NORTHERN ARIZONA UNIVERSITY
Mechanical Engineering

**19F14**
**EBaja Capstone Team**

To: Dr. Sarah Oman

From: Drew Stringer, Shamlan Albahar, LeAlan Kinlecheenie, Fahad Alhowaidi, and Andres Parra

Date: 3 April 2020

Subject: Implementation II Memo

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We are the 2019-2020 senior E-Baja Team from Northern Arizona University. The team is composed of five Mechanical Engineers and four Electrical Engineers. We have been tasked with converting the 2015 NAU SAE Baja car to being fully electric. To convert the car, this requires disassembling the original car, then redesigning the car using only the original frame. The mechanical components being redesigned are the brakes, the front suspension, rear suspension, steering and the gearbox. The front of the vehicle has been completed, allowing the team to focus on the rear of the vehicle. The rear suspension parts are ready to be implemented onto the vehicle. The firewall and trailing arm are ready for pick up in Phoenix and the gear box was ready to be built.
Disclaimer: Production has been halted as the 2020 COVID – 19 pandemic has shut down the school and shops together. This implementation memo will be based on the pieces the team has and the idea of where the team was headed.

# 1 Implementation – Weeks 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. This section will overview which parts are being manufactured and which others are undergoing changes. 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.

## 1.1 Manufacturing

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.

### 1.1.1 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 1: Steel welded on the front suspension

Figure 2: Final design for front suspension

### 1.1.2 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 1.2.2)

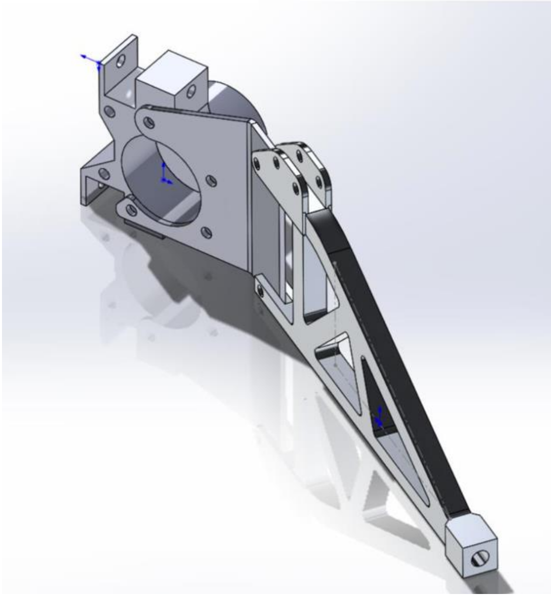


Figure 3: Complete Assembly of the Rear Suspension

### 1.1.3 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.

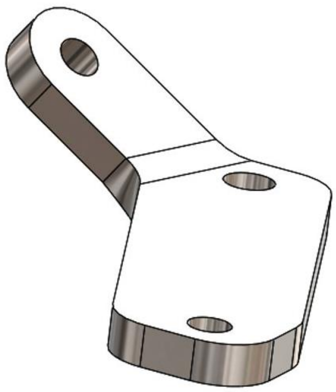


Figure 4: Steering Link

### 1.1.4 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.

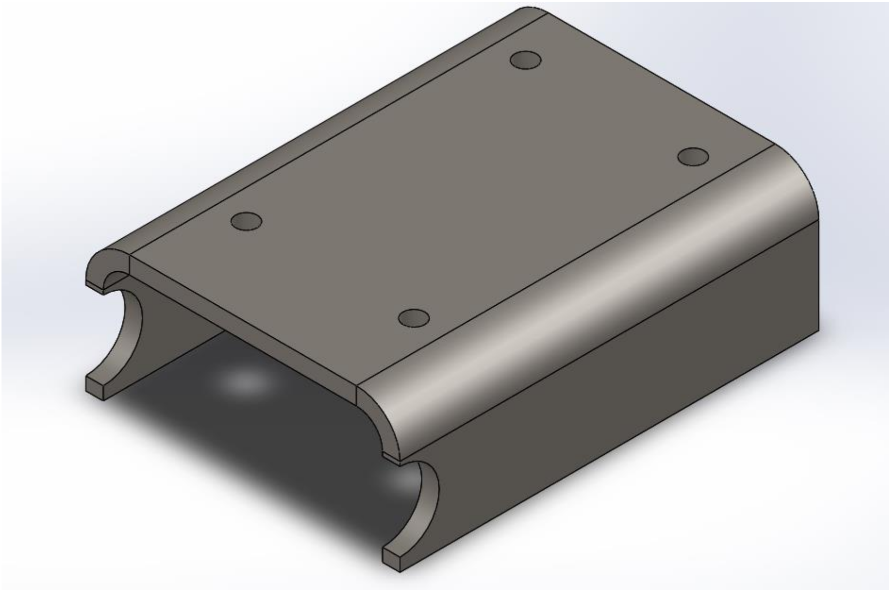


Figure 5: Brake Component Mount

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.

