Electric Baja

Preliminary Proposal

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2019-2020

Project Sponsor: W.L. Gore
Instructor: Sarah Oman
Client: David Willy

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

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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. The idea is to work alongside EE Capstone Team, conform to the E-Baja safety rules, and compete against the 2019 Baja Car model. The project client is Professor David Willy. W. L. Gore is the financial sponsor.

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	5
SAE India E-Baja Rules / Industry Standards	5
Suspension System	5
Brake Design	5
Electric Compatible Drive Terrain	4
New Gear Box	4
Battery Mount	3
Steering	3
Fabrication	2
Cost	1

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, following the rules, suspension system, and brake design (All weighted at 5). The least important is cost and fabrication. That is because the team is willing to do fund raising to increase our budget of 3,000$ which was provided from W.L Gore. In addition, 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. The suspension system, brake design, electric compatible drive terrain, gear box, battery mount, and steering are all considered in the category of reliable, robust, and durable design. And the team decided to brake 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
Safety (Factor of Safety)	1	To Be Determined
Speed (meters/seconds)	2	16.667 m/s = 60 km/h
Cost (Dollars $)	3	$3000 (May Change)
Torque (Newton-meters)	4	To Be Determined
Range of Motion (Degrees)	5	To Be Determined
Weight (Kilo grams)	6	363 Kg = 800 lb. (Restriction used on original design of the vehicle)
Power (Kilo watts)	7	7.5 Kw

Some technical requirements targets have been set to "To Be Determined" since the SAE Baja India rules have not provided details regarding their restrictions. The team decided to follow our client David willy in this issue, which is to follow industry standards. The team is doing research and will do a finite element analysis (FEA) once all parts have been constructed in Solidworks and will run a von mises stress analysis in cases of roll over and, rear and front collision. In addition, the team is currently working on calculations for torque and range of motion.

2.3 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 of this project. It made the team concentrate on the most important engineering requirements, which has been mentioned above.as a result, the team is currently divided into sub-teams to ensure every customer weight and engineering requirements are met.

System QFD

Project:	E-BAJA
Date:	Sept. 16, 2019

	Weight (N)	Range of Motion (Degrees)	Torque (Nm)	Cost ($)	Power (KW)	Safety (n)
Weight (N)						
Range of Motion (Degrees)						
Torque (Nm)	-					
Cost ($)						
Power (KW)	-	-	-			
Safety (n)	+		+	-		
Speed (m/s)		-		-		

	Customer Needs	Customer Weights (5 Best to 1 Least)	Weight (N)	Range of Motion (Degrees)	Torque (Nm)	Cost ($)	Power (KW)	Safety (n)	Speed (m/s)
			Technical Requirements						
1	Safety	5	3	9	1	3	3	9	9
2	SAE India E-Baja Rules / Industry Standards	5	3	3	9		3	9	
3	Battery Mount	3	3		1	1	1	1	
4	Electric Compitable Drive Terrain	4	3	3	9	9	9	9	9
5	Brake Design	5	3	3	3	3	3	9	3
6	New Gear Box	4	9	1	9	9	9	3	9
7	Fabrication	2	9	9	3	9	9	9	3
8	Suspension System	5	3	3	1	9		9	9
9	Steering	3	3	9	1	3		9	9
	Technical Requirement Units		Kg	Degrees	Newton Meters	$	KW	Factor of Safety	m/s
	Technical Requirement Targets		TBD	TBD	TBD	3000	7.5	TBD	16.667
	Absolute Technical Importance		144	151	154	177	138	276	210
	Relative Technical Importance		6	5	4	3	7	1	2

Figure 1: House of Quality

3 DESIGN SPACE RESEARCH

The team will first understand the problem of the project, by talking with the client. The team will divide these problems into subteams to generate solutions for each subsystem of the car. Each team member has a subsystem and during the generation of solutions, they will report back to the team to evaluate the solutions. To better understand this project and how to improve the Baja, the team did research on important parts to designing an E Baja.

3.1 Literature Review

Each team member researched and benchmarked to find alternative designs for their subsystem components. The team researched and examined similar subsystems, literature reviews, and web searches. The following sections are from each team member and what each individual had researched for safety, rear suspension, front suspension, steering system, and braking system.

3.1.1 Shamlan Albahar

Shamlan Albahar was working with Andres Parra to solve the suspension problem that the 2016 Baja vehicle lacked. The sources below explain the best suspensions systems for baja vehicles and basic calculations that the team will take into consideration.

3.1.1.1 UCSB Racing - Baja SAE [1]

The first source shows the process of University of California Santa Barbara students doing the 3-link suspension similar to the vehicle #44 that is in the machine shop building 98C. This source shows how reliably their suspension was and they have put their design into a torturing test going over large logs of wood.

3.1.1.2 Camaro Performance Suspension [2]

The second resource explains the correct position of mounting the shocks. It also shows the angle of the shocks and the forces that will be applied on the shocks. This resource provided calculations for shocks loads and their angles.

3.1.1.3 CAMBER, CASTOR & TOE [3]

The third source explains the effectiveness of camber in vehicles and what types of camber should the team use. Camber is the degree of wheels tilted to provide excellent control in sharp turns.

3.1.1.4 2010 BAJA SAE SUSPENSION Auburn University [4]

The fourth source is the Auburn University Baja team using Lotus and Solidworks FEA to analyze their suspension system. It shows the effectiveness of these program. Also, it showed the durability and reliability of their design, which is featured in NAU's #44 vehicle and UCSB vehicle.

3.1.1.5 Design, Analysis and Fabrication of Rear Suspension System for an All-Terrain Vehicle [5]

The final source Also provides analysis using Lotus and Solidworks. It shows the effectiveness of using A type trailing arm. In addition, it shows the camber analysis for their vehicle. This source agrees on the source above and adding information that the 4th resource lacked which is the proper position of the stabilizer bars mounting.

3.1.2 Fahad Alhowaidi

Fahad Alhowaidi was working on fixing the front suspension and he did his research of how can he fix the front suspension and avoid snapping by fixing the heim joints and the bending bolts.

3.1.2.1 Heim Joints and Rod Ends Video [6]

This video helps with choosing the right heim joints for the car. Its also explains difference of heim joints and how to choose the correct one to avoid snapping.

3.1.2.2 Rod Ends, Sphericals, Rolling Element Bearings, [7]

This source is helpful with making calculation to fix the heim joints on the fron suspension. The calculation found on this source for checking how much load the heim joints will bear for given dimensions. In order to check safety of heim joints, it must sustain the load applied on it.

3.1.2.3 Designing of All Terrain Vehicle [8]

In this website, it shows how suspensions are built and choosing the correct dimensions. It has some CAD drawings examples, and also it shows some helpful calculations for materials on the front suspension.

3.1.2.4 Bearing and Heim Data Sheet [9]

In this source, there was a lot of helpful information of finding dimensions for the materials of the heim joints. It has a lot of materials such as: rod ends, male series, and female series for rod ends. Moreover, it shows a lot of information's of different materials. Finally, we can make a decision which one is best fit out our front suspension.

3.1.2.5 Design and Analysis of Suspension in Baja ATV [10]

This found from the International Journal for Research in Applied Science & Engineering Technology. It has a lot of analysis for the baja car. I will use this source to know what measurements are needed to make my calculations for the front suspensions.

3.1.3 LeAlan Kinlecheenie

LeAlan was in charge of research on the subsystem steering for the E Baja. He needed to determine if the steering components needed an upgrade or repair. The research presented is how to design an efficient steering system for the E Baja and each source will benefit the team and their subsystem components as well.

3.1.3.1 Suspension Geometry and Computation [11]

This source was recommend by the client, David Willy, for information on introduction to steering calculations, analysis, and designs what steering is about. The source gives an indepth analysis on what style of steerings there are and how to calculate the ideal steering for a vehicle. The book also explains how to pair the front suspension with the steering components. It allows a better understanding of how to design the front of the E Baja.

3.1.3.2 2017 Bearcats Baja SAE – Steering System [12]

This article explains the design of a steering system for a SAE Baja from a student perspective and explains the information in a more understanding manner for the team. It describes the process of designing new components when there is not manufactured parts for the final design. The source interprets the calculations in a simpler from and explains which calculations are important for a SAE Baja.

3.1.3.3 Analysis of Steering Knuckle of All Terrain Vehicles (ATV) Using Finite Element Analysis [13]

Steering knuckles are designed differently for varies vehicles and this sources gives an excellent explaination of how the material and geometry of the knuckle is key elements in the a good steering knuckle. The article explains the design of knuckles for a SAE Baja and how they analyze each part of the knuckle with CAD analysis. The article explains how they upgraded their existing steering knuckle and what calculations were needed.

3.1.3.4 Design and Optimization of a Baja SAE Vehicle [14]

The article explains camber of the wheels for the team to better understand. It goes on about designing a full SAE Baja but the sources is being used for the steering component. The article givens information of correlating the front suspension with the steering and how each subsystem effects the other component.

3.1.3.5 Northern Arizona University Baja SAE 2016 – Owner's Manual [15]

This source is used to identify how to maintenance the current Baja vehicle the team is working with. The owner's manual helps the team understand the Baja vehicle they are working on. The team used it to figure out the specifications of the components that are on the vehicle.

3.1.4 Andres Parra

Andres Parra was partnered with Shamlan Albahar to work on the rear suspension of the vehicle. The researched sources below cover general knowledge, safety, technical specifications, and different types of suspensions. Each source provides a summary that explains how the source benefits the team.

