E-Baja Conversion Team

Final Proposal

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DISCLAIMER

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EXECUTIVE SUMMARY

BAJA is the racing car which is to be designed in such a way so that it can withstand the severest elements of bumpy terrain. The objective of this project is to simulate real-world engineering design and their related challenges on BAJA racing vehicle. The reengineering of the Baja Car into a full electric model is important for several reasons. Firstly, electric off-road vehicles are silent than diesel and petrol-based vehicles, with reduced noise pollution. Secondly, an electric model would be cheaper to operate due to higher energy efficiency and low maintenance costs due to less moving parts compared to the original design. Moreover, the project envisions improved safety of the vehicle, with reduced risk for fires and explosions.

For designing of different components of BAJA, team members interacted with all the stakeholders to find the customer requirement that needs to be fulfilled. The team derived the engineering requirement from the various requirements posed by all the stakeholders.

The team did a lot of research on the BAJA that are available in the internet to get the better understanding of it. The team focused on the front suspension, rear suspension, steering and brakes. They discussed among themselves in order to fix them. Each team member was given the task to analyze the problem and come out with the solution. The tool used for evaluation of the individual design is Pugh Chart and decision matrix. The steps those performs well in the evaluation were chosen for developing phase.

The design is validated for four components i.e. Rear Suspension, Front Suspensions, Steering and Brakes. The complications were identified first and after completely analyzing it with theoretical and practical approach. The solutions were obtained for different problems and best solution is implemented which results in the solving the concerned difficulties according to the customer requirements.

The design of rear suspension is built like a truss with triangles and can absorb forces in several directions. This will really increase the suspension performance and rigidity of the suspension in the rear of the car. The front suspension design is improved by increasing the size of the supports and the diameters of the Heims, the suspension will hold up much better. The rack and pinion mechanism is recommended for steering assembly which worked fine and is good enough for this design of the car. The brakes are the critical component for any vehicle which relates to safety, so modifications are done by changing it into four brake assemblies in order to stop the car with an acceleration of 30 mph.

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1 BACKGROUND

1.1 Introduction

With advances in technology, researchers in the field of automotive engineering continuously seek to improve an aspect of existing designs such as efficiency or safety by incorporating new design ideas. The aim of this project is to transform the 2015-2016 Baja Car to a full electric model. The reengineering of the Baja Car into a full electric model is important for several reasons. Firstly, electric off-road vehicles are quieter than diesel and petrol-based vehicles, with reduced noise pollution. Secondly, an electric model would be cheaper to operate due to higher energy efficiency and low maintenance costs due to less moving parts compared to the original design. Thirdly, with the increasing concerns over climate change and global warming, there is growing demand for automobile designs that enhance environmental sustainability. The electric car design envisaged in this project provides an opportunity to enhance the use of renewable energy, reduce environmental pollution from greenhouse gas emissions, and eco-friendly materials. Improved air quality will lead to less health problems. Moreover, the project envisions improved safety of the vehicle, with reduced risk for fires and explosions.

1.2 Project Description

Following is the original project description provided by the sponsor: "Northern Arizona University's (NAU) Mechanical Engineering Department has a student chapter under the Society of Automotive Engineers (SAE) and every year, these students design, build, test and compete in the SAE Baja competitions. After the students have competed, their Baja vehicle is used as educational purposes or scraped for the next year to use. As of the Fall semester of 2019, the Engineering Department has decided to allow a team of Engineering students to use a previous year's Baja vehicle and convert it into a full electric Baja vehicle. The team is divided into two sub-teams, Mechanical Engineering (ME) students and Electrical Engineering (EE) students. The ME team are focused on bringing the vehicle up to safety standards, repairing parts such as adding functional brakes, steering, front suspension, and designing the rear suspension and a new gear box to set up with an electric motor, along with fabrication to mount the electrical components. The EE team are focused on all electrical components such as the batteries, charging, motor, power electronics and controls. The two teams will combine their resources and knowledge to design a full electric Baja vehicle. The vehicle will be showcased at SAE and NAU events. This is a first-year project and a first step to designing electric vehicles at NAU. The project is advised under the project's clients, David Willy (ME team) and Dr. Venkata Yaramasu (EE team). The project is financial sponsored by W. L. Gore and more to come in the project's year." The project description is updated from the original project description to meet the new regulations and standards from the project's clients.

2 REQUIREMENTS

This section provides both the customer and engineering requirements. The customer requirements are provided from the SAE Baja India and the client of this project David Willy. The reason for using the SAE Baja India is that it is the only SAE rules that have electrical based Baja rules.

2.1 Customer Requirements (CRs)

Table 1: Customer Requirements and Weight

Customer Needs	Customer Weights (5 Most to 1Least)
Safety of User	5
Follow SAE E-Baja Rules / Industry Standards	5
Redesign Rear Suspension System	5
Redesign and Provide a Functioning Brake System	5
Electric Compatible Drive Terrain	4
Reinforcing Front suspension	4
Provide Space for Battery Mount	3
Redesign Steering	3
Ease of Fabrication of Components	2

Table 1 shows our customer requirements that the team got from both the SAE Baja India and our client David Willy. The weights are rated 5 being most and 1 being the least important. The highly weighted are safety of user, following the SAE E-Baja rules and industry standards, redesign suspension system, and provide a functioning brake design (All weighted at 5). The least important is fabrication. fabrication is rated at 2 out of 5 is because the team is willing to do minor fabrication to the vehicle sub-systems such as steering and suspension. The team will not do major fabrication for the vehicle frame. Redesigning suspension system provide a functioning brake system, electric compatible drive terrain, providing space for battery mount, and redesigning steering are all considered in the category of reliable, robust, and durable design. And the team decided to break it down to show the concentration of each sub-system in the vehicle.

2.2 Engineering Requirements (ERs)

The engineering requirements generated according to the customer requirements. The engineering requirements were ranked according to the relative technical importance, which was calculated is the House of Quality excel spreadsheet. The engineering requirements are shown in the table below:

Table 2: Engineering Requirements

Engineering Requirements	Relative Technical Importance	Technical Requirements Target	Tolerance for Targets
Safety (Factor of Safety)	1	2.5 or Above	Min of 1.5
Speed of the Vehicle (Miles Per Hours)	2	30 mph	± 10 mph
Cost	3	$3000	NA
Torque of the Vehicle (Newton-meters)	4	Pinion = 85 ft-lbf Gear = 520 ft-lbf	± 20 ft-lbf
Range of Motion of the Steering System (Degrees)	5	60 Degrees	± 15 Degrees
Weight of the Vehicle (lbs)	6	800 lbs	± 100 lbs
Power of Motor (Kilo Watts)	7	7.5 KW	Max of 32 KW

The engineering requirements above satisfies the customer requirements. For instance, safety is considered the most important requirement our target is equal to or greater than 2.5 anything lower than 2.5 should be tested. Speed and torque of the vehicle are both important in order to design the perfect gear that serves the best for the vehicle. The torque value is still to be determined. Cost is set as $3000 which is the original budget provided by W.L. Gore. The tolerance for cost is set as not applicable is because the team is planning to fund raise for the project. The vehicle also lacks steering functionality; therefore, the range of motion is included to fix the steering problem. The target for range of motion is 60 degrees and the tolerance is ±15 degrees. The weight of the vehicle target is 800 lbs and the tolerance is ±100lbs since it will cover the driver weight. Lastly, the power of motor target is 7.5 KW, that is to match the SAE India E-Baja Rules (Only Electric based Baja Rules that follows the Society of Automotive Engineers), the team tolerance is set as max of 32 KW. This is because the Electrical engineering sub team decided to choose a motor which has a maximum power of 32 KW.

2.3 Functional Decomposition

2.3.1 Black Box Model

In this section, the Black Box Model is introduced to facilitate the visualization of this team's project. The purpose of the team is to create a Baja vehicle that will be capable of running on electrical power. Therefore, this model was made based on the need for the entire vehicle to move.

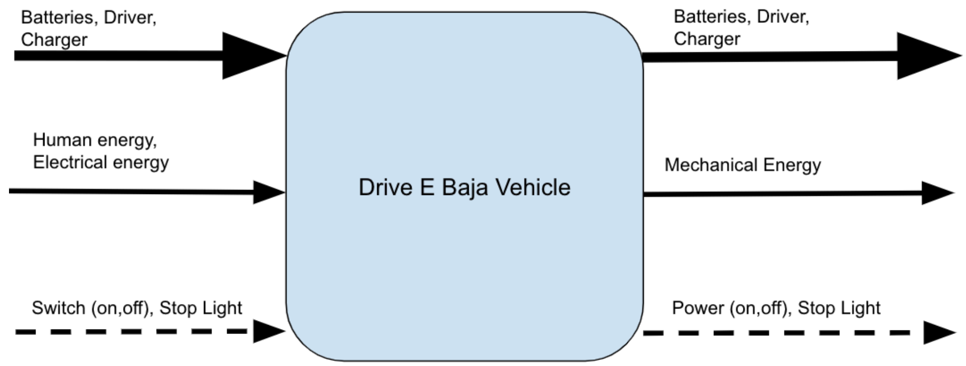


Figure 1: Black Box Model

The materials used to drive the electrical Baja vehicle are batteries, a battery charger, and a driver. All those materials are either replaced, charged, or removed once the vehicle is no longer on. The energy used is electrical and human which gets converted into mechanical energy via an electrical motor. The signals provided are the on/off switch and the stop light that will tell if the vehicle is slowing down. This black box model simplifies the problem outside of the vehicle. The inputs shown in the figure above are the only things necessary to accomplish the team's goal. Everything else is broken into certain subgroups within the functional model.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

This is a continuation of the black box above. It clarifies what happens within the black box. It provides a general illustration of where the inputs go to become the outputs. However, due to client wishes, the vehicle has not been taken apart to create a more accurate representation of internal functions.

