Baja Rear End

Preliminary Report

Marco Sliva
Brooks Grivet
Jordan Sundin

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Northern Arizona University

Project Sponsor: SAE
Faculty Advisor: David Willy
Instructor: David Trevas

DISCLAIMER

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1 BACKGROUND

1.1 Introduction

The purpose of the Rear End Suspension subteam is to design and build a rear suspension for the SAE Baja off road vehicle that will endure an acceleration, braking, hill climb, maneuverability, rock crawl, and four-hour endurance race amongst 100 other schools. The subteam tasks include; main suspension system of choice, wheel hubs, trailing links, shock mounting geometry, disconnectable sway bar, and brakes. This preliminary report will cover all of the systems mentioned above through research, data collection, and team discussion.

1.2 Project Description

The following is a description of the project from SAE.

> "Baja SAE® is an intercollegiate engineering design competition for undergraduate and graduate engineering students. The object of the competition is to simulate real-world engineering design projects and their related challenges. Each team is competing to have its design accepted for manufacture by a fictitious firm. The students must function as a team to design, engineer, build, test, promote and compete with a vehicle within the limits of the rules. They must also generate financial support for their project and manage their educational priorities. Each team's goal is to design and build a single-seat, all-terrain, sporting vehicle whose driver is contained within the structure of the vehicle. The vehicle is to be a prototype for a reliable, maintainable, ergonomic, and economic production vehicle which serves a recreational user market, sized at approximately 4,000 units per year. The vehicle should aspire to market-leading performance in terms of speed, handling, ride, and ruggedness over rough terrain and off-road conditions. Performance will be measured by success in the static and dynamic events which are described in the Baja SAE® Rules, and are subject to event-site weather and course conditions." [1]

1.3 Original System

This project involved the design of a completely new rear end suspension system. There was no original system when this project began.

2 REQUIREMENTS

The customer requirements for this project come directly from the rule book for the SAE competition. These requirements must be met on inspection at the competition in order for the team to compete. The following is a breakdown of the rules and the customer and engineering requirements that the team must meet.

2.1 Customer Requirements (CRs)

The following customer requirements are an interpretation of the rule book for the rear end suspension. They are a set of broad categories to best summarize the 70 page rule book.

Table 1: Customer Requirements

Customer Requirement	Description	Weight
Durability	How long it lasts	.16
Reliability	How well it performs its function	.16
Manufacturable	Rate at which it could be mass produced	.1
Safety	How safe the vehicle is for the driver	.16
Light Weight	Weight of the design	.11
Ease of assembly	Time to assemble the parts	.13
Operate in various conditions	Must be able to handle many different terrains	.11
Inexpensive	Budget of <$30,000	.07

The above customer requirements are taken from the rule book for the SAE mini baja competition. The weights for each category were given based on the importance the team decided that they have. The highest weights of .16 were given to durability, safety, and reliability. These were given the higher weight because they are fundamental to both passing inspection and doing well in competition. The components must work every time and last for the length of the competition at least. This means that this must be a main point in design that the parts are designed to last. Following these high weights comes ease of assembly at .13. This is because the parts must be easily interchangeable in the event that a component breaks at competition. The next weight comes in at .11 for bother operating in various conditions and light weight. These were assigned the weight of .11 because they are important the success in the competition but will not keep us from competing if they are not met. The next lowest weight comes from manufacturing at .1. This is because while it is important that the components can be manufactured by the team, the points awarded in the competition for being able to mass produce the components are minimal. The lowest weighted requirement is to be inexpensive, with a weight of .07. This is because while cost is important, the team is able to fundraise additional funds to meet additional expenses.

2.2 Engineering Requirements (ERs)

The following is a list of engineering requirements created by the team to both meet the rules provided as well as perform optimally at the competition. Each of the requirements has a target value set by the team. These are targets that the team feels it must hit, if it is possible to exceed these then that will be done. For instance the goal weight of 80 lbs is the maximum that the components can weight, if they can be designed to weigh less they will be. When the designs are finalized and minor changes are being made, the goals will be pushed in order of their rank to achieve optimal performance.