3.1.4.1 SAE INDIA [16]

This source educated readers in the rules of the SAE INDIA competition. It covers components of the frame, brakes, different competitions, etc. It taught the team how to correctly name components of the vehicle. This assisted in proper communication with the client who had experience in with the rules. Furthermore, the source has worked as a datum for how the E Baja vehicle will result as it is different from the regular Baja rules.

3.1.4.2 How Cars Work [17]

How Cars Work gave some students their initial knowledge of suspensions. It speaks of non-independent and independent suspensions as well as double wishbone and trailing arm suspensions which are both on the current vehicle being worked on. It gave the team a general idea of what is being worked in and what are some of the positives and negatives of each kind.

3.1.4.3 OSHA [18]

OSHA stands for the Occupational Safety and Health Administration. It is used in multiple industries as a standard for safety protocol. This includes subsections in PPE, Electricity and the four most common accidents. Those are caught between, struck by, falls and electrocutions. Three of which are relevant to the project, especially when the vehicle is in motion. The David Willy has expressed his largest costumer need to be safety. That safety is to be implemented on all subprojects and testing. He also mentioned OSHA being a useful resource which is why the team is using it.

3.1.4.4 Foreign Trailing Arm video [19]

This video functioned as another understanding of what a trailing arm is. The animation allowed for clarity in the parts of the vehicle. It speaks of merits and drawbacks of what a trailing arm suspension offers including simple construction and comparatively cheaper. Drawbacks include the bending of trailing arms which has been an issue with the current vehicle being worked on.

3.1.4.5 Cornell University [20]

This essay talks about active suspension systems for Baja vehicles. An active suspension system would allow the vehicle to run smoother and faster because it will adjust to the terrain the vehicle is racing on. Initially, it identifies why active suspension is not used in Baja vehicles and then it proceeds to name a few companies such as Fox and Polaris who have announced active suspensions for outdoor, recreational vehicles. This source helped the team by widening the potential scope for suspension systems.

3.1.5 Drew Stringer

Drew was in charge of researching the different types of brakes that can be used for the car. He needed to find out how many brake assemblies are needed for the car, the types of braking systems, and the different components that go into an efficient braking system.

3.1.5.1 Engineering Inspiration – Brake Calculations [21]

The first source that was used by Drew was how to calculate the stopping power that was needed for the car. This source was created by “Engineering Inspiration” [21]. On this website, it ran through all the calculations that are needed to come up with an efficient, operating brake system. Through these calculations, the team was able to determine how many brake assemblies are needed for the car and was able to get a good idea for what size and number of master cylinders are needed for the car to brake safely.

3.1.5.2 Selecting and Installing Brake System Components [22]

This source identified all the different components that are needed in a brake system. This source showed the difference advantages of drum brakes and disc brakes. Through this source, the team learned what the different types of brake lines can be used in a system and what is required when running brake lines. There isn’t a substantial difference in the effectiveness of having larger brake lines over smaller ones. The same amount of pressure is going to be applied no matter the brake lines. Since the fluid is relatively incompressible the volume of liquid won’t affect the performance. The team is going to be using flex lines for their design, which is the same as the original design on the vehicle. Due to the movement and fluctuation that is needed for the car, rigid lines would not work for this design.

3.1.5.3 Disc Brake Science [23]

From this source, more detail was learned about the operation of disc brakes. A major part that was learned from this source is the use of a proportioning valve. This valve is used to create equal pressure given to the front brakes versus the rear brakes. This is generally used in disc brakes since they require a larger pressure to operate to overcome the springs in the brake assembly. The team will not need to use a proportioning valve since there is not concern of the rear brakes locking up first and they are not using drum brakes. By using disc brakes all around the vehicle, the same pressure will be applied to both front and rear.

3.1.5.4 Why You Should Bleed Your Brakes [24]

The source from BAP [24] showed the necessities and techniques for bleeding brakes. This included getting water out of the lines as well as air. It talked about how water in the lines will act the same as having air in the lines. Once the water heats up from the pressure, it will turn to water vapor and will cause issues in the lines just like air. The problem with having air in the lines is that the brakes won’t be as responsive. At some points, depending on the amount of air in the system, the brakes won’t even work when the peddle is pushed. With bled lines, the brakes will be more powerful and will be more responsive. This step in the brake installation usually comes near the end, if not last but it is one of the most crucial for a successful system.

3.1.5.5 Brake Pad Selection [25]

As learned from this last source, there are several different options in selecting brake pads. Brake pads are made out of several different materials and have different performance factors. The three types of brake pads that can be bought are non-asbestos, ceramic, and semi-metallic [25]. Each of the brake pad types mentioned all have different properties to them. Either one of the brake pad types would be suitable for what kind of vehicle is being built. The non-asbestos pads are a softer material so on heavier vehicles they don’t last as long, but they are quieter and the brake pad waste doesn’t pollute the surroundings. The ceramic pads are excellent all around, they have excellent stopping power, disperse heat, and are very quiet. The ceramic pad is what is used in most factory cars produced today. The last type, semi-metallic, have great stopping power as well and are exceptional at dispersing heat. As the pads brake, they create more dust which allows for the heat to leave the pads and rotors better. As said earlier, any of these types would work for this project. The team will have to find out what types of pads are made for this size vehicle.

3.2 Benchmarking

As explained in the project introduction, the team will work with the EE Capstone Team. The benchmarking activities involved in this project include visits to the “Society of Automotive Engineers (SAE)” International and Baja SAE design team to examine how the team plans to approach the design problem with the original car model. The team shall also conduct online benchmarking through desktop research to explore the current state of technology and discernable trends and gaps in knowledge. The key areas that would benefit from the benchmarking include the need to reduce the cost of the materials and the need to increase speed.

3.2.1 System Level Benchmarking

3.2.1.1 Existing Design #1: Descriptive Title

Figure 2 shows a low-cost design of an electric car based on the GAY/AG01 Model. This design uses auto 1 speed, hydraulic brakes and 5000W power. Its main advantage is lower cost of $2800. Although it uses cheap materials, if suffers one limitation – it has low speed of up to 40.39 mph.

Figure 2: Full System Benchmark 1 [26]

3.2.1.2 Existing Design #2: Descriptive Title

Figure 3 illustrates an electric car design that can achieve a speed of up to 60 mph. the EPIC Amp model operates in manual 3 speed, with hydraulic brakes and 14.4 kW power. However, this design is expensive, costing $17,900.

Figure 3: Full System Benchmark 2 [27]

3.2.1.3 Existing Design #3: Descriptive Title

Figure 4 shows an electric OffRoad car that has a battery power of 72 V and it is made from china. The price is $5000-$5600 and it can speed up to 37.3 mph. The battery power uses TN power.

Figure 4: Full System Benchmark 3 [26]

3.2.2 Subsystem Level Benchmarking

The project is divided into subsystems: rear suspension, front suspension, steering system, and braking system. At a subsystem level, the team benchmarked other existing designs to compare their design project with. These subsystems make up the E Baja and will be implemented into the final design of the

EBaja.

3.2.2.1 Subsystem #1: Rear Suspension

This subsystem is important for the vehicle to absorb impact and not lose integrity in the structure or attached components. The motor and gear box are in the back which are important pieces to driving the vehicle. The suspension system handles the terrain the vehicle is on and it improves ride quality for the driver. Furthermore, the benchmarking done here is also what will be used for concept generation and selection of the rear suspension. The advantages and drawbacks of each design will be discussed in the later sections.

3.2.2.1.1 Existing Design #1: Double Wish Bone

This system includes two links that are attached to the frame and the lower link attaches to a shock absorber. The following picture is a representation of what it looks like.

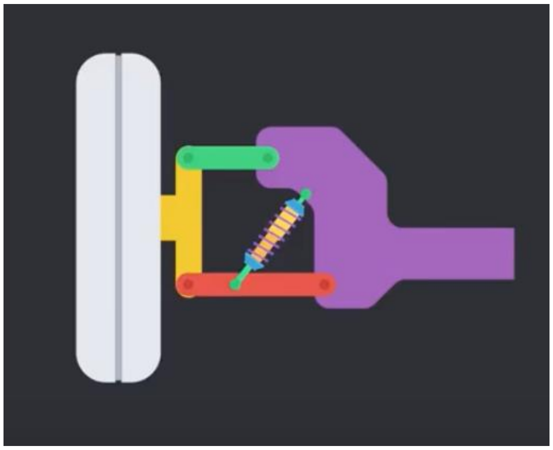

Figure 5: Double Wish Bone Diagram

3.2.2.1.2 Existing Design #2: Trailing Arm and Leading Arm

This system has a simpler design that is less costly and is less complicated to build. The trailing arm is for the rear suspension where the leading arm is for front suspension.

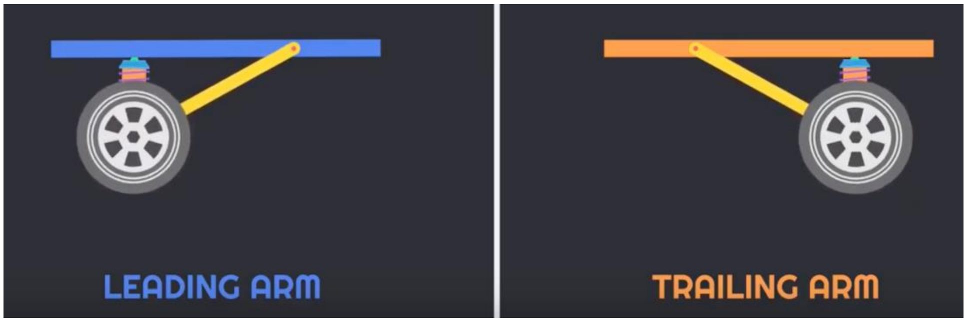

Figure 6: Trailing Arm vs. Leading Arm Diagram

3.2.2.1.3 Existing Design #3: MacPherson Strut Suspension

This design is easier to build but it puts the tire at an angle when the shock deflects too much. It is not good for a vehicle that will be on off road and rugged terrain.

