E-Baja Conversion Team

Final Report

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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. Furthermore, the project was cut about four weeks short due to the COVID-19 pandemic. The final parts of this project were not completed. Sections of this intended report were either omitted or theorized.

EXECUTIVE SUMMARY

A Mechanical Engineer team was tasked with the reverse engineering of an internal combustion engine to the school's first electrically powered Baja vehicle. The objective of this project is to simulate real-world engineering design and their related challenges on BAJA racing vehicle. The reverse engineering of the Baja Car into a full electric model is important for several reasons. Firstly, electric vehicles cause less pollution than gas powered vehicles, allowing the owner to reduce their carbon footprint. Secondly, an electric model would be cheaper to operate due to higher energy efficiency and low maintenance costs because of less moving parts compared to the original design. Moreover, the team envisions improved safety of the vehicle, with reduced risk for flammable materials.

For designing of different components of Baja, team members interacted with all the stakeholders to find the customer needs that needs to be fulfilled. The team derived the engineering requirements from the various requests posed by all the stakeholders including the client, the advisor, and the SAE India Baja competition.

The team did a lot of research on Baja vehicles that are available in the internet to get a better understanding of it. The team focused on the front suspension, rear suspension, steering and brakes. 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 was the Pugh chart and decision matrix. Designs were chosen according to customer requirements then passed through a further evaluation to put into development.

The design of rear suspension is built like a truss with triangles and can absorb forces in several directions. This will 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 heim joints. The rack and pinion mechanism was 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.

ACKNOWLEDGEMENTS

The 2019-2020 Electrical Baja team would like to acknowledge the following people and organizations for helping our project move forward:

David Willy (Client) for helping the project take form and progress.

Sarah Oman (Capstone Advisor) for constantly checking on the team and assuring steady progress from all group memebers.

Perry Wood (Shop Manager) for being present for assistance on hardware and machining whenever the team was in need during the manufacturing of the project.

Tanner Gill (Shop Advisor) for being there when the team needed to clarify issues on building and material purchases. Tanner also helped the team weld everything on the vehicle due to the team's lack of experience.

W.L Gore (Sponsor) for aiding this project with $3,000.

Discount Tire (Tire Donation) for providing brand new tires to the team due to the original tires being worn out.

Copper State Nut and Bolt (Nut and Bolt Donation) for helping the team save money on few nuts and bolts rather than purchasing larger packages.

Coconino High School (Material Donation) for donating the aluminum used to create the trailing arms.

MarZee Waterjet Services (Trailing Arm Manufacturing) for discounting and manufacturing the trailing arms out of the necessary material.

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1 BACKGROUND

1.1 Introduction

[Use this section to introduce the reader to your project. Describe what the project is, project objectives, why it is of interest to the sponsor (project relevance), and how the project benefits the sponsor and other stakeholders, upon completion. A large emphasis in the section should be on why this project is important. What contemporary issues does this project address?]
[You may use the same text from the Preliminary Report here provided all issues have been edited/mitigated and any changes to the project reflected in this report. If comments from the Preliminary Report are not addressed, this may result in a grade of zero for this section.]
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, 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. Secondly, with the increasing concerns over climate change, 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 flammable materials.

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 scrapped 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, 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 is 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. 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 financially sponsored by W. L. Gore and more to come in the project's year." The project description is updated to meet the new regulations and standards from the project's clients.

2 REQUIREMENTS

This section contains the customer needs and the engineering requirements per the SAE India Baja competition rule book. The rules and regulations have helped the team shape the project to be fit for competition. The functional decomposition and house of quality further elaborates the thought process of the team and their goals.

2.1 Customer Requirements (CRs)

Table 1. Customer needs and weights

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
Provide a Functioning Brake System	5
Electric Compatible Drivetrain	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 rulebook 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 because the team is willing to do minor fabrication to the vehicle sub-systems such as steering and suspension. The team will not build major components for the vehicle frame. The redesign of the rear suspension, functioning brake system, electric compatible drivetrain, reinforcing the front suspension and redoing the steering will be focused on being durable and robust. It was broken down by the team to illustrate the focus on these components.

2.2 Engineering Requirements (ERs)

Table 2. Engineering requirements

Engineering Requirements	Relative Technical Importance	Technical Requirements Target	Tolerance for Targets	On Target
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 (ft-lbf)	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 23 KW	✅

The engineering requirements above satisfy the customer requirements. For instance, safety is considered the most important requirement. The team's target is equal to or greater than 2.5 and 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 vehicle. The torque value is 520ft-lbf for the gear and 85 ft-lbf for the pinion. Cost is set as $3000 which is the original budget provided by W.L. Gore. The tolerance for cost is set as not applicable because the team is planning to fundraise 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 800lbs 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, 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

This section covers the black box model and the final functional model. It provided the team with a thought process to make sure that all angles were observed when making decisions.

2.3.1 Black Box Model

The Black Box Model is introduced to facilitate the visualization of this team's project. The purpose 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.

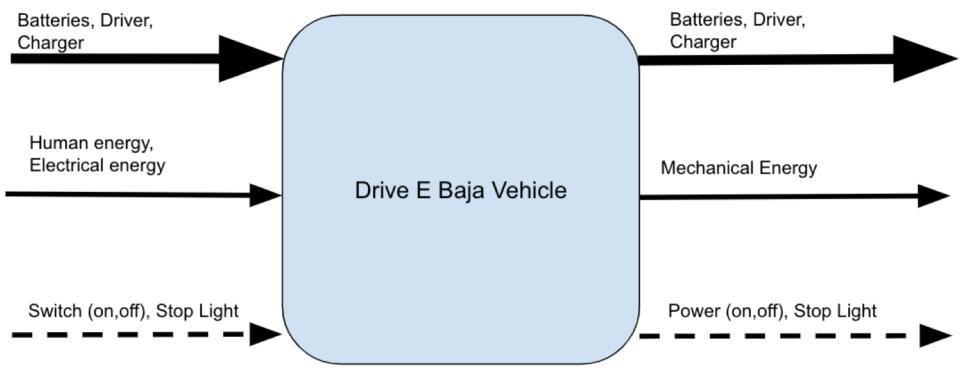


Figure 1. Black box model

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 and mechanical processes such as the brake system. The signals provided are the on/off switch and the brake 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. Following the vehicle disassembly, this model accurately exemplifies what occurs while the vehicle is driving.

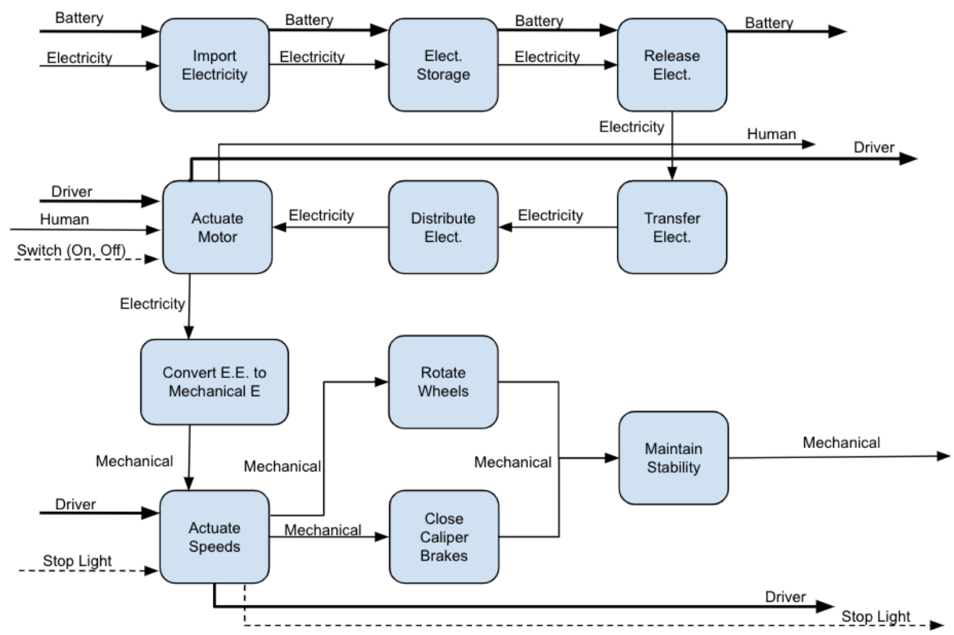


Figure 2. Functional model

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 driveshaft 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 brake 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. The three main components used in the functional model are the electrical, the brakes and the suspension.

2.4 House of Quality (HoQ)

The figure in appendix A shows the House of Quality the team constructed. The top part of the House of Quality compares each engineering requirement 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 requirement 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.

Unfortunately, due to the 2020 pandemic of COVID-19, the team has not been able to proceed with testing. Meaning the team never reassured that the care was reaching the engineering requirements. However, the testing procedures that were supposed to take place are listed below in section 3.

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 SAEIndia C4.3.3	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 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. The SAEIndia C.2.1 section was not used due to the complete stop of the project during the pandemic. However, SAEINDIA C4.3.3 showed specifications for the firewall that the team acted on by purchasing the thin plastic necessary for an electrical vehicle firewall.

3 Testing Procedures (TPs)

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 DESIGN SPACE RESEARCH

This section overviews what the team researched prior to starting the project. Literature reviews showed what has worked and what other schools have done. It educated on details like safety and different designs. Benchmarking added to this knowledge by showing what the current leading models are using.

4.1 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.

4.1.1 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.

4.1.1.1 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.

4.1.1.2 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.

4.1.1.3 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.

4.1.1.4 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.

4.1.1.5 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.

4.1.2 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.

4.1.2.1 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.

4.1.2.2 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.

4.1.2.3 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.

4.1.2.4 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.

4.1.2.5 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.

4.1.3 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.

4.1.3.1 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.

4.1.3.2 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.

4.1.3.3 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.

4.1.3.4 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.

4.1.3.5 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.

4.1.4 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.

4.1.4.1 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.

4.1.4.2 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.

4.1.4.3 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.

4.1.4.4 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.

4.1.4.5 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.

4.1.5 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.

4.1.5.1 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.

4.1.5.2 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.

4.1.5.3 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.

4.1.5.4 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.

4.1.5.5 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.

4.2 Benchmarking

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.

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.

4.2.1 System Level Benchmarking

4.2.1.1 Existing Design #1: GAY/AG01

Figure 3 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 3: Full System Benchmark 1 [26]

4.2.1.2 Existing Design #2: Epic Amp

Figure 4 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 4: Full System Benchmark 2 [27]

4.2.1.3 Existing Design #3: Electric buggy

Figure 5 shows an electric Off-Road 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 5: Full System Benchmark 3 [26]

4.2.2 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.

4.2.2.1 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.

4.2.2.1.1 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.

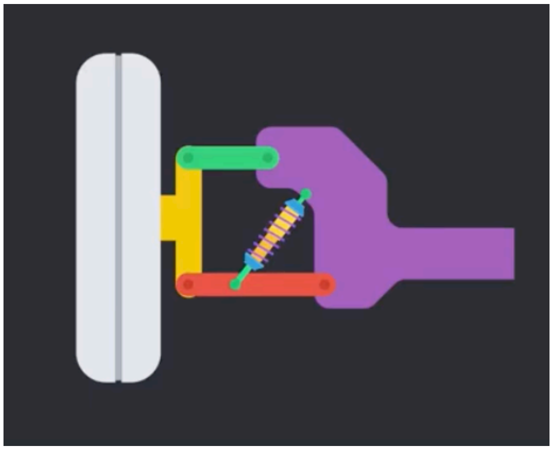


Figure 6: Double Wish Bone Diagram

4.2.2.1.2 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.