Table 2: Engineering Requirements

Requirement	Goal	Rank
Weight	80 lb	7
Clearance	8 in	4
Strength	58 kpsi	1
Toe	0-5 deg	9
camber	0-12 deg	8
Track width	47-52 in	3
Travel	>6 in	5
Sag	5-15%	6
Braking	414 lb	2
Cost	$2,500	10

2.3 House of Quality (HoQ)

The following is a house of quality of the engineering requirements and customer requirements. The team used the chart to help rate technical importance of each requirement. Through the generation of the chart the team found that strength has the highest technical importance, and thus it must be considered first in all design choices. Following strength the team ranked braking as the second most important. This is because the vehicle must be able to lock all four tires as well as stop in a set distance in order to compete in the competition. Some other notable requirements to follow are clearance, travel, and sag. These categories ranked 4, 5, and 6 respectively. These three categories are very related, as a change in one will change the performance of the others. The team has deemed it important to have at least 8 inches of ground clearance, and 6 inches of travel. These goals are important for ensuring that the vehicle does not bottom out on technical parts of the track, as well as ensuring that the components have ample time to absorb large impact forces such as jumps. These requirements are set up in order to help prevent the components from breaking during use. Following these requirements comes weight, camber, toe, and cost. These requirements are not ranked as high as the others because the do not play a fundamental role in the team competing. If these targets are not met, the team may not perform as well at competition but should still be able to compete and finish. The higher rankings requirements went to the ones that are fundamental for completing the competition.

System QFD

Project:	SAE Baja	Rear End Sub team
Date:	10/6/2017	

Correlation	
.++	Strong Positive
.+	Positive
	No Correlation
.-	Negative
.--	Strong Negative

Rear End Characteristics		Weight	Clearence	Strength	Toe	Camber	Track Width	Travel	Sag	Braking	Cost
Weight											
Clearence		.++									
Strength		.++	.-								
Toe				.-							
Camber				.-	.-						
Track Width		.+	.+	.+							
Travel		.+	.++	.-		.-	.-				
Sag		.++	.-					.++			
Braking		.++		.+			.-				
Cost		.+	.+	.++	.+	.+	.+	.+		.+	

		Technical Requirements									
Customer Needs	**Customer Weights**	Weight	Clearence	Strength	Toe	Camber	Track Width	Travel	Sag	Braking	Cost
Durable	0.16	3	3	9	3	3	6	3	3	3	3
Reliable	0.16	3	6	9	3	3	6	6	3	6	3
Manufacturable	0.1	3	3	3	6	6	3	9	9	3	3
Safety	0.16	3	9	9	3	3	9	3	3	9	3
Lightweight	0.11	9	3	3	6	6	3	3	3	6	6
Ease of Assembly	0.13	6	3	3	6	6	3	3	6	6	3
Operate in Various Conditions	0.11	3	9	9	3	3	6	9	3	6	3
Inexpensive	0.07	6	3	3	3	3	3	6	9	3	9
Technical Requirement Units		lb	in	kpsi	Deg	Deg	in	in	%	lb	$
Technical Requirement Targets		80	8	58	0-5	0-12	47-52	>6	5-15	414	2,500
Absolute Technical Importance	**47.79**	4.26	5.1	6.54	4.02	4.02	5.25	4.95	4.41	5.49	3.75
ATI (percent)		0.089	0.107	0.137	0.084	0.084	0.110	0.104	0.092	0.115	0.078
Relative Technical Importance		7	4	1	9	8	3	5	6	2	10

Figure 1: House of Quality Rear End

3 EXISTING DESIGNS

This section contains the research that the team has conducted into what subsystems already exist for rear end suspension components. Researching these systems was mainly done by spectating last year's mini baja competition and seeing which designs worked the best for the other teams.

