



University of Cincinnati  
College of Engineering and Applied Science  
Department of Mechanical and Materials Engineering

Course Code : 20-MECH-5052  
: 20-MET-5092

Course Title : Senior Design II  
: Senior Design III

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# 1 Project Description

Bearcat Solar Car is a design, build, test, and race team with the main goal of competing in the American Solar Challenge (ASC) and the Formula Sun Grand Prix (FSGP). The team is to build a race car powered only by solar power that is to race in these two events. We believed the best way to design an entire race car was to break down the major components of the car and divide them into sub-teams. We have divided our car into six sub teams, five of which are headed by fifth year Mechanical Engineering (ME) or Mechanical Engineering Technology (MET) students. Each of the sub-teams has functioned as a senior design project and each one has had to make design decisions within their individual sub team design.

# 2 Engineering Standards and Codes

During the creation of the vehicle, the team followed American Solar Challenge and American Welding Standards (AWS) D8 regulations. The American Solar Challenge regulations were used to guide the constraints that control the design of the solar car. The welds of the ASTM 4130 steel tubing used in the chassis adhered to AWS D8 welding standards in order to ensure sufficient welds. The standards and codes used during the duration of the design of the bearcat solar car can be found in the appendix of the document.

# 3 Constraints

Several constraints guided the design of the car. The main constraints included cost, design complexity, manufacturability, size, and safety. The cost of the car was an economic constraint of the car. As this school year is the first year the Bearcat Solar Car team has created a solar car, finding enough funding was the biggest challenge. The solar car cost around \$10,000 to construct and race fees amount to around \$6,000 per race. The design complexity was also a constraint during the design of this car. Many of the designs began from nothing and due to schedule constraints, there was not enough time to create the most efficient designs. Our hope is that in future years, our team will use the first iteration design as a foundation and improve the concept we currently have. The manufacturability was another constraint. While designing the car in CAD, we designed a few tubes that would require bends. We found out that several of these bends would be very costly to fabricate. Because of this, we limited our bends to just three tubes on the car. The size of the car is another constraint. With being powered solely by solar energy, only a low amount of power is available during operation. Because of this, several teams worked to keep their design lightweight to have the car require less power to drive. Finally, the safety of the car is an example of an ethical constraint to consider when making the car. When completed, a driver will be in the cockpit of this car. It is our duty as engineers to ensure that our design is robust enough to keep the driver safe throughout the duration of the ride.

Other constraints that were taken into consideration while making the car were the environmental, sustainability, health and safety, and specification constraints. The environmental constraint of this car came with reason to make a solar car and that is because running a car off the sun is a much cleaner source of fuel than those found in modern day internal combustion engine cars. Another constraint while making this car was the sustainability of the car. The car we are designing in our Bearcat Solar Car team is not just for this year's team but the year that will follow. Because of this, we chose material that will last the life of the car. For example, we chose to use steel rather aluminum although aluminum is a lighter material because during the research of the material properties of aluminum when

welded, we found the welded aluminum does not keep its strength years after being welded. With this being considered, we chose to use aluminum to have a car that will have the ability to be used for several year after we are gone. The health a safety constraint came into play while we were fabricating the car. At victory parkway it is required so go through several environmental health and safety (EHS) training before you can pick up a wrench in the shop. Requiring our team members that were involved with the fabrication of the car to take the trainings is an example of a constraint we place to ensure the health and safety of our team members. Finally, the specification of the American Solar Challenge is the key constraint we used in the design of our car. When making this car the end goal was to race in the American Solar Challenge not just built a car that fits the description we make of a solar car. Because of this we followed the constraints placed in the regulation of the American Solar Challenge to let us one day have the possibility of competing in this prestigious competition.

## 4 Schedule

The design of the bearcat solar car began in the Summer of 2021 with the brainstorming of several different design alternatives evaluated throughout weekly teams meeting. The first PDR was completed in the first week of the Fall Semester. The design and analysis of each subteam was created during the fall of 2021 with the fabrication being completed during the Spring 2022 semester. Each subteams design was created and integrated into the solar car by April 14<sup>th</sup> 2022 when the senior design expo was held.

## 5 Chassis Sub-Team – Cameron Aldridge (ME), Stefan Nieschwitz (MET), Matt Wiegandt (ME)

### 5.1 Project Description

The cockpit and the roll cage house the driver. The cockpit contains the controls for the vehicle as well as several safety elements. The roll cage covers the driver while sitting in the cockpit, preventing injury in the event of a collision or a rollover. The cockpit and roll cage design is strictly regulated by the competition rules. The cockpit and roll cage assembly will be designed to be mounted to the chassis. It was designed to allow an easy escape for the driver in case of an emergency. The evaluation of the design will be done using finite element analysis.

The chassis is the main structure of any racecar and is the connection between all components and sub teams. The chassis interfaces with the suspension, roll cage, steering system, and the aerodynamic shell. The chassis needs to be able to withstand all the loads that are applied to any of the sub-team interfaces mentioned. The chassis also must be designed to accommodate constraints and desires of the sub-teams with which it interfaces.

### 5.2 Design Alternatives

There were two main categories of design alternatives that the chassis team discussed when we were designing the chassis and roll cage. The first category of design alternatives was determining what tubing and or piping was and what we wanted to use to construct our car.

We first began our design by becoming familiar with the distinction between tubing and piping to understand what type we would be using on our car. We chose tubing because tubing is widely used for structural applications where the outer diameter is the critical dimension. After we confirmed we were using tubing we began running calculations and simulations to try and determine the material and cross-

sectional area we would need to be able to withstand the forces that the roll cage and the chassis needed to bear according to the ASC regulations.

We first solved a few simplistic cases, where we simplified the tubes in our designs as straight simply supported tubes with a single force applied at the appropriate locations to calculate the max stress values that were applied to the tube for a certain material and a certain cross section. We chose to use ASTM 4130 steel over ASTM 6061-T6 aluminum because of the steel's easier fabrication, weldability, and for its ability to be used for as long as we want. The 6061 aluminum was lighter, but it was more expensive, harder to weld, and would lose some of its strength as time went by.

For determining the cross-sectional area needed we need to model our chassis and roll cage in SolidWorks and simulate the forces being applied to the roll cage and chassis in ANSYS. After a thorough simulation study for 3 different sized tubes, we determined that the 1.5" OD x 0.120" wall thickness ASTM 4130 steel would be used for the roll cage and 2.25" OD x 0.120" wall thickness ASTM 4130 steel would be used on the axle tubing.

### 5.3 Design Methodology to Complete Project

While the chassis sub team worked together throughout the creation of the car to create the skeleton of the solar car, the members on our team took individual team roles over certain aspects of the car during creation. For example, Matt Wiegandt took the lead on the roll cage of the car, Cameron Aldridge took the lead on the chassis of the car, and Stefan Nieschwitz took the solar on the solar array support of the car.

Throughout the last year the creation of the solar car has been through several design stages. In the summer, the focus was on brainstorming and research of the car as well as becoming familiar with the regulation of the Bearcat solar car. Moving into the fall semester, the brainstorming of ideas was ending, and we started to incorporate more aspects of the design of the car through CAD into our design process. During the spring semester, the design and CAD of the solar car was finished, and we began work of the fabrication and manufacturing of the car. Throughout each of these stages of the car's design the Gantt chart was incorporated into our team meetings to keep us on track. We also took notes during our team and sub team meetings as well as took pictures of white boards that contained our ideas and thoughts created during the meetings for future reference.

### 5.4 Conclusion

Overall, the chassis was able to be fully constructed as we had designed without any major changes. We were able to follow all drawings and designs we had created with only a few components that had to have slight changes to them to make fabrication and welding easier. We assisted our professional welder, Jordan Graff, with all fabrication and welding processes. Fabrication of the chassis was completed about eight weeks after the preferred deadline. This delayed integration of the systems of other sub-teams to the chassis. The major causes for the lateness in the completion of the chassis included delays in placing a purchase, material acquisition, and the bending processes from multiple different vendors. We were also unable to add an aeroshell or occupant windshield to the chassis due to the pushback from supply issues. Please see the Chassis section of the Appendix for drawings, simulation results, component list, Gantt chart, time history, supply chain log, and material certification, purchase orders, and references.

## 6 Steering Sub-Team – Ben Morrow (ME)

### 6.1 Project Description

The steering subsystem is designed to give the operator of the solar car reasonable control. Various design considerations were considered. The system must be able to withstand any loads imposed by the

operator. It must be able to, conversely, be easy enough to handle so the operator does not have to exert strenuous force for little response. Turning radius must fall below 16 meters to be ASC compliant. Steering stops must be permanent fixtures of the system. The wheel must be stronger than any hobby grade printing material. The wheel must also resist any backlash and not transmit it to the driver.

## 6.2 Design Alternatives

Being a rather straightforward system, no major breaks from any design norms in other steering systems occurred. The system consists of a wheel which, when applied with torque, turns two shafts that change the direction of the torque through universal joints. That torque is transferred to a simple rack and pinion system transforming it into translational force. This translation force is applied to rods connected to the suspension, in tension on one side, compression on the other. These tension and compression forces turn the suspension, which houses the wheel hubs and tires, in the desired direction of the operator. Despite being straightforward, many minor changes through various design iterations were necessary to: remain compliant, reduce cost, reduce mass, and improve function.

The double universal joint system was selected to give two degrees of freedom when mounting the rack and upper column. Various steering racks were considered, but due to budget constraints the rack from the University of Cincinnati Super Mileage Car (SMC) was used. This rack had considerably less linear translation and width than other racks considered. This caused a redesign of how to connect to the suspension and wheel hubs. The tie points had to be moved closer to the center of rotation for the hubs to impose a wider steering angle for less linear translation, given that the SMC rack had about 1" of translation, about 7" of width, and the car's track width is about 1.5m. This caused the tie rods to also become much longer. Traditional car tie rods posed the issue of buckling under the forces imposed upon them, especially with the increased force to impose the necessary moment on the hubs with the reduced distance to the point of rotation. Due to this traditional tie rods were swapped with ASTM A193 Grade B7 threaded studs. The choice of B7's was due to their use in bolting together heat exchangers. They are designed for high tension applications. These studs provided more strength than traditional rods and held up better during FEA than traditional tie rods.

The SMC rack also posed another design constraint that required redesign. The universal joint that was welded to the input end of the rack was for a 9/16" shaft, which was smaller than what was being considered. The upper column design was centered around a 1" rotary shaft. This was changed to 3/4" to better accommodate the lower column which was stuck at 9/16". Another issue was the upper universal joint needed to fit both shafts. Universal joints are not typically used as reducers as well, to make this work a 9/16" universal joint was ordered, and one end will be machined out to 3/4". To save money the lower universal joint connected the 9/16" input shaft and the lower column shaft was an impact driver shaft with a 1/2" socket machined out to 9/16". This allowed for savings of a few hundred dollars, and still provided a double female universal joint. The drive side of the impact joint was a 1/2" square, to make the lower column fit that, four flats were ground into it, giving the lower column a "keyed" end to fit the impact joint.

The original design of the upper column was a 1" rotary shaft, supported by a sleeve with bearings and an end with a splined stub to attach the steering wheel. After the necessary changes were made to incorporate the SMC rack the sleeve-bearing design was scrapped. A much less expensive and simpler design was made by using a 3/4" rotary shaft, mounting to the chassis with a pillow block ball bearing. For

egress purposes the quick release was moved from the center of the wheel to the back, to give the driver a little more clearance.

All joints not threaded or keyed were adhered together with Loctite 648, an adhesive compound meant for high RPM and high torque applications. While this application is not high RPM, the decision to go above and beyond was for the safety of the driver. No reasons to go with a lower grade adhesive presented themselves.

### 6.3 Design Methodology to Complete Project

Due to the more manageable nature of the steering system, it was handled by a single person. Research began last spring, and preliminary CAD was made during the summer based on original designs. The fall semester was spent finalizing dimensions, adjusting due to available part constraints, and running FEA. At the end of fall semester, in the first weeks of spring semester the parts list was finalized and ordered. Based on this part list a final CAD file was made. Progress was made based on changes and information from other systems, as the steering was not a constraining system. Another draw away from progress was the sole team member juggling other roles within the team, specifically managing the team's CAD, and creating/updating the master assembly. Despite this, as progress was made within other teams, the steering was installed and fully functioning for testing and full use by the senior design expo on 4/14/21. The steering system was designed with concurrent engineering along with the suspension, design for manufacturability for ease of fabrication due to limited resources, and design for assembly around the chassis and roll cage.

### 6.4 Conclusion

The steering system made steady progress and outside of minor changes during fabrication, was installed as planned in the fall semester and was fully functional by the senior design expo. Requirements stipulated in the ASC Regulations (Rev 2022B) were met, and in some cases exceeded. The 16m minimum turning radius turned out to be around 8m which was the initial goal. Driver egress is not impaired when the steering wheel is removed. The B7 tie rods hold up remarkably well, and do not yield when turning the fully loaded car. The system is not without its flaws however and improvements for the future are outlined in Section 11.1. All background research, mathematical proofs, CAD drawings, BOM's, FEA, design logs, and any other information not covered above are found in Appendix 13.2.