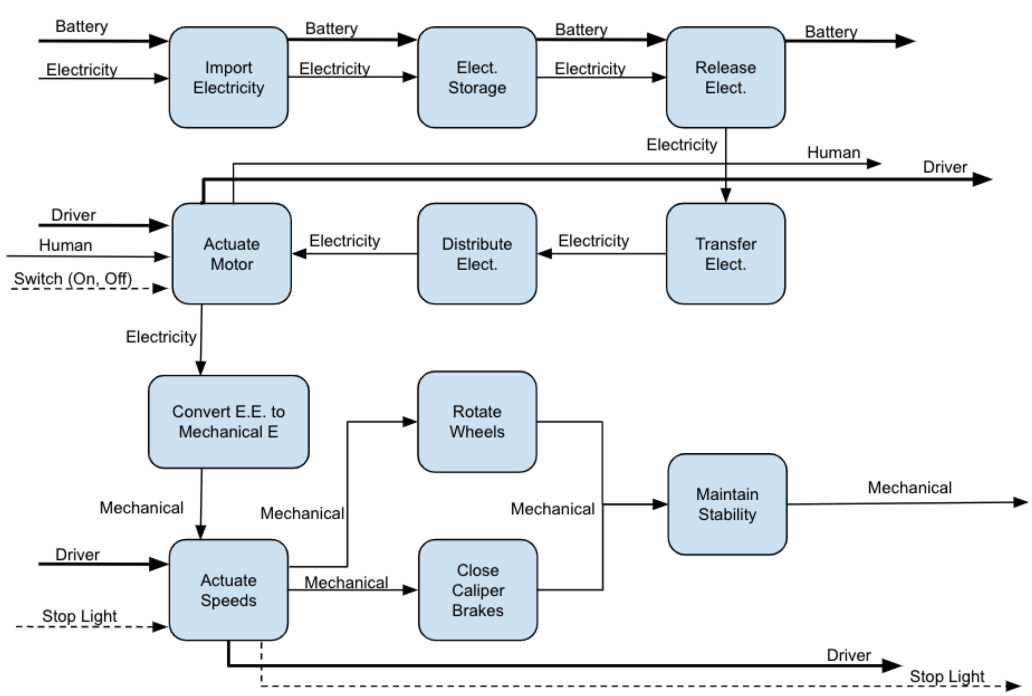


Figure 2: Hypothesized Functional Model

As the black box model begins with the inputs, so does the functional model. Since most of the focus will be on electrical components to move the vehicle, five of the sub functions above were assigned to it. As electricity moves through its components, it eventually actuates the motor to turn the shaft and become mechanical energy in the form of rotation. However, to do that, the driver must turn on the vehicle by using the switch that will complete the circuit. Next, the driver can use that mechanical energy and control the speed by using either the throttle or the brakes. For the final subcomponent in the visual, any dynamic movement of the vehicle will create movement in the suspension system. The suspension is used to create stability through the dynamic movement of accelerating, braking, or the terrain the vehicle is expected to traverse.
This functional model will help the team move forward because it gives a clearer representation of what components affect each other. Also, there is a better understanding of why each component is important. For example, the stop light signal is important when the brakes are being used because it warns the subject behind it that it will stop. It keeps the driver safe which is a necessary material of the black box model. Once the team can dissemble the vehicle, then more subcomponents will become clearer and how they relate to one another. The three main components used in the functional model are the electrical, the brakes and the suspension. The steering is not mentioned cause the team has not found a direct relation yet. Although the team knows the vehicle will not drive without steering, how can it be related to the suspension? Questions like this will be answered after disassembly.

2.4 House of Quality (HoQ)

The Figure below shows the House of Quality team has constructed. The top part of the House of Quality compares each Engineering requirements with each other providing a brief vision on the complexity of the procedure on applying each engineering requirement would result in. The body of the House of Quality shows the Customer and Engineering Requirements compared to each other. The bottom part shows the ranking of each Engineering Requirements based on the Absolute Technical Importance, which has been calculated in the excel spreadsheet. The House of Quality gave the team a clearer vision on meeting the customer requirements. It made the team concentrate on the most important engineering requirements, which has been mentioned above (Section 2.1 & 2.2). As a result, the team is currently divided into sub-teams to ensure every customer weight and engineering requirements are met.

Dividing the car to two parts, front and back. The team started doing research on front suspension first, afterwards started doing the steering and brakes. And similarly, in the back; find total weight first then proceed with the rear suspension and gear. This procedure was used according to the relative technical importance rankings. In addition, this procedure was inspired from the house of quality results, which prevents the team from setbacks.

	Weight of the Vehicle	Range of Motion of the Steering System	Torque of the Vehicle	Cost ($)	Power of Motor	Safety (Will run efficient)	Speed (m/s)
Weight of the Vehicle							
Range of Motion of the Steering System							
Torque of the Vehicle	-						
Cost ($)							
Power of Motor	-	-	-				
Safety (Will run efficient)	+		+	-			
Speed (m/s)		-		-			

		Technical Requirements						
Customer Needs	**Customer Weights (5 Best to 1 Least)**	*Weight of the Vehicle*	*Range of Motion of the Steering System*	*Torque of the Vehicle*	*Cost ($)*	*Power of Motor*	*Safety (Will run efficient)*	*Speed of the Vehicle*
Safety of User	5	3	9	1	3	3	9	9
Follow SAE E-Baja Rules / Industry Standards	5	3	3	9		3	9	
Provide Space for Battery Mount	3	3		1	1	1	1	
Electric Compitable Drive Terrain	4	3	3	9	9	9	9	9
Redesign and Provide a Functioning Brake System	5	3	3	3	3	3	9	3
Reinforsing Front suspension	4	9	1	9	9	9	3	9
Ease of Fabrication of Components	2	9	9	3	9	9	9	3
Redesign Rear Suspension System	5	3	3	1	9		9	9
Redesign Steering (Rack and Pinion)	3	3	9	1	3		9	9
Technical Requirement Units		lbs	Degrees	pounds force feet	$	KW	Factor of Safety	MPH
Technical Requirement Targets		800	60	G = 520 P = 85	3000	7.5	2.5	30
Absolute Technical Importance		144	151	154	177	138	276	210
Relative Technical Importance		6	5	4	3	7	1	2

Figure 3: House of Quality

2.5 Standards, Codes, and Regulations

This portion will discuss what standards the team is following to complete the Baja vehicle. The client has specified to follow the Society of Automotive Engineers. The team also decided to research the American Society of Mechanical Engineers because of the overarching presence of mechanical engineering students in this project. The following table provides information on the standards, codes and regulations found to bound and assist in the project scope.

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
SAE B.10.1.1	Batteries	Specifications on mounting, sealing and capacity of batteries used in vehicle.
SAE B.8.3	Firewall	Provides specification of firewall for safety of driver from motor components.
SAE B.12	Fasteners	Given specifications of all fasteners that are used in high risk components like safety and motor.
SAEIndia C.3.1	Tractive System Accumulator	Specification on battery storage and mounting into vehicle.
SAEIndia C.2.1	Electrical Kit Requirements	Battery, motor and power specifications to not exceed.

These regulations will allow the team to proceed with a more specific scope of work. The fasteners used in the previous project that built the Baja vehicle being worked on yielded due to high impact force. Following SAE B.12 will give the team options of what to choose when connecting parts. SAE B.8.3 will comply with the client's safety desires. The firewall was a part missing from the previous project as well. Battery storage has become a new part of the scope of work. Dr. Yaramasu, the electrical engineering client has asked the mechanical team to create battery storage. Which is why SAEIndia C.3.1 will be helpful to understand how the electrical Baja competition teams create it in India.

3 Testing Procedures (TPs)

The following sections explain the testing procedures to be done on the e-Baja vehicle's subsystems. Each subsystem will be tested in a different procedure. Due to the vehicle not in operation, most testing procedures will be tested until the second semester of the capstone project.

3.1 Testing Procedure 1: Rear Suspension

The team will test the rear suspension system firstly on Solidworks through FEA (Finite Element Analysis) using von mises stress to get the weak links. After that the team will test the system in a an extremely rough drive condition with max speed of approximately 30 mph.

3.1.1 Testing Procedure 1: Objective

The team will run the design thru Solidworks FEA to determine a factor of safety that must be above 1.5. Using Solidworks first is important in order to minimize wasting the team funds, since the rear suspension will be machined. After that the system will be put under rough driving conditions with bumps and dips. If the system does not show any signs of bending, then the system will pass the test.