3.1 Design Research

Design research for the rear end design was done largely by parts of the team visiting the last years baja competition. The team took extensive pictures of other teams and noted how each team performed and ranked, as well as any problems they ran into. The team used much of what was found from this research when making decisions for which designs to select.

3.2 System Level

The whole system for the NAU Baja vehicle would be the complete car with all of its sub systems. There exist four subsystems to the design, one of which is the rear end suspension components. For this report the whole rear end will be considered the main system, with the subsystems being broken down later in the report.

3.2.1 Existing Design #1: NAU Baja 2016-2017

The first existing design that was considered was NAU's 2016-2017 mini baja buggy (Figure 2). The team looked at how the components for the vehicle fit together and functioned as well as what kind of system was used. This baja vehicle used a rear trailing arm suspension in the rear. The design was a tubular design with a short shock mounted in the rear. The team noted a few problems with this design that will be changed to improve on the trailing arm design. The original baja used a shorter shock, leading to less travel in the rear end. The team has decided to go with a larger shock to allow for more travel and ground clearance. In addition to this the team found that the design of last years trailing arm left for little ground clearance and would likely result in a damaged trailing arm. While some aspects of this vehicle are carried over, the team will be redesigning the entirety of the rear end to better fit the needs and engineering requirements decided on.

Figure 2: NAU Baja Vehicle 2016-2017 [2]

3.2.2 Existing Design #2: NAU Baja 2015-2016

The baja vehicle from 2015-2016 was a robust design but unfortunately was not translated to the build. Due to repetitive part failure the vehicle was not completed and could not make it to competition. The baja used a curved trailing arm suspension, pictured below in Figure 3, paired with a smaller shock. This rear end design would be beneficial for smoother terrain such as sand but would not be able to handle rocky environments. This design would not work for this years design as it does not operate well in rougher terrain such as Oregon where the competition is held.

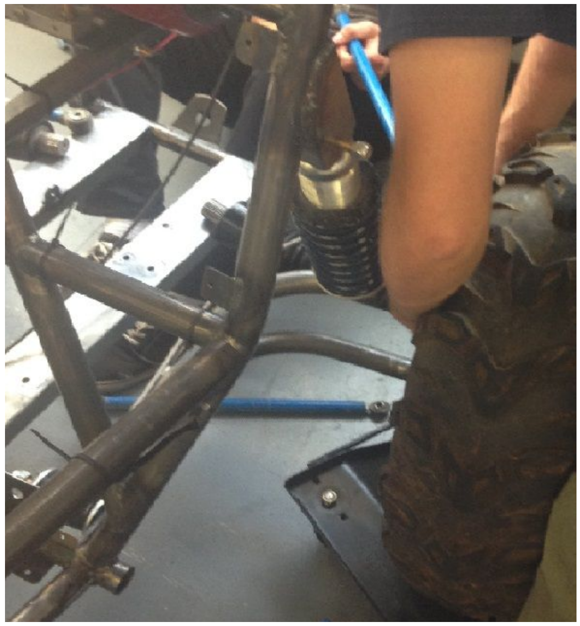

Figure 3: NAU Baja Vehicle 2015-2016 Rear Suspension [3]

3.2.3 Existing Design #3: Rochester Institute of Technology(RIT)

The final design that the team looked at for inspiration in designing was RIT's baja from 2016-2017 (Figure 4). This team utilized a rear trailing arm that was mounted higher up on the frame than a standard trailing arm. This design was well liked by the team as it seems like it will allow for more clearance and travel with a smaller shock. This is optimal because the team was provided with small shocks from a previous baja team and would like to use them the save money.

