SAE Mini BAJA: Suspension and Steering

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Concept Generation

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Introduction

The SAE Mini Baja team at NAU is split into three teams consisting of the drivetrain, frame, and steering/suspension. Our team is steering and suspension, and we will be going over many concepts for our designs. Throughout this report, the front suspension, rear suspension, and steering concepts will be analyzed. In the front suspension, the concepts are Double A Arm, MacPherson, Torsion Bars, and Extended A-Arms. In the previous year, the team chose Double A-Arms. For the Rear suspension, the concepts are Double A-Arms, 2 link, and 3 link. In the previous year, the team chose 3-Link. For the steering, the concepts are back mounted rack and pinion, front mounted rack and pinion, and power assist. The previous team chose back mounted rack and pinion. The gear ratios will also be changed to 4-1 from 2-1 to make it easier to drive. All these concepts will work and will be put through a decision matrix to see what two concepts from each section will work the best

Front Suspension

Concept 1: Double A Arm

The double A arm suspension design is a proven concept across multiple platforms in all areas racing and conventional design. The reason for this is that the setup can be easily tuned and adjusted for camber, caster, and toe angles of the wheel. Also, by having multiple members and mounting points, the design ends up being very durable and resistant to impact on the wheels. An example of a traditional double A arm suspension design can be in Figure 1.

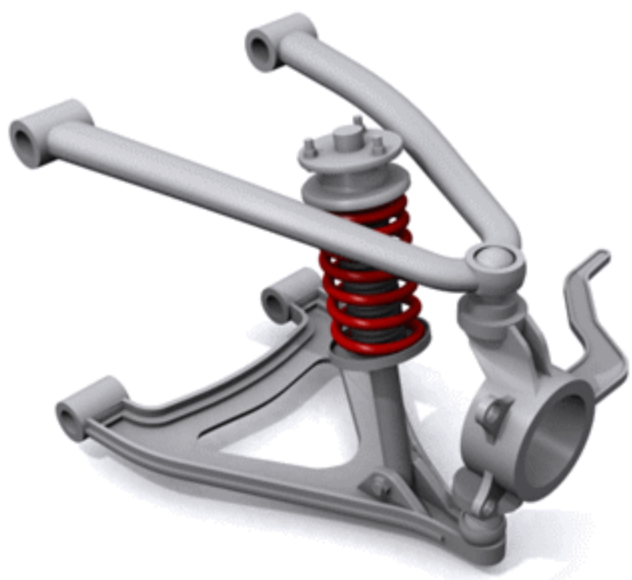

Figure 1: Double A Arm Suspension [1]

This design keeps the suspension members away from potential contact from obstacles because it is mounted on the sides of the vehicle and away from the underneath. The analysis of this design will be more complex due to the multiple mounting points. It also runs the risk of being heavier than other designs. However, since the current design is the same, as long as stress calculations are done correctly the design will end up being lighter.

Concept 2: MacPherson Struts

This suspension setup was chosen in an attempt to reduce weight in the front of the car. While it is not very commonly used, it is favorable for lighter vehicles. This design only requires one lower A arm, because the strut is hard mounted to the top of the hub. A depiction of this suspension design can be seen in Figure 2.

Figure 2: MacPherson Suspension Design [2]

This design is less adjustable than the previous because of the way the strut needs to be mounted. It also puts significantly higher stresses on the strut and lower member, which will require them to be either larger or very well designed. This design is also out of the way of potential impacts by obstacles. The stress analysis would be simplified due to only having two members.

Concept 3: I-Beam Suspension

This design is more prominent with heavy vehicles that experience rough terrain and a high amount of suspension travel. The design is meant to be very durable to impacts and forces experienced during high amounts of travel. The setup can be repurposed for our vehicle by shrinking the members and engineering their geometry to match the shocks we specify. An example of this style of suspension can be seen in Figure 3.

Figure 3: I-Beam Suspension Design [3]

A major problem with this design is its lack of adjustment after it has been designed and installed. This will require a significant amount of forward thinking in the design process to remedy. Another issue is that even with proper analysis and design, the sheer size of the members will increase the weight of the vehicle. Also, because the members run under the vehicle, the ground clearance will be reduced.

Concept 4: Extended A Arms

This design is a modification of the original double A arms. It requires a reduction of the front section of the frame in order to lengthen the A arm members. The extended length will increase the amount of travel that can be seen in the front suspension. This increase in travel does come with a penalty in weight gain due to the extended length of the members. An example of this style of suspension can be seen in Figure 4.