3.1.2 Testing Procedure 1: Resources Required

This test will require the usage of a software which will be Solidworks. In addition, this test requires the whole team (5 members) to be present in case the system fails. Since the vehicle is heavy to transport a trailer and a truck will be required and a rough driving condition location. The team have a truck and a trailer available and may transport the vehicle to Cinder Hills off-road park in Flagstaff, Arizona for testing, since it is open all year and has a rough driving condition.

3.1.3 Testing Procedure 1: Schedule

This test will be as soon as the vehicle is complete. The motor, steering, front suspension, and gears need to be installed. Since it is one of the main parts of making the vehicle safe the team is planning to have it tested in week 8 of next semester. The test should take 15- 30 minutes.

3.2 Testing Procedure 2: Front Suspension

The front suspension system of an automobile is a crucial component which assures safety in driving and comfort of passenger. This system has a shock absorber which is the main element. A damper which is worn-out lessens the contact of tire and rod, consequently it increases ending distances. Likewise, lateral steadiness may be compromised as a consequence of unrestrained rolling actions. In order to continue harmless driving circumstances, it is crucial to confirm the position of the suspension system. Along with shock absorber, various components like Heims and Bolt Joints are also checked.

3.2.1 Testing Procedure 2: Objective

The suspension on the front has a purpose to decrease the abrupt load of impact when an automobile hits an unevenness road, which results in the impact to be stored in the suspension springs and thus releasing this impact energy in the springs coil. The normal method to assess a shock absorber is to push it down by implementing an external load on an automobile corner for a limited time to make it bounce and then stop the external pushing and observe that how long the bounce continues before ending. A shock absorber having good impact absorbing properties must quickly stop the bouncing of the body. The Heims and Bolts are tested by similar way, when load is applied the sound of joints will be observed which will show the status of joints.

3.2.2 Testing Procedure 2: Resources Required

The testing of front suspension does not require too much to perform it. Three persons are enough in order to test the front suspension. One will apply the periodic loading on the front suspension, 2nd will observe the shocks and 3rd will observe the produced sounds. The satisfaction of the result will be confirmed the respective observer. If there are no sounds produced, it means heims and bolt joints are satisfactory. Similarly, if shocks produced by periodic loading vanishes right away, it means that shocks absorber is in good position.

3.2.3 Testing Procedure 2: Schedule

The front suspension testing is very simple process. It will take 3-4 minutes to complete the test. The test should be performed prior to driving. It will give the existing status of front suspension

3.3 Testing Procedure 3: Steering

The testing procedure for the steering will help the team's analysis if the steering components will operate properly. The steering components will be tested using a computer program and visually inspected. The vehicle will need to turn with no problems. The extra attachment should not break, and the wheels should be aligned properly.

3.3.1 Testing Procedure 3: Objective

The testing will be done on computer simulations and with the team rotating the steering-wheel to see if the wheels turn proper. The testing will be to make sure the wheels have an easy, smooth turn without great force and the wheels are aligned. The extra attachment will be tested using FEA on SolidWorks and visually tested while it is on the vehicle and analyzed throughout the driving for any signs of stress or fatigue.

3.3.2 Testing Procedure 3: Resources Required

The test will consist of SolidWorks, Lotus and visual inspections. The only resources are the computer programs, SolidWorks and Lotus, and at least three students (one driver and two on each side of the front wheels) to visually inspect the steering. The team will continue to monitor the steering as the driver continues to drive or while not moving.

3.3.3 Testing Procedure 3: Schedule

The testing should be no longer than a week. To test the steering, it will be tested once the steering components are put into place and when the vehicle is moving and becomes fully operational. The testing during the movement of the vehicle will not be done until next semester when the vehicle becomes operational.

3.4 Testing Procedure 4: Brakes

The test for the brakes is to make sure that the brakes operate and stop the car properly. The team will be following the same testing procedure that is used at the SAE Baja competition. The test requires that all four brakes lock up when the driver presses the brake pedal hard. The car will be driving at about 20 mph and the driver will hit the brakes and if all four brakes lock up when its coming to a stop the car will pass inspection.

3.4.1 Testing Procedure 4: Objective

This test will begin with ensuring that all the brakes are in proper working condition. Once all the brakes are inspected, the driver will start driving and get just over half throttle which will be equal to about 20 mph. When the person inspecting the brake system signals, the driver will fully depress the brake peddle and hold it until the car comes to a stop. The inspector will be watching each of the tires on the vehicle. If all the tires lock up, the car will pass inspection. If there is a tire that doesn't lock up, adjustments will have to be made to the brake system to get more pressure to the system. If all the brakes do lock up, it will ensure that the car is able to stop at the fastest possible time. With the shortest stopping distance, this will help satisfy the customer requirement of keeping the driver safe.

3.4.2 Testing Procedure 4: Resources Required

This test is a simple test to run that doesn't require many resources. The only resources needed are two inspectors (one for each side of the vehicle) and a dirt lot to run the car in. The team needs a dirt lot that the car tires can break free from during the test. The lot could be a dirt road that is long enough for the car to get to speed and come to a full stop during the test.

3.4.3 Testing Procedure 4: Schedule

This test will not be tested until the car is in full operating condition. It is required that the car is fully running with the motor on, steering, and brake system is installed. Due to needing the car to be fully operational, this won't be done until later in next semester. It will probably be tested around week 10 of next semester. This will give the team time before the testing to get the car built, and time after the test to make any required changes. It won't be a major deal to run this test later in the semester because the test only takes approximately an hour to run. This test could also be run the same day that the team is testing the performance of the vehicle. This team will take the car out to a dirt area to test the suspension, drive time, and the braking all in the same day.

4 Risk Analysis and Mitigation

The following sections explains the potential critical failures within each redesigned subsystems of the Baja vehicle. Each potential failure is accounted for when the subsystem begins or when it will fail. The sections give warnings to the driver and owner of this vehicle and explains how each failure will happen.

4.1 Critical Failures

4.1.1 Potential Critical Failure of Rear Suspension

4.1.1.1 *Bends due to Impact*

The L-shaped trailing arm is connected by a hinge to the frame. It will be replaced by a heim joint to release the pressure and add a small degree of freedom. Also, the current damper could not have the necessary shock absorption for certain terrain impact. This can lead to bending of the frame or of the trailing arm. The correct damper will be chosen in advanced of it's corresponding terrain. The driver will be notified what impact the vehicle can take and shall not move into rougher terrain.

4.1.1.2 Shears due to Impact

Connecting rods can snap if impact with the ground. They must be low to hold the wheel the correct way but will be exposed to rough terrain. They must be examined after every use to ensure safety of the driver. The fasteners used to attach the connecting rods and the trailing arm to the knuckle and back to the frame can shear due to excessive force of impact. These pieces must also be examined after every use to ensure they have to yielded. Design must be ready withstand the force.

4.1.2 Potential Critical Failure of Front Suspension

4.1.2.1 Shears due to impact

The shear due to impact is caused when the suspension is compressed state which results in stresses. Its function is to connect A-arm to vehicle frame which is caused by faulty steering and driving. The wear must be checked in order to work safely. Also, Its function is to replaces hinge joint to release force resistance. It is caused by Faulty Steering and Driving. The driver must be prepared for vehicle control and it should be examined after use.

4.1.2.2 Bends due to impact

The bend due to impact is caused when the suspension is compressed state which results in stresses. Its function is to Absorb elastic deformation the knuckle and shock force onto the vehicle. It is caused when the car is not drive for long time state. The wear must be checked in order to work safely.

Figure 4:Bending from old heim joints

4.1.2.3 Snaps due to excessive forces

The snap due to excessive forces is caused when the suspension is compressed state which results in stresses. Its function is to Absorb elastic deformation the knuckle and shock force onto the vehicle. It is caused when the car is not drive for long time state. The bumpy terrains increase the suspension impact which must be avoided.

4.1.2.4 Shears/Bends due to impact

The shear/bend due to impact is caused when it is exposed to "Rougher" ride. Its function is to absorbs impact from ground. It is caused by impact beyond fabrication point. The driver must examine the vehicle after use.

4.1.3 Potential Critical Failure of Steering

The follow explains the main potential critical failures that could happen on the steering components. The main failures consist of the stress, bends and shear on the extra attachment or bolts that connect the extra attachment to the front steering knuckles.

4.1.3.1 Stress/Bends on Extra Attachment

The extra attachment is a redesign of the old design that currently sits on the Baja vehicle, this new attachment will be built and designed by the team. This design will be longer and more durable; however, the design is still prone to failure. There will be forces applied to the attachment and it will cause stresses and bending moments on the attachment. The attachment should not experience forces high enough to cause critical failure but are subject to these failures over a course of time.

4.1.3.2 Shear/Bends on Bolts

There will be bolts connecting the attachment to the front steering knuckles. Each bolt currently on the Baja vehicle will be replaced due to lack on consistence of types of bolts and missing nuts on the end of the bolts. These bolts will experience forces causing shear stress and bending moments. The bolts should not experience forces high enough to cause critical failure but are subject to these failures over a course of time.