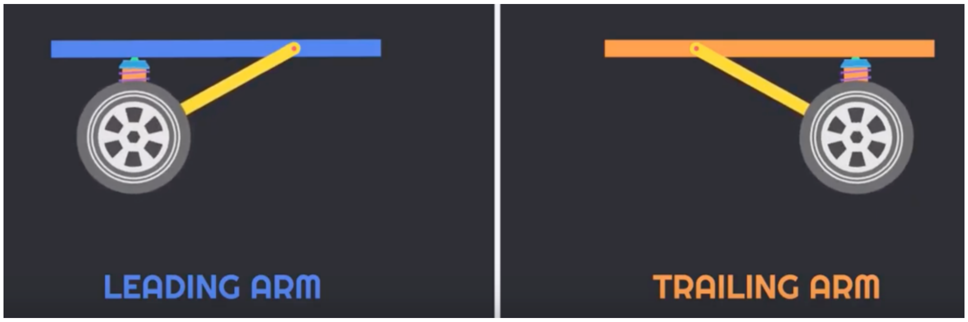


Figure 7: Trailing Arm vs. Leading Arm Diagram

4.2.2.1.3 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.

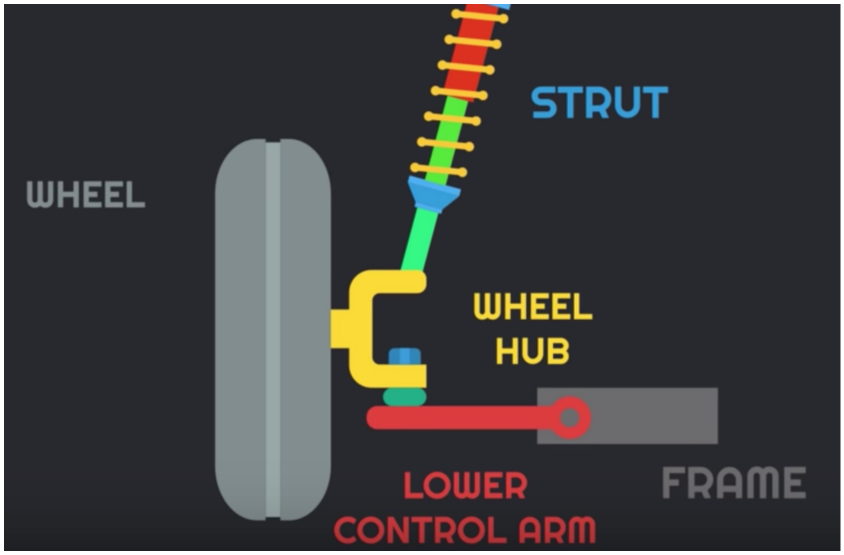


Figure 8: MacPherson Strut Suspension

4.2.2.2 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.

4.2.2.2.1 Existing Design #1:front suspension

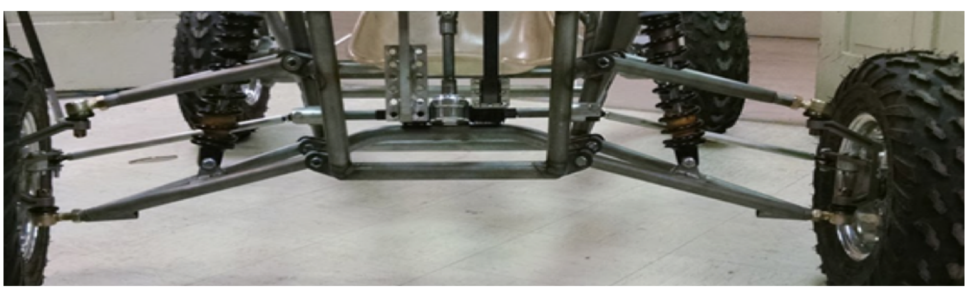


Figure 9: Existing Front Suspension

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

4.2.2.2.2 Existing Design #2: lower arm

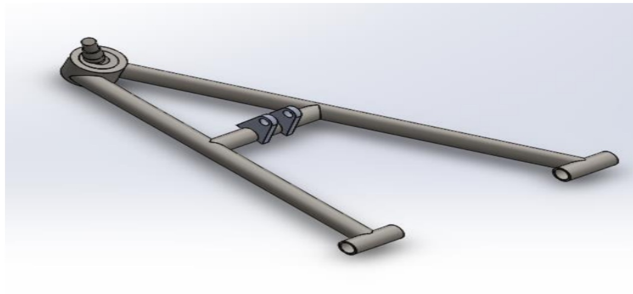


Figure 10: Lower A-arm Diagram

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

4.2.2.2.3 Existing Design #3: Heim joints

Figure 11: 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 and to increase safety.

4.2.2.3 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.

4.2.2.3.1 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 12. This design is the one the team is going to use, it is a simple mechanical design and is already on the Baja.

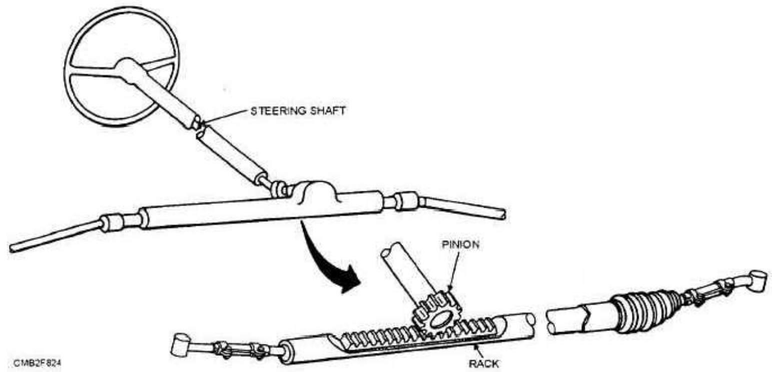
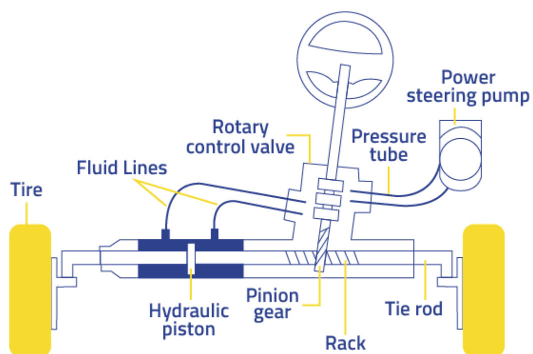


Figure 12: Rack and Pinion Diagram [28]

4.2.2.3.2 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 13, 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.



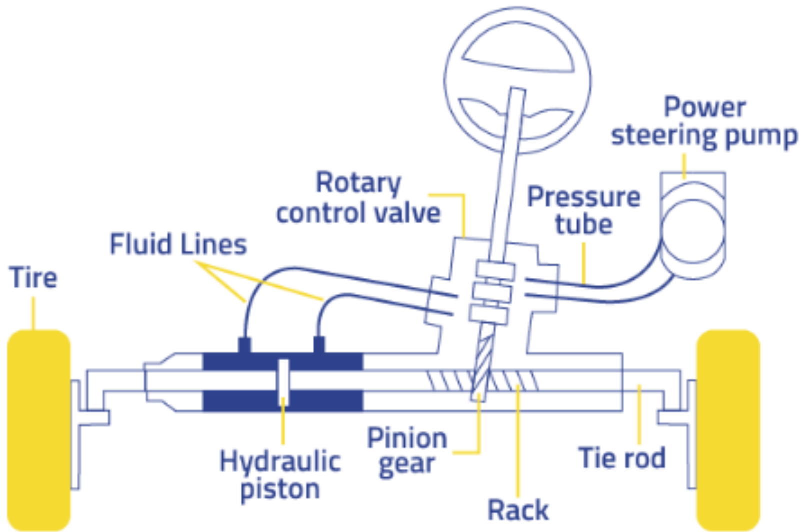


Figure 13: Hydraulic Steering Diagram [29]

4.2.2.3.3 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 14 shows the set up and how an electrical steering system looks like.

Figure 14: Electric Power Steering Setup [30]

4.2.2.4 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.

4.2.2.4.1 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 15 shows a diagram of what a drum brake consists of.

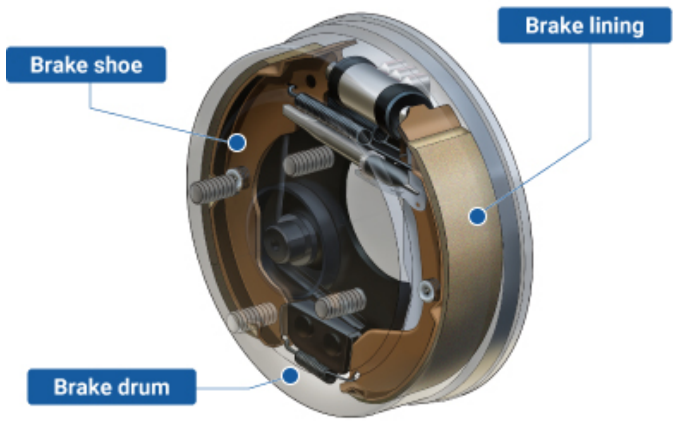


Figure 15: Drum Brake Diagram [31]

4.2.2.4.2 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 16 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.

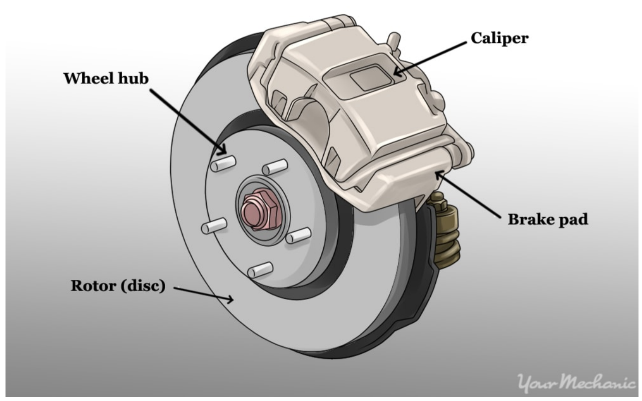


Figure 16: Rotor and Brake Disc Diagram [32]

4.2.2.4.3 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 17, all the different parts of the master cylinder are seen.

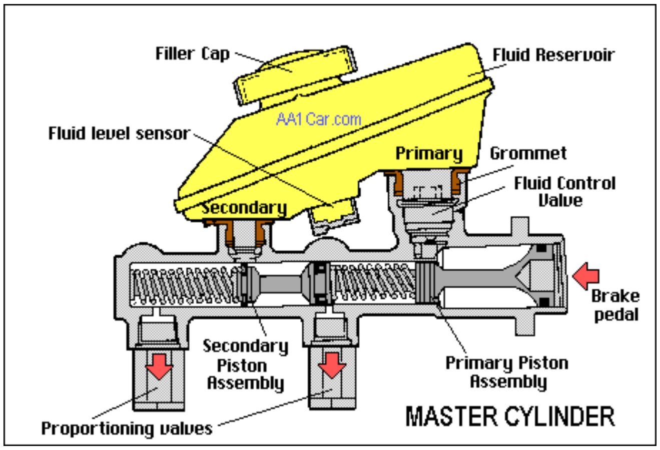


Figure 17: Master Cylinder Diagram [33]

5 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.

