5
	5	5	4	3	3	3



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Figure 8: House of Quality

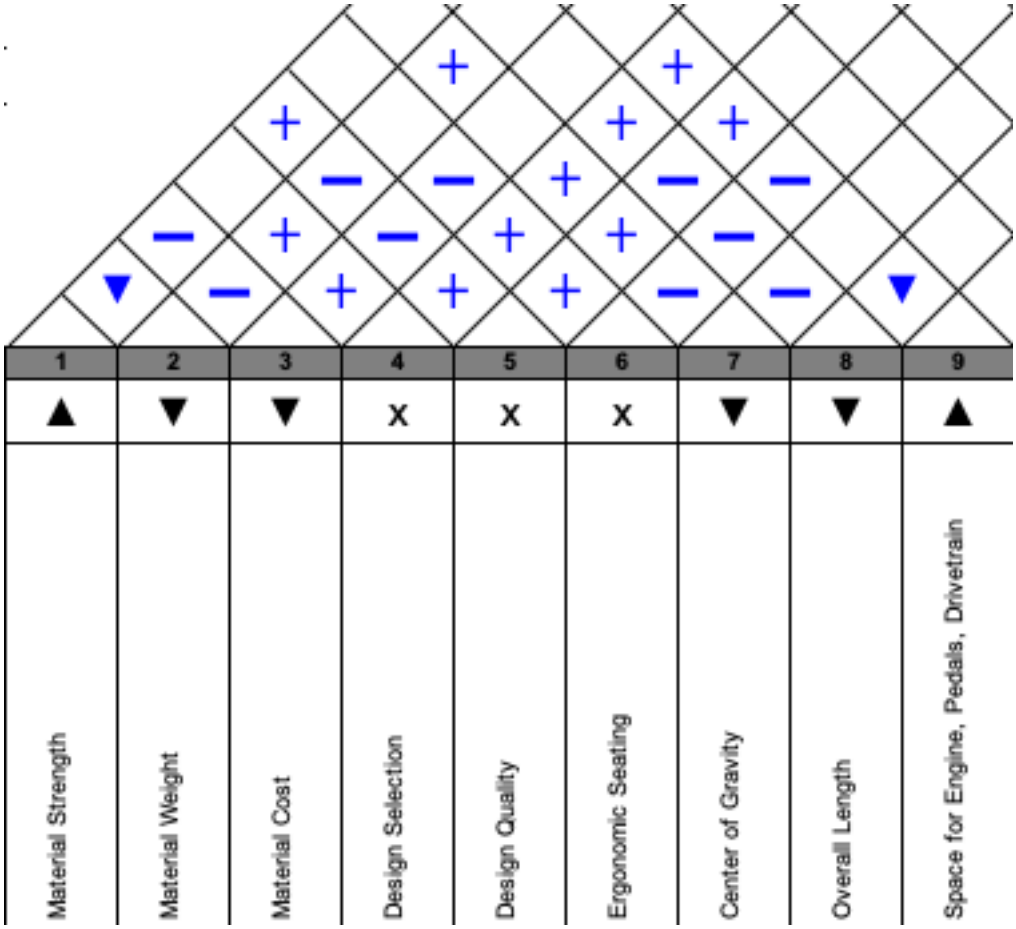


Figure 9: Integration Matrix

Product Objectives

Safety:

- The frame will be designed based on specifications outlined in the 2020 Baja SAE rulebook
- Minimum clearances will be met to protect the driver in case of a crash or rollover
- Material strength calculations will be done to ensure the frame can withstand impact

Lightweight:

- Thin walled material will be used for secondary members
- Frame will be designed to keep overall length and individual member length to a minimum

Ergonomics/Egress

- Mid-section components such as roll hoop and side members will be designed to ensure the 95th percentile male as well as the 5th percentile female can easily drive the car.
- Side impact members will have a bend to allow easy egress from the vehicle.

Mounting Clearance/Space for Components

- Front member will bend below the frame and lateral cross members will be raised to add space in the front of the vehicle.
- Seat will be raised to allow the driveshaft to run underneath, but still within the frame body.
- Rear end will be widened to allow space to drop the drivetrain and space for suspension arms.

Cost:

- Material will be donated from AK Steel.
- All fabrication will be done in house.