Figure 4: RIT Baja Vehicle 2016-2017 (Credit: Marco Sliva)

3.3 Functional Decomposition

The rear suspension subteam has divided the system hierarchy into multiple stages in order to better determine how systems are integrated into one another and their relationship to each other. The main functions of this project include the; trailing arms, trailing links, brakes, disconnectable sway bar, and hubs. As seen in Figure 6, the hierarchy of components all begin with the problem which is to design and build a mini baja vehicle. Within that includes all the subteams of; front end, rear end, drivetrain, and frame. Of rear end and its design, the integration between the drivetrain and brakes must be accounted for in order to have a suspension that will adequately adapt to the vehicle. The system hierarchy will keep the subteam in track of their goals and project boundaries.

3.3.1 Black Box Model

The black box model is used to analyze and clarify what the system must do. The black box acts as an unknown system that has inputs and outputs. By determining what the inputs and outputs must be, the team can better identify how to approach the problem.

The rear end black box, Figure 5, of the baja vehicle is simple, the function is to absorb impacts. The surface and the baja vehicle enter and leave the system, while force from the terrain is inputted and is translated to vertical movement out.

Figure 5: Rear End Black Box Model

3.3.2 Hierarchical Task Analysis

The baja design competition has been broken down using the Hierarchical Task Analysis, shown below in Figure 6. The entire project can be categorized into 4 main tasks: Design, Design Integration, Dynamic Simulation & Final Design. Design is broken down further by frame, front end, rear end and drivetrain design each with specific tasks.

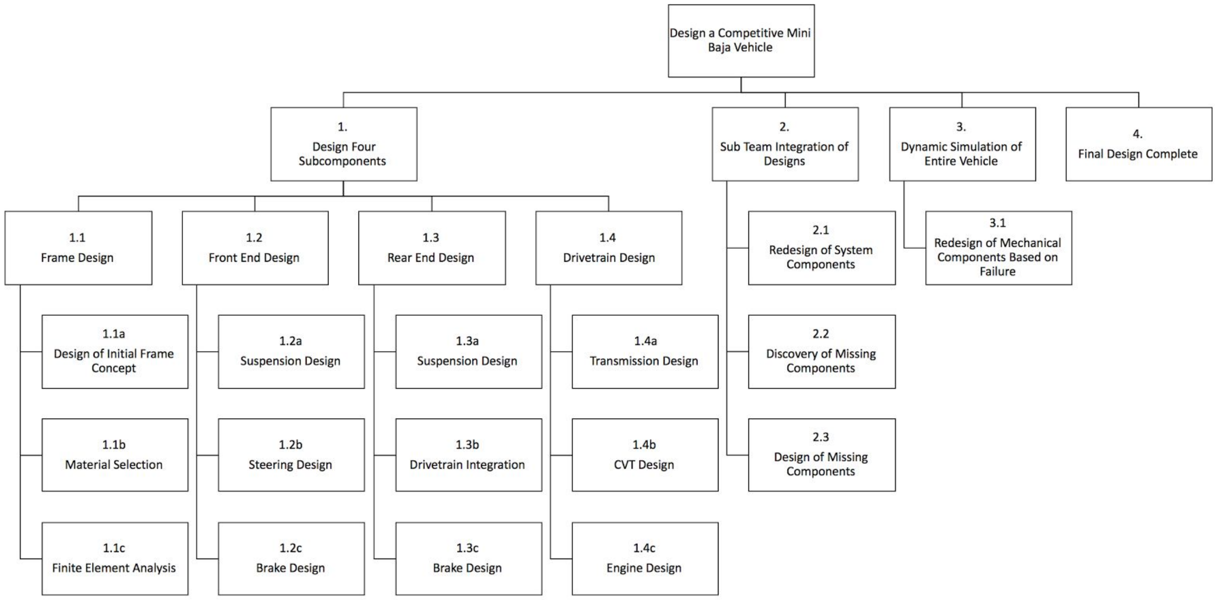

Figure 6: Hierarchical Task Analysis

The hierarchical task analysis is a beneficial tool to the team. This allows for a simple visual representation of the entire project. Though it is not the most detailed outline, each task is now easily identifiable along with the order that each task must be completed. Throughout the rest of the project the hierarchical task analysis will be reference to determine what major tasks are completed, in progress and must be done.