4.1.4 Potential Critical Failure of Brake

In the brake system, there are not many places that it can fail. Due to the brake system being crucial to the safety of the driver, this system is made to have very little chance for failure. The brake system currently has a factor of safety of 2.7 which is much higher than the client was asking for. The client for this car was asking for a factor of safety of 1.5. With this being the case, it is possible for the car to lose functionality of one of the brake assemblies and still be able to stop. The required stopping distance for the car would increase but would still stop, keeping the driver safe.

4.1.4.1 Brake Line Cut

One way that the brake system could stop working is if the brake lines get cut somehow. If one of the brake lines is cut, it would eliminate both brakes on that line. The team is trying to eliminate this possibility by running the lines tight to the frame as well as having steel braded brake lines. This will help keep the lines out of the way of any obstacles and if they do catch, the steel tubing will be harder to cut.

4.1.4.2 Loss of a Brake Cylinder

The car is equipped with two brake cylinders, one for the front brakes and one for the rear. This makes it so that if one of the cylinders goes bad while driving, there are still brakes for the other end of the car. The failure of a brake cylinder is super small because there isn't much stress being applied to that system of the car.

4.2 Risks and Trade-offs Analysis

For the car that the team is designing, safety is the number one requirement that the client has given us. Whatever the team does, the driver's safety is the number one priority. Due to this being the case, there are not a lot of places that the team can cut out of the design. There are certain areas where lighter materials can be used but there aren't many cases for that. The frame that the car is made with, is an extremely durable design and has heavy duty materials. The frame is really heavy compared to current Baja cars but it is also much stronger. There is not safety concern with the frame at all. The goal of the team is to make the car perform the best it can and for long as it can. To obtain this, the team is trying to make the car as light as possible. The team can save this weight in parts such as the gearbox where safety isn't a major concern. The trade-off with this is that a lighter gearbox means that it isn't as robust. The car may run a bit faster, but the gearbox won't last quite as long. The team isn't looking for the car to last for forever and won't be driven much once it is up and running. Having lighter parts like the suspension and the gearbox will do just fine for the team.

As mentioned above, safety and performance are the teams number one goals. The Ebaja team doesn't have to worry too much about making the car super light because the motor that is going to be used has an extreme amount of power. This motor has approximately four times as much power as what was previously on the vehicle. This will help with the moving of the car at a faster speed and accelerating much faster as well.

5 DESIGN SELECTED – First Semester

The team went through concept generations, decision matrixes, and concept calculations to better design a Baja vehicle based on customer and engineering requirements. The team appointed lead positions to each team member for individual subsystems on the Baja vehicle. The follow subsystems are the rear suspension, front suspension, steering, brakes, and gear box. Each lead position came up with ideas to better design the vehicle's subsystems and presented each idea to the whole team. The team assisted in deciding how to design the new subsystems. The follow sections explain the design selections that were made to become part of the e-Baja vehicle.

5.1 Design Description

5.1.1 Rear Suspension

The rear suspension is considered one of the main components to provide a well-functioning vehicle. The team have considered doing an individual technical analysis to both current installed and proposed suspension system, which are still in process. A comparison will be made between both results and the final decision will be decided upon those results. The team is currently convinced on changing the current design which is an L shaped trailing arm to an A shaped trailing arm shown in the figure below.

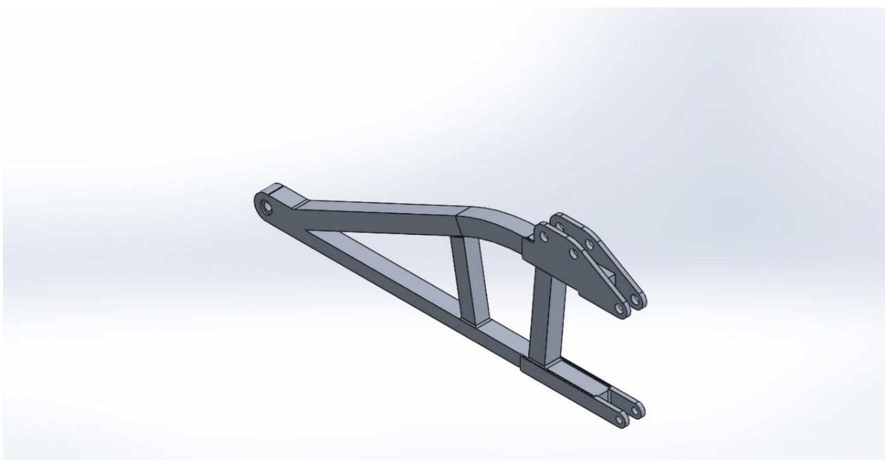


Figure 5:A shaped trailing arm CAD model

The team have conducted geometry calculations (see Appendix A). In order to obtain the length of the trailing arm. The team is using a program called Lotus that calculates over 15 specifications of the vehicle suspension analysis such as toe angle, camber, droop, bump, etc. In addition, the team will run a finite element analysis to obtain the weak points and modify the final design to match the customer and industry requirements. The proposed design also provides an extra 24 cm in each side to provide the electrical engineering sub team with extra space. The length of the trailing arm will be 44 cm angled at 33 degrees from the center. The shock total length is 53 cm and upon completion of the technical analysis the team will have the decision of the angle the shocks should be installed. The proposed design will show a higher degree of freedom than currently installed. The team is carful and patient with the rear suspension design and uses all available resources in order to prevent failure and costing the team unnecessary expanses. The proposed design is currently used by ATV manufacturers such as Polaris as shown in the figure below.

Figure 6: Polaris RZR 1000 Rear Suspension system (Stuff, n.d.)

5.1.2 Front Suspension

The front suspension design is also going to be an improvement compared to what is on the car now. The car in the past has had issues with the components snapping or bending. By increasing the size of the supports and the diameters of the heims, the suspension will hold up much better. None of the angles or main front suspension need to be changed due to already being a great base design. With small improvements, this design will work great for the car. The calculations for the heim diameter can be seen in the Appendix B below.

5.1.3 Steering

The steering design will continue to use the rack and pinion design and the current front steering knuckle but add a new attachment to assist in proper turning for the car. The new attachment will give the car an ideal Ackermann angle for acceptable turning. Ackermann angle is the angle for which the wheels can turn with an ideal radius and avoid the wheels from scrubbing, this allows the front wheels to turn at different angles (reference from the vehicle's center of axis) and the wheels' perpendicular axis line up with the rear wheels axis, all meeting at one point as shown in Figure 7.

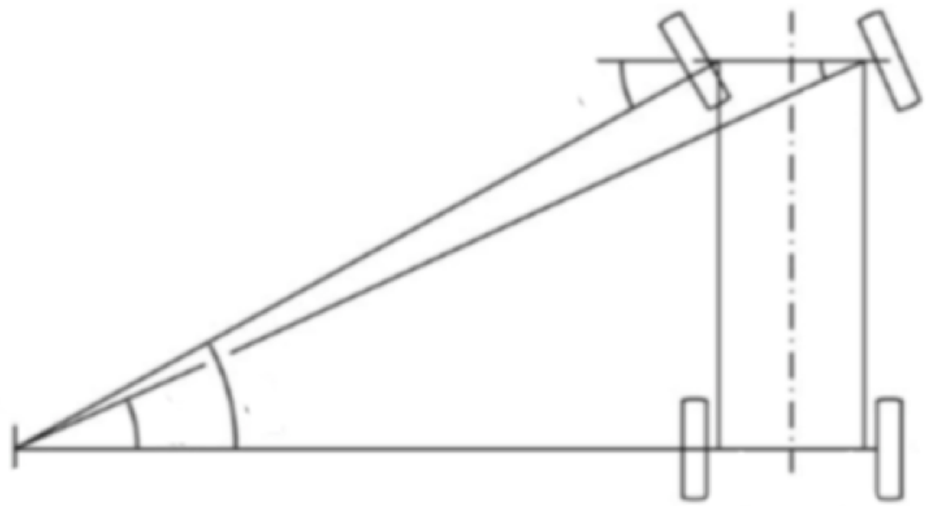


Figure 7: Diagram of Proper Turning Geometry

The calculations for the ideal Ackermann angle came to be 26.48 degrees. With this new angle, the attachment needed to be redesigned for a better placement. With the new location, the tie rods will need to shorten to have a better geometry tie in. In Appendix A shows the calculations for the design of new attachment and the geometry of the tie rods. Along with these redesigns, the lower ball will be realigned. These fixtures were decided using a decision matrix and analyzing the vehicle's geometry for a better steering system. These designs will allow the vehicle to perform at a better level.

5.1.4 Brakes

The brake design is going to stay the same from what was originally proposed in the preliminary report. There are going to be four disc brakes on the car, one on each hub assembly. This is required for the weight of the vehicle and stopping at the required acceleration of 15 ft/s^2. The vehicle will also be equipped with two master cylinders, one for the rear brakes and one for the front brakes. This will allow for more pressure to the system with the same amount of force applied to the pedal. The system will have a separate fluid reservoir for each of the cylinders as well. These reservoirs will be attached via a tube which allows for more convenient mounting locations. These will be mounted right behind the steering column on the car which is open for each access. The master cylinders themselves will mount in the same location as the old cylinders were mounted. There are already mounting brackets in this location as well as easy access to mounting the brake pedal to them. The team is ready to place the order for the brake components so that by next semester, the brakes can be installed immediately. The validation calculations for the brakes are shown below in Appendix D.