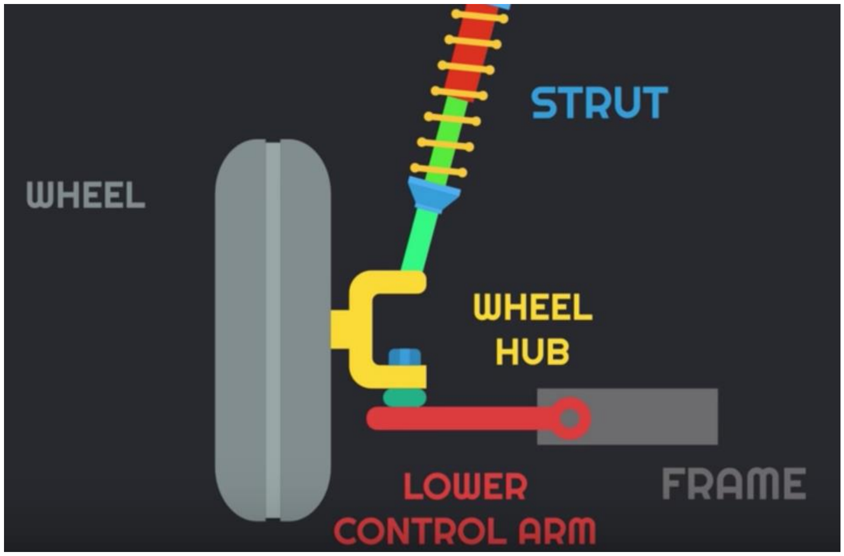

Figure 7: MacPherson Strut Suspension

3.2.2.2 Subsystem #2: Front Suspension

The front suspension is very important because it helps with keeping the wheels in contact with the road. Also, the main component which can make the wheels more stable with the road is the stabilizer. We need to make sure that the sway bar are connected to each other in both control arms. It helps with transferring the movement of the wheels when the car is not going on a straight road (off-roading). Moreover, when one of the wheels are not hitting the street, the sway bar will transfer the movement to the other wheels. Lastly, to avoid losing traction, we need to make sure that the control arms are horizontal with the ball joints, and it need to be matched with the spring size.

3.2.2.2.1 Existing Design #1:front suspension

Figure 8: Existing Front Suspension

This is one of the designs that I found which will make the car reduce weight from the front. Losing weight will increase the speed of the car.

3.2.2.2.2 Existing Design #2: lower arm

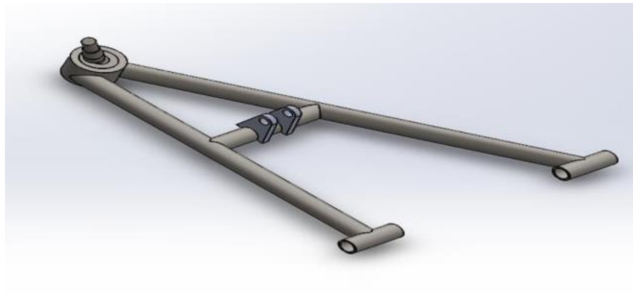

Figure 9: Lower A-arm Diagram

This lower arm design with an A-arm is common for cars. It helps with having a more powerful suspension.

3.2.2.2.3 Existing Design #3: Heim joints

Figure 10: Heim Joint

The heim joints on the front suspension need to be strong enough to hold the front suspension. If we are having a heim joint that is weak, snapping and bending of the front suspension will occur. We need to make sure to have a strong enough heim joint to avoid the car from snapping.

3.2.2.3 Subsystem #3: Steering System

The steering system of a vehicle is to have maneuverability during driving, while the most conventional steering system is to turn the front wheels, there are different types of steering. Steering is mostly mechanical movement but other styles of steering offer hydraulic or electrical assistants, for easier turning. This section will explain the different styles of steering.

3.2.2.3.1 Existing Design #1: Rack and Pinion Steering

A rack and pinion design is completely a mechanical design, this design is the original design for other styles of steering. Most vehicle uses do not use this design directly, due to difficulty in turning a large heavy vehicle and requires the person operating to use more strength. This system is not outdated because it is used in smaller go-kart sized vehicles and is still in some older model vehicles, it is easy to repair and replace. The design is simply just a pinion gear rotating on a gear rack as shown in Figure 11. This design is the one the team is going to use, it is a simple mechanical design and is already on the Baja.

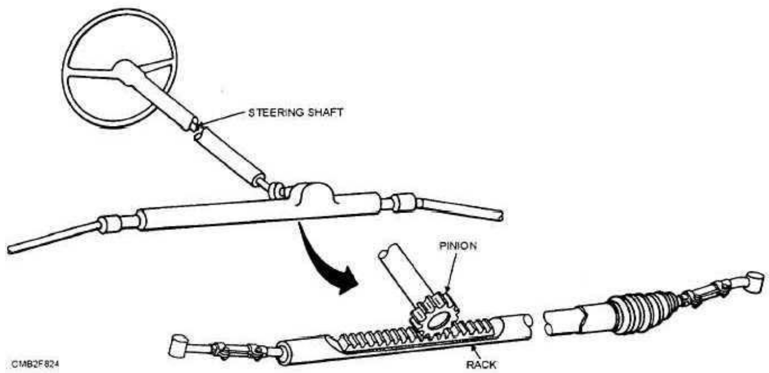

Figure 11: Rack and Pinion Diagram [28]

3.2.2.3.2 Existing Design #2: Hydraulic Steering

Most current vehicles on the road today use hydraulic steering, due to it making steering a full-sized vehicle easier. Hydraulic steering uses the rack and pinion design but adds a fluid that produces pressure on a piston enclosed on the steering rack that allows the rack to move more efficient than just the rack and pinion. As seen in Figure 12, moving the steering shaft allows fluid to rush to either side on the piston to allow the steering rack to move side to side. This design would allow the team to have an easier turning experience with the Baja but will require more maintenance and is more expensive for the team.

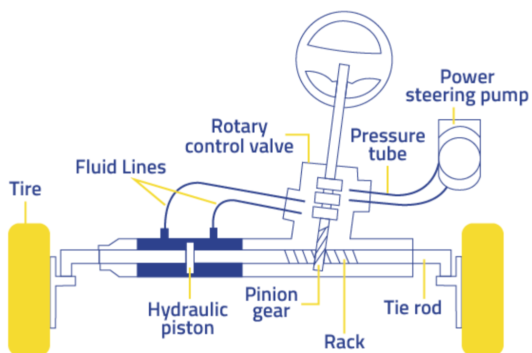

Figure 12: Hydraulic Steering Diagram [29]

3.2.2.3.3 Existing Design #3: Electric Steering

Vehicles that are currently being sold and produced are now being designed with electrical assistive steering. This design still uses a rack and pinion design but consist of an electrical motor that helps rotate the steering shaft with less rotating of the steering wheel from the driver. This design is expensive and will not be used on the E Baja, due to limited time and limited budget. Electric steering is a useful design for allowing the driver to turn easier, in Figure 13 shows the set up and how an electrical steering system looks like.

Figure 13: Electric Power Steering Setup [30]

3.2.2.4 Subsystem #4: Braking System

For a braking system, there are multiple ways to slow down a car. For the most part, cars all brake the same way. There are a few different designs that car manufacturers go with when designing cars. This section will look at different braking systems on the market today.

3.2.2.4.1 Existing Design #1: Drum Brake

One existing brake design that is already out on the market is the drum brake. This brake is an expansion braking method rather than a clamping method. When the brake is applied, two "brake shoes" are expanded by a piston and press up against the "brake drum". This creates the friction and force required to stop the car. These are commonly used on the rear of vehicles but are not reasonable for our car. They are relatively bulky and are more complicated to mount than a rotor and caliper. Figure 14 shows a diagram of what a drum brake consists of.

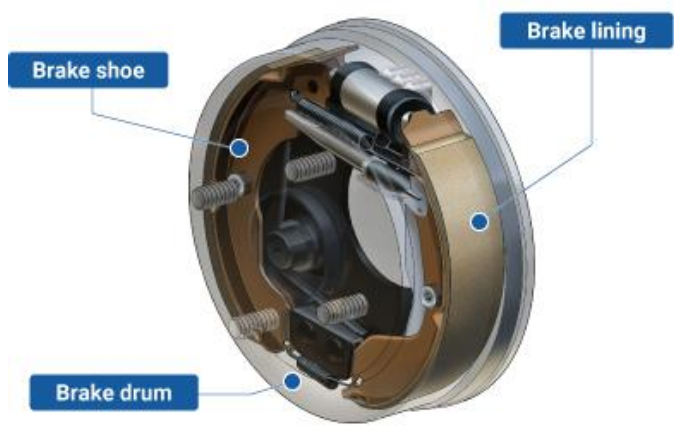

Figure 14: Drum Brake Diagram [31]

3.2.2.4.2 Existing Design #2: Rotor and Brake Caliper

The most common braking system that is on cars today is the use of a rotor with a brake caliper. This uses two brake pad that clamp onto the rotor to stop the car. This is a simple setup and doesn't take much room to install on a car. These are seen on the front hubs of cars and generally in the rears on newer cars as well. Figure 15 shows the diagram of how a rotor and caliper is assembled. This is likely the design that the team will use on the Baja car.