## 7 Suspension Sub-Team – Mike Brassfield (MET)

### 7.1 Project Description

The suspension serves to absorb impacts and keep all the wheels in good contact with the ground. The suspension also serves as the interface between the steering system and the wheel. As drag is one of the major limiting factors in the top speed, the suspension needs to have as small a frontal cross section as possible. Per the race regulations, the suspension is required to withstand a combined loading condition of 1G braking (X axis), 1G steering (Y axis) and 2G bump (Z axis), where G is the weight supported by that wheel.

### 7.2 Design Alternatives

Alternative designs considered included a traditional double wishbone suspension, a “pogo stick” suspension, and the selected trailing link inspired design. While the double wishbone is a well understood system, it has significant drag penalties due to the area of the two arms extending from the chassis to the

wheel hub and the turbulence generated by air flowing around those arms. To minimize the frontal cross section, the chassis team elected to use a single arm extending laterally from the chassis, and a vertical segment to support the suspension. The next design considered was a “pogo stick” where the wheel hub would have a cylindrical bore that would slide over the vertical segment. The vertical segment would have been threaded to accept a nut, and a spring would have been positioned between the hub and top nut. This was discarded due to difficulties in threading the upright and finding springs with suitable strength and travel distance.

The chosen design evolved from the trailing link suspension found on some motorcycles and scooters (e.g., Vespa). This design comprises of a fixed arm, connected on one end to the steering pivot and on the other to a second arm by a pin connection. The moving arm is connected back to the fixed arm by a shock absorber. In a motorcycle, the steering pivot is above the suspension, whereas our chassis connects below. This required packaging the trailing link into a self-contained “shell”, and this intermediary shell is what connects to the steering pivots. The shell is comprised of 1/4” ASTM 1020 mild steel plate, cut to shape using the waterjet at the 1819 Makerspace and MIG welded together using ER80S wire. The control arm is made from offcuts of the 1.5” OD x 0.120” wall ASTM 4130 chassis rail, TIG welded together using ER70S filler rod, connecting to the shell via a polyurethane bushing and a 1/2"x20 Grade 8 bolt. The shock absorbers connect to the shell and the control arm via 5/16"x16 Grade 5 bolts.

### 7.3 Design Methodology to Complete Project

The design methodology was very similar to the Steering sub-team. Mike Brassfield handled the design work, and worked with two underclassmen, Cara Baah-Binney and Nick Clark, who assisted with the CAD modelling and shock absorber selection, respectively. The model was analyzed using Ansys Workbench Mechanical by applying the proof loads at a remote point corresponding to the expected center of the tire’s contact patch. The results showed the points where the bearing carriers attached to the control arms had excessive stress. This feedback was passed to the wheel hub team where reinforcing material was added.

### 7.4 Conclusion

The suspension came together very well and functions fully to the design specifications. The entire suspension assembly fits behind the upright and has sufficient range of motion for the full travel of the steering rack. Ensuring the axis of the wheel axle remained parallel with the axis of the control arm pin was challenging, future design iterations should consider incorporating DFA methods for this interface. Access to the lower mounting bolt is restricted, requiring the entire suspension module to be assembled with no bolts to allow the control arm to move enough that the bolt can be installed. Access to the preload adjustment on the shocks is likewise restricted, requiring the use of tools to adjust.

## 8 Aerodynamics Sub-Team – Ayaz Yasin (MET)

### 8.1 Project Description

Due to a limited supply of power, the design of the solar car must rely on its aerodynamics to reduce drag and induced power losses. The objective of this project is to design and analyze the outer geometry of the solar car. The design is based upon the shape of the chassis and other components, with an aerodynamic skin. This shape will be analyzed using CFD methods as well as wind tunnel testing.

## 8.2 Design Alternatives

Several alternatives to the design were considered to optimize the aerodynamics of the car. These included the common shapes preferred for solar cars, as well as designs based on airfoils. Initial designs were based on asymmetric NACA airfoils. NACA airfoils are well characterized shapes that allow for easier analysis in a variety of different flow conditions. Though such designs are popular among solar car teams, they require an aerodynamic shell made using composite materials. Due to a lack of access to such materials, these designs were opted against in favor of more manufacturable shapes.

Another promising alternative was the use of lateral symmetric NACA airfoils. These shapes would have the benefits listed above and could also be approximated by construction methods that did not require molding.

## 8.3 Design Methodology to Complete Project

An outer design that closely follows the shape of the chassis was ultimately chosen in order to minimize the additional construction required on the car. This would restrict us from achieving an ideal aerodynamic shape but would allow us to construct the car within the restrictive timeline and budget.

CAD assemblies of all major sub-systems of the car were generated to best approximate the influence of each component. Computational analysis of the airflow around the car was conducted using OpenFoam. The shape of the car was iterated upon by modifying areas that contributed to high drag and conducting CFD analysis to identify such areas. A scaled model of the car was tested in a wind tunnel to help validate the computational results.

Qualitative tests were conducted on the available heat-shrink skin material to ensure its stiffness for application on the outside of the car.

## 8.4 Conclusion

CFD analysis with mesh-independence studies show the car geometry design would produce a drag coefficient of 0.18 at 10 m/s (22.34 miles per hour), this was validated using the experimental data. The heat-shrink material was also found to be durable for application on the outside of the car.

# 9 Motor/Motor Hub Sub-Team – Josh Bitner (MET) & David Meiners (MET)

## 9.1 Project Description

The motor and wheel help to power and move the car and are critical components that must be designed and analyzed in a way that maximizes the power and speed of the vehicle. This project shall include designing a hub for the hub motor to connect it to the suspension and chassis, as well as designing a way to mount the hub motor to the back wheel and tire. These will be analyzed using finite-element analysis and then using the results for the fabrication of the necessary parts. This project shall also include defining the specifications for the motor so it can be powered by the solar array and calculating the torque and speed requirements for the motor. The project also must include specifying an electronic controller for the motor and with other sensors to control and regulate the motor's speed and temperature, as well as monitoring the battery's temperature and health from the driver seat of the car.

## 9.2 Design Alternatives

We needed a solution to ensure the motor shaft would be locked into place and stay within the regulations of the American Solar Car Challenge. Originally, we investigated using a flex loc nut or a lock washer. We determined this design could not withstand the vibrations and repetitive cycling of the motor. Regardless, diving more into the ASC regulations, we found that it was determined that the lock washer was banned due to this exact issue. A second design was to weld bolts onto the hub and feed through the suspension. This design would increase the level of difficulty for manufacturing. This design would also lose strength compared to other designs. A third design was to use a castle nut and cotter pin which is allowed in the ASC regulations. The issue we had was the shaft of the motor has our wires running through the center. The wire harness is large enough to where we could not drill without drilling through this and decided we needed a new solution.

The design we chose was to use a hex nut, wire lockable hex screws, and stainless-steel wire to ensure the motor be locked into place. The idea is to run the wire through the hex nut and run through the hex screws in a way that allows the nut to stay locked onto the shaft and pressed against a steel block. This design accounts for vibration and the repetitive cycle of a motor. The block is made of 3" x 3" square 1018 cold roll steel. The hex screws have a black oxide coating and are ¼"-20 thread size, 1" long. The hex nut is an M30 x 1.5 mm thread size. The wire is made from 304 stainless steel wire, 0.032" diameter. The other part of our hub design is to utilize the extra 4130 ¼" material that Michael is using for the suspension and utilize that to make a piece of sheet metal that is bent twice to form a C-Chanel and fit on the outer side of the block and be secured using 8x ¼"-20 thread size hex screws. This plate will then be welded to the end of tubing used on Michael's suspension arm.

## 9.3 Design Methodology to Complete Project

Throughout this academic year, there have been many changes to the entire hub and motor system. We started with finding the speed and torque requirements for the hub motor and then began searching for suitable hub motors online that could also minimize cost with our limited budget (at the time). Once we searched through a thorough list of hub motors, we finally settled on one that we felt would best meet our needs (17-inch 2000W 273 Qs Motor). We then worked with Michael Brassfield who is designing the suspension system to work through a solution that would allow our selected hub motor to connect to his suspension design. In the fall semester, Michael was making an original suspension design with some influence from other teams. It presented an initial challenge to find a suitable solution that would work and fit within the regulations of the American Solar Car race since there were not off the shelf parts that could assist with the unique suspension design. By the end of the fall semester, we had a design for the hub of the hub motor that was validated by our FEA, a selected motor controller, and we were ready to order the hub motor.

Starting the spring semester, we were confident in our plan and schedule. However, we immediately ran into issues as we found that the hub motor was not ordered by the UC purchasing department before Christmas as we were originally planning, and Michael was changing his suspension design to relate to another Solar Car team's suspension design more closely. We immediately worked with the UC purchasing department to get the hub motor ordered, although it would affect our initial timeline for the semester. We also had to change our hub design as the way we would connect to the suspension would no longer be valid with the new suspension design. We were able to produce a new hub design that worked with the new suspension design and was validated by FEA. The new design ensured that the

hub motor could still be easily removed if needed for maintenance and was still a valid design per the ASC regulations.

Despite the motor shipping delays, we were still able to machine a hub for the motor once it arrives. We machined a 1018 steel block into a hub by cutting out a center section for the motor shaft and drilled and tapped holes around the block to lock in safety wire to the bolts and the connect the c channel. The c channel was cut from the waterjet at the 1819 innovation hub using ¼" steel (the same used for the suspension to save material costs), and then was bent with the assistance of Jordan Graff. The C Chanel just needs to be welded onto the arm of the suspension once the motor arrives. The c channel was not welded to the suspension for tech expo as the c channel was unable to support one of the other wheels so we just connected a 4<sup>th</sup> wheel for expo so that the car could more easily move.

Unfortunately, through the spring semester, the motor never arrived from the manufacturer due to a COVID shutdown in Shanghai. We were able to get the hub component machined and ready to be installed once the motor does arrive. We have done research on how we will need to wire the motor to the system once it does arrive, so we believe we have all the other components necessary to complete the system once the motor does arrive.

#### 9.4 Conclusion

Overall, we were on pace to complete our project for most of the semester. If the motor had been delivered when we originally thought it was, we would have had time to complete and implement our entire design. We were able to get a lot of the testing materials, wires and other components needed to get the motor and car up and running the way we designed, and we completed the design and fabrication for the hub connection of the motor to the suspension. Our design and project moved along nicely, we just encountered an issue with the supply chain and shipping delays with the motor we ordered.

## 10 Wheels Axles Hubs and Brakes – Will Name (ME)

### 10.1 Project Description

The original objective of the senior design project was to build the braking system, in particular sourcing the rotors and fastening the brake calipers to the chassis. Due to the novel nature of the suspension system, there was no prior design off which the caliper fastening system could be modeled. Furthermore, the team did not have wheels selected or any method of attaching them to the suspension. Because the components outboard of the suspension are so interconnected, the scope of the project crept to include selecting and sourcing parts and integrating them. Parts specified and sourced in my senior design included the wheels, tires, brake rotors, calipers, master cylinders, and bearings. Then, axles, hubs, and an adapter plate were designed to integrate all components. The challenge was creating an easily manufacturable design that integrated all these then-unpurchased parts that also met the packaging requirements of the chassis and integrated with the suspension. The hubs and axles were modeled to meet the wheel offset requirements set by the hub motor that was purchased, work well with the then-unseen suspension design, and meet ASC regulations.

### 10.2 Design Alternatives

Multiple iterations of the system were considered and revised. In one iteration, the brake rotor was to be on the opposite side of the hub from the wheel. This would have made packaging easier. The wheel could have been spaced far from the suspension by simply using a longer axle, while keeping the

brake rotor close to the hub so that the caliper attachment point was stronger and less complicated. This design was scrapped because it would have significantly reduced the manufacturability and ease of installation of the axles. In the end, the design of the axles and hubs was selected for its ease of manufacture and simplicity.

Just before manufacture, the team was alerted that the hub motor would not be arriving and that the carefully calculated wheel offset was no longer relevant to the design. In a last-minute decision, I reduced the length of the axles to reduce the (very large) wheel offset to reduce forces on the suspension, axle, and bearings. I modeled a simple wheel to check that the offset selected cleared the suspension and chassis, but unfortunately this simple wheel model was insufficient to accurately determine packaging requirements. This would lead to a condition where the wheel rubs on the chassis when the car is steering, and the suspension is compressed. I will expand on ways this design oversight could have been mitigated at the end of the next section.