5.1.5 Gearbox

The gearbox is a new subsystem that has been added since the preliminary report. These calculations were done to determine what kind of gear ratio needs to be put in the gearbox to get the proper speed and torque requirements for the car. The speed that the team is going to try for is 35 mph so the calculations are done off of this. The data sheet is seen below in Figure 8. The figure shows The gear ratio that is needed to get the goal speed. The gear ratio that the team is going to use is a 6:1 ratio. This number was calculated using the rotational speed of the motor and the diameter of the tire that the team is using for the car.

Tire Diameter (in)	25						
Tire Circumference (in)	78.54						
Target Speed (mph)	35						
Motor Speed (rpm)	3000						
Gear Ratio 1:	6		Spur Gear Teeth	18	20	22	24
Output Gear Speed (rpm	500		Gear 2 Teeth	108	120	132	144
Tire Speed (in/min)	39269.91		Spur Diameter (in	2.5	2.75	3	3.25
Tire Speed (mph)	37		Face Width (in)	1.5	1.5	1.5	1.5

Figure 8: Gearbox Calculations

5.2 Implementation Plan

With the design of the car basically finished, the team is ready to start working on making the changes. There are going to be several different improvements being done at one time. With each person being in charge of a different section of the car, there can be different operations going on at one time. Some items need to be finalized but a lot is ready to be worked on. The brakes are totally ready for ordering and assembly, the front suspension is ready to be reinforced, and the steering is ready to be disassembled and improved. The team is now waiting on approval to order the brakes and to start the rest of the building. At the start of the spring semester, the designs will be finalized and we will have all the approval from our client to work on the vehicle.

All the parts that the team knows are needed at the moment are listed in the Bill of Materials (BOM). The BOM is shown in detail in Appendix E. There are components in that list that are not needed to be purchased for the car, but will be reused from what is on the car right now. The BOM is a list of all the components that are needed to get the subsystems up and running. In the list of costs, the “N/A” means that the part is going to be reused from the current car. There are also some items that don’t have a cost due to having to be manufactured from the shop and we aren’t positive what the shop rates are. With the current list of items that need to be purchased, the team has allocated around $1900 from their budget. This will allow for the costs of manufacturing the gearbox, and any other costs that come up through the project.

The timeline for what the team is trying to get done next semester is shown in the Gantt chart. The full Gantt chart is shown in Appendix F. The timeline is subject to change as some items won’t take as long and others will have issues arise during the process. The timeline is tentative for now. The goal is for the team to have the car in driving order by the end of week 7 of next semester. This is to allow time for the EE team to put on electronics and do any redesign that may be required once it is running.

18	Brakes	Drew
19	front supension	Fahad, LeAlan
20	Rear suspension	Shamlan, Andres
21	Gearbox	Drew, Shamlan
22	Steering	LeAlan
23	Mounting Electronics	Andres, Fahad

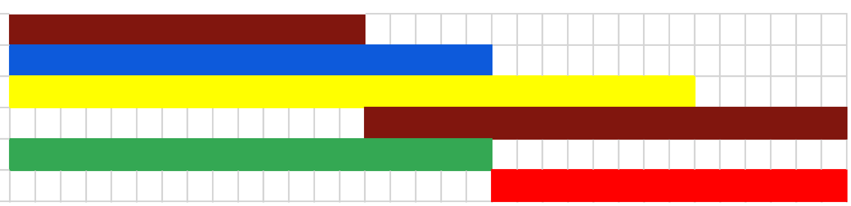


Figure 9: Semester 2 Task Breakdown

The car design isn’t finalized in the CAD model quite yet. The team is still working on getting all the components in the drawing. There general idea of the car is all on paper but has to be converted to the 3D drawing. There are a lot of dimension errors that the team has ran into while “reverse engineering” the CAD frame model. Most of the individual components have been drawn up in Solidworks but still need to be added to the car assembly.

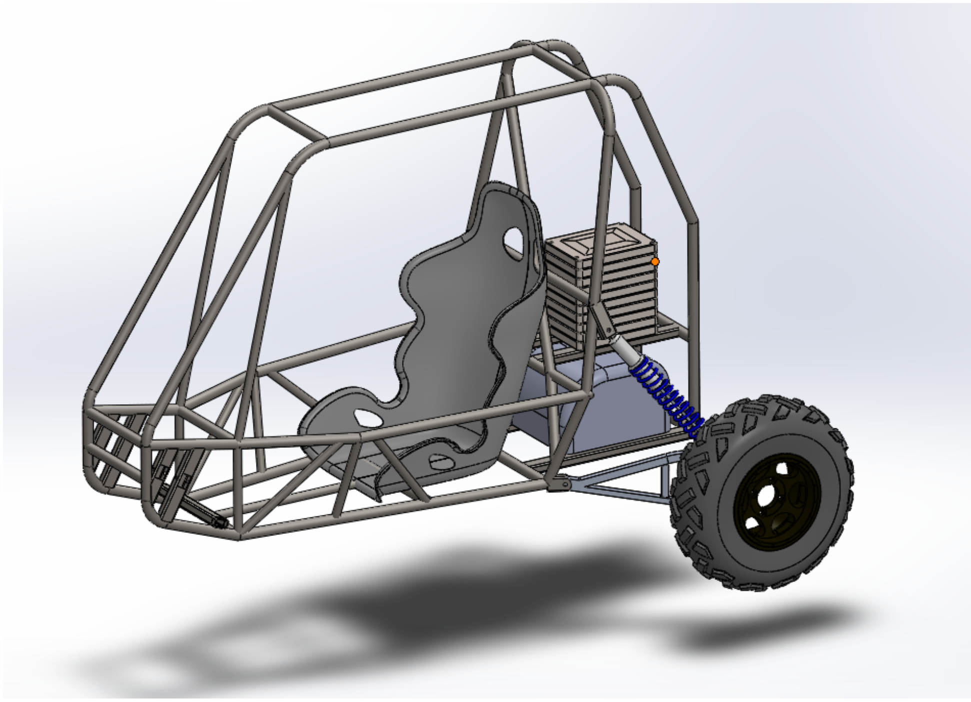


Figure 10: CAD Model

6 CONCLUSIONS

The main purpose of this report is to convert the BAJA vehicle into electric vehicle. Different components were analyzed using theoretical and practical approach. The Engineering requirement were defined which includes the safety, speed of the vehicle, cost, torque of the vehicle, range of motion of the steering system and weight of the vehicle. The rear suspension design, trailing arm, was decided upon because of how sturdy it is. This design is built like a truss with triangles and can absorb forces in several directions. This will really increase the suspension performance and rigidity of the suspension in the rear of the car. This design outranked all the others in the decision matrix and the Pugh chart. This design also allows for quite a bit of travel. This will be important when the car is taken off road and goes over bumps. It will keep the car suspension from bottoming out and possibly ruining components. It is also super simple to make this suspension stiffer or softer depending on how heavy the rear of the car is. The front suspension design is also going to be an improvement compared to what is on the car now. The car in the past has had issues with the components snapping or bending. By increasing the size of the supports and the diameters of the heims, the suspension will hold up much better. None of the angles or main front suspension need to be changed due to already being a great base design. With small improvements, this design will work great for the car. The calculations for the heim diameter can be seen in the Appendix below.

For the steering part of the car, the biggest change that needed to be addressed was the knuckles. The ball joints where the steering linkages and the wheels connected were breaking and needed to be redesigned to be able to steer properly. From this need came a better and more sturdy design. While still using the same ball joint that is on the car now, the team will just recreate a bracket to go on the knuckle to solidify the design. Remanufacturing knuckles would cost the team a lot of time and resources so just creating new linkages is the best idea for this part. By making the connection between the steering linkage and the knuckle stronger, the car will steer great during testing. This is the only part that needed to be changed in the steering section of the car. The rack and pinion all worked fine and is good enough for this design of the car. This is not a current concern of the teams.

The brakes are the component of the car that is critical for safety. Due to this, there are several parts of the brake system that had to be tested. In the decision matrix and Pugh chart, only the braking device itself was compared. After these comparisons, the disk brake and rotor were the best design which is what will be used on the car. There are already four disk brakes on the car already, so this will not need to be changed. For the back of the envelope calculations, there were several calculations that were done. Since the brakes are critical to the safety of the car, these calculations are extremely important This sheet is made to plug in different values of the brake lever, the weight of the car, number of brake calipers, and several other factors to determine if the setup is safe enough to stop the car. All these calculations were obtained from "Engineering Inspiration". These calculations showed that it is needed for the team to have four brake assemblies in order to stop the car with an acceleration of 30 mph^2. This will allow the team to keep the brakes the same and just get two new master cylinders.