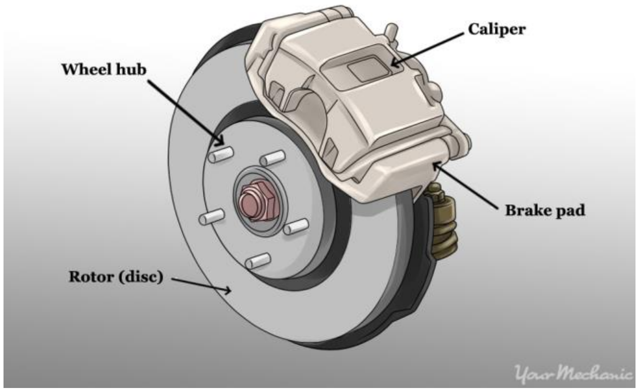

Figure 15: Rotor and Brake Disc Diagram [32]

3.2.2.4.3 Existing Design #3: Master Cylinder

One of the most important components in a brake system is the master cylinder. This is what causes the piston to expand in either the Caliper or the Drum brake. The fluid is contained in the reservoir and is fed into the system through different ports. The brake pedal is typically attached to the master cylinder. Without the master cylinder, the whole brake system doesn't work. In all cars these days, there is some sort of master cylinder in them. The team will most definitely have one of these on the vehicle. In Figure 16, all the different parts of the master cylinder are seen.

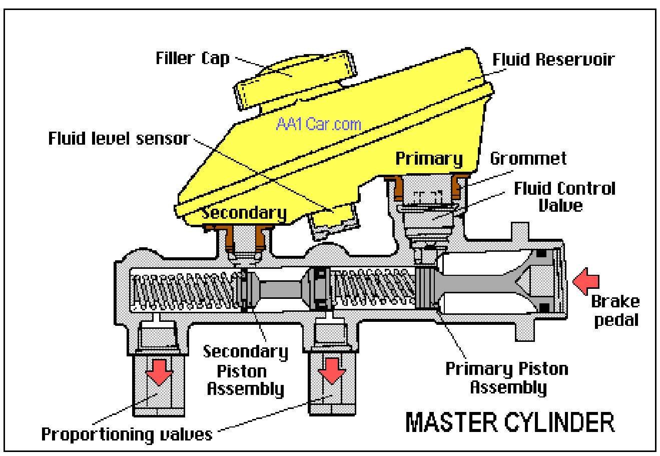

Figure 16: Master Cylinder Diagram [33]

3.3 Functional Decomposition

This section contains a black box model that elaborates on the inputs and outputs for the vehicle to function. To elaborate on that model, a hypothesized functional model was also created. The second model expands on what happens within the vehicle to make it drive. The subsystems focused on were the electrical components, the braking, and the suspension. These are some of the main components that were directly correlated. However, there are other components such as steering that are important. Due to the clients wishes, the team has not disassembled the vehicle which makes it difficult to see how closely certain things are related.

3.3.1 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.

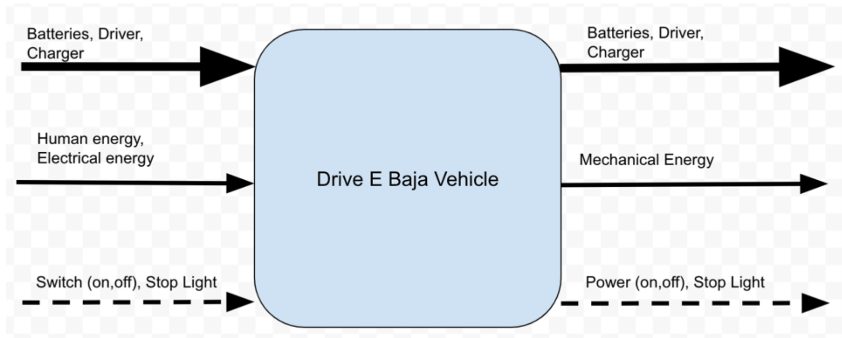

Figure 17: Black Box Model

The materials used to drive the electrical Baja vehicle are batteries, a battery charger, and a driver. All of 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.

3.3.2 Functional Model

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.

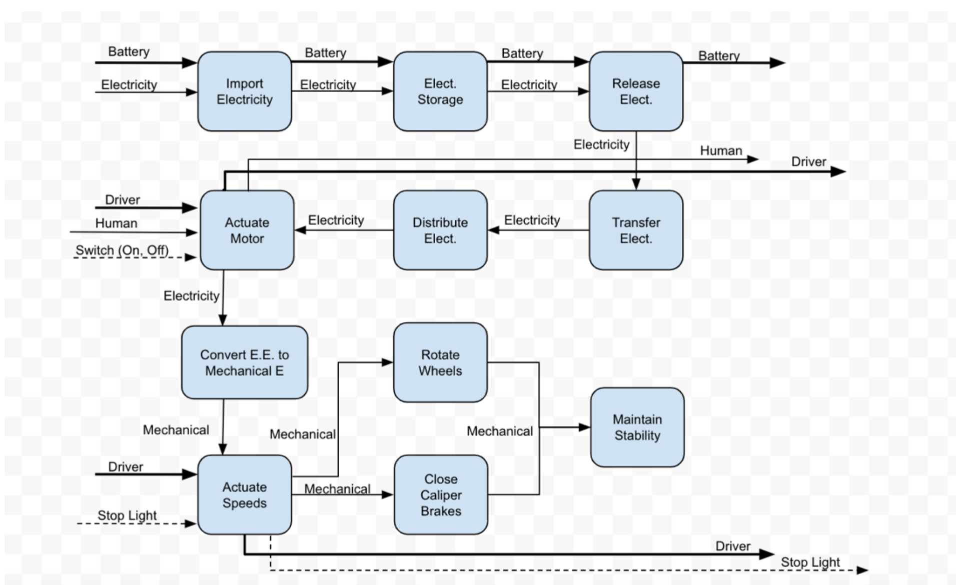

Figure 18: Functional Model

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 subfunctions 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 is able to 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.

4 CONCEPT GENERATION

The project will not consist of a full system design concept due to using a previous capstone's Baja project. In place of the full system design concept, the team will continue their research, analysis and concept generation on subsystems for the project. Each team lead for their subsystem created concepts and shared them with entire team to get feedback and narrow down the final design concept for the subsystems.

4.1 Subsystem Concepts

For this project, there are multiple subsystems that the team evaluated. Due to this project having an already set Full system design, the team did five different concepts for the subsystems. This made it so that there were more options for designing each component. Below are the four different subsystems that were evaluated. For the full decision matrices, they can be found in Appendix A: Decision Matrix.

4.1.1 Subsystem #1: Rear Suspension

This section contains the subconcepts spoken about in the benchmarking. It elaborates on advantages and drawbacks of each concept. The concepts are based on the benchmark items due to the type of project. The client wish is to fix the vehicle to move forward with the electrical portion. Therefore, the concepts generation is based on our benchmarks.

4.1.1.1 Design #1: L-Trailing Arm

This is the original design that exists on the vehicle. It is an L-shaped trailing arm mounted on the wheel and the frame. Also, attached in the top of it is the shocks.

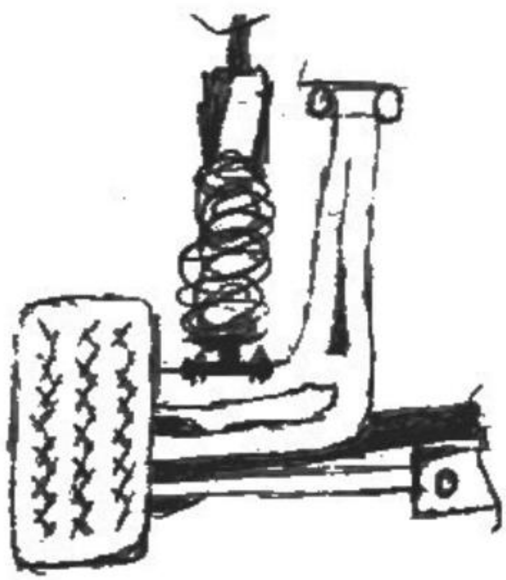

Figure 19: L-Trailing Arm Diagram

Pros:

- Saves money and time if used.

Cons:

- Low degree of freedom.
- Unreliable and low safety.
- Low space.

4.1.1.2 Design #2: Mac Pherson Strut

This design has a single reverse A-shape type wishbone mounted on the lower part of the wheel which has the larger length between links. The narrower part is mounted on the frame itself. The shocks are mounted on a support on the top part of the system.

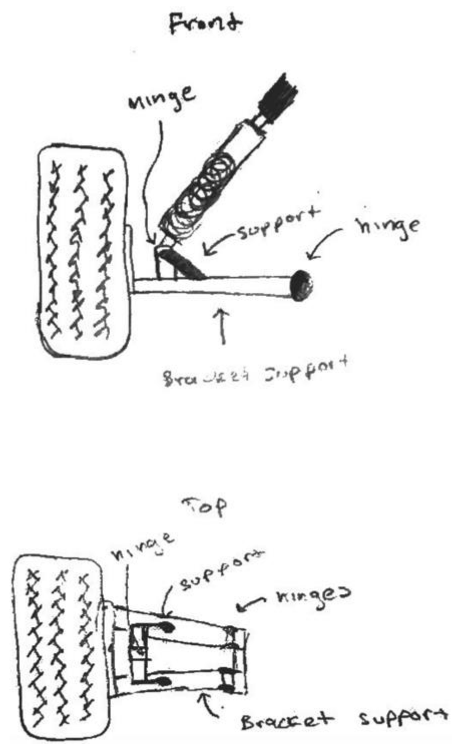

Figure 20: Mac Pherson Strut Diagram

Pros:

- Safe.
- Can support battery and motor.