### 1.1.5 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.

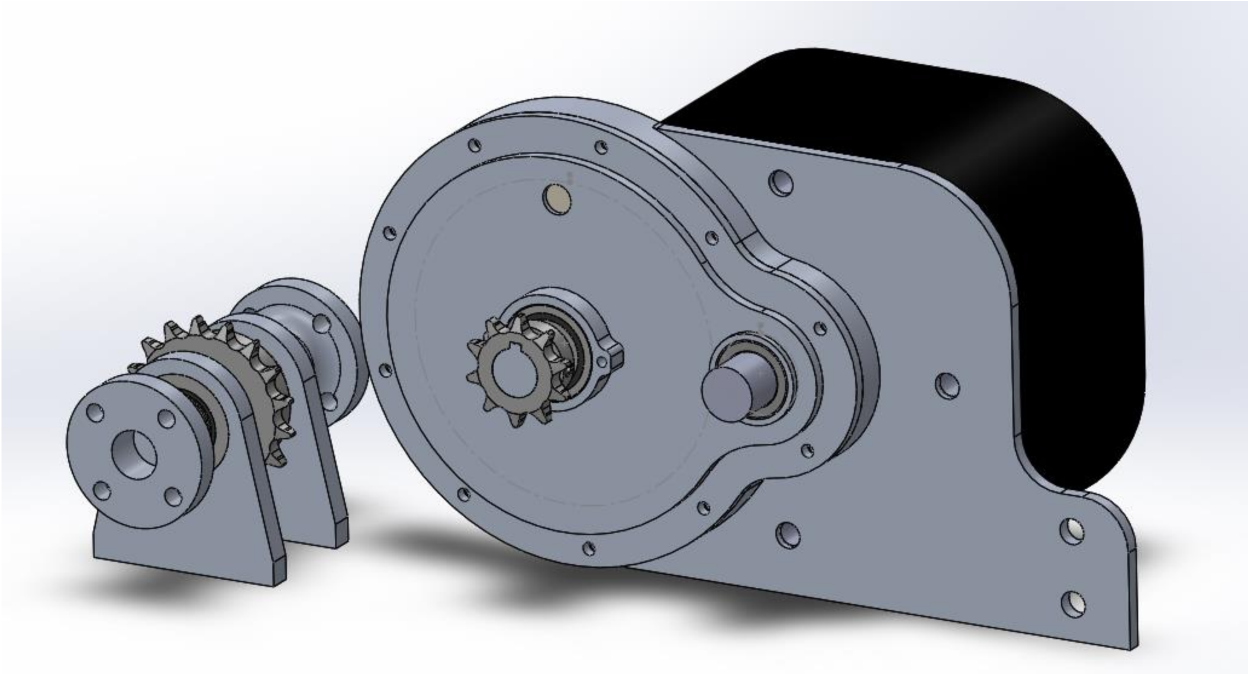


Figure 6: Gearbox Assembly Design

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.