7 REFERENCES

SAEIndia. (2020). *SAEIndia.* Retrieved from https://www.bajasaeindia.org/pdf/BAJASAEINDIA_2020_RULEBOOK_REV002.pdf

Stuff, S. b. (n.d.). *ATV Aluminum Rear Suspension Links*. Retrieved from Side by Side Stuff: https://www.sidebysidestuff.com/super-atv-aluminum-rear-suspension-links-polaris-rzr-xp-1000-xp-turbo.html

8 APPENDICES

8.1 Appendix A: Rear Suspension Concept Geometry

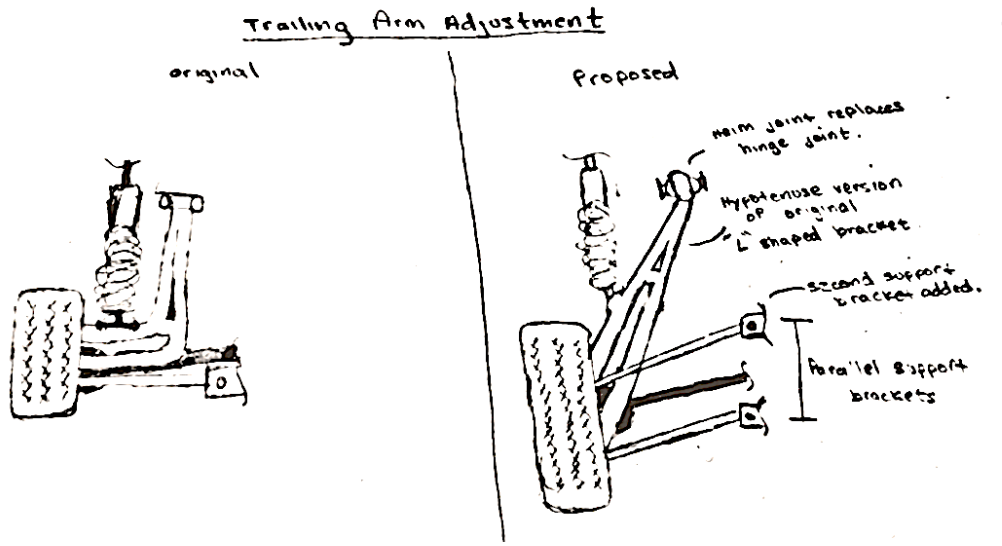


Figure 11: Old vs New Rear Supsension Design

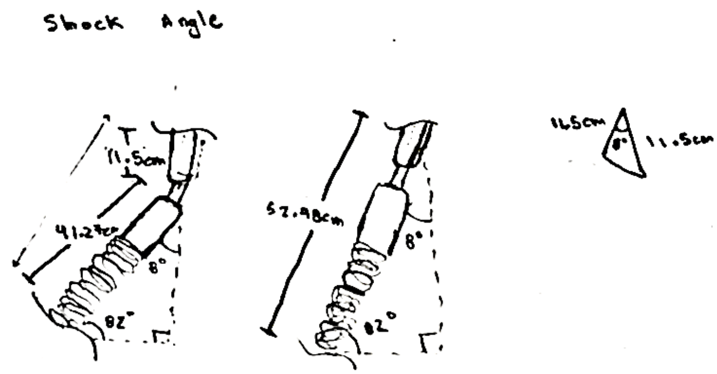


Figure 12: Difference between the old and new computations of the shock angle and length

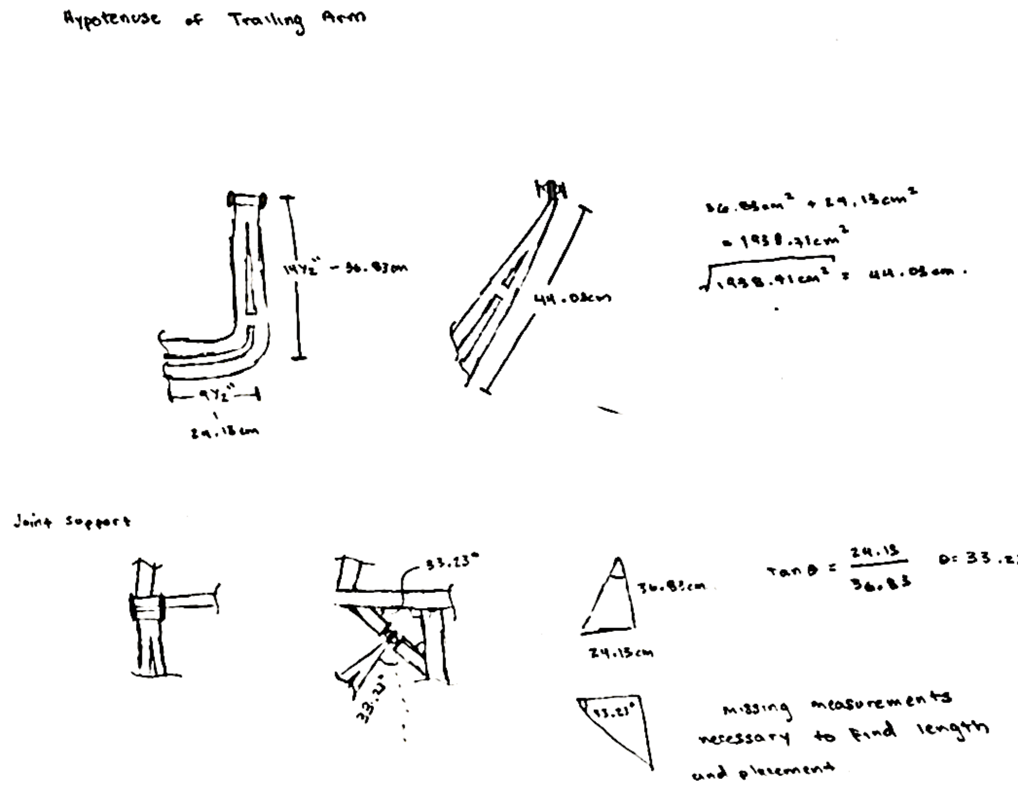


Figure 13: Calculating the hypotenuses to determine the length of the trailing arm

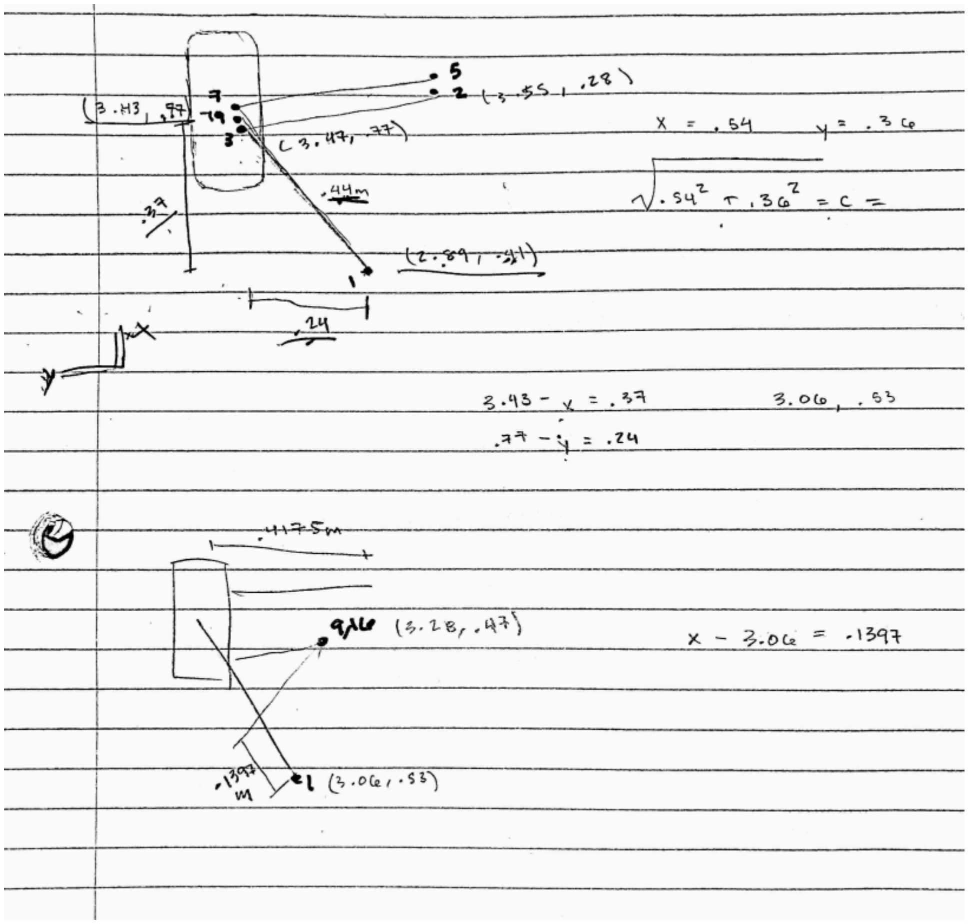


Figure 14: Calculating Vectors to Snap Lotus Points into Place

8.2 Appendix B: Front suspension calculations

Given Parameters (Bottom Heim Joint)			
Ball Diamter	E	1.312	in
Housing Width	H	0.687	in
Head Diameter	D	1.750	in
Minor Dia of thread	M	0.750	in
Allowable Material Stress	X	30,000	PSI
Calculated Values			
Rod End Head Strength	T	6535	lbf
Male Thread Rod End Strength	S	13163	lbf
Maximum Static Radial Load		6535	lbf
Maximum Static Axial Load	A	7766	lbf

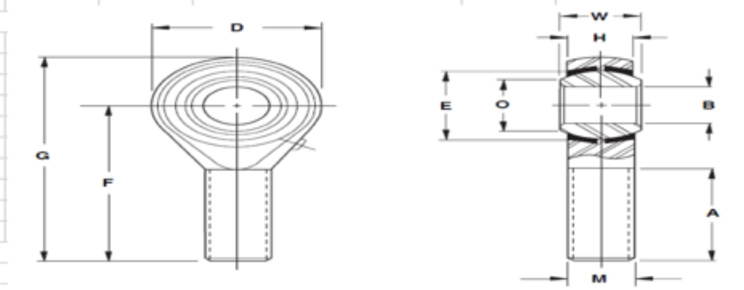


Figure 15: Calculations for new heim joints

8.3 Appendix C: Steering Calculations

E-Baja: Steering calculations and update report

Finding the ideal Ackermann angle for the e-Baja, using equation 1.

$$\theta_{St.A.} = 0.8\frac{T}{L} \qquad (1)$$

T is the wheel track, the distance between the center of the right and left wheel. L is the wheelbase, the distance between the center of the front and rear wheel.