### 10.3 Design Methodology to Complete Project

Where possible, commercial off-the-shelf parts were used. The team saved time and money by using commercially available aluminum alloy wheels from a Segway project. The wheels met the requirement to match a 17" motorcycle tire set by the hub motor. This automotive – style wheel allowed the wheel to be supported from one side with lug nuts and a center bore, unlike motorcycle or bicycle wheels. Additionally, the wheels are compliant with SAE J2530, which sets performance and test requirements for vehicle wheels, demonstrating a degree of safety and dependability. Likewise, the calipers and master cylinders were sourced from a major vendor of car racing products, and the rotors were designed for motorcycles.

Due to the bespoke nature of the suspension, there were no commercial products or designs that could meet our particular needs. Therefore, I designed an axle, hub, bearing, and adapter assembly that could be machined with common tools available to us, and that would exceed whatever strength requirements the car could throw at it. The hubs, which held large 2" OD 1" ID sealed ball bearings, were designed such that they reduced the radial forces on the bearing and kept thrust and preload to a minimum. The hubs and axles were designed to be fully turned from round steel stock, ensuring they could be manufactured on a manual lathe with minimal tooling requirements. I worked with the steel supplier to choose a steel that was easily machinable, weldable, and well suited to our automotive-style strength requirements while keeping the cost reasonable. The wheel adapter is a flat sheet of ¼ steel. The major requirements of the wheel adapters were that the bolt hole location tolerances were tight, and that the bolt patterns were highly concentric with the center of the axle to avoid runout. The design was revised to include an additional threaded fastener in the center of the axle and wheel adapter. The only purpose of this bolt was to center the axle and wheel adapter for welding. This helped hit near perfect concentricity of the axle and wheel without the need for any measurement or alignment. The locations of the bolt holes for the wheel lugs and brake rotor bolts were highly accurate because the adapter plate was CNC water jet cut. Additional rounds of metal were cut from the scrap of the water jet cutting, which also had a center hole for the bolt to hold center with the axle. After machining and cutting, the axle, wheel adapter, and hub bore rounds were bolted together and welded. Welding significantly warped the wheel adapter and hub bore rounds, but this was to be expected. Because the concentricity was held by the bolt and I had intentionally oversized the diameters of the rounds, the entire welded assembly could be turned on a lathe. This gave us a machined flat surface for the wheel to

adapter interface and a round surface to interface with the hub bore that was concentric with the axis of rotation. In conclusion, the design of the system was very satisfactory in that the wheels spun practically without eccentricity, and we were able to create ideal mating surfaces without expensive tooling or time consuming and unreliable processes like measurement and alignment. After over 30 labor hours of machining and welding, the highly manufacturable design achieved the engineering goals of the system despite varying machine operator experience.

#### 10.4 Conclusions

Despite the novel design, the manufacturing of the hubs and rotors went nearly flawlessly, except where mistakes were made by novice volunteer machine operators. The problems included not facing the round stock to length and removing too much material from the bearing mating surface on both the hubs and axles. This unfortunately created far too much clearance between the bearings and bearing mating surfaces, where a close slip fit that could be filled with a retaining compound was desired. In the future, this could be remedied by metal spraying, machining, and sleeving, or re-making the affected parts. Because the round stock used to make the hubs was neither sawed nor faced to length, there were fewer threads exposed on the axles than desired. This can be remedied by selecting a nut that is less tall, while still meeting strength requirements. Due to the fact that the size of the nuts was set by the OD of the axle, and not by strength requirements, I do not think this will be an issue.

Upon assembly, it was found that the wheel would rub on the chassis rail when steering and the suspension was compressed. This would not have been a problem if the original wheel offset was used, and was an unforeseen complication of my changing the wheel offset just before manufacturing. Again, the simplified wheel that I created in the AutoCAD model was not sufficient to confirm there were no interference problems. One way I could have avoided my design error was to give way more offset than I thought was necessary. Because we already had the wheels in hand at this point, and because it would have been difficult to fully model the wheel in AutoCAD, in retrospect I wish I had scanned the wheel and created a 3D object from it to import into the AutoCAD model. This is currently very feasible for a student project thanks to low-cost lidar and 3D scanning devices such as late model Apple iPhones and Xbox Kinect sensors, which were available to the team. The learning experience here is that simplified models cannot be used to check clearance and packaging when fully digitally designing a product.

### 11 Conclusion

Overall, the bearcat solar car team produced a car that was able to be presented at the senior design expo. Although the car was not able to be driven due to not receiving a motor in time, the chassis of the car had been created along with functioning suspension, wheel hubs, wheels, and steering systems. The chassis system successfully carried the weight of the car and safely protects the driver. The suspension system successfully absorbed impacts that appear while driving. The wheel hub system fit within the suspension and allowed the wheels to be easily rotated. The steering system successfully allowed the wheels to turn while driving. This car served as a great starting point for the Bearcat Solar Car which can be approved upon in year to come. Senior designs in the coming years will work on aspects of the car such as the solar array system, aerodynamic shape optimization, and a battery pack design and constraining structure with the goal to compete in the 2023 Formula Sun Grand Prix.

## 12 References

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## 13 Appendix

### 13.1 Bearcat Solar Car Future Work

## Mechanical Improvements Ideas to the BCSC 2022 designs

### Priority Scale

Critical

High

Low

#### 1. Overall System Design

##### a. Energy/Power Balance/ Load Calculations

Calculate the overall energy needs of the car. Include in these calculations, Aero Losses, Mechanical Losses, Electrical Losses, and Solar Losses. This will involve the knowledge of all subsystems and of relevant topics such as the basics of Solar Energy, Fluid Dynamics, Electrical Usage, and Heat Transfer. This is a critical task that requires the completion of Aero, Mechanical, and Electrical subsystems. Recommend 1-2 students for this project as a senior design.

#### 2. Chassis

##### a. Battery Box Structure

Create a supporting and containment structure for the battery assembly. Needs to be in accordance with the American Solar Challenge Regulations for battery safety and removal. Must also be able to fit within the “truck” space of the chassis, behind the driver and below the solar array architecture. Recommend this to be a sub project of the overall chassis project team.

##### b. Solar Array Support Architecture

Create a solar array support structure to support the new the solar panels. Must be in a relevant aerodynamic shape that has a limited front cross sectional area and is able to support the forces or a side wind at roughly 45 mph. Array support must either sit on the existing support structure or student must create his/her own structure that attaches to the chassis, specifically the rear arch of the roll cage.

### c. Axles

Move the axle tubing from the lower plane of the chassis to the middle plane of the chassis (in plane of top side rails). This would require removing the current axles and every tube attached to them, trying to scrap as much material and components as possible to reuse. See the image below for design idea. Would limit the moment on the suspension uprights, would lower the CG of the car, and could therefore reduce the track width possibly. Would require a fair amount of fabrication and welding work and time and know how. Recommend talking to Jordan Graff about providing help. Would probably be something to look at doing in future year for 1-3 students.

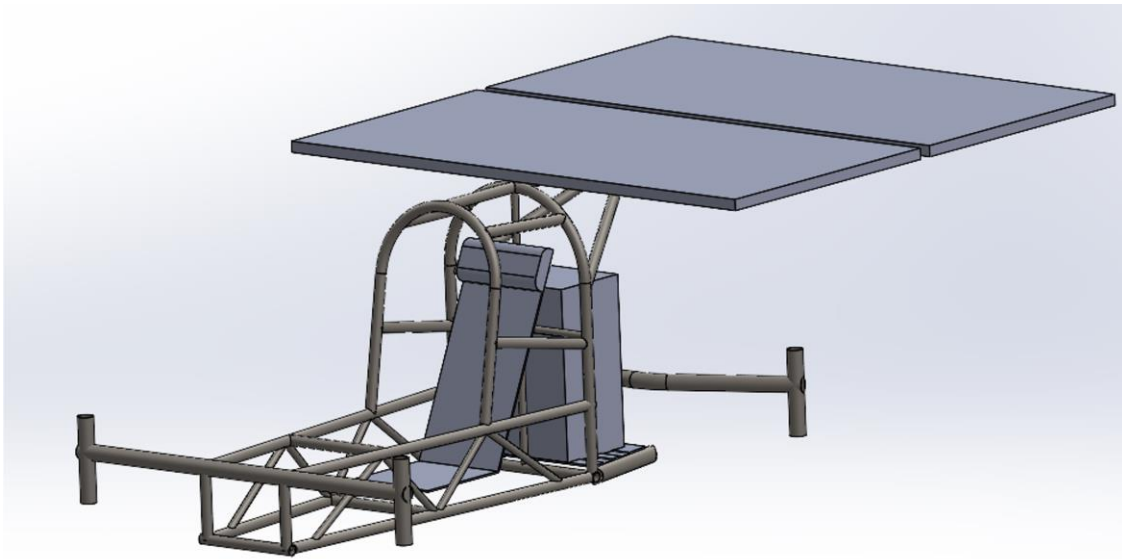


Figure 1. Movement of Axles to Top Chassis Rail

### d. Reduce overall Chassis Weight

Reduce the amount of weight for the chassis. Currently sits around 175 lbs. or 80 kg. Recommend using a composite type of material or a lighter form of metal. Should be able to try and get the overall chassis weight down to around 50 kg or 120 lbs. Would require a basically full overall rebuild of the chassis. Might be able to scrap some components but an entire redesign and rebuild will be necessary. Require roughly 3-4 students.

### e. Encapsulate the driver

Create the aerodynamic shell that needs to encapsulate the driver so that wind/air will flow smoothly over the chassis/roll cage of the car. Planned on using the old Super High Milage car that is in VPC for the bubble structure. Needs for the encapsulation are, driver needs to be able to exit the car under 10 seconds, needs to be compliant with ASC Regulations, and needs to withstand the forces of winds at 45 mph. If using the super high milage bubble this project would require 1 student, if a redesign of the model is in the budget would require roughly 2-3 students.

## 3. Steering

### a. New steering rack

Re-design the current steering rack of the car. Need to include 3 major improvements on the current design, increase linear travel, greater tie rod connections, increased input shaft connection. Need to be able to withstand higher forces and have greater turning capabilities. Will require 1 student.

#### **b. Replace Lower U Joint**

Replace the current U joint with a stronger impact driver joint. The current U joint assembly was scraped together from cheap components that were needed to keep the car under the \$4600 budget we were originally working under. If the car is to race in any event it will need to have a much stronger U joint assembly so that it can withstand the long stretches of driving that are needed.

#### **c. Replace Tie Rods**

Replace the current tie rods with stronger thicker material to withstand a much higher load than the current tie rods. Current tie rods were purchased to fit the steering rack that was taken from the super high mileage car. If the car is to race in any event it will need to have much stronger tie rods so that it can withstand the long stretches of driving that are needed.

#### **d. Change Steering Wheel/Wheel Removal for Egress**

Change the steering wheel design and make it easier to enter and exit the vehicle. Currently it is a little tight for any driver that is of a larger stature to get into and out of the vehicle. Would basically need a complete overhaul of the design and need to change nearly every component of the steering system. Would require roughly \$1000 for the component redesign.

### **4. Suspension**

#### **a. Remake Shell out of Thinner (less than 1/4") sheet instead of 1/4"**

Remake the suspension shell with a thinner material. This could reduce the overall weight of the suspension. Would need to re-analyze the suspension FEA to confirm that the loadings applied to the suspension are able to be maintained by the new design.

#### **b. Dial in Optimum Pre-Load Setting for shock absorbers**

Need to dial in the pre-loading condition of the shock absorbers to allow for the most clearance between the bottom of the chassis axle tube and interior rim of the front wheels. Once the setting is found all suspension shock absorbers should be set to a similar setting. This is best done by using a set of pliers while the car is jacked up off the ground.

### **5. Aerodynamics**

#### **a. Design Constraints for the Chassis / Shape Optimization**

Create the constraints for the aerodynamic shell based upon the current structure of the car. Need to create an aerodynamic shell that reduced the drag coefficient of the car to allow for continuous driving.

#### **b. Better CFD Models**

Iterate the CFD models of the car to better reduce the coefficient of drag and optimize the shape for continuous driving. Set a target drag coefficient using energy balance.

#### **c. Cooling system**

Use the stagnation pressure at the front of the car to bleed air into the batteries to provide convective cooling.

### **6. Wheel Hubs & Axles**

#### **a. Ensure Wheel Rim Clears Front Chassis at Full Bump and Turn**

- i. Increase overall length of axles: This can be done using wheel spacers and longer bolts. This is probably the easiest option. The wheel adapter plate part would be useful for this. A second “wheel adapter plate” would be waterjet cut from sheet steel and bolted in place. The adapter plate should be flat unless welded, so it should be turned down flat if it is welded. The DXF files for the adapter plates should be in the braking hubs and axles files. The plate cutting job can be sent to 1819. They should be able to supply sheet metal. The offset that is required is not known and should be determined by the team.
- ii. Change suspension attachment point. The suspension can be attached perhaps on its side or corner, instead of directly behind the upright. It is not known if this would fully fix the clearance issues, so this should all be investigated by the team. Also, this would change the steering geometry in some ways and longer steering rods may be required.
- iii. Find wheels that have less offset/backspacing: this is a worst-case scenario. Backspace is the distance from the back of the mounting pad to the back lip of the wheel. Wheels with less backspace should give more clearance, all things being equal.