5.1 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 **Error! Reference source not found.**.

5.1.1 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.

5.1.1.1 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.

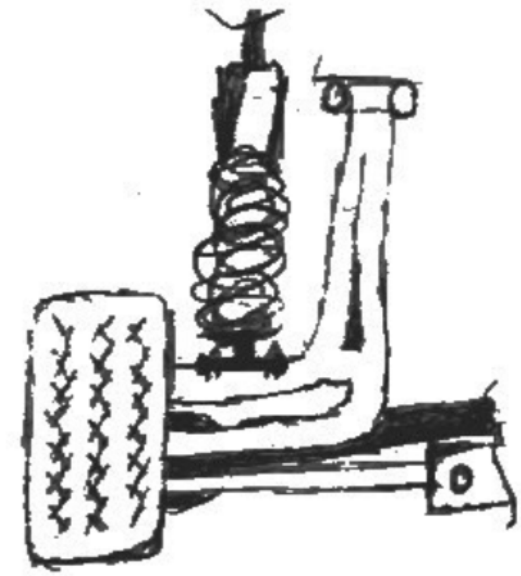


Figure 18: L-Trailing Arm Diagram

Pros	Cons
Save money and time if used	Low degree of freedom
	Unreliable and low safety
	Low space

5.1.1.2 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.

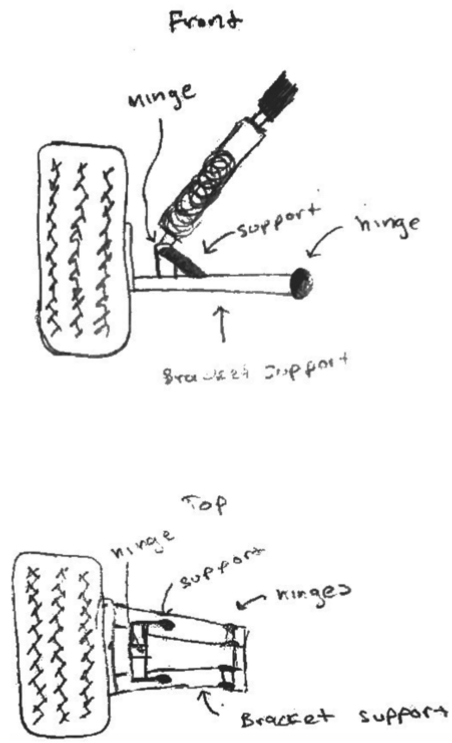


Figure 19: Mac Pherson Strut Diagram

Pros	Cons
Safe	High cost of machinery.
Can support battery and motor	Complex design (require extra fabrication).
	Provides less space.

5.1.1.3 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.

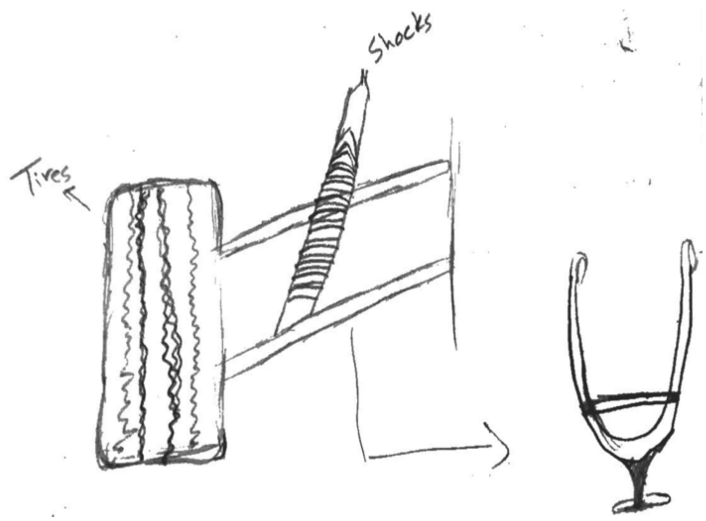


Figure 20: Bottom Mounted Wishbone Diagram

Pros	Cons
Safe	Requires maintenance (increases cost)
Support battery and motor	New mounts (more fabrication to the frame)
	Provides less space.

5.1.1.4 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.

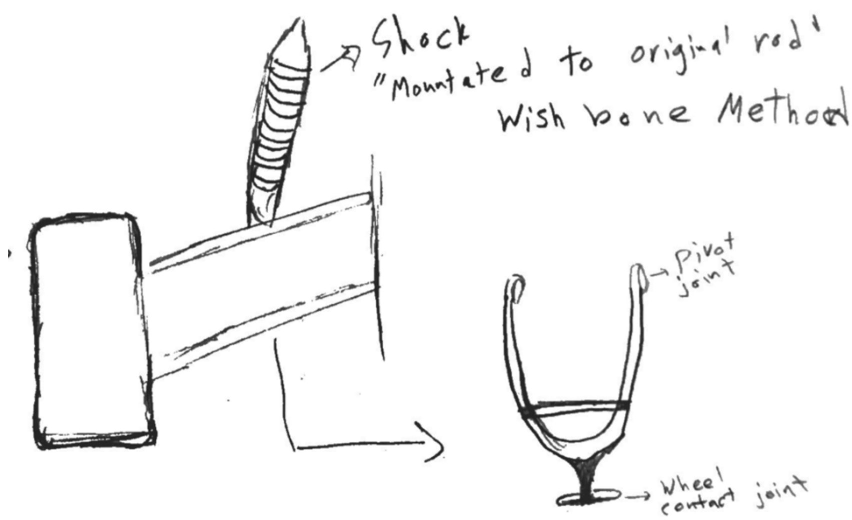


Figure 21: Top Mounted Wishbone Diagram

Pros	Cons

Safe	New mounts (more fabrication to the frame)
Low cost	Provides less space
Support battery and motor	
Reliable	

5.1.1.5 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.

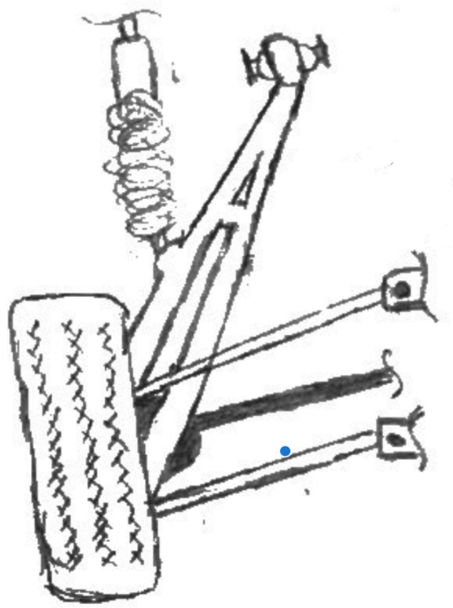


Figure 22: A-Trailing Arm Diagram

Pros	Cons
Safe and Reliable.	Almost expensive.
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	

5.1.2 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.

5.1.2.1 Design #1: A-arm

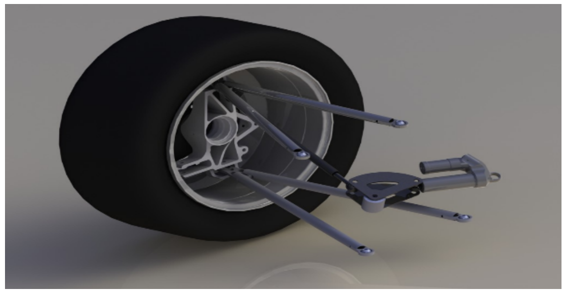


Figure 23: A-arm Diagram

Pros	Cons
Alignment wheels	Easy to break
Less weighted	More expensive
Better traction	

5.1.2.2 Design #2: MacPherson strut

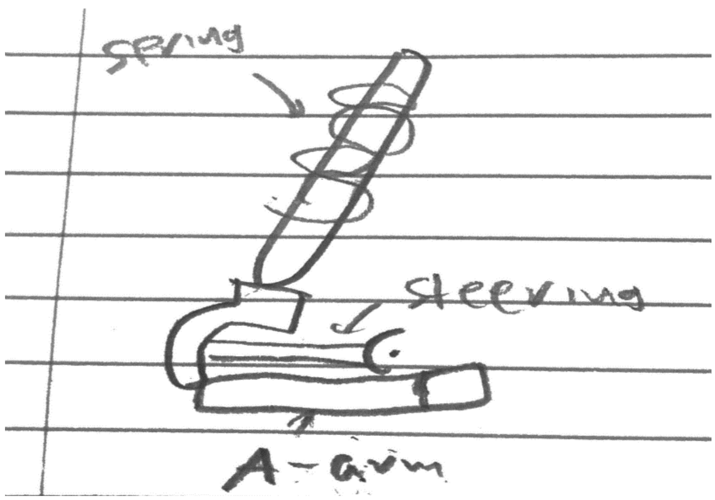


Figure 24: MacPherson Strut Diagram

Pros	Cons
Easier designing	Less handling
Less components	Easy to break
Lighter weight	
Less cost	

5.1.2.3 Design #3: Double front suspension

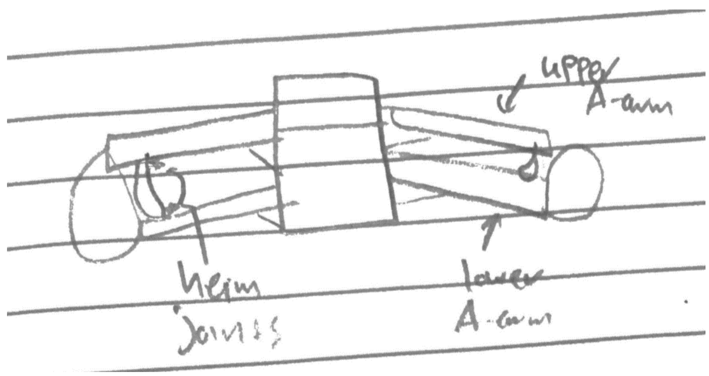


Figure 25: Double Front Suspension Design

Pros	Cons
Better stability	Expensive
Strong enough for off-road use	Hard to design
Well performance	

5.1.2.4 Design #4: semi trailing arm

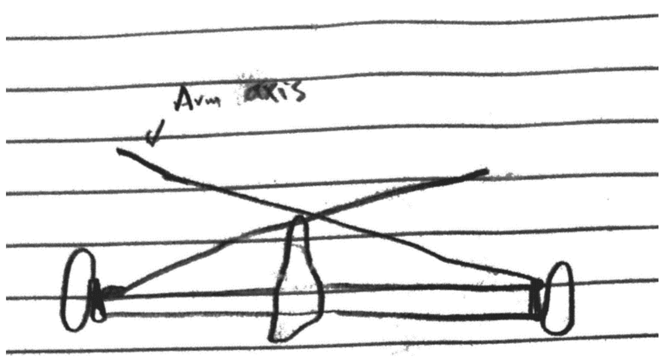


Figure 26: Semi Trailing Arms

Pros	Cons
Simple design	Easy to break
Few materials	Arms are expensive
Well performance	

5.1.2.5 Design #5: Control arm

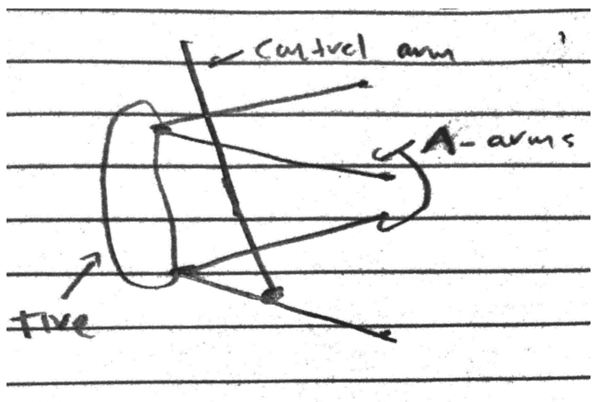


Figure 27: Control Arm Diagram

Pros	Cons
Improve wheels travel	Reduce ride quality
Less cost	Cause huge suspension damage when off-roading
Better quality	

5.1.3 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.