Cons:

- High cost of machinery.
- Complex design (require extra fabrication).
- Provides less space.

4.1.1.3 Design #3: Bottom Mounted Wishbone

The lower wishbone is suspension system that has two identical wishbones mounted parallel to each other. This method cancels the trailing arm from the system. The shocks here are mounted in the bottom wishbone. This will have contact between the shocks and upper wishbone, which may result in damaging the shocks in the long term. And adding extra cost for maintenance.

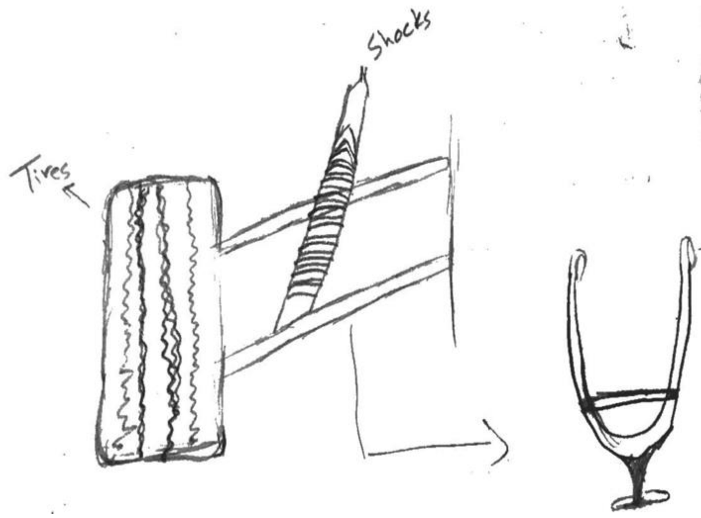

Figure 21: Bottom Mounted Wishbone Diagram

Pros:

- Supports battery and motor.
- Safe

Cons:

- Requires maintenance (increases cost).
- New mounts (more fabrication to the frame).
- Provides less space.

4.1.1.4 Design #4: Top Mounted Wishbone

The upper wishbone method is similar to the lower one. It also cancels the trailing arm. But the difference is that the shocks are mounted in the top wishbone making it better in terms of less damage. The upper type is more reliable than the bottom one.

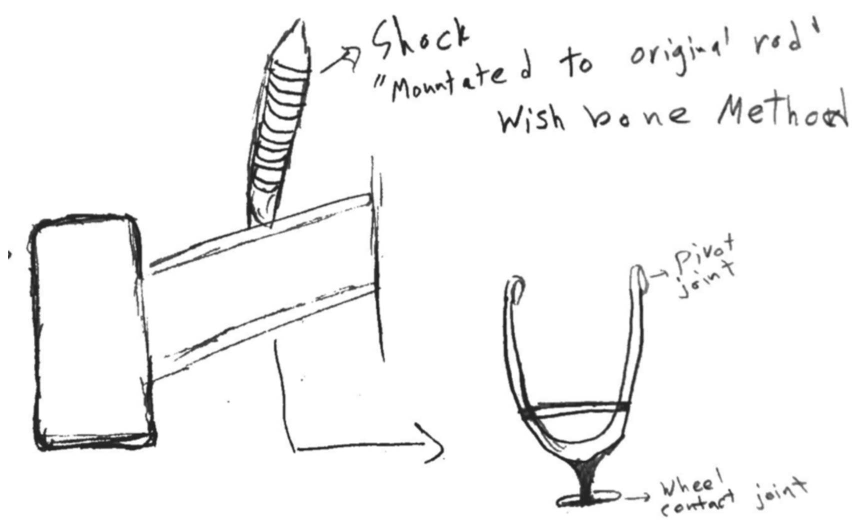

Figure 22: Top Mounted Wishbone Diagram

Pros:

- Safe.
- Low cost.
- Supports battery and motor.
- Reliable.

Cons:

- New mounts (more fabrication to the frame).
- Provides less space.

4.1.1.5 Design #5: A-Trailing Arm

This design is mostly used in the SAE Baja competitions and industry. It is an A-shaped trailing arm mounted in an angle to the frame and wheels. It has two stabilizer bars that is connected perpendicularly between the wheels and frame. This is the design that matches the team needs according to the decision matrix.

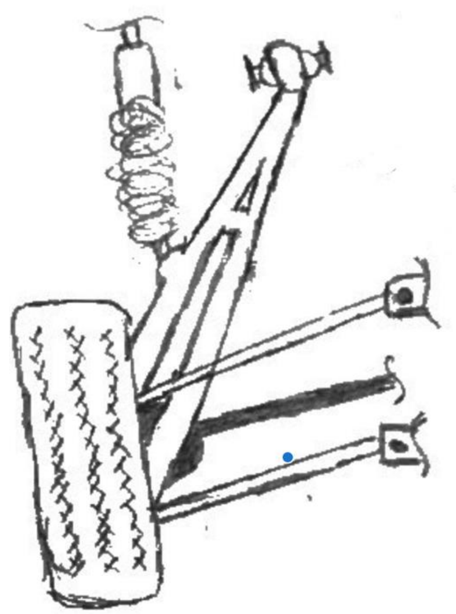

Figure 23: A-Trailing Arm Diagram

Pros:

- Safe and Reliable.
- Supports heavy weight.
- High degree of freedom.
- Perfect for camber control.
- Less fabrication (Can be mounted on existing joints).
- Provides more space for battery and motor mount.

Cons:

- Almost expensive.

4.1.2 Subsystem #2: Front Suspension

For this subsystem, the team has made several Ideas to which design is better for our car front suspension. Each idea has some advantages and disadvantages. The pros and cons are discussed below.

4.1.2.1 Design #1: A-arm

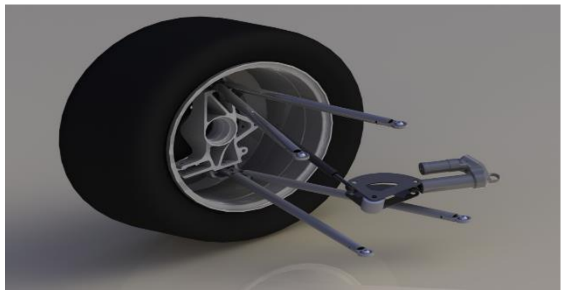

Figure 24: A-arm Diagram

Pros:

- Alignment wheels
- Less weighted
- Better traction

Cons:

- Easy to break
- More expensive

4.1.2.2 Design #2: MacPherson strut

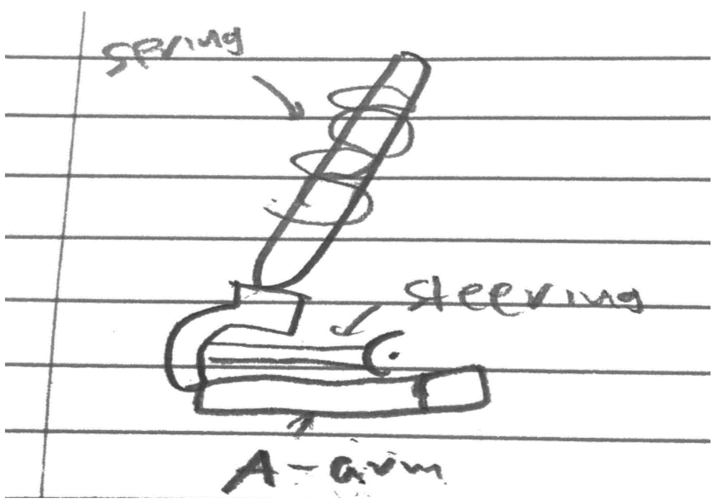

Figure 25: MacPherson Strut Diagram

Pros:

- Easier designing
- Less components
- Lighter weight
- Less cost

Cons:

- Less handling
- Easy to break

4.1.2.3 Design #3: Double front suspension

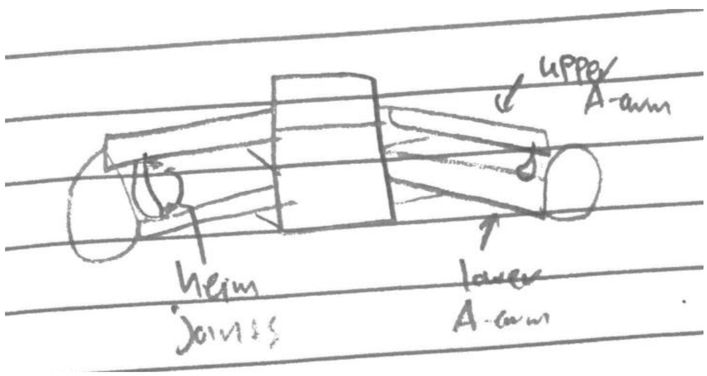

Figure 26: Double Front Suspension Design

Pros:

- Better stability
- Strong enough for off-road use
- Well performance

Cons:

- Expensive
- Hard for designing

4.1.2.4 Design #4: semi trailing arm

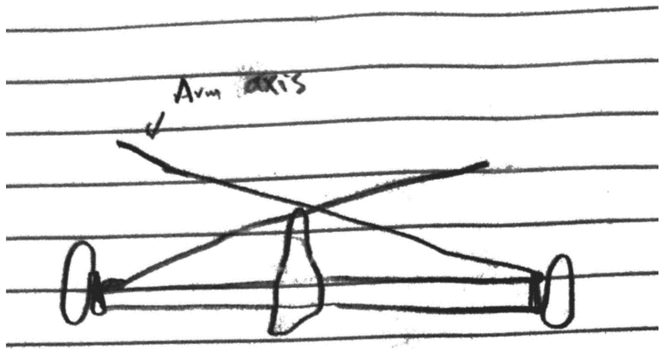

Figure 27: Semi Trailing Arms

Pros:

- Simple design
- Few materials

Cons:

- Easy to break
- Arms are expensive

4.1.2.5 Design #5: Control arm

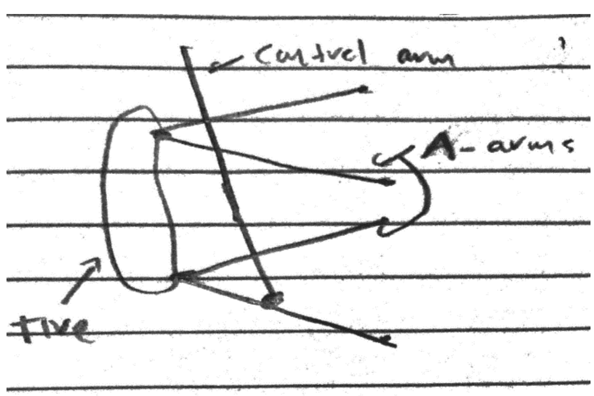

Figure 28: Control Arm Diagram

Pros:

- Improve wheels travel
- Less cost
- Better quality

Cons:

- Reduce ride quality
- Cause huge suspension damage when off-roading

4.1.3 Subsystem #3: Steering System

There are different components to the steering system, in this section the team will discuss the different design concepts that will change or repair the steering system. Each set up will help the team create a more efficient steering system for the E Baja. After using a decision matrix, the team narrow down the concepts to fixing the current steering knuckle design, keeping the original ball joints, keeping the same pinion gear, and moving the location of the rack and pinion for optimal steering.

4.1.3.1 Design #1: Fix Current Steering Knuckle Design

The current steering knuckle has an extra attachment made by the previous team that worked on the Baja, it has been cracked and welded back together. The current team is going to upgrade the extra attachment for better durability and optimal turning. Figure 29 shows the current design on the steering knuckle.

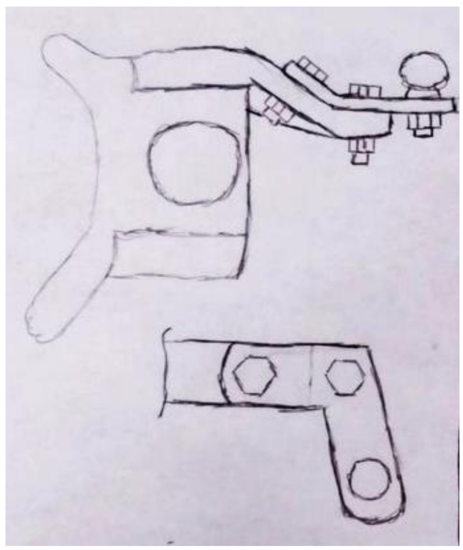

Figure 29: Fix Current Steering Knuckle

Pros:

- Low cost
- Client approval

Cons:

- Requires more fabrication

4.1.3.2 Design #2: Design a New Steering Knuckle

Creating a new steering knuckle would make it more durable than the current design. It will have the ability to be last longer than the current design. The team is still considering designing a new knuckle. Figure 30 shows the concept design for the new steering knuckle.

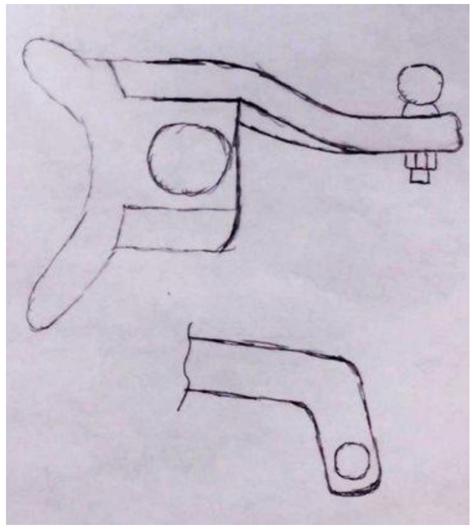

Figure 30: New Steering Knuckle

Pros:

- Safer than current knuckle
- More durable

Cons:

- High cost

4.1.3.3 Design #3: Change Location of the Rack and Pinion

The team is still doing calculations on changing the location of the rack and pinion. The current set up is not straight towards the knuckle heim joint. The tie rods are angled back a small distance from the rack and pinion to the connection of the knuckle. Changing the location to have an ideal straight connection without any angle change would make the turning more efficient. Figure 31 shows the ideal placement of steering system for an ideal Ackemann angle.

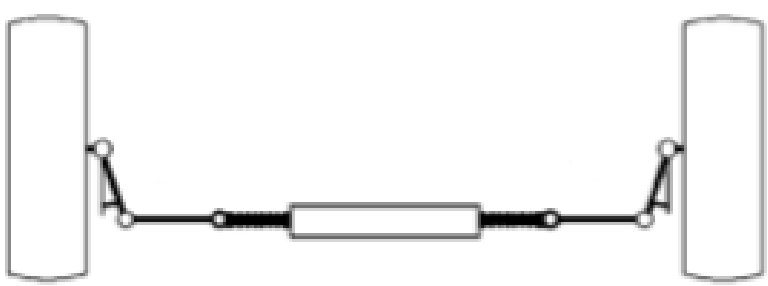

Figure 31: Change Location of the Rack and Pinion [11]

Pros:

- Ideal Ackemann angle
- Safer turning

Cons:

- High cost

- Requires more fabrication

4.1.3.4 Design #4: Keep Original Location of the Rack and Pinion

As stated above in design #3, the current rack and pinion set up is not straight, however the turning still works with minor problems that are not affected by the placement of the rack and pinion. Keeping the original location will save the team on cost and will require no fabrication to relocate the rack and pinion. Figure 32 shows the current placement of steering system, current system does not look like the Figure 31 but the figure shows a dramatic effect that changes the Ackemann angle.

Figure 32: Original Location of Rack and Pinion [11]

Pros:

- Low cost
- Less fabrication

Cons:

- Not ideal for Ackemann angle

4.1.3.5 Design #5: Replace Current Pinion Gear for a Bigger Pinion Gear

This design is not major requirement, but the team would like to decrease the number of turns on the steering wheel for the driver. Therefore, the team will address this design later if there is time to modify the small components on the car such as this design concept. Figure 33 shows different size gears, not the gears used or will replace the pinion gear. Using a bigger gear will result in an easier turning for the driver.

Figure 33: Larger Gear Ratio Diagram [34]

Pros:

- Easier turning

Cons:

- Requires more fabrication

4.1.4 Subsystem #4: Brake System

For the brake system, there were different setups and braking methods that were evaluated using a decision matrix. After plugging the designs in the decision matrix, it was determined that the disk brake is going to be the design that will be used on the car. It outranked the rest of the designs.

4.1.4.1 Design #1: Disc Brake and Rotor

As seen in the benchmarking, a disc brake and rotor are compact and simple way to go about stopping a car. There isn't a lot to it and is very common in modern cars. The brake pads are cheap and easy to get ahold of. This design also is exceptional at stopping a car. This method doesn't take very much pressure in the system to clamp onto the rotor, in turn stopping the car.

Figure 34: Disc Brake [35]

Pros:

- Simple
- Stops Effectively
- Compact

Cons:

- Required on each wheel

4.1.4.2 Design #2: Drum Brake

The drum brake was also evaluated in the benchmarking process. This braking method is also super effective. The downfall to this one is that it has a more complex setup and it requires more force to activate the brake. Drum brakes tend to last quite a while due to having a large surface area that is stopping the car which is nice.

Figure 35: Drum Brake [36]

Pros:

- Clean looking
- Last a long time

Cons:

- Heavy
- Complicated Setup
- High Force Required

4.1.4.3 Design #3: Motor Braking

Motor braking is done by having complex computer components on the car that turns the motor backwards when braking to stop the car. When the motor applies a force opposite of the motion, the car will come to a quick stop.

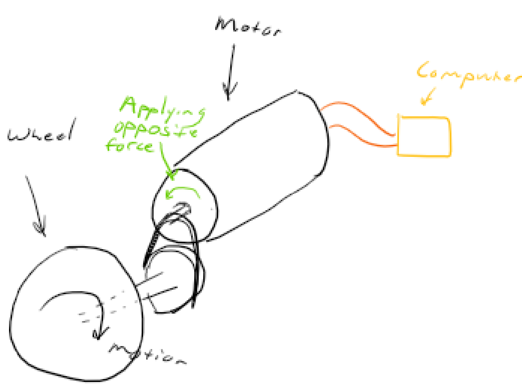

Figure 36: Motor Braking Diagram

Pros:

- Light

Cons:

- Expensive

- Complex computer components needed

4.1.4.4 Design #4: Single Hand Brake

A single hand brake is generally going to be like a drum brake. By pulling on the lever it applies a force to a rotating wheel which creates a friction, in turn stopping the car. While this is a simple design, it isn't as effective as real brakes.