For the e-Baja, T = 104 cm (40.95 inches) and L = 180 cm (70.87 inches). Using equation 1, the ideal Ackermann angle equals to approximate of 26.48°.

Using the Ackermann angle, figure 1 was drawn to help visualize the design of a new attachment.

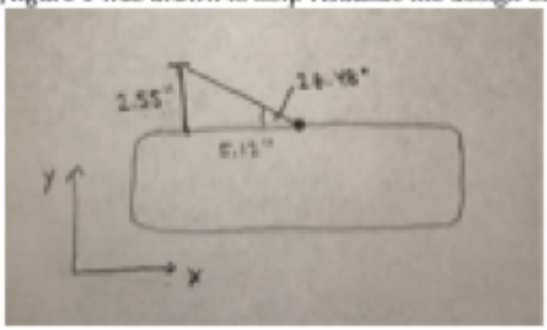


Figure 1. Location of new position for the connection from the tie rod.

The tie rods meet the tire at 13 cm (5.12 inches) from the kingpin; this gives the idea of where the new point for the tie rod to connect to the wheel. Using triangle relations, to find the proper location from the tire is given in equation 2.

$$\tan\theta = \frac{opposite}{adjacent} \qquad (2)$$

$\theta = 26.48^{o}$ and the adjacent length = 13 cm (5.12 inches), rearranging equation 2 to solve for the opposite length, this gives the opposite length = 6.48 cm (2.55 inches). Using figure 1, the connection point of the tie rod should be 5.12 inches on the x-axis from the kingpin and 2.55 inches on the y-axis from the kingpin.

Figure 2 shows the repositioning of the tie rod; due to the new placement of the tie rod connection to the knuckle, the length of the tie rod needs to be updated. Using the Pythagorean theorem, the length of the tie rod could be found in equation 3.

$$c = \sqrt{a^2 + b^2} \qquad (3)$$

c is the tie rod length, a = 5.5 inches and b = 11.5 inches from the car frame. Using equation 3, the tie rod length equals approximately 12.75 inches.

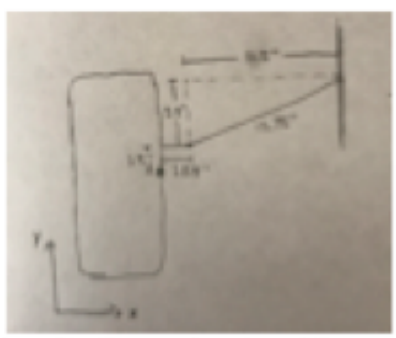


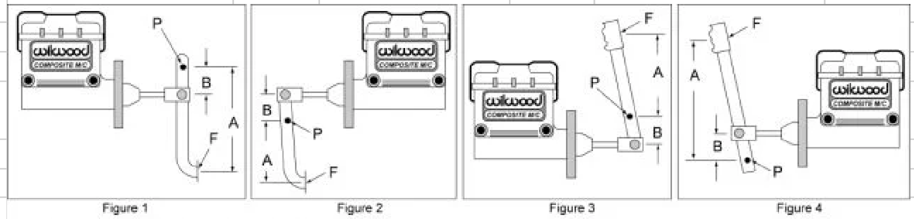
Figure 2. Image of the tie rod to the new location of the connection from the tie rod.

8.4 Appendix D: Brake Calculations

Front Cylinder	
Cylinder Size (in)	Bore Area (in2)
5/8	0.31

Rear Cylinder	
Cylinder Size (in)	Bore Area (in2)
5/8	0.31

http://www.engineeringinspiration.co.uk/brakecalcs.html



Pedal Dimesions				
A (in)	B (in)	F (lbs)	Pedal Ratio	Pedal Force Out
12.11	1.72	50	7.04	352

A = Distance from pivot point to middle of push/pull point
B = Distance from pivot to point of push on master cylinder
P = Pivot point
F = Force or push

Force Required	
Car Weight (lbs)	800
Stopping Acceleration ft/s^2	15
Braking Force Required	12000.00

Brake Torque	
Braking Force/wheel (lbs)	3000
Radius of Tire (in)	12.5
Disc brake radius (in)	4
Speed ratio btwn wheel/bra	3.1
Braking Torque (Ftlbs)	12000

Disc Outer Diameter	8
Disc Inner Diameter	6.5
Effective Radius	3.6

Coefficient of Friction	0.4
Number of friction faces	2
Clamp Load (lbs)	4123

Clamp Force/wheel	1031

Total Clamping Force (lbs)	2788

Front Cylinder	
# of Calipers on Cylinder	2
Force from Cylinder (lbs)	574
Force/Caliper (lbs)	287

Rear Cylinder	
# of Calipers on Cylinder	2
Force from Cylinder (lbs)	574
Force/Caliper (lbs)	287

LF Brake	
Caliper D (in)	1.25
# of piston	2
Net Bore Area (in^2)	2.5
Braking Force	704.07

RF Brake	
Caliper D (in)	1.25
# of piston	2
Net Bore Area (in^2)	2.5
Braking Force	704.07

LR Brake	
Caliper D (in)	1.75
# of piston	1
Net Bore Area (in^2)	2.4
Braking Force	689.99

LR Brake	
Caliper D (in)	1.75
# of piston	1
Net Bore Area (in^2)	2.4
Braking Force	689.99

Figure 16: Brake Calculations

8.5 Appendix E: Bill of Materials

Table 4: Bill of Materials

Part #	Part Name	Qty	Description	Functions	Material	Company
1	Steering - Knuckle Link	2	Extra attachment to the steering knuckle	For a better steering angle	Steel	
2	Steering Knuckles	2	Multiaxis unit on wheel	Connects Suspension and wheel	Steel	Amazon
3	Tie Rod	2	Rod between the wheel and the rack	connects steering wheel to the wheel for steeri	Steel	Empi Components
4	Tie Rod Heims	2	joint with added degree of freedom	Connects rod to knuckle	Steel	American Star Chromoly
5	Rack Heims	2	joint with added degree of freedom	connects rack to tie rod	Steel	American Star Chromoly
6	Kingpin Heim	4	joint with added degree of freedom	connects knuckle to A-Arms	Steel	Joint Right Thread Chromoly
7	Rack and Pinion	1	Rod with teeth connected to pinion gear	Connect wheels to steering wheel	Steel	SSB Store
8	Steering Shaft	1	Shaft directed from wheel to rack and pinior	Connects wheel to pinion	Steel	Grainger
9	Steering Wheel	1	Wheel for rotation	Connected to steering shaft	Steel	Carid
10	Steering Heim	1	Support holding the steering shaft	Hold steering shaft in place for steering	Steel	Joint Right Thread Chromoly
11	Steering - Knuckle Link Bolts	4	Fasteners on link	Holds link together to knuckle and tie rods	Steel	Home Depot
12	Brake Caliper	3	Clamp on brake rotor	Tightens to create friction and stop rotation	Steel	Apple Tree Auto
13	Brake Rotors	4	Metal plate attached to wheel	Rotates until clamped	Steel	Empi Components
14	Brake Peddle	1	Swing Mount Brake Pedal	Applies force to cylinder	Alum	Wilwood
15	Fluid Resevoir	2	Contains fluid for brake cylinder	Holds fluid	Plastic	Wilwood
16	Brake Cylinder	2	Compresses fluid to apply pressure to lines	Contains brake fluid to transfer to calipers	Steel	Apple Tree Auto
17	Caliper Bolt	6	Fasteners on caliper	Connects caliper to knuckle	Steel	Home Depot
18	A-Arm Heim	8	joint with added degree of freedom	connects A-Arm to vehicle frame	Steel	American Star Chromoly
19	A-Arm Heim Bolt	8	Fastener on frame for heim	Connects heim to frame	Steel	Home Depot
20	Angle Trailing Arm	2	Arm attached to shock and to rear knuckle	Absorb elastic deformation the knuckle and sho	Steel	
21	Heim Joint	2	joint with added degree of freedom	Replaces hinge joint to release force resistance	Steel	Joint Right Thread Chromoly
22	Connecting Rods	4	parallel rods from frame to knuckle	Maintains stability of wheel	Steel	Amain Hobbies
23	Rear Shocks	2	Resists Motion in the vertical direction	Absorbs impact from ground	Steel	Fox Suspension
24	Trailing Arm Bolt	8	Fastener on frame for heim	Connects heim to frame	Steel	Home Depot
25	Support Bracket Bolt	8	Fastener for keeping in place	Connects support bracket to frame and knuckle	Steel	Home Depot
26	Heat Shield	1	Metal plate between driver and motor	Protects driver from energy	Plastic	
27	Frame Member	2	Added member in secondary section	Attachment of parallel support bracket	Steel	
28	Drive Line	2	Shaft connected to drive train	Power transfer from motor to wheels	Steel	
29	Tire	4	Offroad	offroad traction	Rubber	Discount Tire
30	Pinion Gear	1	18 teeth	Connects motor to gearbox	Steel	
31	Gear 2	1	108 teeth	Connect spur gear to drive line	Steel	