#### **b. Skeletonize Axles to reduce weight while meeting strength requirements**

The axles were manufactured in a way that they can still be turned on a lathe. The axles were designed stronger than necessary. They could be bored out to remove mass from the center of the shaft. Someone could run FEA to determine how thick of walls are necessary in each place, then drill them out. While this would not make much of an impact on the overall performance of the car, it would be a good senior design for someone who wants to learn FEA but does not want to spend too much time at victory parkway. Would probably have a good weight reduction percentage to put on a resume. Would suggest doing this with the skeletonizing the wheel adapter plate portion.

#### **c. Skeletonize Wheel Adapter Plate**

This should be pretty easy and would remove some unsprung and rotational weight. Could be done by drilling away unneeded material on a drill press after CAD modeling. Would be good to do with the skeletonized axles.

#### **d. Improve Bearing Shaft Fit**

- i. Research Process
  - 1. Welding – Not sure if this would be ok but might be the easiest way to add material to the shafts. Would weld to add material, then turn down to size.
  - 2. Hot/Cold Material Spray – Probably the most proper way to do this but is a skilled process and requires special tools
  - 3. Machine or bore out & Sleeve – This is probably the only option for the hubs, should be pretty easy for the axles. On the hubs, this might really screw up the parallelism between the two bearing races, so a student might find ways to do this more properly than with a hand drill. Would be good research and learning experience.
- ii. Goal to Get to Press Fit – The bearings should fit very closely, ideally press fit. Then, should be installed with retaining compound to hold them in place and prevent the outer bearing ring from spinning in its race.

#### **e. Interface with Braking System**

The hubs were designed with extra metal around where the bearings go so hopefully the brake caliper adapter can be welded or otherwise fastened to the hub without totally screwing up the bearing race. But the student machining the bearing races already took out way too much metal anyways. I suggest welding the brake caliper adapter to the hubs, then boring and sleeving the bearing races. This should

be done in a way that produces a round hole and preserves the parallelism of the bearings' races. If the hubs are bored and sleeved after welding, then the warping effect of welding will not be an issue.

## **7. Braking**

### **f. Install Braking System**

The entire braking system need to be installed. We already have the major components except for brake hoses. The hardest part will be fastening three brake calipers to each of the front axles. Look to the Naledi car for design inspiration. This is an entire senior design worth of work.

## **Electrical Improvements Ideas to the BCSC 2022 designs**

### **1. Car's LV System and Data Collection**

This project would entail finishing and improving the low voltage system's program, including the GPS system, to minimize time and energy use by the Raspberry PI. This project could also include the program development for collecting, reading, analyzing, and displaying data received by the car's sensors and other data-collecting components.

We propose this project could be applicable to 1-2 CS students.

### **2. Car's Telemetry**

This project would involve determining what information through measurements, readings, or other forms must be acquired and transmitted to monitor and manage the car's performance and vitality. This project would include the research, implementation, testing, and data analysis for external sensors needed. Also, the project will involve development of a transmit-receive interface for the monitoring car to view real-time data collection and analysis from the sensors and battery management system.

We propose this project for approximately 2-4 students, applicable to EE/EET/CS. The sensors component could fulfill those minoring in robotics.

### **3. Car's Battery**

This project can encompass the design, building, and implementation of a battery pack that will be charged by the solar array and adhere to the regulations of the American Solar Challenge (ASC). The project also entails the testing and analysis of the battery's performance and efficiency. This project could also include potential improvements to the battery management system.

We propose this project is suitable for 2-3 EE/EET students, specifically EESG minors.

### **4. Car's Solar Array**

This project will include improvements or original design of the car's solar panels, adhering to ASC regulations. It will also include the design and implementation of the solar array's layout and supporting architecture on the car, such as location or positioning. Another part of the project will be testing and analyzing the solar array's design to maximize energy capturing, conversion, and charge rate for the main battery.

We propose this project for 3-4 EE/EET students, specifically EESG (energy) minors.

## 13.2 Chassis

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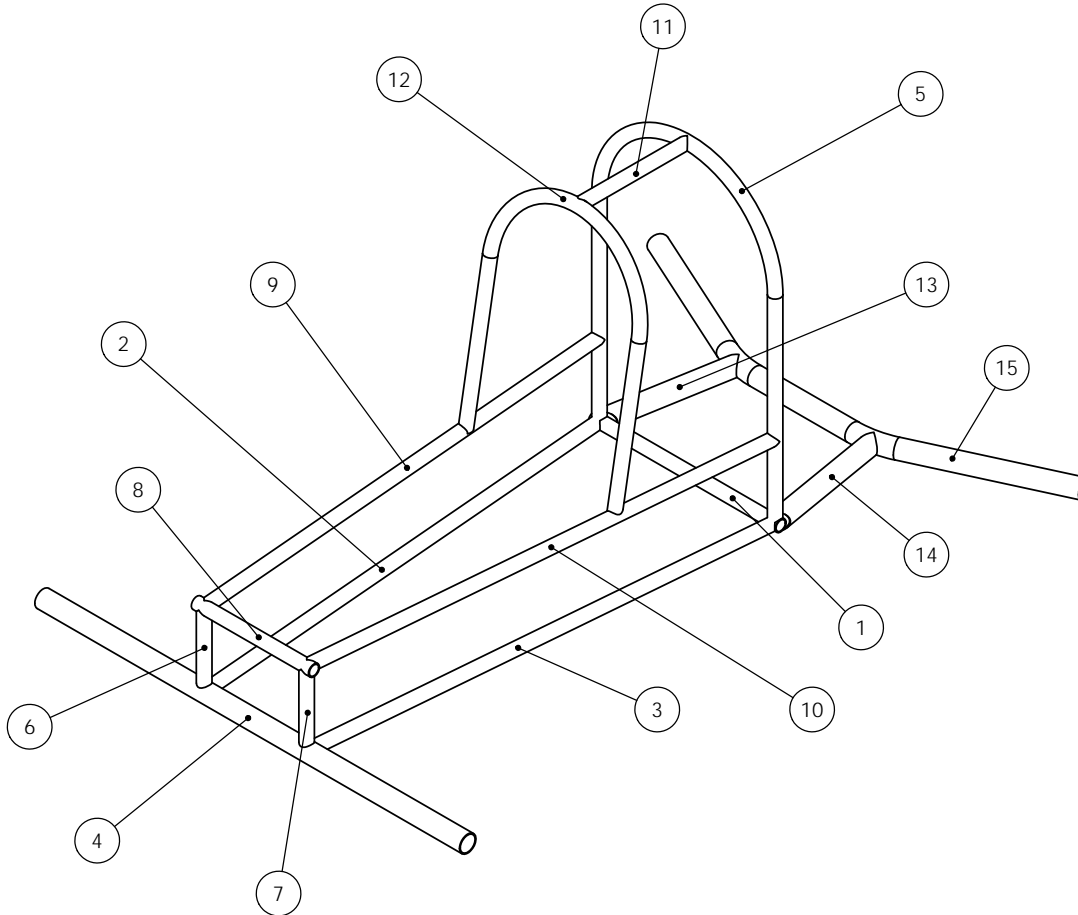
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B	SHEET 2 ADDED	2/16/2022	CTA	MJW

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05	BACK ARCH	CS-TUB-150-093-01
06	RIGHT FRONT VERTICAL	CS-TUB-150-011-01
07	LEFT FRONT VERTICAL	CS-TUB-150-011-02
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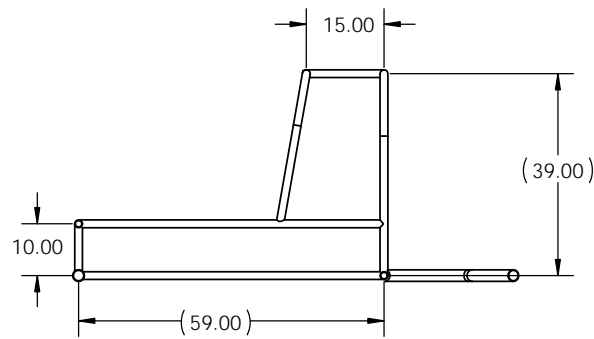
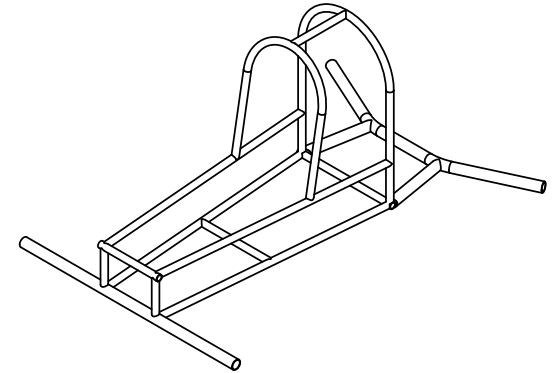
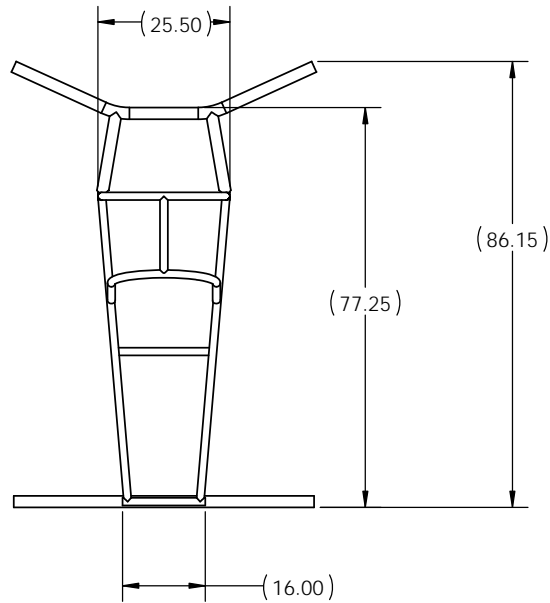
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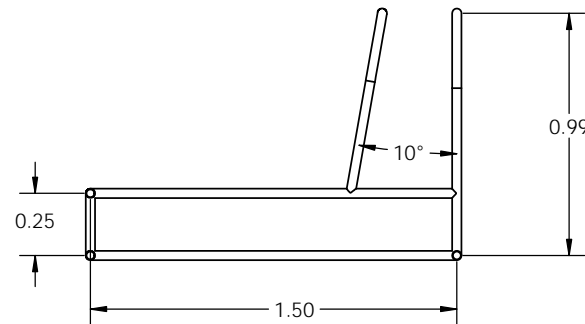
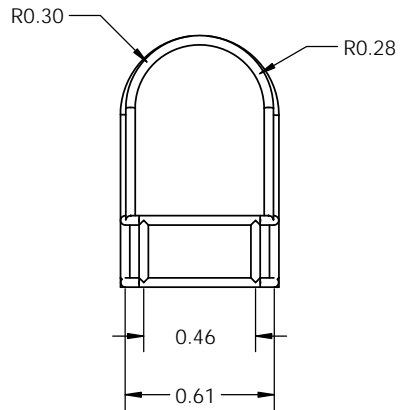
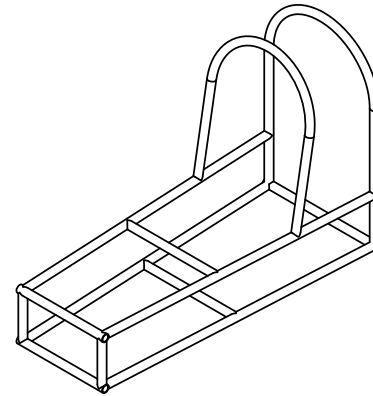
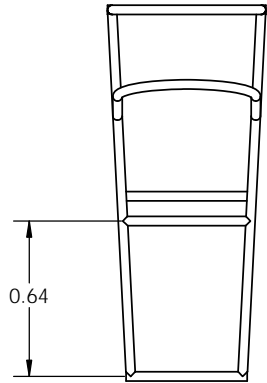
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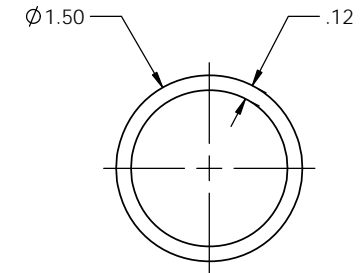
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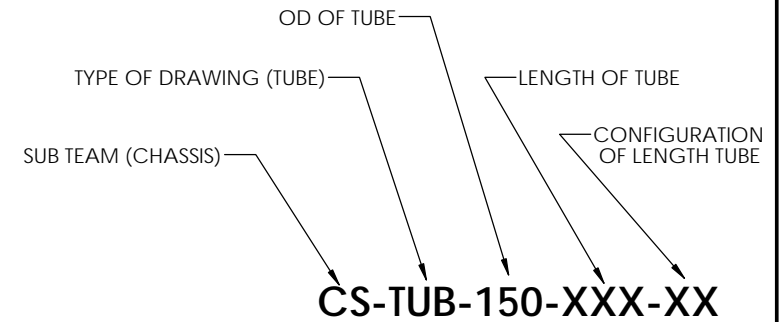
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SCALE 1:1