5.1.3.1 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 28 shows the current design on the steering knuckle.

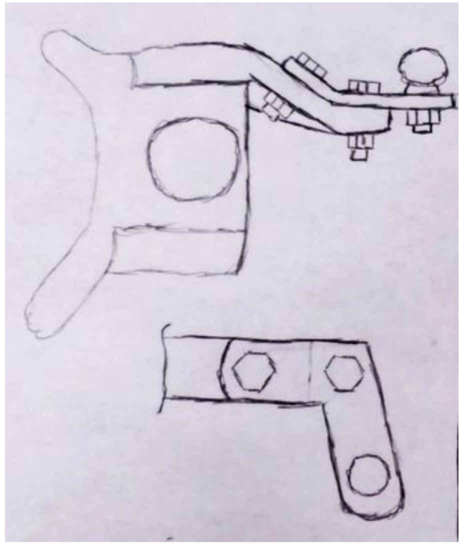


Figure 28: Fix Current Steering Knuckle

pros	Cons
Low cost	Requires more fabrication
Client approval	
Better quality	

5.1.3.2 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 29 shows the concept design for the new steering knuckle.

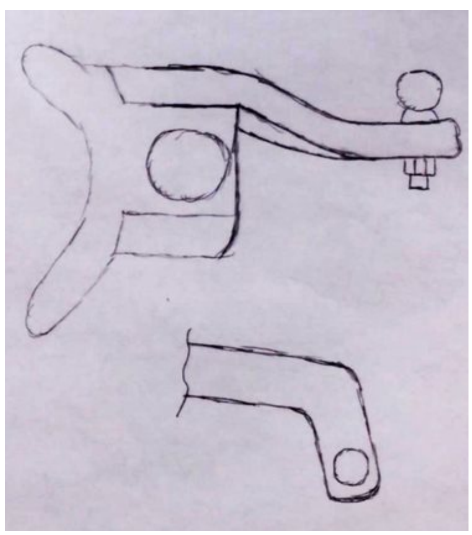


Figure 29: New Steering Knuckle

pros	Cons

Safer than current knuckle	High cost
More durable	

5.1.3.3 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 30 shows the ideal placement of steering system for an ideal Ackemann angle.

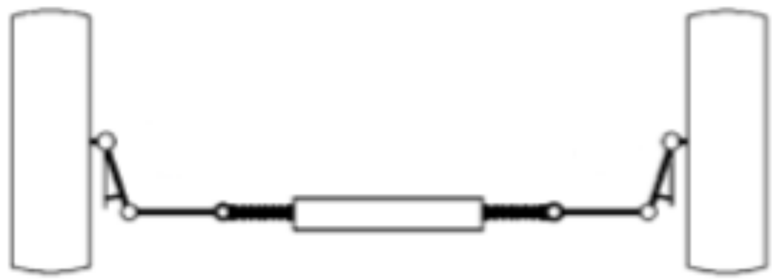


Figure 30: Change Location of the Rack and Pinion [11]

Pros	Cons
Ideal Ackemann angle	High cost
Safer turning	Requires more fabrication

5.1.3.4 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 31 shows the current placement of steering system, current system does not look like the Figure 30 but the figure shows a dramatic effect that changes the Ackemann angle.

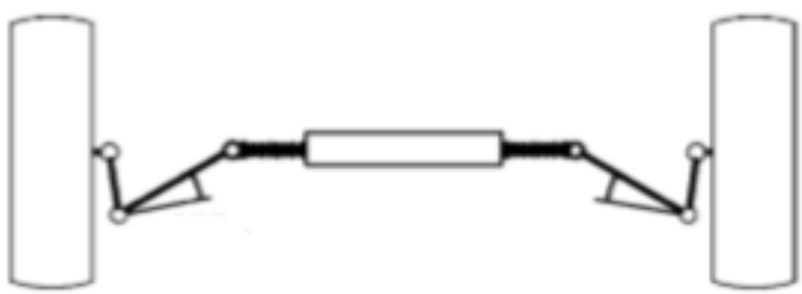


Figure 31: Original Location of Rack and Pinion [11]

Pros	Cons
Low cost	Not ideal for Ackemann angle

Less fabrication	

5.1.3.5 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 32 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 32: Larger Gear Ratio Diagram [34]

pros	Cons
Easier turning	Requires more fabrication

5.1.4 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.

5.1.4.1 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.

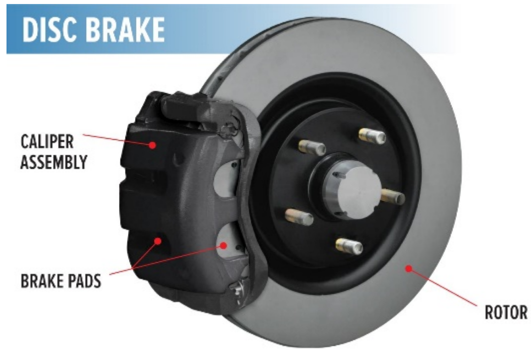


Figure 33: Disc Brake [35]

pros	Cons
Simple	Required on each wheel
Stops Effectively	
Compact	

5.1.4.2 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.

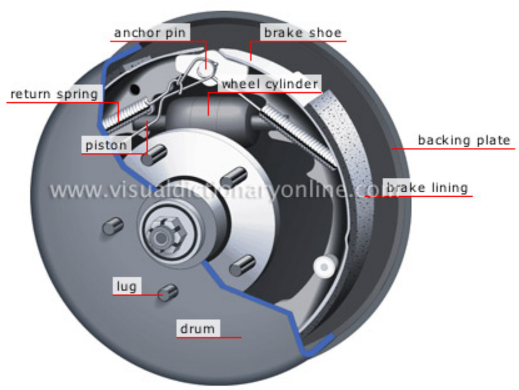


Figure 34: Drum Brake [36]

pros	Cons
Clean looking	Heavy
Last a long time	Complicated Setup
	High Force Required

5.1.4.3 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.

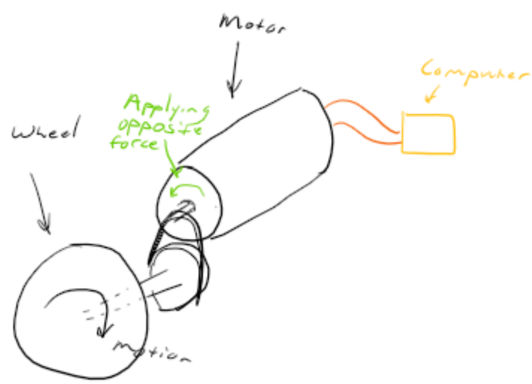


Figure 35: Motor Braking Diagram

pros	Cons
Light	Expensive
Last a long time	Complex computer components needed

5.1.4.4 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.

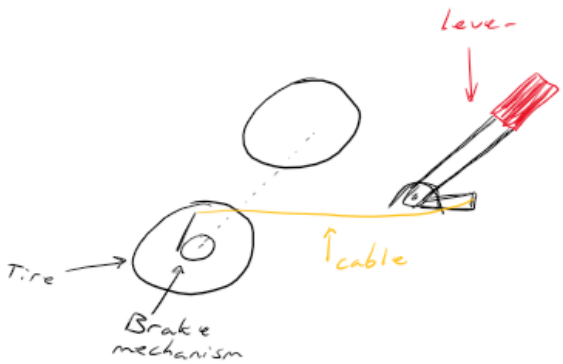


Figure 36: Single Hand Brake Diagram

pros	Cons
Simple design	Doesn't stop well
Light	Potential to break
Cheap	

5.1.4.5 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.

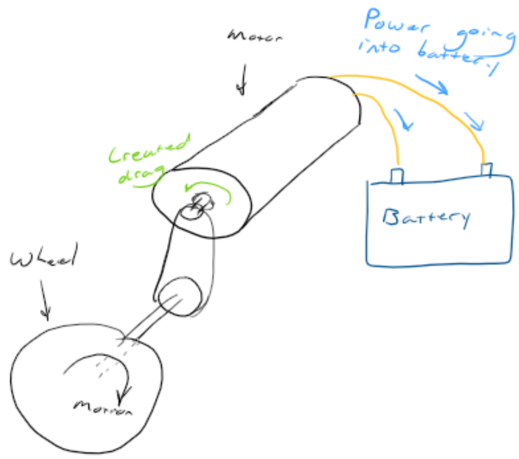


Figure 37: Regenerative Braking Diagram

pros	Cons
Cheap	Way less stopping power
Light	
Saves Energy	

6 DESIGN SELECTED – First Semester

This section talks about the process the team took to select their design in the first semester. Here, it explains the thinking that the team went through to arrive at the goal.

6.1 Design Description – First Semester

These are all the items that were created the first semester and put into play second semester. The process is what lead the team to where they are and would later help accomplish the goal.

6.1.1 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.

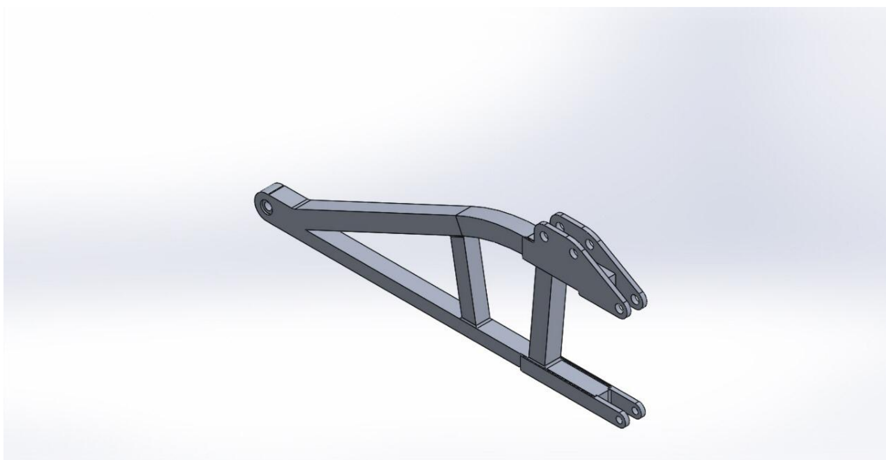


Figure 38:A shaped trailing arm CAD model

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

6.1.2 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 joint can be seen in the Figure 59 and 60.

6.1.3 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 40.