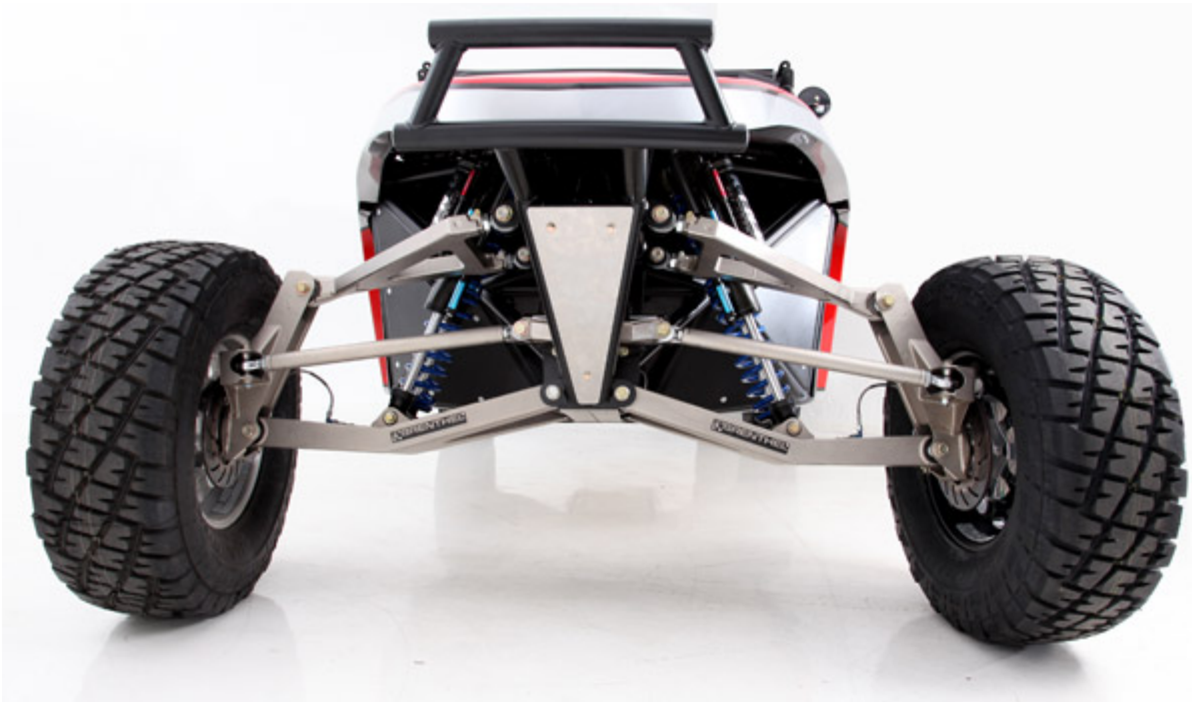

Figure 4: Extended A Arm Suspension Design [4]

The only negatives to this design as opposed to the original double A arm setup is an increase in weight and a decrease in durability. The reduction in durability comes from the increase in lower member length. If the lower member was to impact an obstacle it would experience a significantly higher bending stress.

Front Suspension Design Analysis

In order to analyze the designs to more effectively choose which designs to carry forward in the design process, a decision matrix has been implemented. As seen in Table 1, the decision matrix has the designs listed on top with chosen engineering requirements to the left. Each requirement is weighted out of one hundred and the design is ranked on a scale from one to five.

Table 1: Front Suspension Design Decision Matrix

Front Suspension	Weight	McPherson	Double A-arms	Torsion Bars	Extended A arms
Cost	10	4	4	3	3
Weight	30	3	3	3	3
Strength	15	3	4	4	4
Ease of Machining	7.5	4	4	4	4
Ease of Design	7.5	3	5	3	3
Safety	2.5	4	4	4	4
Durability	10	3	4	4	4
Ground Clearance	10	3	3	3	4
Total Travel	7.5	3	3	3	3
Raw Total	100	30	34	31	32
Weighted		3.2	3.6	3.4	3.5

The raw total and weighted total can be seen at the bottom. The highest weighted engineering requirements are weight, strength, durability, and ground clearance. From this decision matrix, the highest scoring designs are the Double A Arms, and the Extended A Arms. Therefore, these are the designs that will be analyzed further in the design process.