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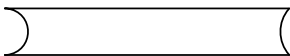
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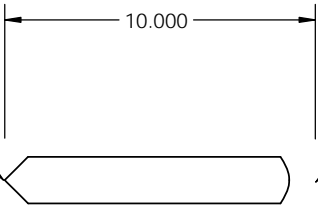
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2.250" OD COPE  
3 TUBE INTERSECTION

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**CS-TUB-150-011-02**

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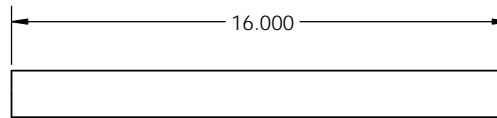
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15.000

### CS-TUB-150-016-02

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		N/A
TITLE:		CHASSIS TUBE 1.5" OD
DWG. NO.		CS-TUB-150
SCALE: 1:4		WEIGHT:
		SHEET 4 OF 15



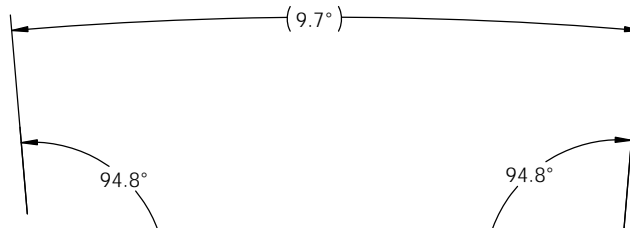
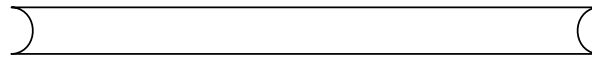
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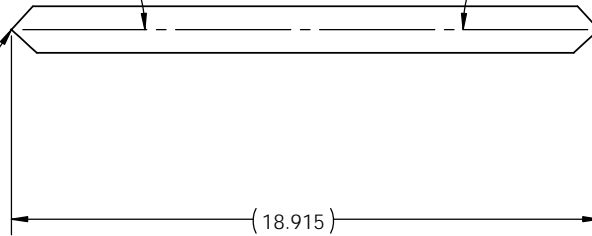
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1.500" OD COPE  
2 TUBE INTERSECTION



1.500" OD COPE  
2 TUBE INTERSECTION

### CS-TUB-150-020-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE 1.5" OD
<b>Bearcat Solar Car Team</b>	DWG. NO.	CS-TUB-150
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4

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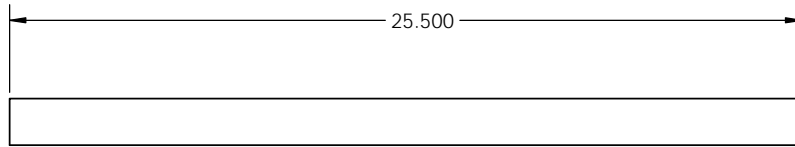
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### CS-TUB-150-027-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		N/A
		TITLE:
		CHASSIS TUBE 1.5" OD
DWG. NO.		CS-TUB-150
SCALE: 1:4	WEIGHT:	SHEET 6 OF 15

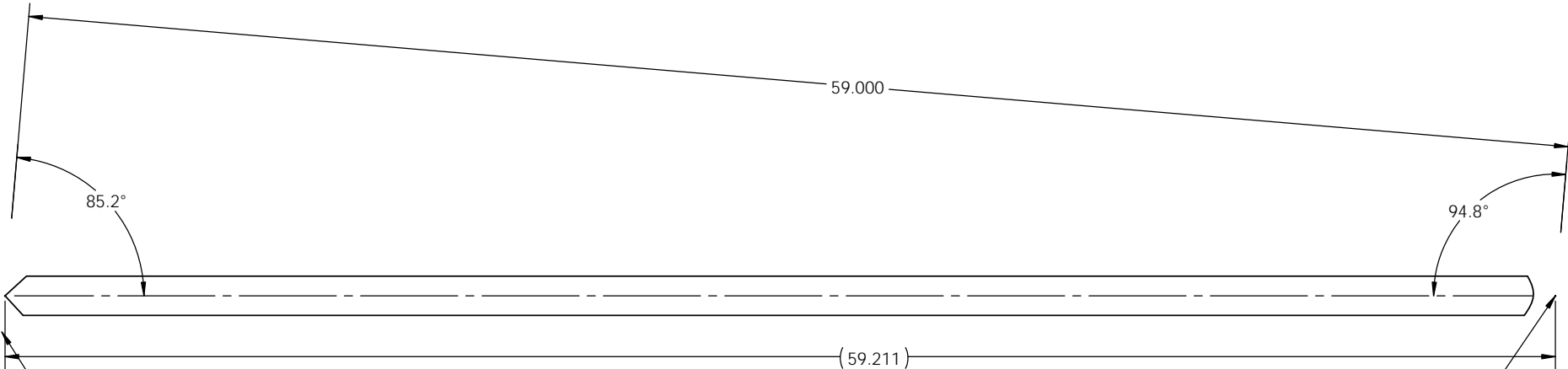
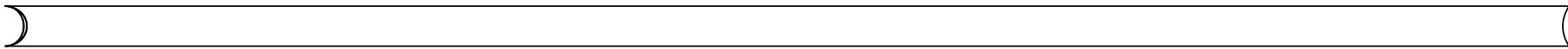
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DO NOT SCALE DRAWING



1.500" OD COPE  
4 TUBE INTERSECTION

2.250" OD COPE  
3 TUBE INTERSECTION

### CS-TUB-150-61-01 CS-TUB-150-61-02

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		N/A
TITLE:		CHASSIS TUBE 1.5" OD
DWG. NO.		CS-TUB-150
SCALE: 1:4		WEIGHT:
		SHEET 7 OF 15



4

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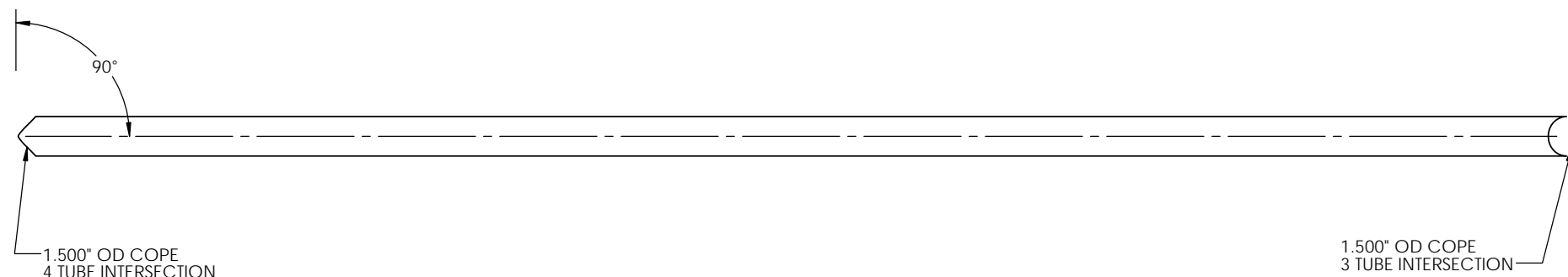
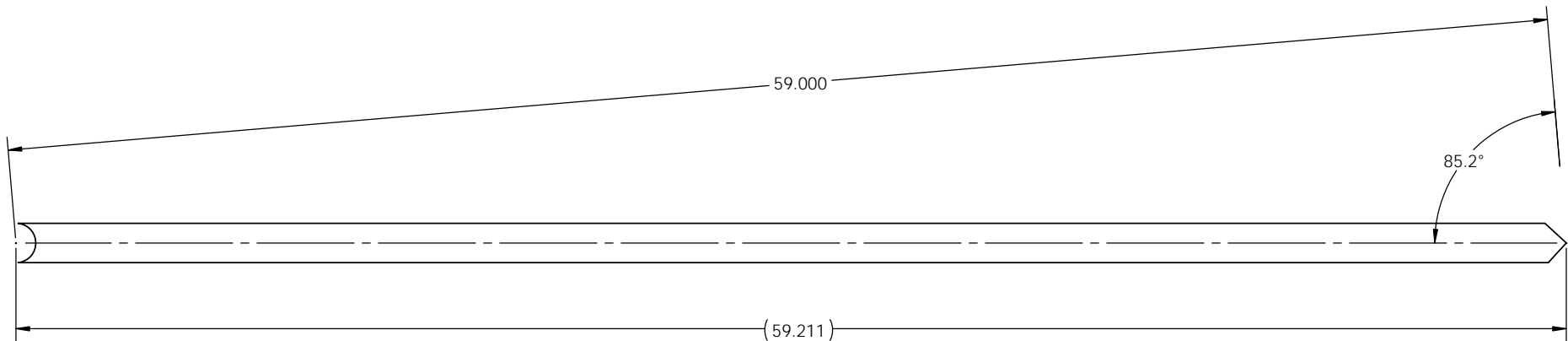
DO NOT SCALE DRAWING

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A

**CS-TUB-150-061-03**  
**CS-TUB-150-061-04**

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE 1.5" OD
		DWG. NO.
		CS-TUB-150
		SCALE: 1:4
		WEIGHT:
		SHEET 8 OF 15



4

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DO NOT SCALE DRAWING

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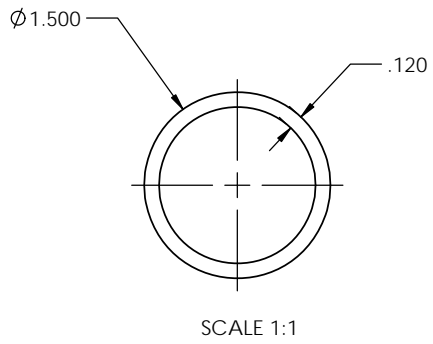
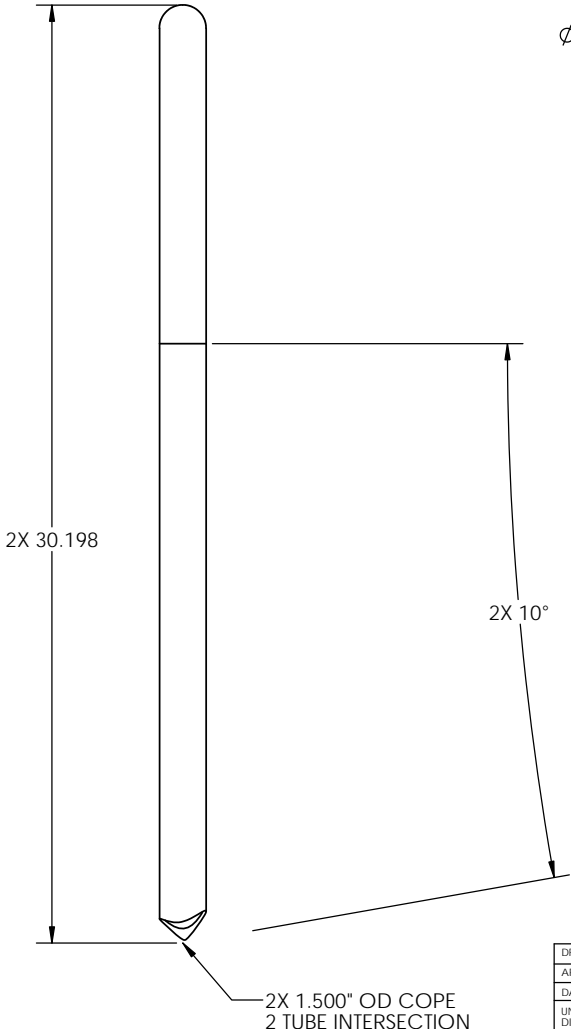
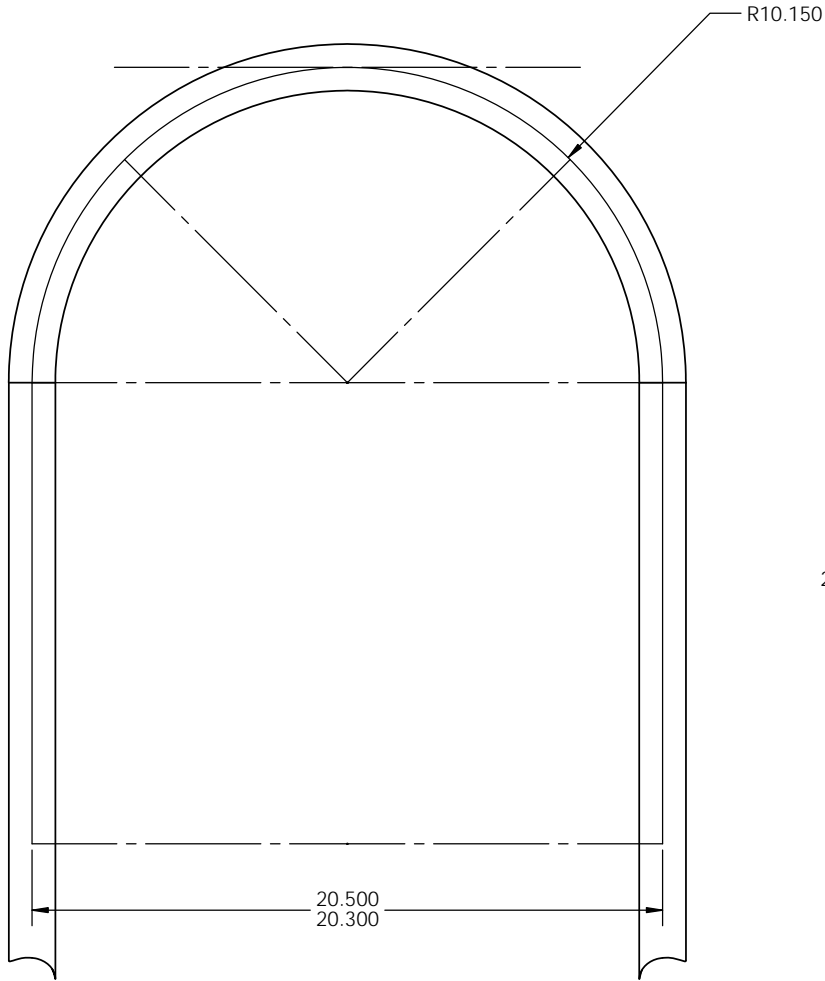
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### CS-TUB-150-072-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE 1.5" OD
<b>Bearcat Solar Car Team</b>	DWG. NO.	CS-TUB-150
	SCALE: 1:4	WEIGHT:
		SHEET 9 OF 15