Design

Concept Drawings

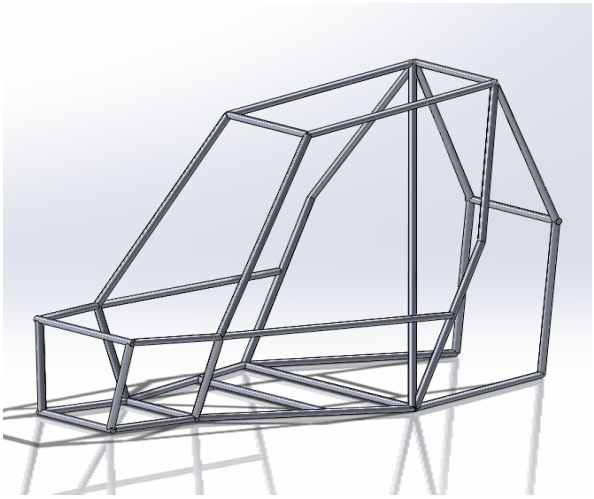


Figure 10: Initial Design 1

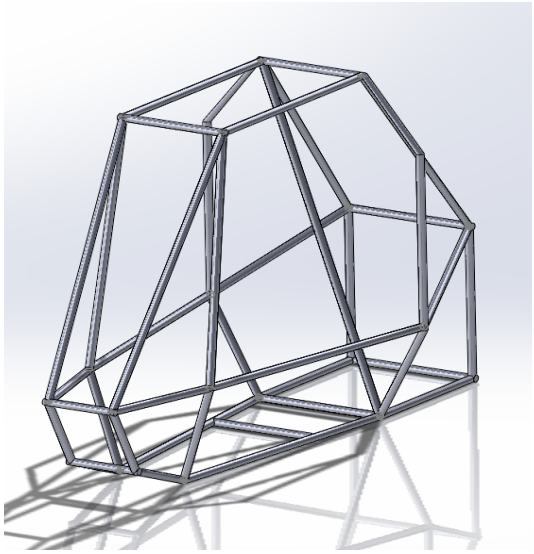


Figure 11: Initial Design 2

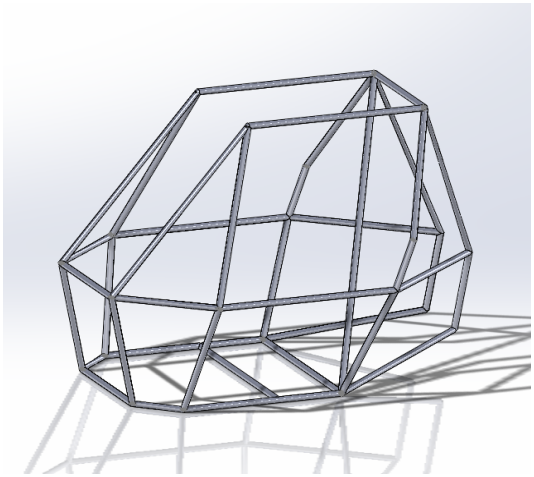


Figure 12: Initial Design 3

The figures shown above were the initial concept designs for this year's frame. The idea was to get multiple designs that had many differences between them so the team could pick and choose the best features from each one and put it together into one final frame. Listed out below are the parts that were adopted into the final design from each concept.

Concept 1	**Concept 2**	**Concept 3**
Reclined roll hoop to lower center of gravity	Front braced frame design	Front braced frame
4 part roll hoop for manufacturing simplicity	Sloped front end to avoid snow plowing effect	High side impact and lateral cross members to allow more space up front
Longer rear end to allow more room for drivetrain	Wide rear members to drop drivetrain	Shorter mid-section to reduce overall length