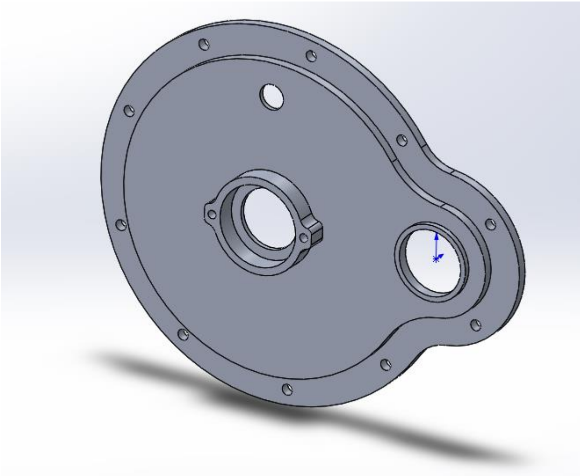


Figure 7: Gearbox Case Cover

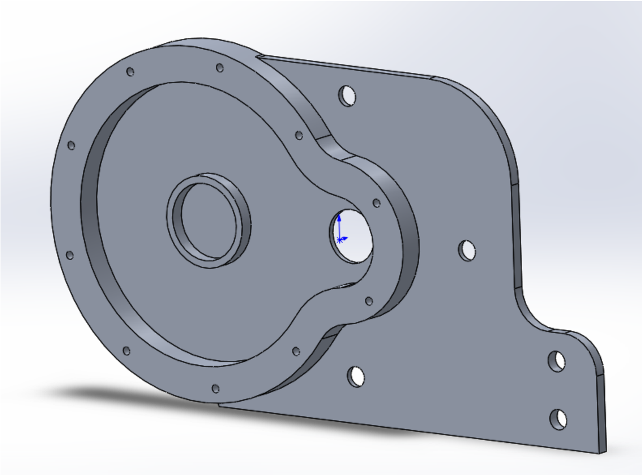


Figure 8: Gearbox Case Base

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.

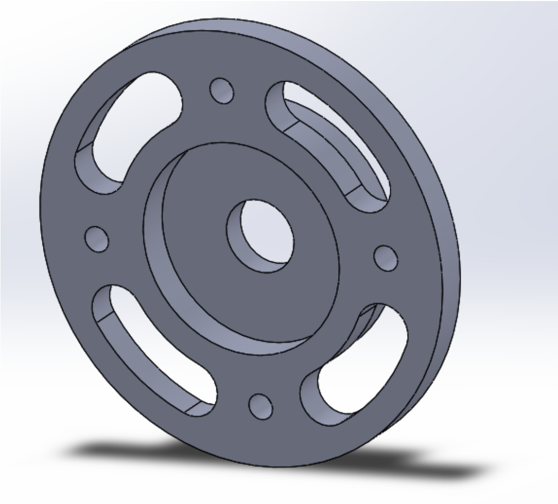


Figure 9: Large Gear Hub

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.

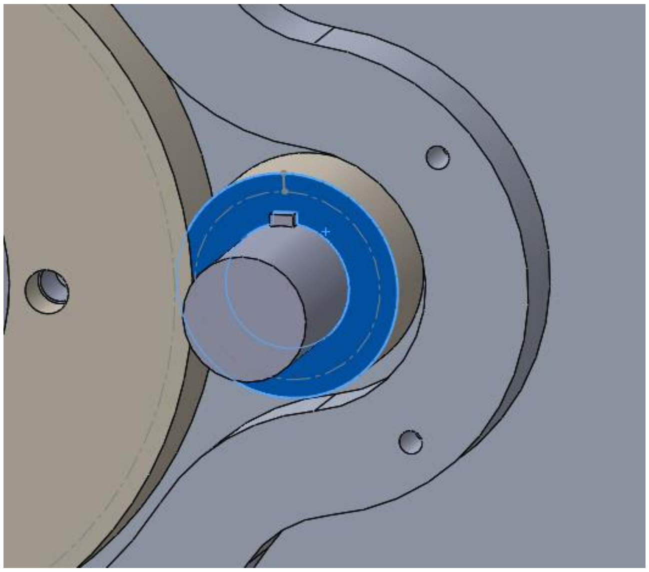


Figure 10: Small Gear Visualization

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.

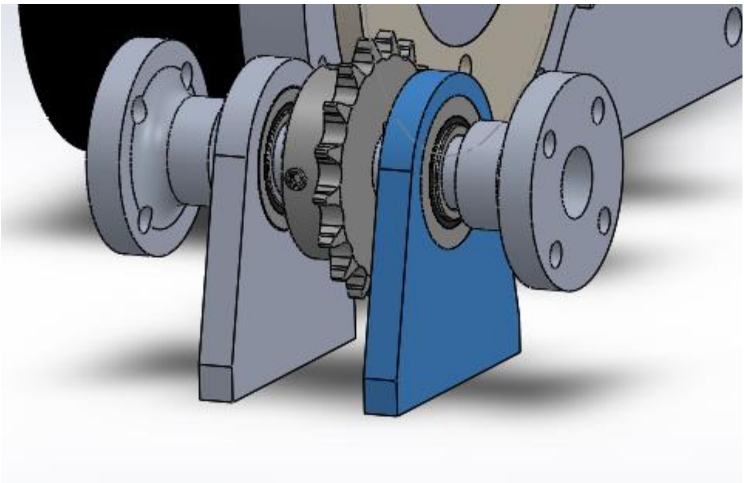


Figure 11: Bearing Block Assembly

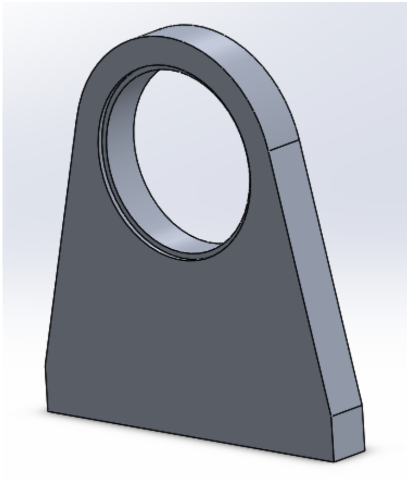


Figure 12: Bearing Block

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.