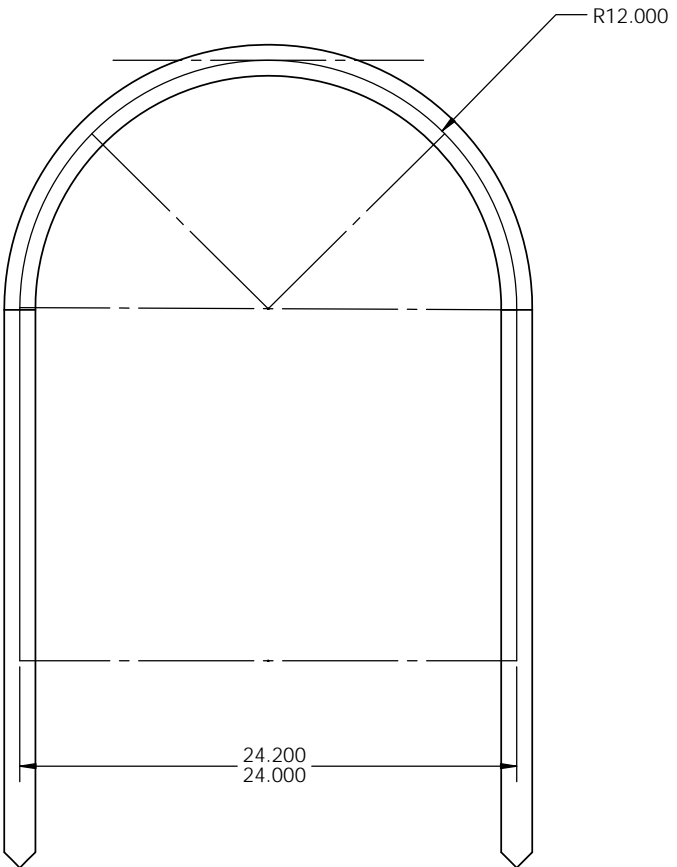
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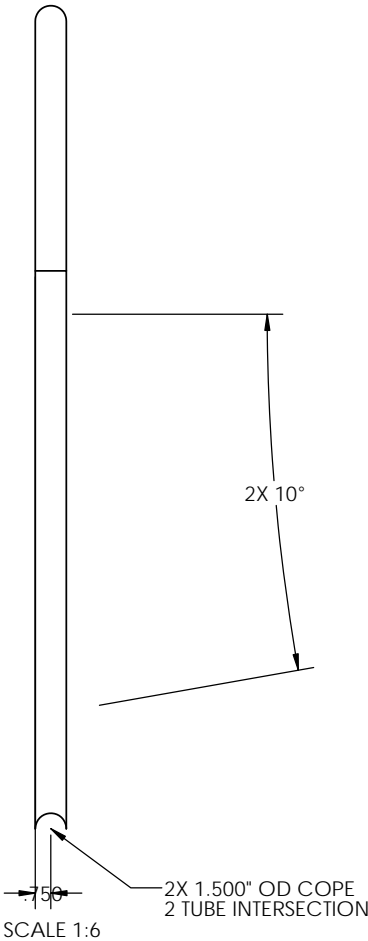
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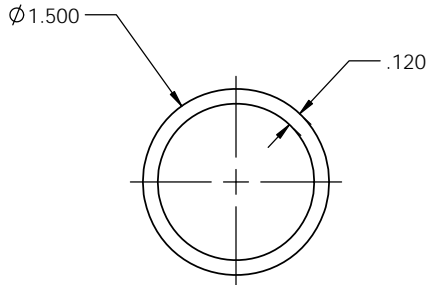
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SCALE 1:6



SCALE 1:6



SCALE 1:1

### CS-TUB-150-093-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES. LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE 1.5" OD
<b>Bearcat Solar Car Team</b>		DWG. NO.
		CS-TUB-150
SCALE: 1:4	WEIGHT:	SHEET 10 OF 15

4

3

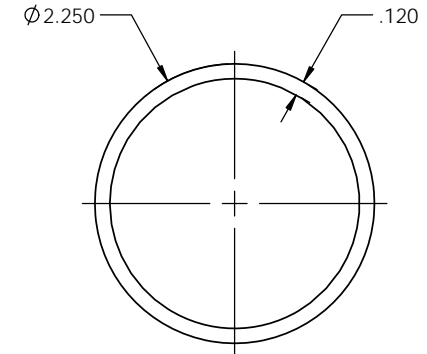
DO NOT SCALE DRAWING

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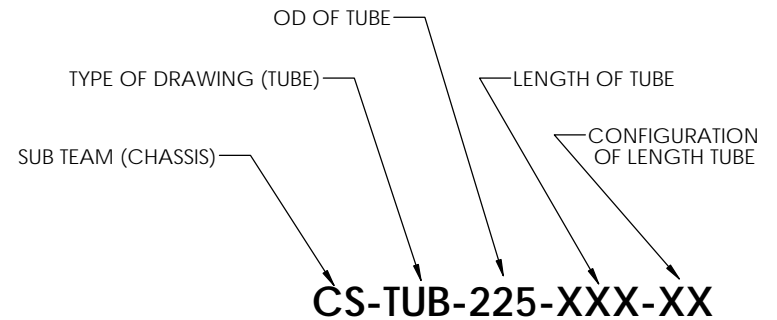
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REVISIONS				
REV.	DESCRIPTION	DATE	DRAWN	APPROVED
-	ISSUED	01/31/2022	CTA	MJW
A	ADDED CS-TUB-225-015	4/20/2022	MJW	CTA

PART NO.	WELD ORDER	DESCRIPTION	CUT TO LENGTH
CS-TUB-225-018-01	13	REAR AXLE SUPPORT RIGHT	18.000
CS-TUB-225-018-02	14	REAR AXLE SUPPORT LEFT	18.000
CS-TUB-225-058-01	04	FRONT AXLE	58.000
CS-TUB-225-062-01	15	REAR AXLE	62.000
CS-TUB-225-015-01	-	VERTICAL SUSPENSION FR	15.000
CS-TUB-225-015-02	-	VERTICAL SUSPENSION FL	15.000
CS-TUB-225-015-03	-	VERTICAL SUSPENSION RR	15.000
CS-TUB-225-015-04	-	VERTICAL SUSPENSION RL	15.000



SCALE 1:1



DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES. LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE
<b>Bearcat Solar Car Team</b>		DWG. NO.
		CS-TUB-225-XXX-XX
SCALE: 1:4	WEIGHT:	SHEET 11 OF 15

4

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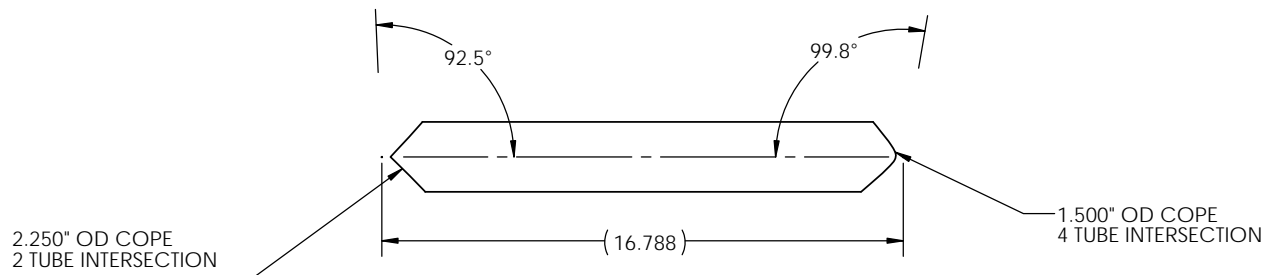
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3

DO NOT SCALE DRAWING

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**CS-TUB-225-018-01**  
**CS-TUB-225-018-02**

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		N/A
TITLE:		CHASSIS TUBE 2.25" OD
DWG. NO.		CS-TUB-225
SCALE: 1:4		WEIGHT:
		SHEET 12 OF 15



4

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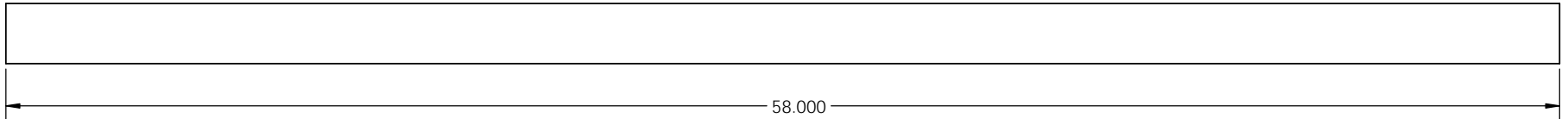
DO NOT SCALE DRAWING

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### CS-TUB-225-058-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		N/A
		TITLE:
		CHASSIS TUBE 2.25" OD
DWG. NO.		CS-TUB-225
SCALE: 1:4	WEIGHT:	SHEET 13 OF 15

4

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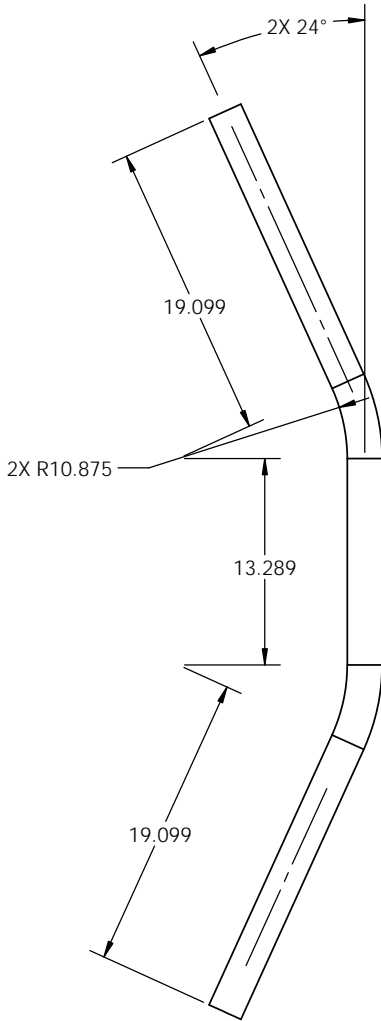
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DO NOT SCALE DRAWING



1:8 SCALE

# CS-TUB-225-062-01

DRAWN BY: C. ALDRIDGE	SIZE	MATERIAL
APPROVED BY: MJW	<b>B</b>	ASTM 4130 STEEL
DATE: 1/24/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± 0.125 ANGULAR: ± 2°		TITLE:
		CHASSIS TUBE 2.25" OD
		DWG. NO. CS-TUB-225
SCALE: 1:4	WEIGHT:	SHEET 14 OF 15