Table 1: Concept drawing comparison

Final Design

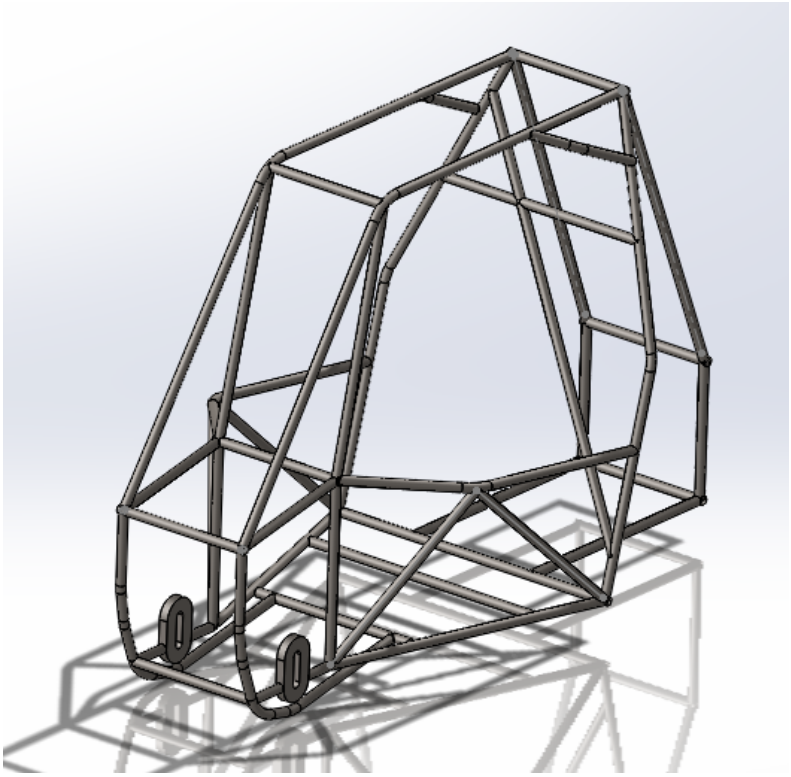


Figure 13: Final Frame Design

The figure above shows the final result of many redesigns on the frame. Features were adopted from the concept drawings as well as many other changes that were made after discussion with other project leads. As mentioned before, the biggest change to this year's competition is the 4WD/AWD requirement. This made the drivetrain design much more complex and certain parts of the frame had to be adjusted to account for this new design, mainly in the front of the car. This is where the steering, brakes, and differential for the drivetrain all need to be mounted. To account for all of these components, the front cross members were raised, and the lower side members were bent underneath the rest of the frame. Doing this greatly increase the space available up front for all those components but also resulted in part of the frame getting in the way of the front axles. To avoid this, a section of the frame was going to be cut out and hoops were going to be put in to create a slot for the axle to move up and down in. This is represented by the oval looking pieces shown in the model.

There were also some changes to the rear end of the frame to allow for the rear drivetrain mounting and maintain the space necessary for the suspension. To allow the driveshaft to run under the seat, the drivetrain gearcase needed to be lowered therefore widening the rear of the baja. There is also a minimum space needed for the rear suspension arms so as that section widened, the roll hoop width also widened. The length of the rear end was based on the minimum space needed from the drivetrain to keep from making the frame unnecessarily long. The length of the middle section was determined by placing a model of the 95th percentile male into the frame and shortening it as much as possible without making it ergonomically uncomfortable. All of these factors needed to be accounted for in the final frame design so the team would not run into problems during the manufacturing stage.

Material Selection

There are different requirements for the material that can used for primary and secondary members. The type of material should remain the same so they can be easily welded together but the size can vary based on the type of member, outside diameter, and wall thickness. Most teams will use 4130 chromoly tubing since it has a high yield strength, as well as being easy to machine and weld. For this year's frame 1020 carbon steel was used since it has similar properties and was available to be donated from AK Steel. For secondary members, the minimum outside diameter and wall thickness allowed by the rulebook was chosen to limit the weight added. For primary members, a 1 inch outside diameter with a 0.12 inch wall thickness was chosen. This was determined based on equivalency calculations showing that the material met the minimum requirements laid out in the rulebook. These calculations are shown below.

Bending Stiffness:

E = Modulus of Elasticity (205 GPa for all steels)
I = Second Moment of Area for the structural cross-section

Required Definition: 25.0mm x 3.00mm, 1018

D_o = 25.0mm
D_i = 19.0mm

$I = (\pi/64)*(D_o^4-D_i^4)$
$= (\pi/64)*(25.0^4-19.0^4)$
$= 1.28E+04\ mm^4$
$= 1.28E-08\ m^4$

$K_{b,req} = E*I$
$= (205GPa * 1.28E-08\ m^4)$
$= 2.62E+03\ N*m^2$

Design Definition: 25.4mm x 3.05mm, 1020

D_o = 25.4mm
D_i = 19.3mm

$I = (\pi/64)*(D_o^4-D_i^4)$
$= (\pi/64)*(25.4^4-19.3^4)$
$= 1.36E+04\ mm^4$
$= 1.36E-08\ m^4$

$K_{b,des} = E*I$
$= (205GPa * 1.36E-08\ m^4)$
$= 2.79E+03\ N*m^2$

Bending Strength:

S_y = Yield Strength (minimum specification value)
C = Distance from the neutral axis

Required Definition: 25.0mm x 3.00mm, 1018

S_y = 365 MPa
C = 12.5mm
= 0.0125m

$S_{b,req} = (S_y * I)/C$
$= (365MPa * 1.28E-08\ m^4)/(0.0125m)$
$= 3.74E+02\ N*m$

Design Definition: 25.4mm x 3.05mm, 1020

S_y = 551.39 MPa
C = 12.7mm
= 0.0127m

$S_{b,des} = (S_y * I)/C$
$= (551.39MPa * 1.36E-08\ m^4)/(0.0127m)$
$= 5.90E+02\ N*m$

These calculations are outlined in the rulebook and are also required in the roll cage documentation that needs to be submitted for competition. In the left column is the required stiffness and strength that must be met, and the right column shows the calculations for the material that this year's team selected. These calculations are only required for the material used for the primary members of the frame. From them, it can be seen that the material has a greater stiffness and strength than the required material therefore meeting the requirement for competition.