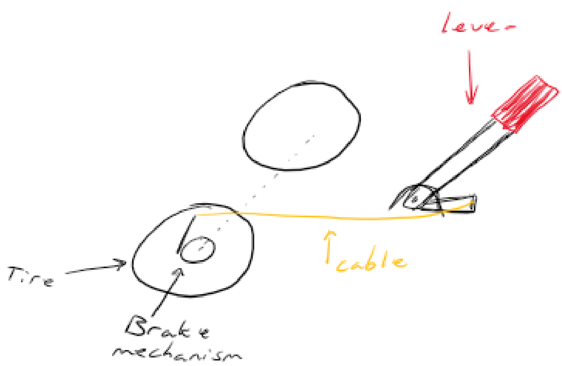

Figure 37: Single Hand Brake Diagram

Pros:

- Simple design
- Light
- Cheap

Cons:

- Doesn't stop well
- Potential to break

4.1.4.5 Design #5: Regenerative Braking

This type of braking is just using the resistance in the motors to stop the car. It is a slower stopping process but saves a lot of energy. This method shuts off power to the motor and then the motor then acts like a generator, shoving electricity back into the battery.

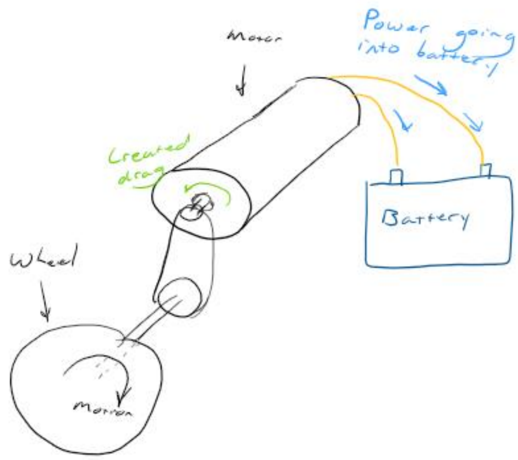

Figure 38: Regenerative Braking Diagram

Pros:

- Cheap
- Light
- Saves Energy

Cons:

- Way less stopping power

5 DESIGNS SELECTED – First Semester

This section of the report shows the final designs that the team has decided upon to build the car. It will show the reasoning behind the decisions and how the other options ranked up. For this project, the car frame is not supposed to have any major changes to it. Due to this, the only major changes are going to be done to the subcomponents. The client wants the team to keep the frame the same and only adjust mounting points and frame supports. This makes it so there are no full system concept generation ideas. In the decision matrix there are only subcomponents. Each of the ideas that have been generated all have to work with the original frame and comply with the SAE Baja and SAE Ebaja competition rules.

5.1 Technical Selection Criteria

The main customer needs addressed in this report consist of the car being safe, following SAE India E Baja Rules/Standards, suspension system, brake design, steering and fabrication. To identify the costumers, the team met with the client and he is the main customer for this project along with the team that will drive the car. During meetings with the client, he specified these requires be fulfilled during the first semester of the project. The team assisted a lead on each subsystem to work on each subsystem and having other team members to assist in the designs and build. This was to break down and identify each task the project will consist of. Each lead talked with their team partners to generate concepts that will meet both the customer needs and engineering requirements. Some engineering requirements pertaining to the beginning of the project designs are safety factor, speed, cost, range of motion, and weight. These requirements helped make quantitative decisions for the design of the car.

These customer needs and engineering requirements were put into Pugh Charts to help narrow down the design concepts that satisfied if the customer need met with the engineering requirement. This process helped to put these design concepts into Decision Matrices for a ranking of which design concepts were better than the others. The Decision Matrices were created for each individual subsystem for the car. Each lead on the subsystem ranked the design concept based on the customer needs and engineering requirements. After the rankings, the lead reported back to the other team members for team inputs on the decisions. The Decision Matrices were used to help rank which design concept to continue working on and improving the design.

5.2 Rationale for Design Selection

From the subsystem components that the team researched and designed, they were able to come up with two designs that would work well for the vehicle. With the current customer needs and engineering requirements, the team was able to come up with a final design of the car. All the designs were plugged into decision matrices to determine which design was the best. The more important parts like the rear suspension and the brakes were plugged into a Pugh chart as well to get the best design. These full charts can be seen in the Appendix below.

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 was the best design which is what will be used on the car. There are actually 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. An Excel sheet was created and can be seen in Appendix 7.3.4. 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" [21]. 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 15 ft/s^2. This will allow the team to keep the brakes the same and just get two new master cylinders.

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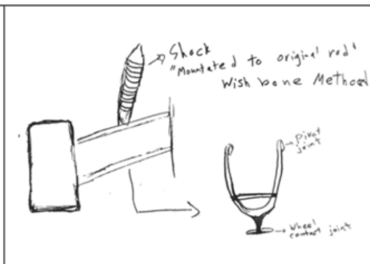
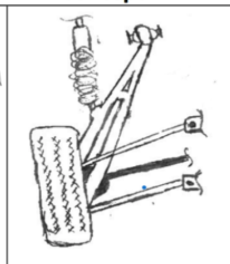
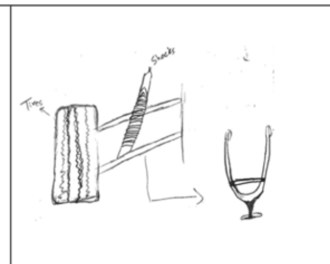
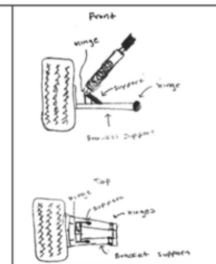
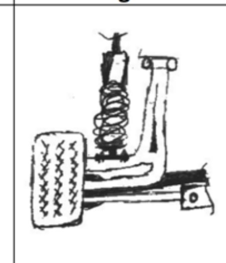
7 APPENDICES

7.1 *Appendix A: Decision Matrix*

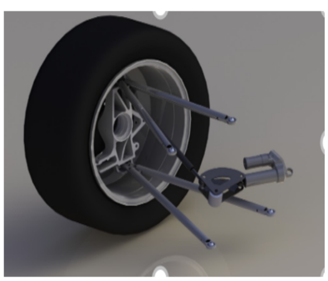
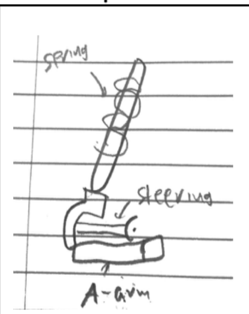
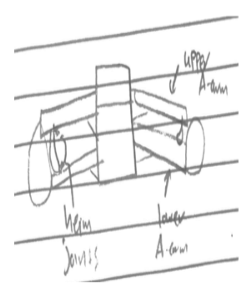
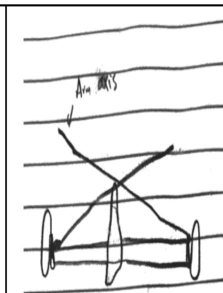
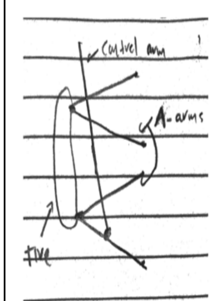
7.1.1 Rear Suspension

Table 3: Rear Suspension Decision Matrix

		Concept								Original	
Criteria	Weight										
		Top mounted Wishbone Method		A-Trailing Arm		Bottom mounted Wishbone Method		Mac Pherson Strut		L-Trailing Arm	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Safety	0.25	75	18.75	90	22.5	75	18.75	85	21.25	25	6.25
Cost	0.1	75	7.5	60	6	40	4	25	2.5	45	4.5
pports Battery / Mo	0.25	80	20	100	25	75	18.75	70	17.5	15	3.75
Less Fabrication	0.15	50	7.5	65	9.75	10	1.5	5	0.75	35	5.25
Space	0.25	25	6.25	100	25	15	3.75	10	2.5	25	6.25
Total (%)	1		60		88.25		46.75		44.5		26
Relative Ranking			2		1		3		4		5

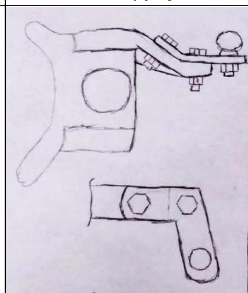
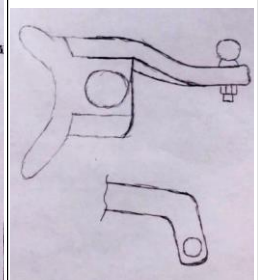
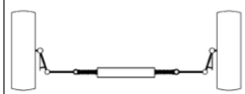
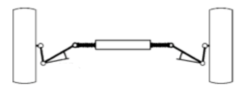
7.1.2 Front Suspension

Table 4: front suspension Decision Matrix

		Concept									
Criteria	Weight										
		A-Arm		MacPherson		Double front suspension		Semi trailing arm		Control arm	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Safety	0.25	80	20	55	13.75	90	13.75	65	16.25	60	15
Cost	0.1	80	8	90	9	45	9	75	7.5	60	6
Supports Battery / Motor	0.25	70	17.5	45	11.25	80	20	70	17.5	60	15
Less Fabrication	0.15	60	9	65	9.75	75	11.25	60	9	65	9.75
Space	0.25	60	15	70	17.5	90	22.5	70	17.5	75	18.75
Total (%)	1		69.5		61.25		76.5		67.75		64.5
Relative Ranking			2		5		1		3		4