4

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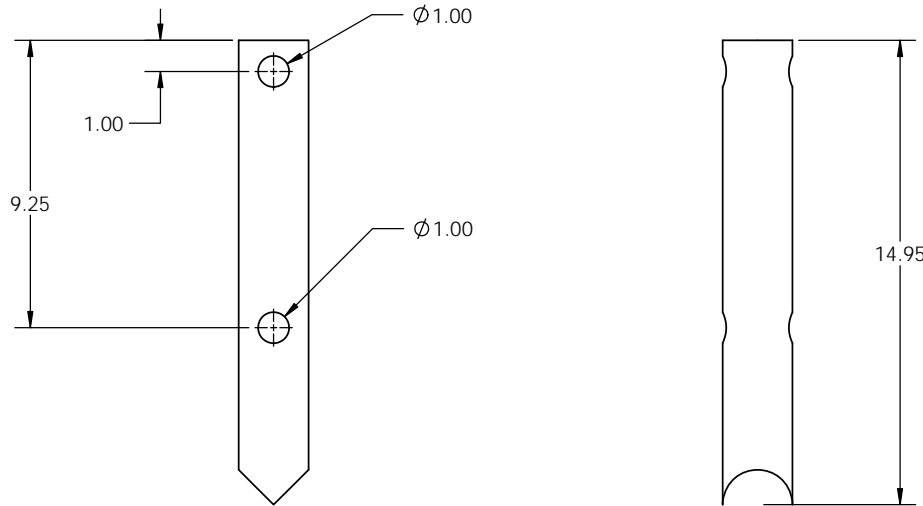
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3

DO NOT SCALE DRAWING

2

1



2.250" OD COPE  
2 TUBE INTERSECTION

**CS-TUB-225-015-01**  
**CS-TUB-225-015-02**  
**CS-TUB-225-015-03**  
**CS-TUB-225-015-04**

DRAWN BY: MJW	SIZE	MATERIAL
APPROVED BY: CTA	<b>B</b>	ATSM 4130
DATE: 4/20/2022		FINISH
		N/A
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES. LINEAR: ± .XXX ANGULAR: ± 2°		TITLE:
		CS TO SUS UPRIGHTS
<b>Bearcat</b> <b>Solar Car Team</b>	DWG. NO.	CS-TUB-XXX-XXX-XX
	SCALE: 1:4	WEIGHT:
		SHEET 15 OF 15

4

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# Chassis Simulation Result Summary

## 1. Roll Cage

Table 1. Summary of all Roll Cage Loading Cases Tested

Force Location	Front Arch (MPa)	Rear Arch (MPa)	Front Arch (mm)	Rear Arch (mm)
5g Down	750	531	2.7	3.2
5g 45	782	~2481	11.2	18.4
5g 90	~1430	~1344	11.4	20.8
Combined Loading	860		15.2	