Rear Suspension

Concept 1: Double A Arm

The double A Arm suspension, as described previously in the Front Suspension section, is a proven design across multiple platforms, from off-road to on-road use. The basic design of a double A arm suspension system consists of two A arms that provide a connection between the chassis and the hub of the vehicle. The two points at the base of the "A" connect the arms to the chassis and the tip of the "A" connects the arms to the hub. An example of a double A Arm rear suspension can be seen in Figure 5.

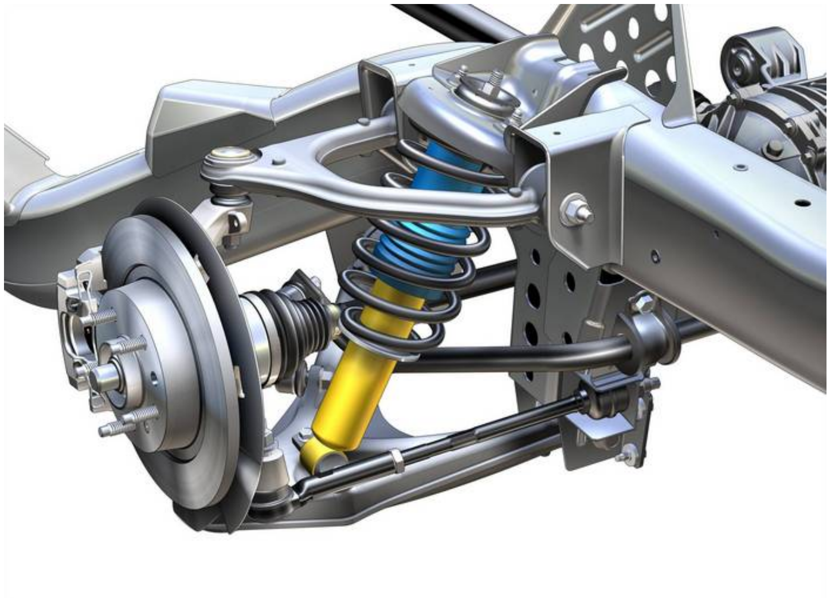

Figure 5: Double A Arm Rear Suspension Design [5]

Some advantages of using this type of design include: versatility, amount of ground clearance, increased handling characteristics, and lightweight. A double A arm suspension system can have a high versatility because of how well the suspension system can be adopted to all four corners of the vehicle. Once one corner of the suspension system is analyzed and engineered it can easily be replicated to the other three corners, because it can be assumed that the other corners of the vehicle will see the same impact and load. This type of design also provides a large amount of ground clearance. With this type of design, the A arms are mounted to the side of the frame, meaning there are no suspension members running underneath the frame. This means that suspension members will be higher off the ground compared to other suspension systems that would need members to run under the frame. Depending on how we design the A arms, we can provide increased handling characteristics utilizing this design. Increased handling can be accomplished by using a shorter upper A arm compared to the lower A arm. This increases handling because when entering a corner the suspension compresses and the wheel to the outside of the corner will produce negative camber, providing an increased contact patch between the tire and the ground. This type of suspension system can also provide a lightweight. Depending on which A arm we mount the shock strut to, we can lighten the other A arm by utilizing a lightweight material such as Aluminum to provide a slightly lighter weight compared to making all members out of a heavier material.

Some disadvantages to this type of design include: difficulty to produce, high cost, and space constraints. This design could potentially be difficult to produce because of the complexity of the members. The A arms could potentially be difficult to machine with the tools we have access to at the machine shop. If this design is chosen, it will be important make sure we have all tools needed to produce the A arms. This type of design also comes at a higher cost. The high cost can mainly be attributed to the fact that this type of system utilizes more material than other suspension systems. With more material being used, we will have an increase in weight. By utilizing this type of design in the rear, we could run into space constraints between the placement of the driveshaft and shock. The driveshaft will need to be mounted in the centerline of the rear suspension, so we will have to design the rear suspension taking this factor into account.

Concept 2: 2 Link

This type of suspension design utilizes two links to connect the suspension system to the frame of the vehicle, like the name implies. This type of design is very similar to the double A arm except that the suspension members connecting the frame to the hub are not in the shape of an A. One suspension link is connected to the frame and the top of the hub, while the other link is connected to the frame and the bottom of the hub. An example of a two-link suspension is depicted in Figure