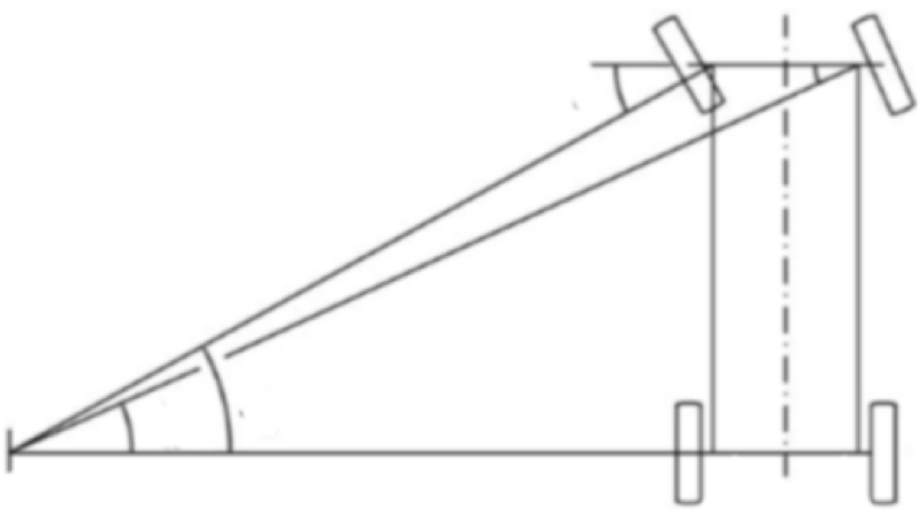


Figure 40: Diagram of Proper Turning Geometry

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.

6.1.4 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.

6.1.5 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 **Error! Reference source not found.**. 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

6.2 Implementation Plan – First Semester

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.

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.

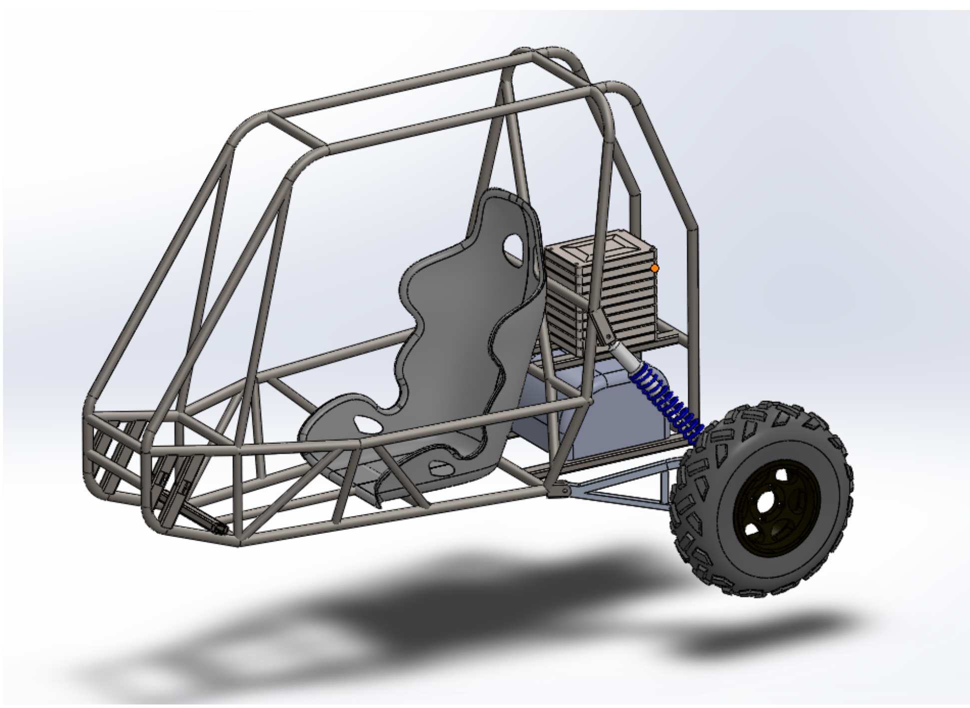


Figure 42: CAD Model

7 IMPLEMENTATION – Second Semester

7.1. Manufacturing Week 7-11

During these weeks, many parts were manufactured and placed onto the vehicle. The front of the vehicle has been completed with brakes, suspension, steering and a skid plate. The team began to focus on the rear of the vehicle in the latter weeks of this period to see full completion by April 3rd. April 3rd was the desired day of completion of the project where we have every sub-system tested. But due to the pandemic of COVID-19, the final product will be what we have achieved prior to spring break, which was the last day we have physically attended our meeting. This section will overview which parts have been manufactured. Then it will report on how these changes affect implementation of the project and will go into detail on how future parts will be designed and created with the time constraint in mind.
There are several parts that needed to be manufactured in the last few weeks of the project. To successfully finish the car, we had a whole list of parts that needed to be manufactured. We had several parts that were manufactured in the shop by our team members and a few parts that were outsourced. There were parts that were manufactured for each subcomponent of the car.

7.1.1 Front Suspension

For the front suspension, the team decided to replace the heim joints and bolts to make it stronger. The team did disassemble the old front suspension and started manufacturing. The first process was drilling holes on the old arms which will fit the new heims and rod ends. After that, the team did tap the new wholes using the tapping tool to make it fit better. Then, the team did cut from the steel to weld it on the front. Before welding the team did some grinding on the front in the machine shop to make it flat for welding. Then the team did weld the steel on the front for placing the new helms as shown in figure 1. Lastly, the team did assemble the front suspension by placing the new Hm8 heims on the top of the front suspension and Hm10 rod ends on the bottom of the suspension as shown in figure 2.

Figure 43: Steel welded on the front suspension

Figure 44: Final design for front suspension

7.1.2 Rear Suspension

The rear suspension system contains two main components. Firstly, the trailing arm which is being manufactured in company called Marzee located in Phoenix, Arizona, which is using a water jet cutter to cut the trailing arm in one piece. Secondly, the rear suspension link is manufactured in the university machine shop by the team. The team used steel sheets and bended them thru hydraulic press. The drill holes where made using the mill for precision. The rear suspension link will be attached to the trailing arm angling it to the wheel hub. Further analyses and calculation are discussed in the design iteration (section 7.2.2)

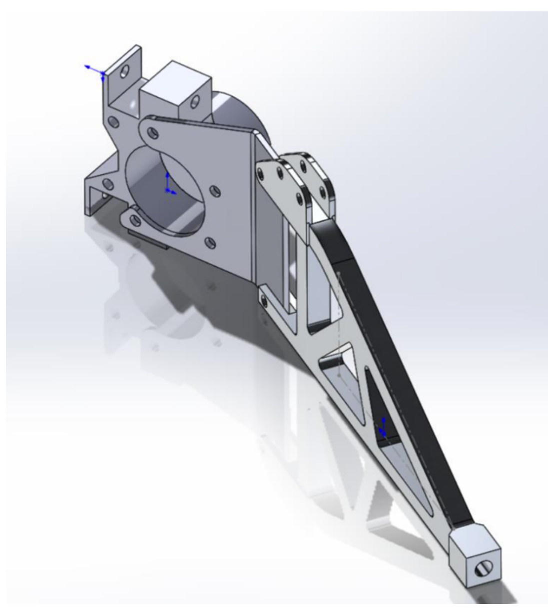


Figure 45: Complete Assembly of the Rear Suspension

7.1.3 Steering

The steering system was in good condition from the previous year it was built. The main components such as the steering knuckle, tie rods, rack and pinion, steering column, and steering wheel did not need manufacturing. The steering knuckle had an extra attachment to assist in the steering radius, this component was named, “steering link.” The steering link was made from a ¼ inch steel plate, it was cut to specific dimensions to fit on the steering knuckle and provide the ideal steering radius for the size of the car. The sheet of metal was cut with a cutoff blade on a grinder and holes were drilled on a drill press. After the dimensions of the link were done, it was bent on a “metal worker” in the machine shop.

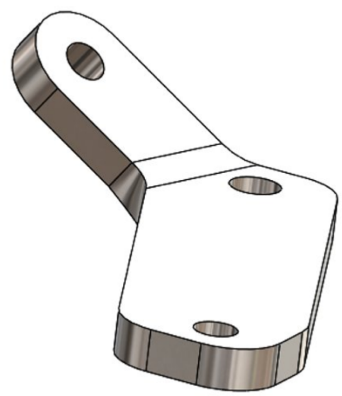


Figure 46: Steering Link

7.1.4 Brakes

The brakes didn’t have very many parts that needed manufacturing. The only part that had to be created was the mount for the brake pedal. The brake pedal mount had several features in the one mount that could mount several braking components. The mount was created using ¼ inch steel that was cut out using a cutoff blade on a grinder. The avocados were created using the grinder and a 1 ¼ inch end mill on the manual mill. The part was then bent on the “metal worker” in the shop.

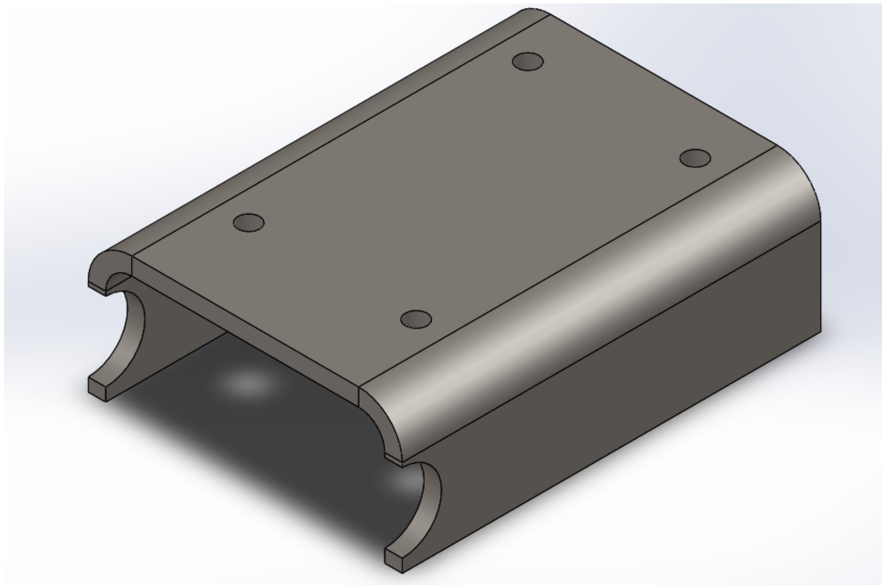


Figure 47 Brake Component Mount

The part had holes drilled in the top of that was able to mount the brake pedal. This brake pedal also had attachments to attach the master cylinders. Lastly, on the side of the bracket there were holes that were drilled to attach the fluid reservoirs. With the implementation of mounting the reservoirs to the pedal mount, it allowed to compact mounting and less mounting parts needed to be made for the car. Once this mount was created and everything was bolted to it, the mount was welded to the frame of the car.

The rest of the parts for the braking system were all able to be either used from last year or were purchased. The team was able to buy brakes lines from "GoAZ Motorsports" to run to the front brakes. The rear brakes on the car were not able to be mounted yet due to waiting on the trailing arms. There were not any parts that needed to be manufactured for the rear brakes. The rear braking system was going to be as easy as "plug and play". All of the parts had been manufactured for the braking system.

7.1.5 Gearbox

The gearbox had several parts that needed to be manufactured in order to fully assemble this part. The team was originally going to have the gearbox machined at 98C but found out it would take too long. We were quoted about five weeks after spring break which would be way to long for our original plan. The second plan was to have the case machining outsourced, but when the team got the quote back it was almost 1000 dollars. Due to that not being in the budget, the team decided to use an old contact from one of the team members. The gearbox machining process was started by a teammate in a local machine shop during spring break. Due to the cancelling of the project build, the gearbox manufacturing was never finalized.