### 1.2 Design Changes -Weeks 7-11

The team only had one design change during the last few weeks of building. 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.

#### 1.2.1 Design Iteration 1: 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.

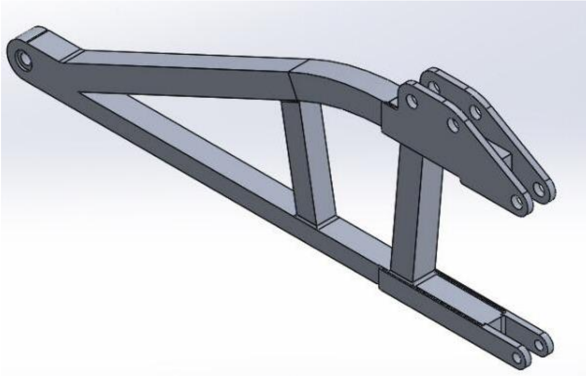


Figure 13: Original Propose Trailing Arm Design

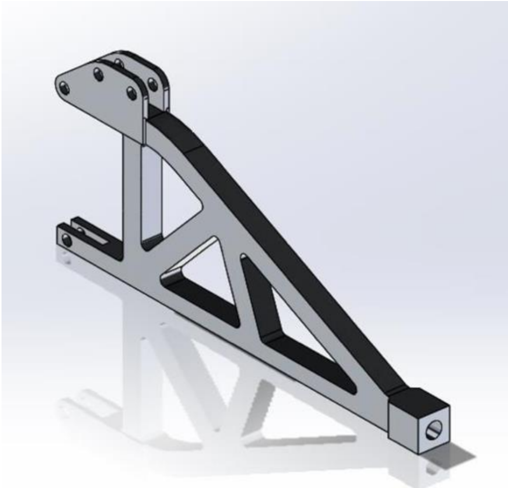


Figure 14: Final Trailing Arm Design

## 2 Standards, Codes, and Regulations

The standards of code and regulation the team is following is mainly the SAE and SAE India. This is because the team is constructed of five mechanical engineers, and the society of automotive engineers clearly addresses the Baja rules and regulations. The team also used the SAE India which has a section discussing the Electrical Baja rules.

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

### 2.1 Standards applied to project

Table *1*: Standards and Codes

| Standard Number or Code | Title of Standard | How it applies to Project |
| --- | --- | --- |

| | | |
|---|---|---|
| SAE B.10.1.1 | Batteries | Specifications on mounting, sealing and capacity of batteries used in vehicle. |
| SAE B.8.3 | Firewall | Provides specification of firewall for safety of driver from motor components. |
| SAE B.12 | Fasteners | Given specifications of all fasteners that are used in high risk components like safety and motor. |
| SAEIndia C.3.1 | Tractive System Accumulator | Specification on battery storage and mounting into vehicle. |
| SAEIndia C.2.1 | Electrical Kit Requirements | Battery, motor and power specifications to not exceed. |
| ASNI/AAMI HE 74:2001 | Human Factors Design Process for Medical Devices | Helped in the design of how the device interfaces with the user in a safe manner. |

# 3 Risk Analysis and Mitigation

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.

## 3.1 Potential Failures Identified Fall Semester

**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.

## 3.2 Risk Mitigation

Since the team wanted to replace the parts that frequently fail, the FEA showed that the heim joint 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 B). 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.

**Appendix A: 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.

**Appendix B: 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 15: 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)

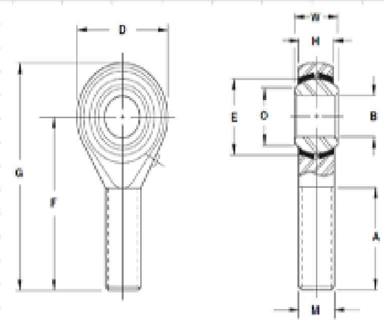



Figure 16: HM8 heims calculation

| Given Parameters (Bottom Heim Joint) | | | |
|---|---|---|---|
| Ball Diamter | E | 1.125 | in |
| Housing Width | H | 0.562 | in |
| Head Diameter | D | 1.500 | in |
| Minor Dia of thread | M | 0.625 | in |
| | | | |
| Allowable Material Stress | X | 52,000 | PSI |
| **Calculated Values** | | | |
| Race Material Compressive Strength | R | 32877 | lbf |
| Rod End Head Strength | T | 8068 | lbf |
| Male Thread Rod End Strength | S | 15944 | lbf |
| Maximum Static Radial Load | | 8068 | lbf |
| Maximum Static Axial Load | A | 5424 | lbf |
| | Factor of safety = | 1.8 | |