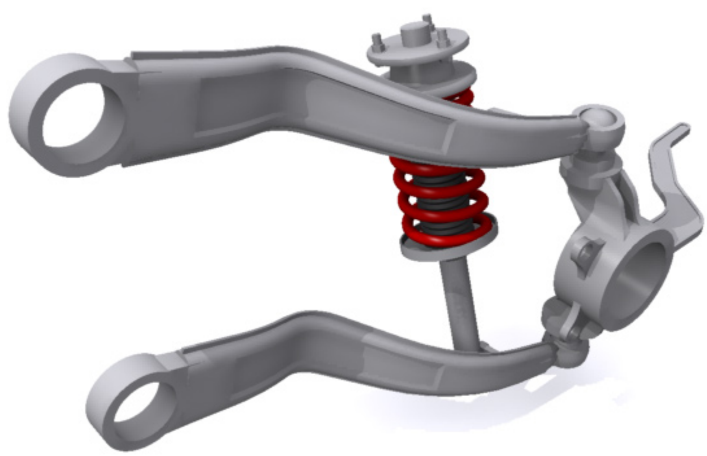

Figure 6: 2 Link Rear Suspension Design [6]

Some advantages to this type of design include: decrease in weight, and lower cost. This design can provide a decrease in weight of the entire suspension system because usually less material is used to make the members compared to other types of suspension. This type of design also provides a lower cost because the design is very simple and makes use of a small amount of material. Since less material is needed for the design, we won't need to spend as much money on material for the members.

Some disadvantages with this type of design include: lower strength, decreased ground clearance, and decreased handling characteristics. This design makes use of only two members, usually in the form of bars, connecting the frame to the hub, and because of this, the strength of the system could be an issue. By utilizing this design, we also will have compromised ground clearance. One of the members would need to be mounted under the frame. By having a member under the frame, the chance of that member hitting a large boulder or rock is more likely, lowering the reliability of the suspension system. This design could also potentially decrease the handling characteristics of the vehicle. Because of the way the suspension is designed, the adjustment of camber, caster, and toe will be difficult to adjust once the suspension is mounted.

Concept 3: 3 Link

This type of suspension utilizes three links to connect the suspension system to the frame of the vehicle, like the name implies. Usually, a large suspension link runs from the middle of the frame to the hub, and the 2 other suspension links run from the rear of the frame to the hub. Of the two suspension links in the rear, one link mounts to the top of the hub, while the other link mounts to the bottom of the hub. This type of design is depicted in Figure 7 below.

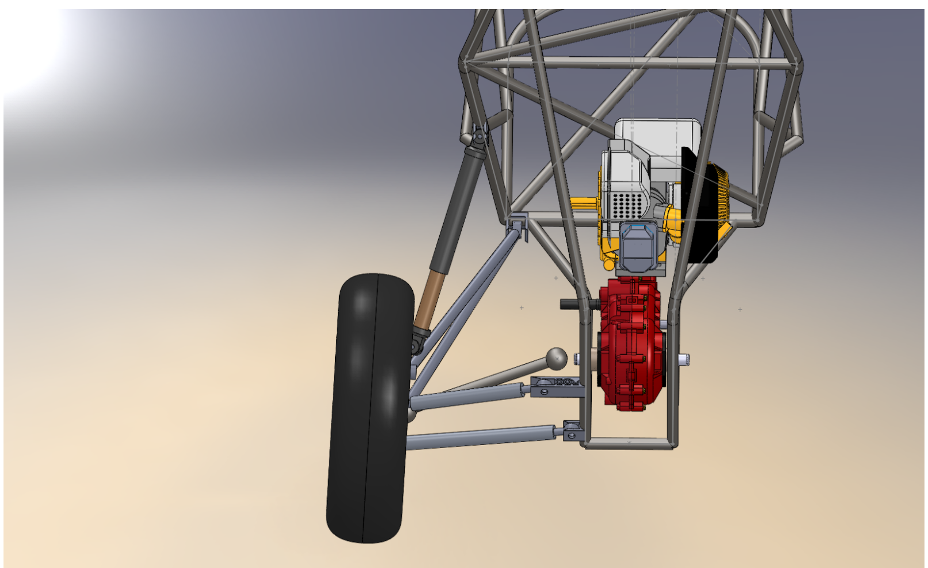

Figure 7: 3 Link Rear Suspension Design [7]

Some advantages to this design include: High strength, and reliability. A three-link suspension can provide our team with a high strength system because this type of suspension has the highest amount of members connecting the frame to the hub. With the use of three links, we can distribute the forces encountered by the wheel to three separate links, meaning that each link won't see as high of forces as other designs. Yet another advantage to utilizing this type of design is the high reliability. A high reliability can be achieved because in this design there are more suspension links that distribute forces encountered at the wheel. By having more members we hope that the suspension will be more reliable to impacts from various objects during the competition.