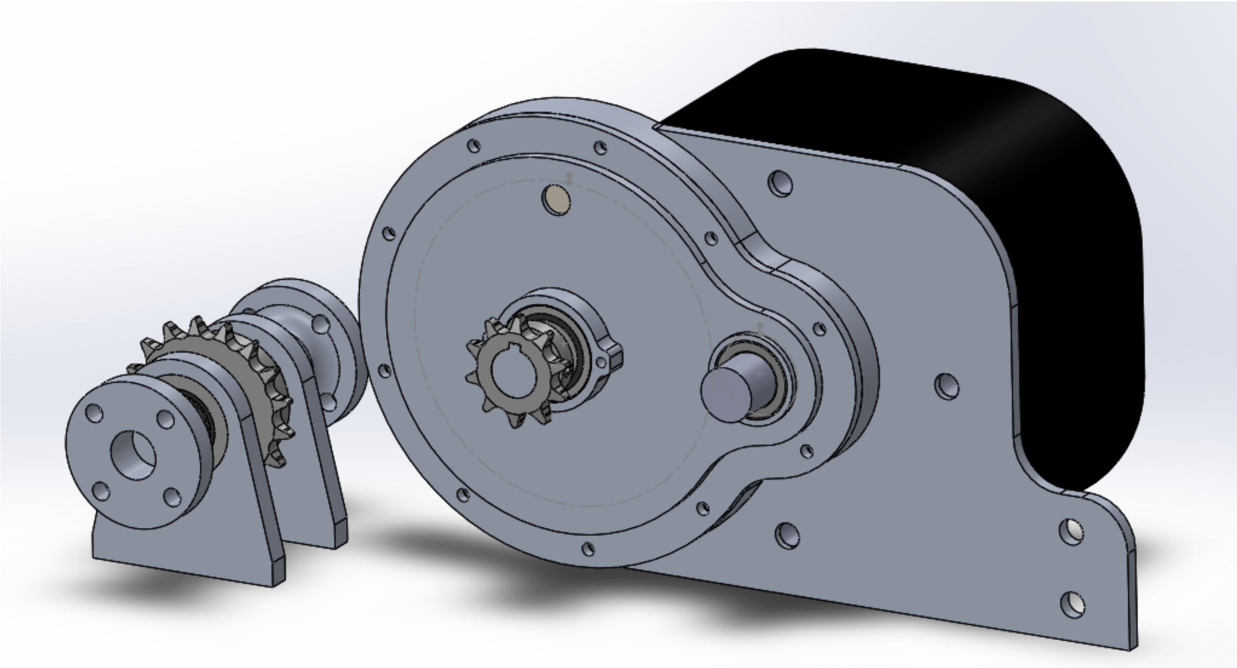


Figure 48: Gearbox Assembly Design

As mentioned above, there were several parts that needed machining in the gearbox. The first and largest part were the two sides of the case. These are shown in the figures below. These parts were going to be machined on a CNC mill. They were designed to be milled out of Aluminum sheeting that was 1 inch thick. The CAM code was written for the part but chips never started being cut on the machine.

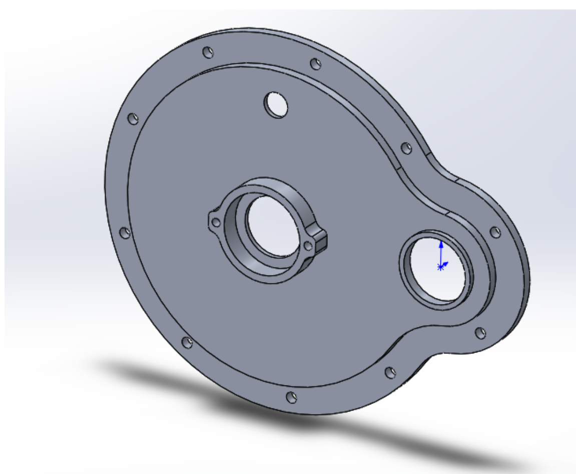


Figure 49: Gearbox Case Cover

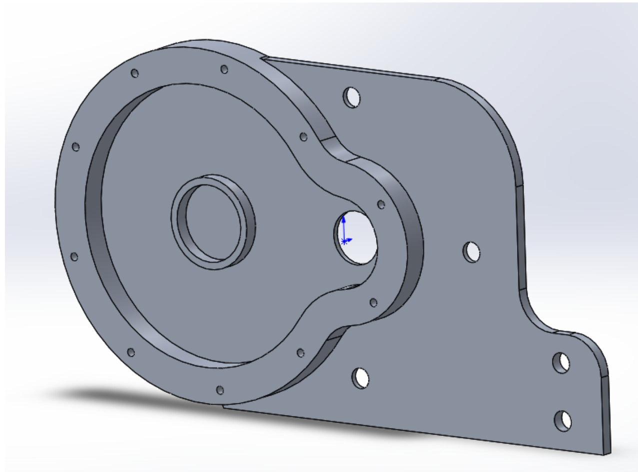


Figure 50: Gearbox Case Base

The second part that needed machining was the hub for the large gear in the gearbox. This hub was going to be machined out of the same 1 inch aluminum as the gearbox case. This was also going to be cut out on the CNC mill after the case was machined. This part only had minor tolerances on it. The only part that had a high tolerance was the part that located the center of the gear. The high tolerance was needed on this due to the fact that if it was out of concentricity, the gears wouldn't mesh properly.

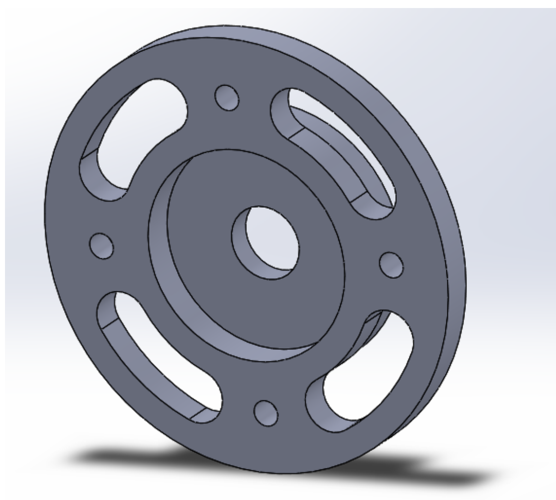


Figure 51: Large Gear Hub

Another part that needed to be machined on the gearbox was the small gear on the gearbox assembly. This gear was from the previous gearbox that the team took off the car and did not have the right bore size. The bore of the gear needed to be enlarged from a 1 inch hole to a 1 1/8 inch hole. This was going to be done on the manual mill in the 98C machine shop. Using a boring bar and a quality carbide insert, the hole was going to be enlarged. Once the hole was enlarged, a keyway was going to be created through the hole. This was going to be done using a broach and a press in 98C.

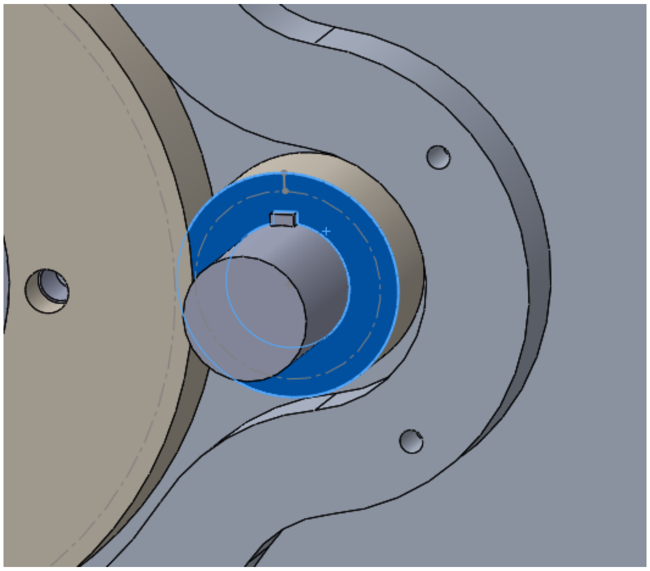


Figure 52: Small Gear Visualization

The last part that needed to be manufactured to finish the gear assembly were the bearing blocks for the sprocket. The blocks were going to hold the shaft that the sprocket was attached to. The CV axles were also going to be attached to the blocks. These block were going to have bearings pressed into the once they were made. The blocks were going to made on the CNC mill at the same shop as the case was machined. They were also going to be machined out of the 1 inch thick aluminum plate.

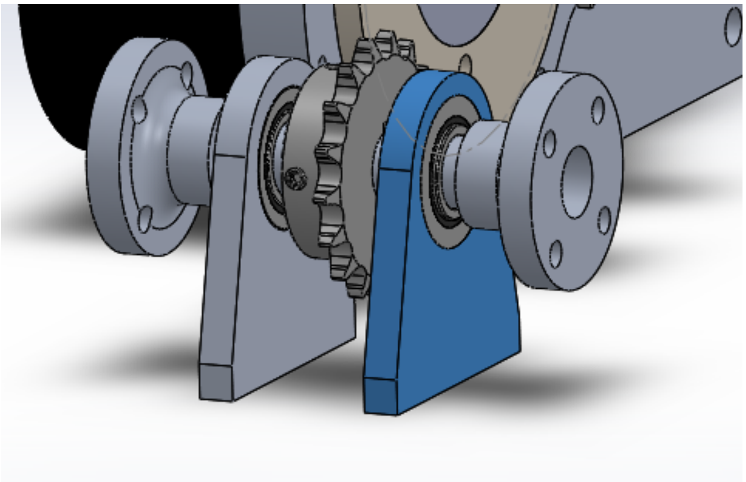


Figure 53: Bearing Block Assembly

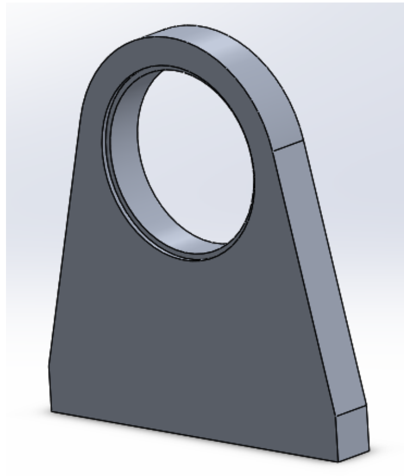


Figure 54: Bearing Block

The machining of all these parts were planned for the week of spring break and the week after. These components would have completed the assembly of the gearbox. Once all of the parts were put together, the motor could attached and the car would be ready to be hooked up to all the electric.

7.2. Design Changes

The team only had one design change during the last few weeks of building (Week 7-11). This change was on the trailing arms in the rear of the car. The rest of the car was all designed prior to this semester starting. The client pressed heavily on having the car fully designed before the second semester started. Due to this, the second semester has been mostly full of just manufacturing.

7.2.1 Design Iteration: Change in rear suspension discussion

The original proposed design of the trailing arm, which is the main component in the rear suspension system, was considered a rough sketch after getting to the final design. The original proposed design had the idea of inserting a ball joint in the frame-trailing arm connection. This will have a similar movement to the human shoulder adding a multiple degrees of freedom than the existing 2015 design on the car which have only one degree of freedom which is within the Y-axis. After consulting the client several times, the team found faults in the proposed design since it did not pass the client safety requirements. A case study was provided to the client of worst-case scenario that the vehicle might experience. The scenario was the vehicle traveling on full speed and have to experience trajectory and land on one wheel. The final force on one wheel was 57,057.55 Newtons. Therefore, the team needed to alter the design to sustain the final force. The team also have to take into consideration ease of manufacturing and choosing the material. The team used 6160 T6 Aluminum which was donated for free. The team also removed the idea of inserting a ball joint and replace it with a male heim that will be screwed in the bottom of the trailing arm. The team also increased the thickness of the bottom part from 1 in to 1.5 in this is to provide the several options to choose heims for the trailing arm. Since the manufacturer of heims provided with all information regarding radial load and factor of safety the team choose HMX12G size heim.