(Material-55 300 Series)

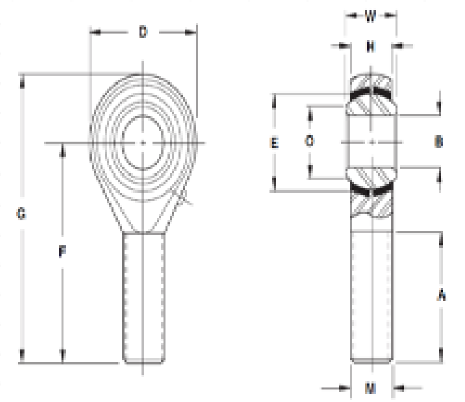
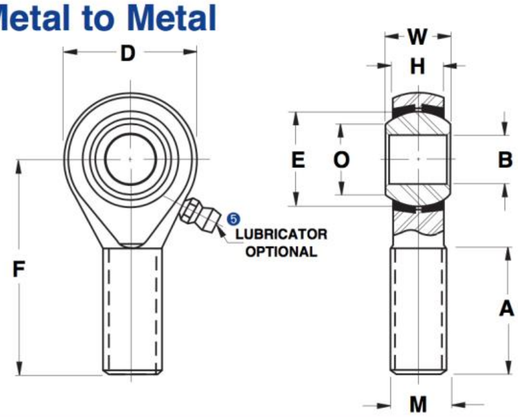



Figure 17: HM10 Rod end calculation

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 WITH LUBRICATOR (LBF) | MAXIMUM STATIC RADIAL LOAD WITHOUT LUBRICATOR (LBF) | 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 18: : 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 | 1,080 | .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 19: HM  series heims information provided by the manufacturer (HM 8 and HM 10 will be used for the front suspension)

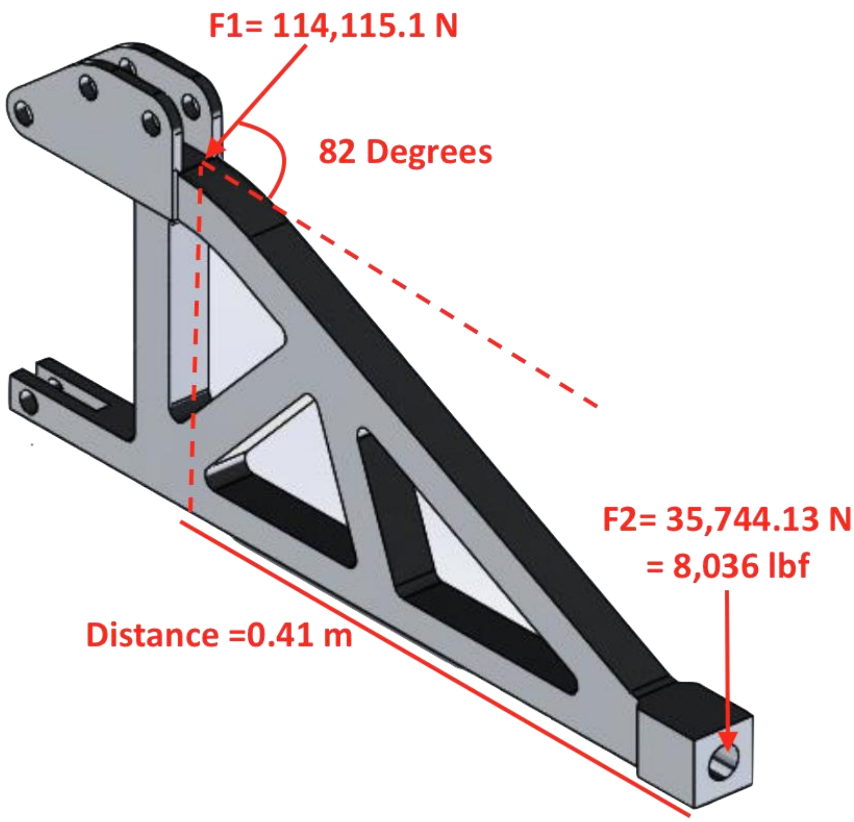



Figure 20: Free Body Diagram on calculating the force at the heim position.