Project Management

Project Budget

Category	Cost	Source of Income
Tubing	$0	AK Steel
Sheet Metal	$165.62	Team Funds
Manufacturing	$0	Team Labor
Tooling	$89.95	Team Funds
Misc.	$161.48	Team Funds
Total	**$417**	

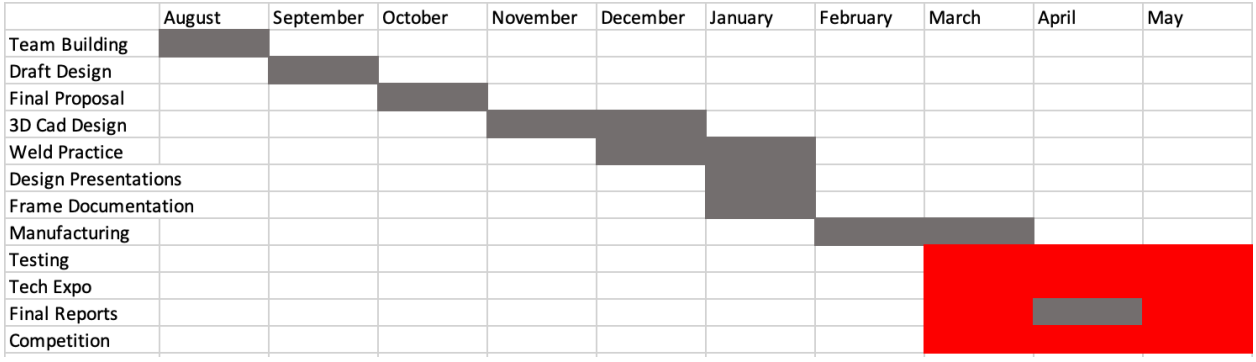
Table 2: Project Budget

Bill of Material

Item #	Manufacturer	Part Number	Quantity	Description	Vendor	Cost per Piece	Cost Total
1	AK Steel	SP-T33269	5	20' 1" OD x 0.93" ID 1020 Steel	Ferguson	$0	$0
2	AK Steel	SP-T33360	5	20' 1" OD x 0.76" ID 1020 Steel	Ferguson	$0	$0
3	Metal Supermarkets	HSH120	2	4' x 4' x 0.12" Hot Rolled Steel	Metal Supermarkets	82.81	165.62
4	Central Machinery	42324	1	Tubing Notcher	Harbor Freight	$60	$60
5	Chicago Electric	62863	1	Bandfile Belt Sander	Harbor Freight	$29.95	$29.95

Table 3: Bill of Material

Project Timeline



- COVID-19 Outbreak

Table 4: Project Timeline

Project Summary

Due to the COVID-19 outbreak, the manufacturing stage for this project was cut short. Almost all of the frame was constructed minus a few members and the mounting pieces. This project was much different from previous years with the new 4WD/AWD rule. This altered everyone's design from what they would typically do including the frame. There were many alterations that needed to be made to account for the new drivetrain especially in the front end. Being the frame lead is a great experience considering it involves solidworks design, material calculations, document management, welding/machining skills, and a great deal of communication with other members of the team to incorporate everyone's project. This Bearcat Baja team was cut short on manufacturing, but next year's team will have a great head start and should be able to finish the car and be successful in competition.

References:

[1] Baja SAE Rules Committee. “Collegiate Design Series Baja SAE Rules.” SAE International, 8 Sept. 2019.

[2] “Student-Designed Transmission Passes Test for Baja Automotive Engineering Event.” *Penn State University*, 18 Apr. 2019, news.psu.edu/story/570022/2019/04/18/student-designed-transmission-passes-test-baja-automotive-engineering-event.

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[5] Forrest,Jonathon. “2016 Baja SAE Series Frame Design.” University of Cincinnati, Apr. 2016.

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[8] Tschaenn, Charles. “2019 University of Cincinnati SAE Baja Frame.” University of Cincinna