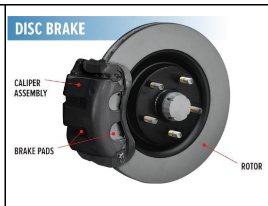
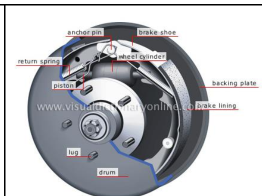
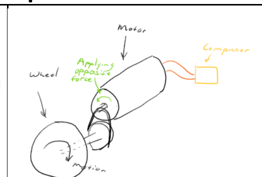
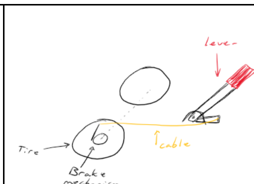
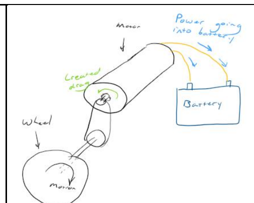
7.1.3 Steering

Table 4: Steering Decision Matrix

		Fix Knuckle		New Knuckle		Change Location		Keep Original Location		Change Pinion Gear	
											
Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Safety	0.25	75	18.75	85	21.25	95	23.75	85	21.25	85	21.25
Low Cost	0.15	95	14.25	30	4.5	30	4.5	95	14.25	30	4.5
Support Suspension System	0.10	100	10	100	10	100	10	100	10	100	10
Durability	0.20	70	14	95	19	85	17	85	17	90	18
Less Fabrication	0.10	35	3.5	70	7	10	1	85	8.5	20	2
Client Requirement	0.20	90	18	50	10	50	10	50	10	50	10
Total (%)	1		78.5		71.75		66.25		81		65.75
Relative Ranking			1		2		4		3		5

7.1.4 Brakes

Table 5: Brakes Decision Matrix

		Concept									
Criteria	**Weight**										
		Disc Brakes		**Drum Brakes**		**Motor Braking**		**Single Hand Brake**		**Regenerative Braking**	
		Rating	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**
Safety	0.25	100	25	100	25	70	17.5	55	13.75	60	15
Cost	0.1	75	7.5	75	7.5	10	1	75	7.5	75	7.5
Stops Quickly	0.25	90	22.5	75	18.75	75	18.75	50	12.5	20	5
Less Fabrication	0.15	75	11.25	65	9.75	75	11.25	75	11.25	90	13.5
Space	0.25	75	18.75	65	16.25	90	22.5	75	18.75	90	22.5
Total (%)	1		85		77.25		71		63.75		63.5
Relative Ranking			1		2		3		4		5

7.2 Appendix B: Pugh Chart

7.2.1 Rear Suspension

Table 6: Rear Supsension Pugh Chart

Engineering Requirements	L-Trailing Arm(Datum)	A-Trailing Arm	Bottom mounted Wishbone	Mac Pherson Strut	Top mounted Wishbone
Safety	0	+	+	+	+
Cost	0	-	-	-	-
Supports Battery / N	0	+	S	+	S
Less Fabrication	0	S	-	-	-
Space	0	+	S	S	-
Sum +		3	1	2	1
Sum -		1	2	2	3
Sum S		1	2	1	1
Total	0	2	-1	1	0

7.2.2 Brakes

Table 7: Brake Pugh Chart

Engineering Requirements	Disc Brake (Datum)	Drum Brake	Motor Braking	Single Hand Brake	Regenerative Braking
Safety	0	S	S	-	-
Cost	0	S	-	+	+
Stops Quickly	0	S	S	-	-
Less Fabrication	0	-	+	-	+
Space	0	-	+	+	+
Weight	0	-	S	+	S
Sum +		0	2	3	3
Sum -		3	2	3	2
Sum S		3	3	0	1
Total	0	-3	-1	3	2

7.3 *Appendix C: Back of Envelope Calculations*

7.3.1 Rear Suspension

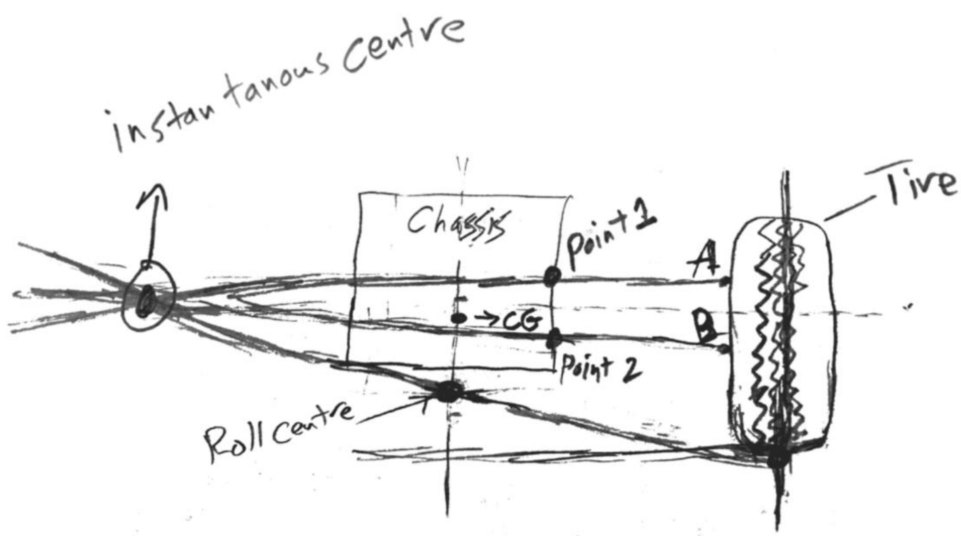
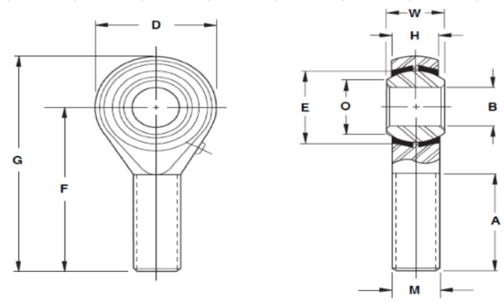


Figure 39: Raw Sketch on Finding the Stabilizer Bars Position for Camber Analysis

7.3.2 Front Suspension (Heim joints)

Given Parameters (Bottom Heim Joint)			
Ball Diamter	E	0.694	in
Housing Width	H	0.390	in
Head Diameter	D	1.012	in
Minor Dia of thread		0.410	in
Dia of Drilled hole in Shank of Male Rod End	N	0.300	in
Allowable Material Stress	X	35,000	PSI
Calculated Values			
Race Material Compressive Strength	R	9473	lbf
Rod End Head Strength	T	3404	lbf
Male Thread Rod End Strength	S	2132	lbf
Maximum Static Radial Load		2132	lbf
Maximum Static Axial Load	A	2730	lbf

Table in Report (Material-SS 300 Series)



Given Parameters (Top Heim Joint)			
Ball Diamter	E	0.625	in
Housing Width	H	0.344	in
Head Diameter	D	0.875	in
Minor Dia of thread		0.3125	in
Dia of Drilled hole in Shank of Male Rod End	N	0.25	in
Allowable Material Stress	X	35,000	PSI
Calculated Values			
Race Material Compressive Strength	R	7525	lbf
Rod End Head Strength	T	2281	lbf
Male Thread Rod End Strength	S	960	lbf
Maximum Static Radial Load		960	lbf
Maximum Static Axial Load	A	2166	lbf

Table in Report (Material)

Figure 40: Heim Calculations

7.3.3 Brakes

Front Cylinder	
Cylinder Size (in)	Bore Area (in2)
7/8	0.60

Rear Cylinder	
Cylinder Size (in)	Bore Area (in2)
1	0.79

Pedal Dimesions				
A (in)	B (in)	F (lbs)	Pedal Ratio	Pedal Force Out
7.5	2.25	50	3.33	167

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)	5
Speed ratio btwn wheel/bra	2.5
Braking Torque (Ftlbs)	15000

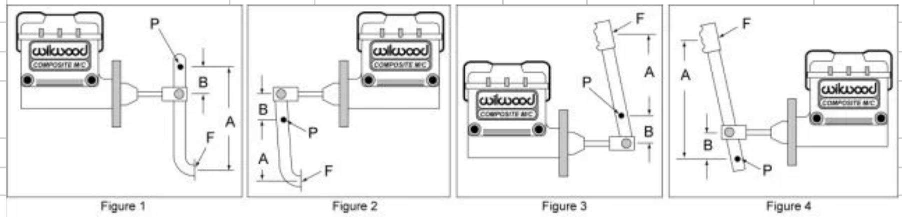
Disc Outer Diameter	10
Disc Inner Diameter	8
Effective Radius	4.5

Coefficient of Friction	0.4
Number of friction faces	2
Clamp Load (lbs)	4150

Clamp Force/wheel	1037

Total Clamping Force (lbs)	875

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



Front Cylinder	
# of Calipers on Cylinder	3
Force from Cylinder (lbs)	277
Force/Caliper (lbs)	92

Rear Cylinder	
# of Calipers on Cylinder	0
Force from Cylinder (lbs)	92
Force/Caliper (lbs)	92

LF Brake	
Caliper D (in)	1.5
# of piston	2
Net Bore Area (in^2)	3.5
Braking Force	326.53

RF Brake	
Caliper D (in)	1.5
# of piston	2
Net Bore Area (in^2)	3.5
Braking Force	326.53

Rear Brake	
Caliper D (in)	1.75
# of piston	1
Net Bore Area (in^2)	2.4
Braking Force	222.22

Figure 41: Brake Calculations