3.4 Subsystem Level

The rear end of the baja buggy can be broken down into three separate subsystems that are: suspension, drivetrain, and brakes. Each of these systems had a few options for design that the team had to consider when picking a design.

3.4.1 Subsystem #1: Suspension Type

The followings section contains the options the team considered for the suspension of the vehicle. Each of the existing designs are types of suspension that have been used in the past for off road vehicles. The team researched each option as well as compared to what other successful baja teams have done in the past. The suspension system is important for mitigating the effect of rough terrain on the driver and vehicle. This is needed to prolong the life of the vehicle, provide a smooth ride for the driver, and help deliver the power to the ground at all times.

3.4.1.1 Existing Design #1: Trailing Arm

Trailing arm suspension consists of two beams, one for each real wheel that extend from the frame back to the hub of the wheel. Trailing arm suspension is quite common among baja and sand rail vehicles. The popularity of trailing arms is due to the success in higher speed off roading, which may prove useful during the endurance portion of the competition.

3.4.1.2 Existing Design #2: Wish Bone

Double wishbone suspension is a form of suspension using two members to connect the wheel to the frame. These members have a wishbone shape and this is where the name comes from. The design allows a large amount of control over the camber angle and toe throughout travel of the system. The advantages to this design come from the large amount of control of angles. The problem the team found with this design is it is heavy, expensive, and difficult to design. The design is also not seen very often in off road applications, making it less desirable for the team to utilize.

3.4.1.3 Existing Design #3: Solid Axle

The solid axle is named after its physical attributes, the entire axle from the differential to each wheel is one solid part. The solid axle suspension setup is one of the most widely used suspension types. Solid axles have been used heavily for both on road and off road use. The design is known to handle heavy loading as well as off road terrain because of the rugged design. The solid rear axle could potentially be beneficial at the SAE Baja competition due to the durable design.

3.4.2 Subsystem #2: Drivetrain Integration

This section discusses how the drivetrain components will be implemented into the rear end. The team researched different ways that drive shafts can be connected to the wheels and broke these options into three possible systems. It is important to deliver the power from the engine to the wheels effectively to achieve the best performance. Each subsystem deals with different hub designs and brake mounting locations.

3.4.2.1 Existing Design #1: Repurposed Hub

One of the options the team considered for hubs for the wheels is to reuse old hubs off of an atv or small utility vehicle. Doing so would save the team much design and manufacturing time, and present a component that is likely to work and hold up for the entirety of the competition. The problem the team has found with doing this is that it limits us to using what we can find, and will likely cost more to purchase than it would to design and manufacture in house. The repurposed hubs would also likely be more difficult to replace if they broke, as having a second set would be unlikely.

3.4.2.2 Existing Design #2: Manufactured Hub with Disc

The second design the team considered for hubs is to design and manufacture the hubs ourselves, with the disk for the brakes attached to the hub. This design is similar to many cars on the road and would likely be the easiest and most cost effective to manufacture. The problem with this design is that it leaves the large and weak disks exposed to getting hit by debris and rocks in the path.

3.4.2.3 Existing Design #3: Manufactured Hub without Disc

The final design considered for wheel hubs is to manufacture the hubs in house, but to mount the disks for brakes elsewhere. Moving the disks farther in from the wheel hubs makes them less prone to breaking. The wheel hubs for both option 2 and 3 would be very similar, and pose the same benefits over repurposing wheel hubs.

3.4.3 Subsystem #3: Brakes

The following section discusses the different options the team considered for incorporating brakes into the design. The team considered both types of brakes, as well as where to put the brake system. This is relevant because each brake type has advantages and disadvantages, and the mounting location has to not interfere with other components or risk hitting the ground.