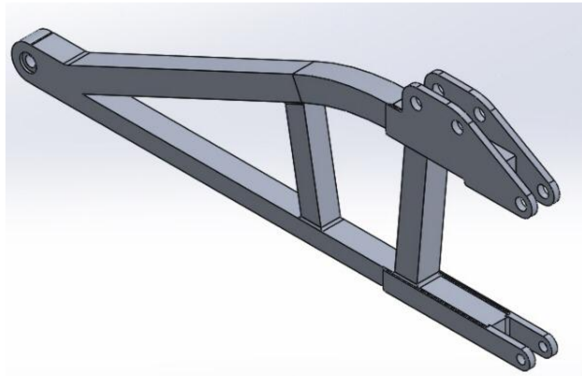


Figure 55: Original Propose Trailing Arm Design

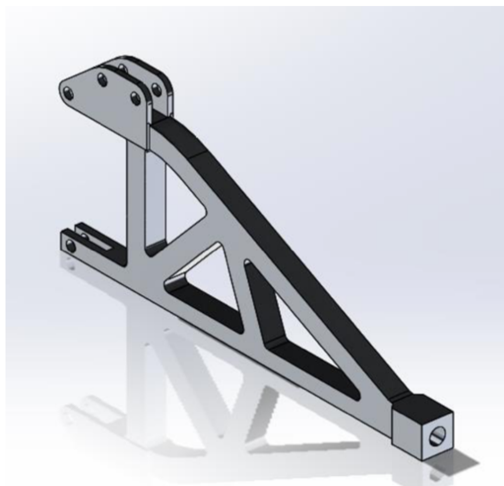


Figure 56: Final Trailing Arm Design

8 RISK ANALYSIS AND MITIGATION

8.1 Potential Failures Identified Fall Semester

To start, since the team knew there was no competition and no long-term use for this vehicle, it was implemented in that fashion. The design was created for lesser use and more failure where the team could easily substitute the part that yielded. Meaning, the team gained insight into what fails the most during competition and have made sure that will be the first to fail. Instead of losing an entire component, the team only loses a heim joint for example.

8.2 Potential Failures Identified Fall Semester

8.2.1 Potential Critical Failure of Rear Suspension

8.2.1.1 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. Since the joint will be an attached male end heim, the joint will be susceptible to bending at the first or second thread inside the insertion point of the trailing arm.

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 its corresponding terrain. The driver will be notified what impact the vehicle can take and shall not move into rougher terrain.

8.2.1.2 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.

8.2.2 Potential Critical Failure of Brake System

8.2.2.1 Break due to pressure

Although the brakes placed on the vehicle are proper for the design, if the brakes fail then it is considered critical. Due to this, the mechanical team has communicated with the electrical team to add a kill switch to the motor. Since the motor is electrical, once the kill switch is activated then the motor should slow to a quick stop.

8.2.3 Potential Critical Failure of Steering System

8.2.3.1 Stress/bends on steering link

The steering link is a longer and more durable than the previous design but is still prone to failure. The link can be presented to a force/torque great enough to bend the link pass its yield stress limit, which will cause the steering system to fail and not turn proper.

8.2.3.2 Shear/bends on bolts

The bolts holding the steering link to the steering knuckle and/or tie rods could shear or bend while the vehicle is driving. The bolts could also experience a force great enough to shear or bend the bolts causing the steering link to move or fall off the steering knuckle.

8.2.3 Potential Critical Failure of the front suspension

8.2.3.1 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

8.2.3.2 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

8.2.3.3 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.

8.2.3.4 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.

8.3 Risk Mitigation

8.3.1 Rear Suspension

Since the team wanted to replace the parts that frequently fail, the FEA showed that the heim joint for the rear suspension would fail the most. However, the joint was chosen because the max force it can take is about 30,000lbf of static radial load (Appendix D). The vehicle should only exert 4,000lbf on it which will mitigate the risk of failure. The change was made because it was easier for the manufacturer to make, minimizing the price of the item and it would be difficult to replace if it yielded the original way. This new way does seem like it will fail frequently because heim joints often do. If that is the case, the heim joints are easily replaceable and will not ruin the trailing arm. Therefore, the change was made.

8.3.2 Brakes

As previously mentioned, in case the pressure from braking overcomes the specifications of the brake cylinder, a kill switch has been added to bring to vehicle to a slow stop. The kill switch will deactivate the electrical motor and it will stop rotating.

8.3.3 Steering

The team bought new and stronger bolts to replace the older bolts and to hold the steering link in place and to keep from failing while driving the car within the life of the car. The steering link itself could last the car’s lifetime; it is durable enough to last under 1,000 lbf in a car collision.

8.3.4 Front suspension

The team did replace the old heims with a stronger heims to avoid the bending on the vehicle. The new heims has a maximum load of 9500 lbf. First the team choose to have a Hm 12 brass heims. Then, the team realized that Hm12 is too big to install it on the front suspension. The team decided to change the material from brass to steal due to the fact that steel can handle more load. After Making calculations and FEA analysis, the team did choose heims Hm 8 and Hm10 on the front suspension and they can handle more load than size Hm12 for brass.

9 TESTING

Testing was not performed due to the initial disclaimer of this report.

10 FUTURE WORK

The team did finish the work as planned in the gantt chart expect few things for the rear suspension that was supposed to be done after spring break.

1- The team was going to thread the support rods for the rear suspension
2- attach the heims and bolts to finish from installing the rear suspension.

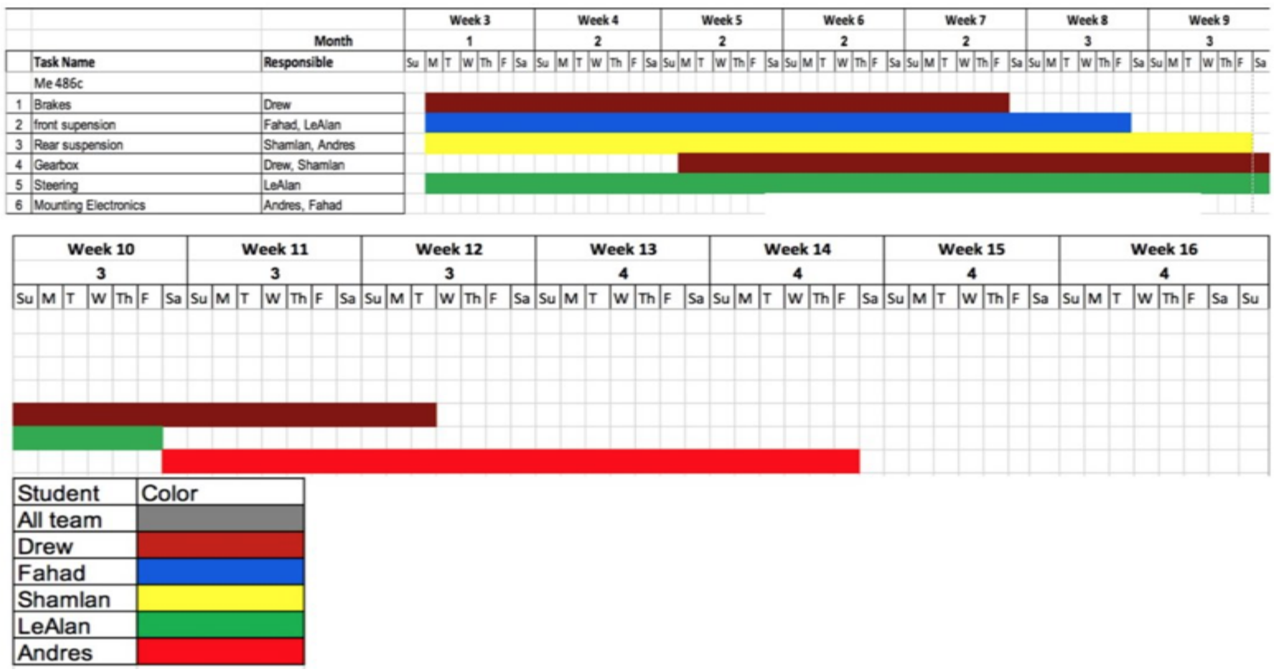


Figure 57: Gantt chart

11 CONCLUSIONS

11.1 Contributors to Project Success

The team had a mission to complete the first NAU electric vehicle ever. However, due to the curent pandemic the world is under, the team was unable to complete their project. All the goals were being met as the team moved forward still. Although there was rough patches in motivation and inexperience, The team managed to pull through and complete the front of the vehicle on time. The rear end of the vehicle was ready to be put together because all the pieces were already received. With the experience the team had in producing the front suspension, the rear suspension was going to be produced quicker and more presentable. The team was able to minimize cost and learn the process that the client and advisor were looking for. Whether it was FEA, proper drawings, or fundraising, the team was always on top of their due dates by working early, asking questions, and saving money. The team was able to gather and split work evenly. If there was a teammate struggling and running out of time, the rest helped to produce the work. They would also do decision making this same way. If one was sure and could back up the decision, then that is the way the team would go. But if a team member had doubts, the rest of the team was easy to consult and would pool resources and knowledge together quickly to make a decision. That is how the trailing arms were ordered so cheaply. Not only was the job well done, but the manufacturing of each part cost $50.00. This was due to a member who interviewed one of the old Baja members that pointed him and that direction.

Nevertheless, the team did struggle with many things. It was difficult for the team to remain organized because members were often self-sufficient and tying everything together was tedious. Having to contact each other to explain certain organization and implementing it into one's own work. Meaning that much of the documenting was difficult to bring forward and present. The fact that we were so keen to being productive on our own time hindered the time when we were together. Being self-sufficient often led to not wanting to do meetings. The team continuously had to approach each other to make sure we were all on the same page and moving forward. The client, David Willy continuously told us to document and communicate better. However, since everyone communicated on what needed to be done, it did not seem like a fault in the team. But there was a lack of the team coming together with all the findings and reporting it in a professional manner.

Next time, there has to be more meetings to work. Not just work individually but bringing the group together to create better chemistry and begin solving organizational problems up front will lead to better individual performances since each person does not have to solve the small things on their own. With more team meetings, there will be more written down, and more questions answered right away to move forward more swiftly and with better quality.

From there, the team will be able to take advantage of each other’s strength better. Everyone did bring something new to the table such as mill training, prior vehicle experience, dynamic and static FEA. If the team could focus on details, the new technical skills would have provided much better quality work with much better understanding for the project and each individual skill.

11.2 Opportunities/areas for improvement

The team struggled with experience in designing and building a vehicle, some of the team understood key components of the vehicle but had to learn more about the terminology and how each component function. This caused the team to spend the entire first semester learning more about automotive engineering and redesigning the subsystems mentioned throughout this report. With the help of their client, he provided resources to learn from and how to design components in computer software to better the teams knowledge. Using the entire first semester to design the vehicle, it ensured the subsystems were safe and reliable to be added to the car.

Our client, David Willy, mentioned to the team in the last E-Baja meeting that the team did not perform proper documentation for the CAD drawings. The drawings could have had detailed dimensions, specifications of the materials, and how to design them with the CNC, mills and lathes. With these documents and files, the CAD model would be easier for the next team to build and do minor changes to the design. With the lack of these documents and files, the team also had some difficulty building the components while in the machine shop. However, the team would communicate to one another for the correct dimensions and to properly make the components. David Willy, told the team that we could improve our skills with CAD and documenting information for our future careers to help us and others understand our designs, ideas, and researched information.