Table 5: Current Tentative Cost

Part #	Part Name	Qty	Unit Cost	Total Cost
1	Steering - Knuckle Link	2	N/A	$ -
2	Steering Knuckles	2	N/A	$ -
3	Tie Rod	2	$ 35.00	$ 70.00
4	Tie Rod Heims	2	$ 19.48	$ 38.96
5	Rack Heims	2	$ 19.48	$ 38.96
6	Kingpin Heim	4	$ 60.00	$ 240.00
7	Rack and Pinion	1	N/A	$ -
8	Steering Shaft	1	N/A	$ -
9	Steering Wheel	1	N/A	$ -
10	Steering Heim	1	N/A	$ -
11	Steering - Knuckle Link Bolts	4	$ 1.36	$ 5.44
12	Brake Caliper	3	N/A	$ -
13	Brake Rotors	4	N/A	$ -
14	Brake Peddle	1	$ 176.94	$ 176.94
15	Fluid Resevoir	2	$ 64.74	$ 129.48
16	Brake Cylinder	2	$ 70.19	$ 140.38
17	Caliper Bolt	6	N/A	$ -
18	A-Arm Heim	8	$ 7.98	$ 63.84
19	A-Arm Heim Bolt	8	$ 1.36	$ 10.88
20	Angle Trailing Arm	2	N/A	$ -
21	Heim Joint	2	$ 120.00	$ 240.00
22	Connecting Rods	4	$ 20.00	$ 80.00
23	Rear Shocks	2	N/A	$ -
24	Trailing Arm Bolt	8	$ 1.36	$ 10.88
25	Support Bracket Bolt	8	$ 1.36	$ 10.88
26	Heat Shield	1	$ 120.00	$ 120.00
27	Frame Member	2	N/A	$ -
28	Drive Line	2	N/A	$ -
29	Tire	4	$ 78.00	$ 312.00
30	Pinion Gear	1	$ 68.00	$ 68.00
31	Gear 2	1	$ 132.00	$ 132.00
Total Cost				$ 1,888.64

8.6 Appendix F: Gantt Chart

	Me 486c	
1	Self learning	All members
2	Hardware review 1	All members
3	Peer evaluation 1	All members
4	Website check	Fahad
5	Midpoint Report	All members
6	Individual analysis 2	All members
7	Device summary	All members
8	Peer evaluation 2	All members
9	Drafts of poster	All members
10	Testing proof	All members
11	Final poster	All members
12	operation manual	All members
13	Final presentation	All members
14	Final report	All members
15	Cad package	Drew
16	website final	Fahad
17	Peer evaluation 3	All members
18	Brakes	Drew
19	front supension	Fahad, LeAlan
20	Rear suspension	Shamlan, Andres
21	Gearbox	Drew, Shamlan
22	Steering	LeAlan
23	Mounting Electronics	Andres, Fahad

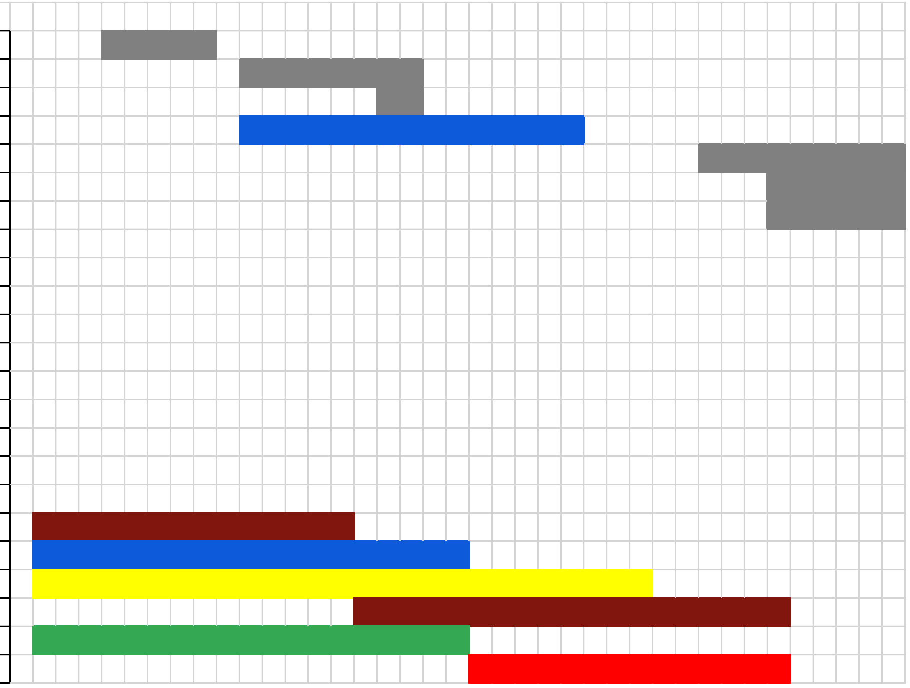


Figure 17: Gantt Chart Part 1

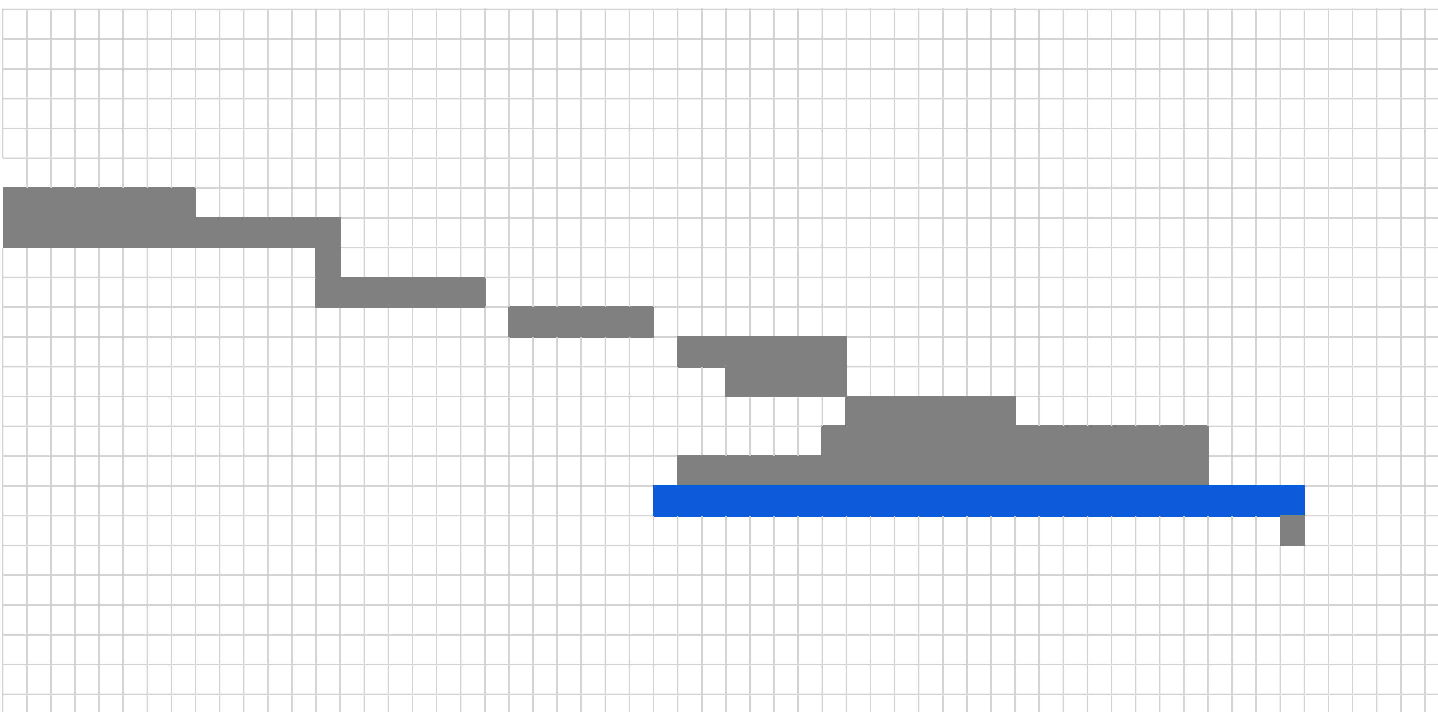


Figure 18: Gantt Chart Part 2

Student	Color
All team	
Drew	
Fahad	
Shamlan	
LeAlan	
Andres	

Figure 19: Gantt Chart Key