Some disadvantages to this design include: difficulty of engineering analysis, increased weight, and increased cost. This design could be difficult to analyze because of the various points of placement of the members to the hub and frame. Have all these variables could increase the amount of analysis that will need to be done to utilize this design. This design would also increase weight of the suspension system. This design would increase weight because more members are needed to complete the design, compared to other suspension systems. Weight would also increase because one member needs to be fairly large to account for impacts from large boulders and rocks. Utilizing this design would also see an increase in cost. Since this design uses the most amount of suspension members when compared to others designs, this design will cost more because of the amount of material needed to complete the design.

Rear Suspension Design Analysis

To compare how the various rear suspension designs discussed will help or hurt our design goals for the vehicle, a decision matrix was created. Multiple design goals were compiled, and weighted with respect to how important they are to our design. Each goal is weighted out of one hundred and the design is ranked on a scale from one to five. The decision matrix for the rear suspension design can be seen in Table 2.

Table 2: Rear Suspension Design Decision Matrix

Rear Suspension				
	Weight	Double A arm	2 link	3 link
Cost	10	3	4	4
Weight	30	3	3	3
Strength	15	5	4	3
Ease of Machining	7.5	3	4	3
Ease of Design	7.5	5	3	3
Safety	2.5	5	5	5
Durability	10	5	4	4
Ground Clearance	10	5	3	3
Total Travel	7.5	4	4	4
Raw Total	100	38	34	32
Weighted		4	3.6	3.3

From this decision matrix, the highest scoring designs are the Double A Arms, and the 2 link design. The lowest scoring design was the 3 link, and will not be analyzed any further. Therefore, the designs that will be analyzed further in the design process will be the Double A Arms and 2 link design.

Steering

The designs that follow denote where, on the wheel hub, the tie rod end will be attached. The rack must be mounted on the same side of the wheel center as the tire rod end for the best possible performance. Because of this, the rack can either be mounted forward of the centerline or behind the centerline.

Back Mounted Rack and Pinion:

The back mounted design uses attachment points on the back of the hub to mount the tie rod end. This design is often much more durable because the tie rod is shielded from debris, that may hit the front of the front of the vehicle, by the suspension components. A downside to this design is that there is less room for the drivers legs, which could make it difficult for the driver to get in and out of the vehicle. There is also a possibility for the u-joints in the system to bind if not designed properly, which would lead to a vehicle that cannot turn.

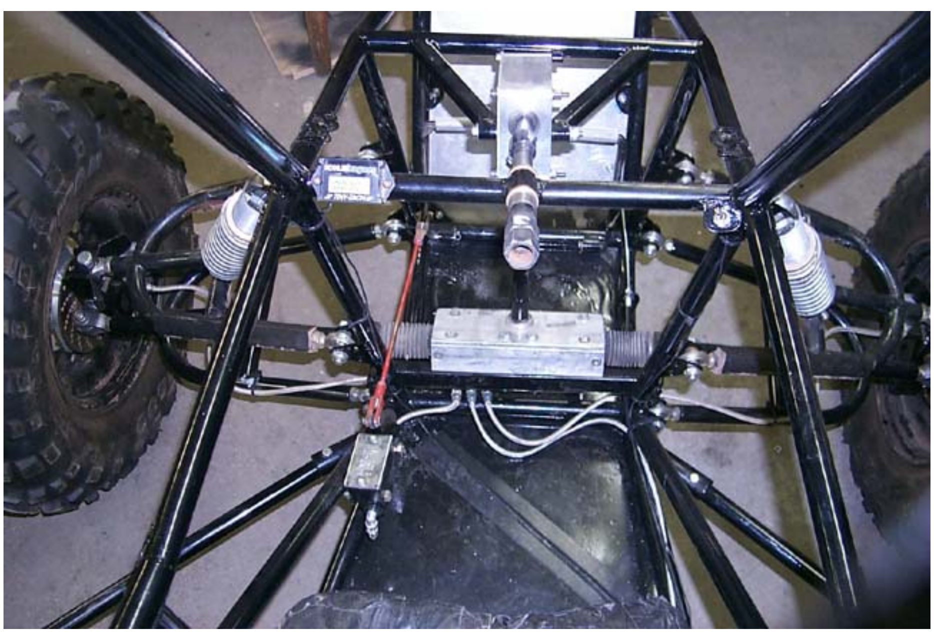

Figure 8: Back Mounted Rack and Pinion [8]

Front Mounted Rack and Pinion:

The front mounted system is much more popular with other teams at competition because of the room that it gives the driver. Much needed space is cleared up when the rack is pushed as far out as possible. The driver could more easily get in and out of the vehicle. However a side effect of pushing the rack farther away from the driver is weight. More material is needed to attach the steering wheel to the rack thereby increasing the weight. Another disadvantage of this design is that the tie rod is exposed in front of the suspension components making it less durable.