During the second semester, the team faced some difficulty with building the components with their own hands. Some of the team members had little experience operating tools in the NAU machine shop, which required taking safety training courses to work in the machine shop. With little to no experience with working in a machine shop, the team had to rely on other student employees or a certain team member to work on the proper machines to get the part done. This required the team to request time for the person to work on the component. Through the second semester, the team learned to work with the tools and machines in the machine shop and were improving their skills.

The team could have gotten the car done, but due to the pandemic and NAU shutting down the machine shop, the team did not have the resources to finish the car. This problem stopped the finished production of the E-Baja car. The team finished the front of the car, which included the brakes, front suspension, and steering. The team was working on the rear suspension, gearbox, and brackets for the motor, battery and electrical components. With those finished, the car would have been ready for the EE team and ready to drive within a week.

12 REFERENCES

[Include here all references cited, following the reference style described in the syllabus. There should only be one Reference list in this report, so all individual section or subsection reference lists must be compiled here with the main report references. If you wish to include a bibliography, which lists not only references cited but other relevant literature, include it as an Appendix.]

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13 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles. For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc.]

13.1 Appendix A: House of Quality

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)		-		-		

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*
		Technical Requirements						
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 58: House of Quality

13.2 Appendix B: Descriptive Title

13.3 Appendix C: Potential Risks

1. Potential Critical Failure of Rear Suspension

I. 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. Since the joint will be an attached male end heim, the joint will be susceptible to bending at the first or second thread inside the insertion point of the trailing arm.

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 its corresponding terrain. The driver will be notified what impact the vehicle can take and shall not move into rougher terrain.

II. 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.

2. Potential Critical Failure of Front Suspension

I. 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.

II. 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.

III. 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.

IV. 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.

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.

I. 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.

II. 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. 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.

I. 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.

II. 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.

13.4 Appendix D: Calculations

Mass	kg	363	lbs	800.415	
Gravity	m/s^2	9.81			
Height	m	1			
Velocity	m/s	13			
Velocity	mph	29.081			
Work	kJ	34,234.53			
X (distance)	m	0.3			
Force	N	114,115.10		lbf	25,655.37
F on one side	N	57,057.55		lbf	12,827.69

14655.0949	Moment (Nm) @ heim			
Heim				
f	35,744.13	N	8,036.00	lbf
f/2	17,872.07	N	4,018.00	lbf

Figure 59: Excel calculation shows force in a trajectory on the system and the heims

Given Parameters (Bottom Heim Joint)			
Ball Diameter	E	0.937	in
Housing Width	H	0.500	in
Head Diameter	D	1.312	in
Minor Dia of thread	M	0.500	in
Allowable Material Stress	X	52,000	PSI
Calculated Values			
Race Material Compressive Strength	R	24362	lbf
Rod End Head Strength	T	7462	lbf
Maximum Static Radial Load		7462	lbf
Maximum Static Axial Load	A	7003	lbf
	Factor of safety=	1.664	

(Material-SS 300 Series)

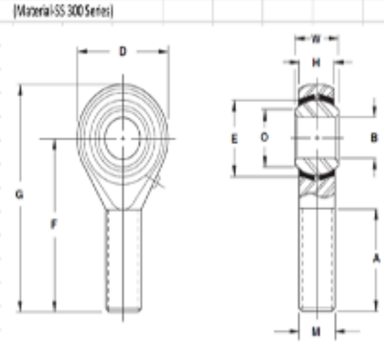


Figure 60: HM8 heims calculation

	Given Parameters (Bottom Heim Joint)			
1	Given Parameters (Bottom Heim Joint)			
2	Ball Diamter	E	1.125	in
3	Housing Width	H	0.562	in
4	Head Diameter	D	1.500	in
5	Minor Dia of thread	M	0.625	in
6				
7	Allowable Material Stress	X	52,000	PSI
8	Calculated Values			
9	Race Material Compressive Strength	R	32877	lbf
10	Rod End Head Strength	T	8068	lbf
11	Male Thread Rod End Strength	S	15844	lbf
12	Maximum Static Radial Load		8068	lbf
13	Maximum Static Axial Load	A	9424	lbf
14				
15		Factor of safety =	1.8	

(Material-SS 300 Series)

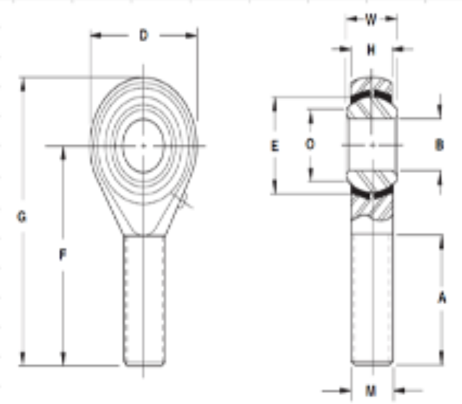
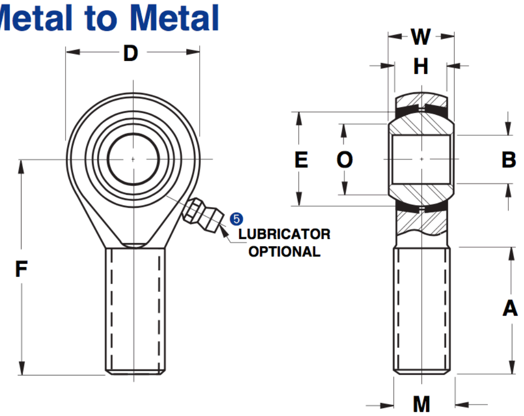


Figure 61: HM10 Rod end calculation

RBC BEARINGS

Precision Extra Capacity Series

Four Piece - Metal to Metal



Series HMX G

ROD END NUMBER	BORE B +.0015 -.0005	BALL WIDTH W +.000 -.005	HOUSING WIDTH H +.005 -.005	HEAD DIAMETER D +.010 -.010	LENGTH TO CENTER OF BALL F +.010 -.010	THREAD LENGTH A +.062 -.031	THREAD SIZE M UNF -3A	BALL DIAMETER E REF	BALL FLAT DIAMETER O REF	MAXIMUM STATIC RADIAL LOAD LBF WITH LUBRICATOR	MAXIMUM STATIC RADIAL LOAD LBF WITHOUT LUBRICATOR	APPROX WEIGHT LBS
HMX4G	.2500	.375	.281	.750	1.562	1.000	.3125-24	.515	.353	3,260	6,680	.06
HMX5G	.3125	.437	.344	.875	1.875	1.250	.3750-24	.625	.447	4,920	8,410	.09
HMX6G	.3750	.500	.406	1.000	1.938	1.250	.4375-20	.718	.516	7,240	11,160	.13
HMX7G	.4375	.562	.437	1.125	2.125	1.375	.5000-20	.812	.586	7,620	13,660	.18
HMX8G	.5000	.625	.500	1.312	2.438	1.500	.6250-18	.937	.698	11,920	19,340	.30
HMX10G	.6250	.750	.562	1.500	2.625	1.625	.7500-16	1.125	.839	13,940	21,080	.46
HMX12G	.7500	.875	.687	1.750	2.875	1.750	.8750-14	1.312	.978	21,570	29,800	.72

Figure 62: HMX G series heims information provided by the manufacturer (HMX12G will be used in the rear suspension)

ROD END NUMBER	DIMENSIONS IN INCHES									MAXIMUM STATIC RADIAL LOAD	APPROX WEIGHT
	BORE	BALL WIDTH	HOUSING WIDTH	HEAD DIAMETER	LENGTH TO CENTER OF BALL	THREAD LENGTH	THREAD SIZE	BALL DIAMETER	BALL FLAT DIAMETER		
	B	W	H	D	F	A	M	E	O		
	+.0025 -.0005	+.005 -.005	+.010 -.010	REF	REF	+.062 -.062	UNF-3A	REF	REF	LBF	LBS
CMHD3	.1900	.312	.250	.625	1.250	.750	.1900 32	.437	.306	800	.03
CMHD4	.2500	.375	.281	.750	1.562	1.000	.2500 28	.515	.353	1,060	.05
CMHD5	.3125	.437	.344	.875	1.875	1.250	.3125-24	.625	.447	1,575	.08
CMHD6	.3750	.500	.406	1.000	1.938	1.250	.3750 24	.718	.516	2,150	.12
CMHD7	.4375	.562	.437	1.125	2.125	1.375	.4375-20	.812	.586	2,600	.17
CMHD8	.5000	.625	.500	1.312	2.438	1.500	.5000-20	.937	.698	3,425	.26
CMHD10	.6250	.750	.562	1.500	2.625	1.625	.6250-18	1.125	.839	4,625	.41
CMHD12	.7500	.875	.687	1.750	2.875	1.750	.7500-16	1.312	.978	6,600	.64

Figure 63: HM series heims information provided by the manufacturer (HM 8 and HM 10 will be used for the front suspension)

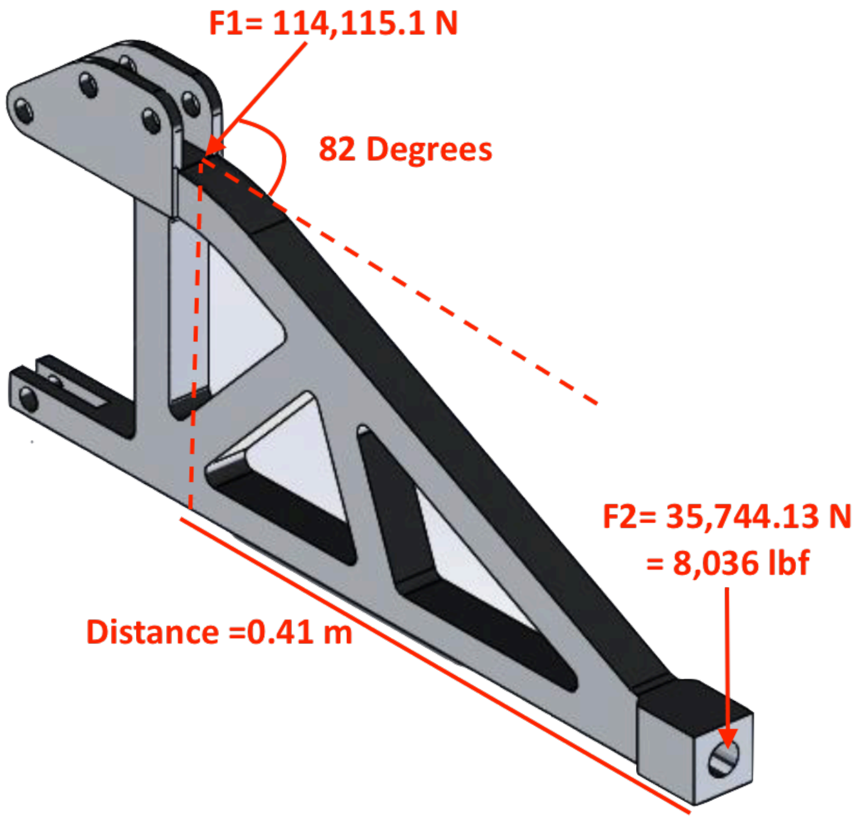


Figure 64: Free Body Diagram on calculating the force at the heim position.