3.4.3.1 Existing Design #1: Drum

One design considered for rear brakes is to use a brake drum system. This is an old style of brakes that is easy to design and manufacture. This is advantageous for the team as it would be save time and money to utilize. The problem with brake drums is they are much heavier than disk brakes, and are not as effective, especially when wet or muddy.

3.4.3.2 Existing Design #2: Hub Mounted Disc

Another design considered for brakes is to use disk brakes mounted to the wheel hubs. As mentioned before, this is an easy way to mount disk brakes that is found in most vehicles. The advantage to this is it should be easy to design and manufacture. However the disk brakes will be exposed to breaking from the rough terrain, and are also more likely to get mud on them, which may reduce braking efficiency.

3.4.3.3 Existing Design #3: CV Mounted Disc

The final design considered for brakes is it use disc brakes mounted on the CV. This option moves the brake discs up and away from the wheels and out of harm's way. Mounting the discs here will be slightly more difficult to design and manufacture, but should perform better. In addition to be less likely to be damaged in this location, the pads will also encounter less mud and water from the track, allowing the brakes to work effectively at all times.

4 DESIGNS CONSIDERED

Due to the tight schedule and competitive nature of baja, starting at the beginning of the design process is unrealistic. The designs considered are based off of existing designs but will be completely redesigned and manufactured by the team. The concepts below are individual design concepts the team is currently evaluating. After evaluation the best concepts will then be combined for the final design. The concepts pictured below are actual photographs as this is the best format to accompany a design explanation. The team Design concepts 1-6 are found directly below, while designs 7-10 can be found in Appendix A.

4.1 Design #1: Elevated Trailing Arm

The elevated trailing arm is comprised of simple square tubing trailing arm system but instead of having a low arm-to-frame pickup point location, theirs is mounted higher along the hoop, similar to what is shown in Figure 7.

Advantages:

- Higher ride height
- Simple to manufacture in house

Disadvantages:

- Difficult to determine optimal geometry

Figure 7: RIT Baja- Elevated Trailing Arm (Credit: Marco Sliva)

4.2 Design #2: Custom Hubs

The hubs are required to withstand high forces in the possibility of terrain impact. The hubs will also need to be easily disassembled for replacement in the possibility of an ETA or CV axle failure. By making the hubs there is no need to try and hack existing hubs to fit, the hubs can be make to the specifications needed. If the disc brakes were able the be mounted on the CV axles the design would look similar to what is in Figure 8.

Advantages:

- Strongest design
- Light Weight

Disadvantages:

- Time to design and manufacture takes away from other critical components

Figure 8: RIT Baja-Rear Hub (Credit: Marco Sliva)

4.3 Design #3: CV Mounted Disc Brakes

The CV Mounted disc brakes are mounted next to the differential on the CV axle, similar to Figure 9. This design allows for a simpler hub design while providing sufficient braking power. Most vehicles have brakes mounted at the hubs because to the brake torque that is generated between the tire and surface. But with the baja the weight of the vehicle is much less, causing the brake torque to be less of a factor during braking.

Advantages:

- Simpler hub design
- Away from ground, avoiding damage

Disadvantages:

- CV axle becomes more complex

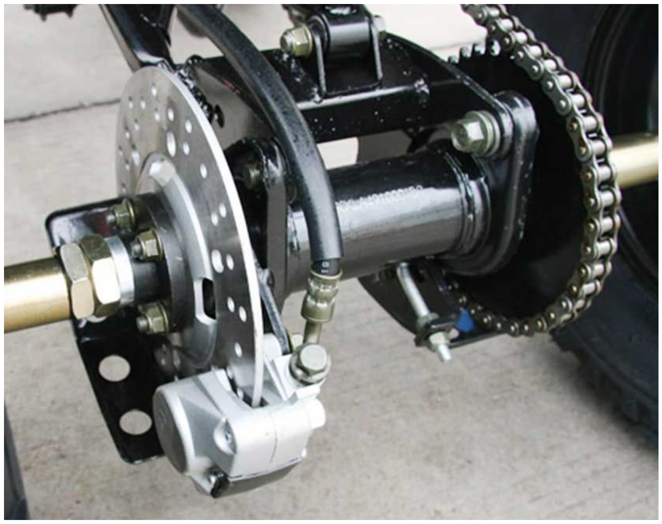

Figure 9: CV Axle Mounted Disc Brake [4]

4.4 Design #4: Air Shocks

Air Shocks can provide the most comfortable ride while also providing the most tunable suspension. These shocks are extremely complex and would be bought off the shelf.