Figure 9: Front Mounted Rack and Pinion [9]

Power Assist Steering:

A power assist system uses either electric power to run a pump or a pump mounted to the engine to run the fluid through the system to turn the wheels. This system can be tuned to driver comfort as well as response giving a much better handling vehicle. The major disadvantage of the system is the weight and power needed to run the pump. The pump would sap about half of our engines power, which is only just enough to move the vehicle. Any loss in power to the wheels would decrease the competitiveness of our vehicle dramatically. The system would also increase weight by at least 100%.

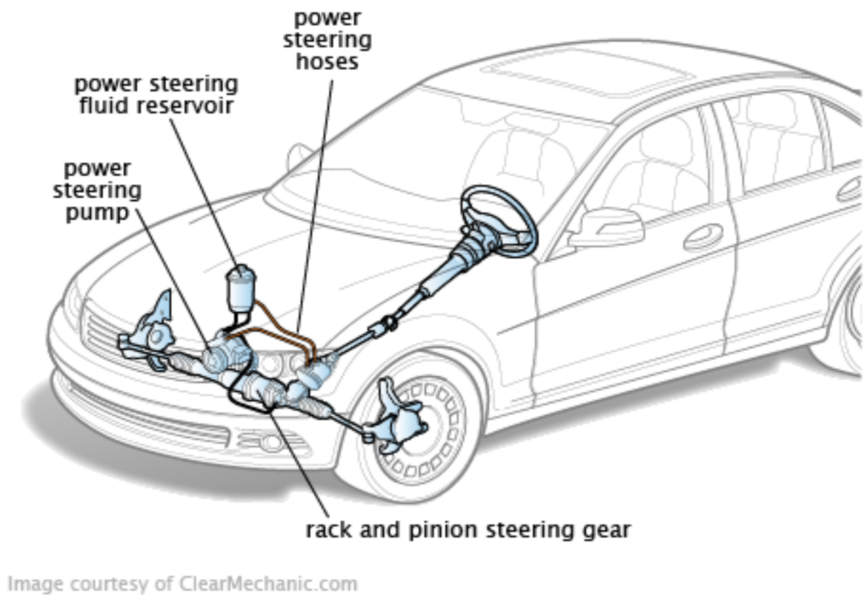

Figure 10: Power Assist Steering [10]

Steering Design Analysis:

Table 3: Steering Design Decision Matrix

Steering				
	Weight	Back Mounted 4-1	Front Mounted 4-1	Power Steering
Cost	10	4	4	1
Weight	15	4	4	2
Strength	10	2	2	4
Ease of Machining	5	4	4	1
Ease of Design	5	5	5	1
Safety	5	4	4	4
Durability	10	5	3	4
Turning Radius	20	5	5	3
Ease of turning	15	4	4	3
Foot room	5	2	4	3
Raw Total	100	39	39	26
Weighted		4.1	4	2.7

The designs were put into a weighted matrix. The design with the highest score would be the best design for our goals. The Back Mounted design received the highest score. The Front Mounted design received a score just slightly smaller than Back Mounted. The Power Assist design received the lowest score and therefore will not be evaluated any further. The Back Mounted and Front Mounted will be re evaluated with the entire vehicles ergonomics in mind before a final design is chosen.

Conclusion

The final designs have been selected for the front suspension, rear suspension, and the steering. For the front, the Double A-Arms and Extended A-arms were selected. The team selected these because A-Arms worked great for the previous team and our current team can improve on the previous design. For the rear suspension, the double A-Arms and the 2-Link were chosen. The double A-Arms were chosen because they are a common rear suspension in the previous mini Baja races. In addition, if Double A-Arms were selected in the front, less analization time will be needed to improve on the design; this is because the data from one wheel can be transferred to all wheels. For the steering, the back and front mounted rack and pinion were selected, both with a 4-1 gear ratio. All these designs have been carefully selected to improve on the suspension and steering systems of this Mini Baja. Further design and analysis will be conducted to see what component will be implemented on the final Baja car.

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