Advantages:

- Tunable
- Best ride

Disadvantages:

- Cannot manufacture in house
- Expensive

4.5 Design #5: Trailing Arm mounted Shocks

The baja team already has a pair of Fox Podium shocks that were used in previous baja builds. These shocks are a bit smaller than what normally would be on rear suspension, about 6 inches of compression. If the decision is made to move forward with these shocks, one potential design to allow for more travel is to mount the shock to the trailing arm and upper rear hoop, shown in Figure [6]. This mounting location allows for the best location when the shock is limited to a smaller height.

Advantages:

- Best location for smaller shocks

- More travel than what the shock allows
- Simpler hub design

Disadvantages:

- Difficult to determine optimal geometry
- The trailing arm is subject to centralized forces

Figure 11: Cal Poly Baja - Trailing Arm Mounted Shock [5]

4.6 Design #6: Disconnectable Sway Bar

During the maneuverability event, it would be idea to use a sway bar to help the vehicle feel more connected through the chassis. A sway bar, Figure 12, would allow the ETA's to become more in unison with one another during off camber corners. It would not be idea during the rock crawl or endurance event and therefore would become disconnectable for more suspension articulation.

Advantages:

- Better maneuverability
- Disconnect for better tire articulation

Disadvantages:

- Extra weight
- More moving parts to potentially break

Figure 12: Sway Bar [6]

5 Conclusion

Through research, the team has narrowed the schools to follow to be RIT and UBC for their simple, strong, and effective designs. The goals for the design have been clearly stated and are within the grasp of what is capable with our current resources and budget. Each task on the timeline has been met and completed in time and under the proper instructions. This preliminary report has covered the rear suspension systems mentioned above through research, data collection, and team discussion. Going forward the team will be completing calculations to finalize design choices.

6 References

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7 APPENDICES

7.1 Appendix A: Design Concepts 7-1

Design #7: Standard Trailing Arm

The standard trailing arm would be a simple design to implement seen in figure 13. The design has been proven to be reliable as many off road vehicles such as trophy trucks and sand rails use the design. But this would provide a lower ride height for the rocky trails of Oregon.

Advantages:

- Proven to be reliable

Disadvantages:

- Lower clearance in the rear

Figure 13: Trailing Arm[7]

Design #8: 2 - Link

Links are essential to most rear suspension components. The link provides support to the hub while also allowing for small adjustments to toe and camber. The 2 two link system provides support to the upper and lower portions of the hub.

Advantages:

- Simple
- Easy to manufacture

Disadvantages:

- Weaker than other systems

Figure 14: 2-Link (Credit: Marco Sliva)

Design #9: 3-Link

The 3 link system, Figure 15, provides the same task as 2 link but with the extra stability of an extra link.

Advantages:

- Adjustability

Disadvantages:

- More parts to manufacture
- More parts to potentially break

Figure 15: SDSU's 3-link system(Credit: Marco Sliva)

Design #10: Hub Mounted Disc Brakes

This system is similar to most vehicles, the disc brake is mounted directly to the hub, seen in Figure 16. It is a simple design with most repurposed hubs already accommodating for disc brakes. But makes team built hubs more difficult to design.

Advantages:

- Proven functionality

Disadvantages:

- Makes hub more difficult to design
- Easier to damage

Figure 16: Hub Mounted Disc Brake [8]