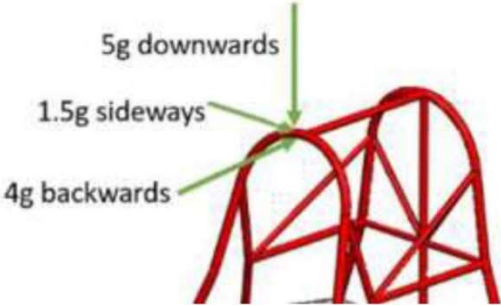


Figure 1. Combined Loading Representation

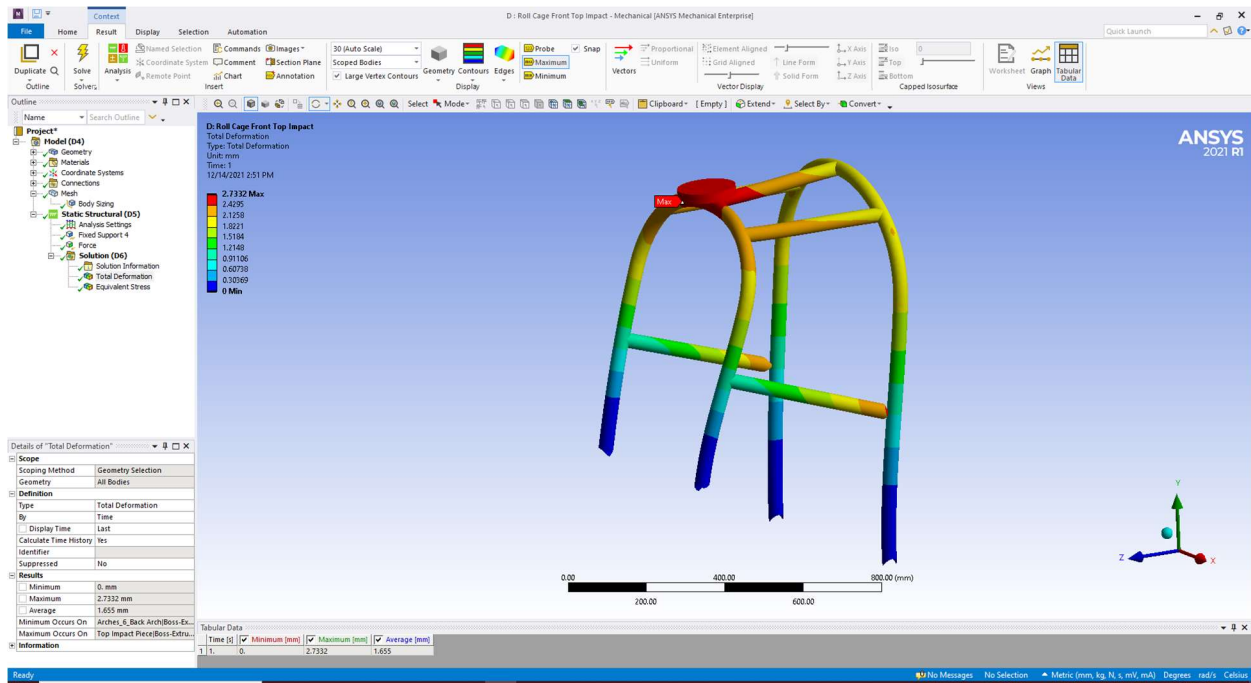


Figure 2. Front 5g Down Displacement

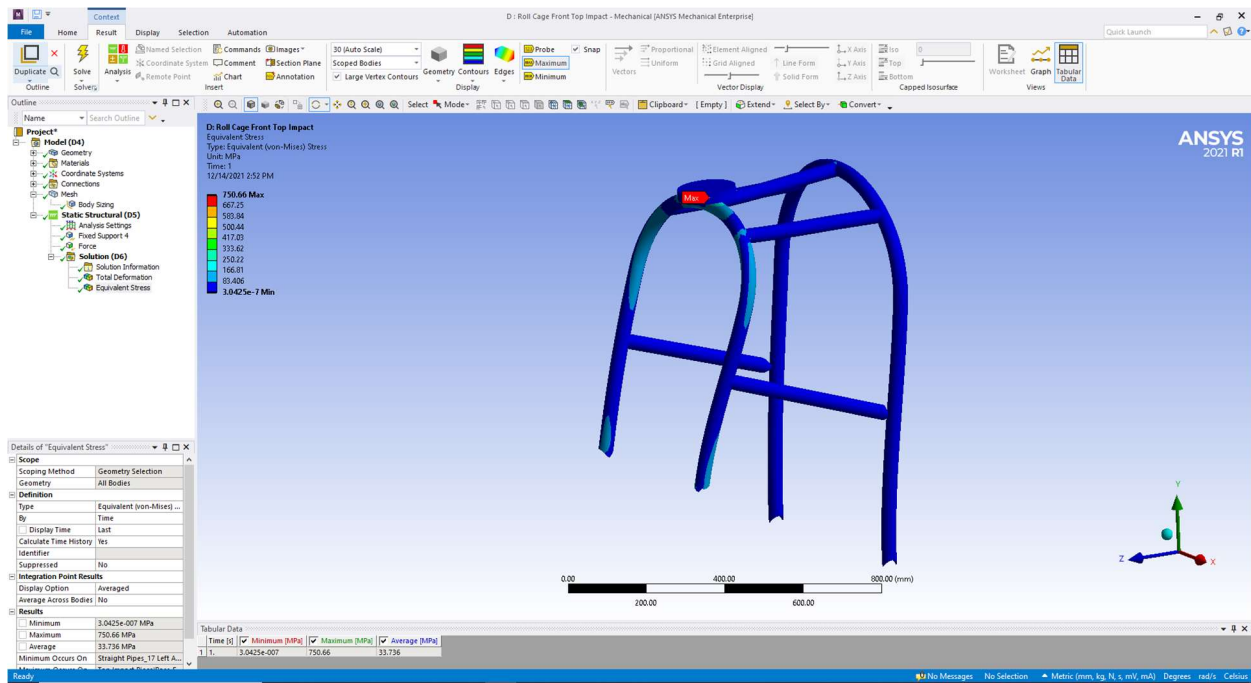


Figure 3. Front 5g Down Stress

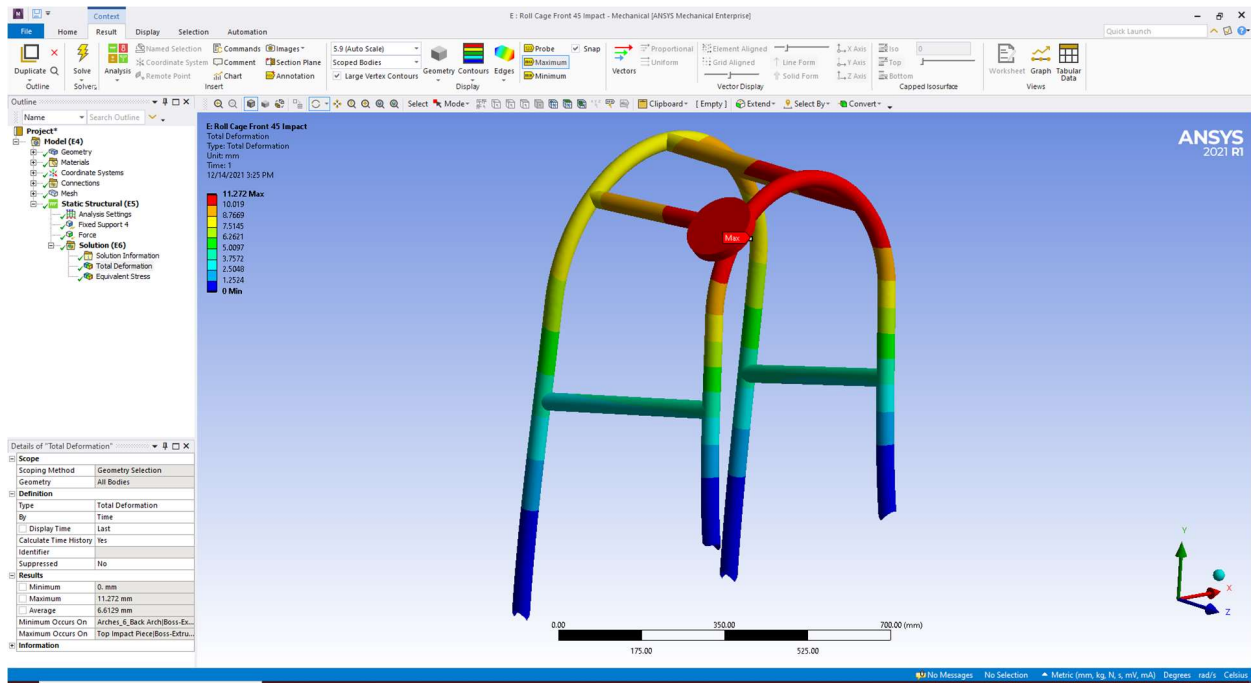


Figure 4. Front 5g 45 Displacement

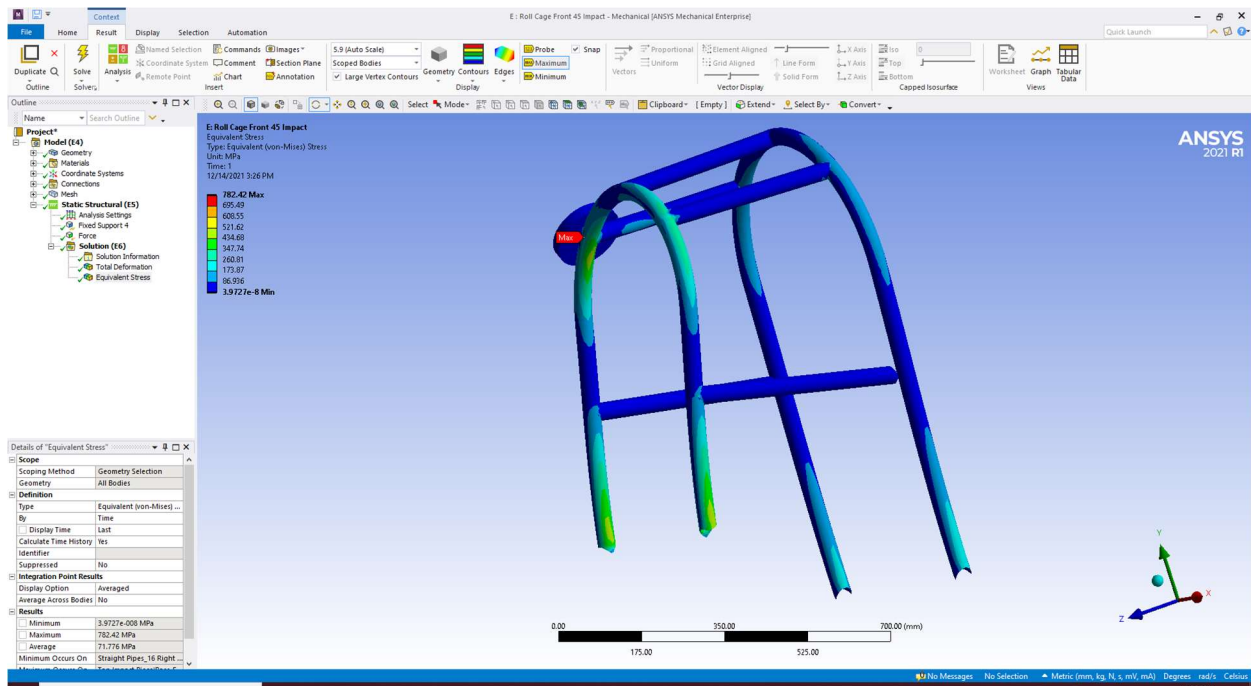


Figure 5. Front 5g 45 Stress

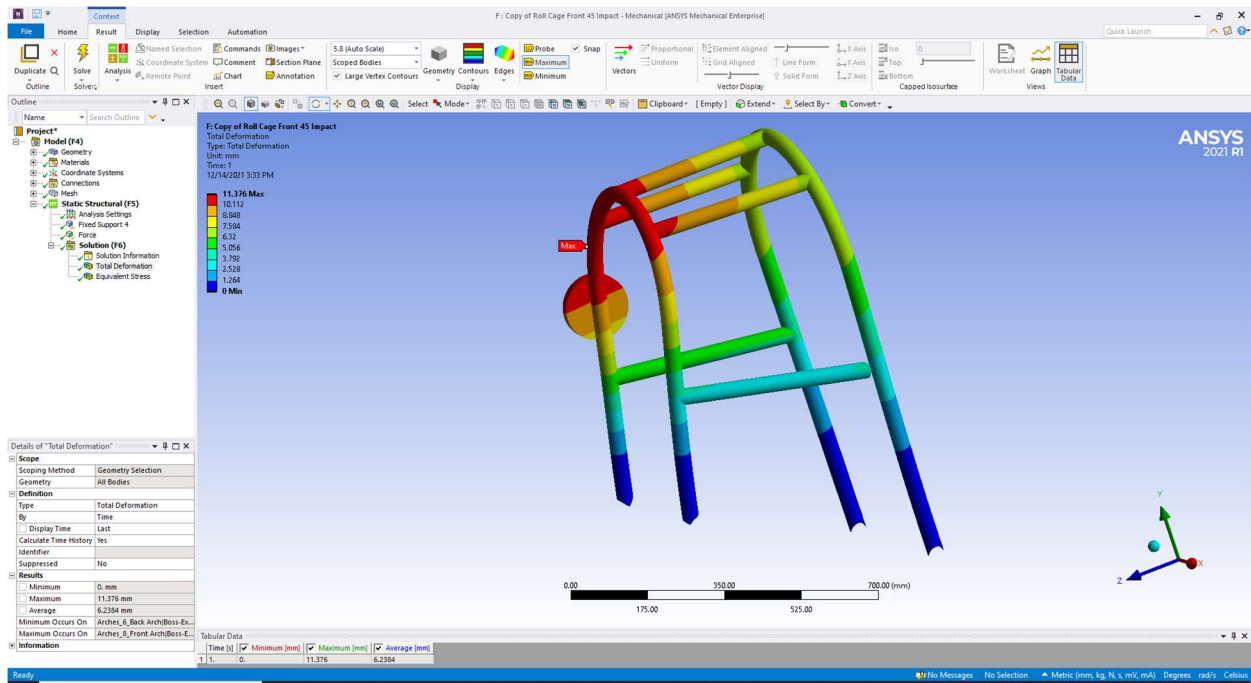


Figure 6. Front 5g 90 Displacement

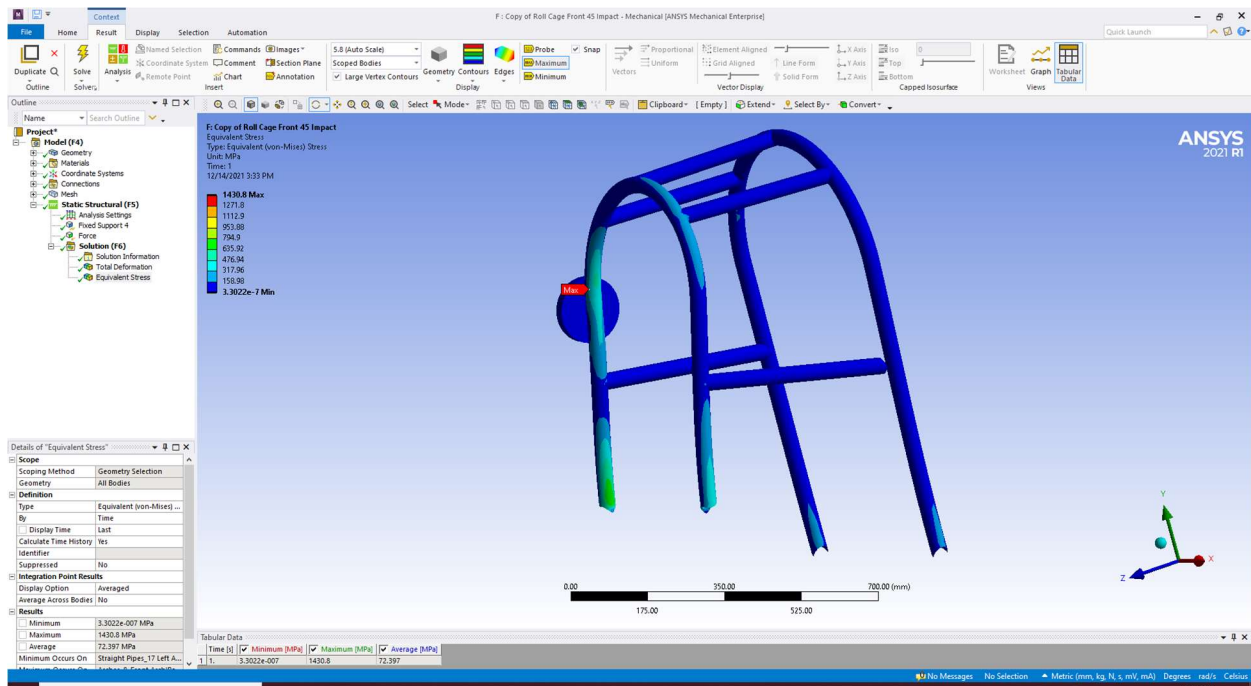


Figure 7. Front 5g 90 Stress

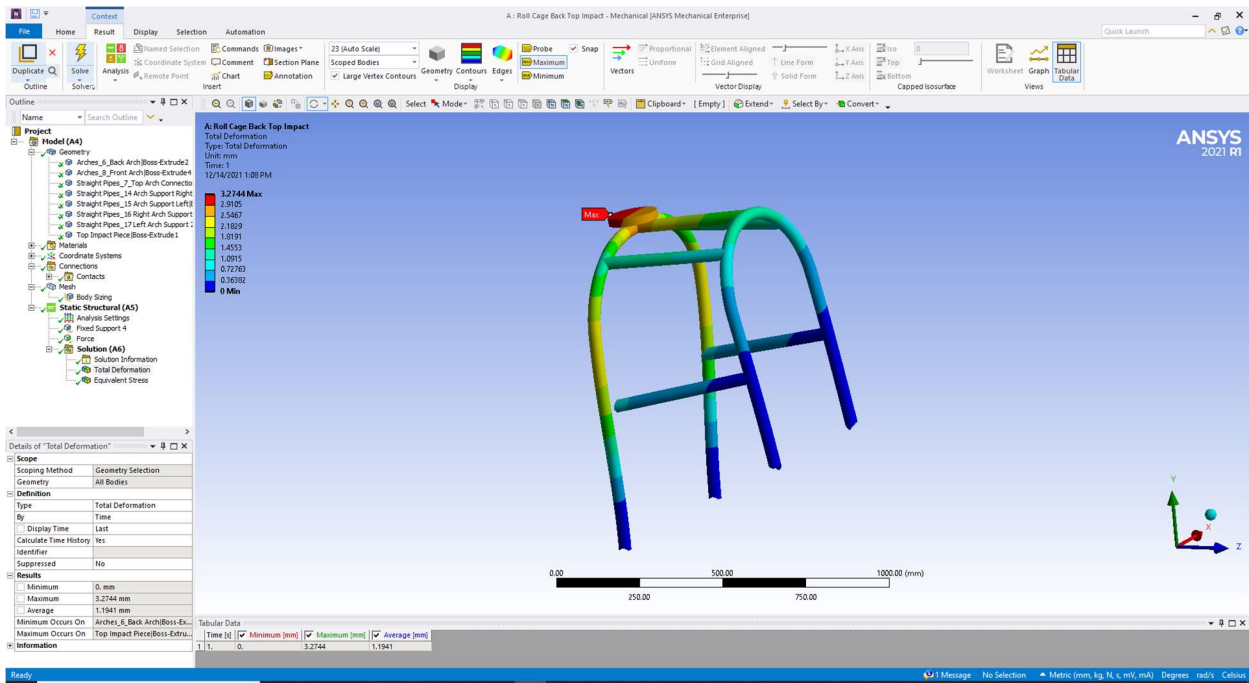


Figure 8. Rear 5g Down Displacement

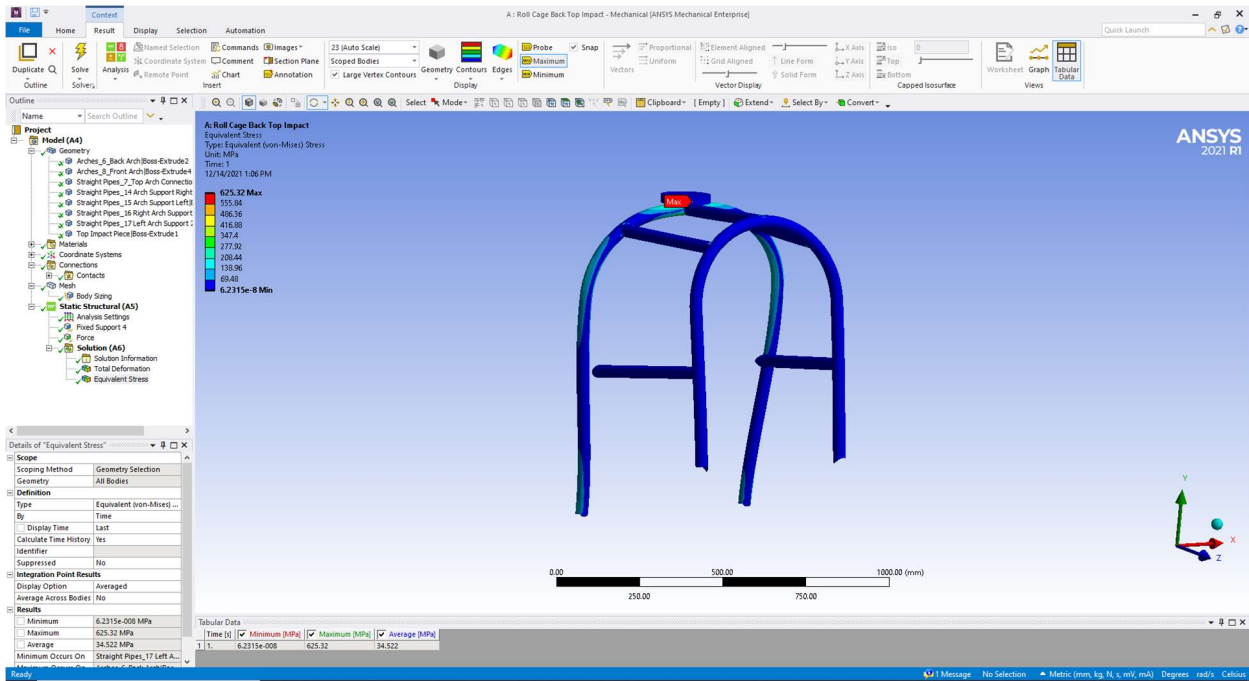


Figure 9. Rear 5g Down Stress

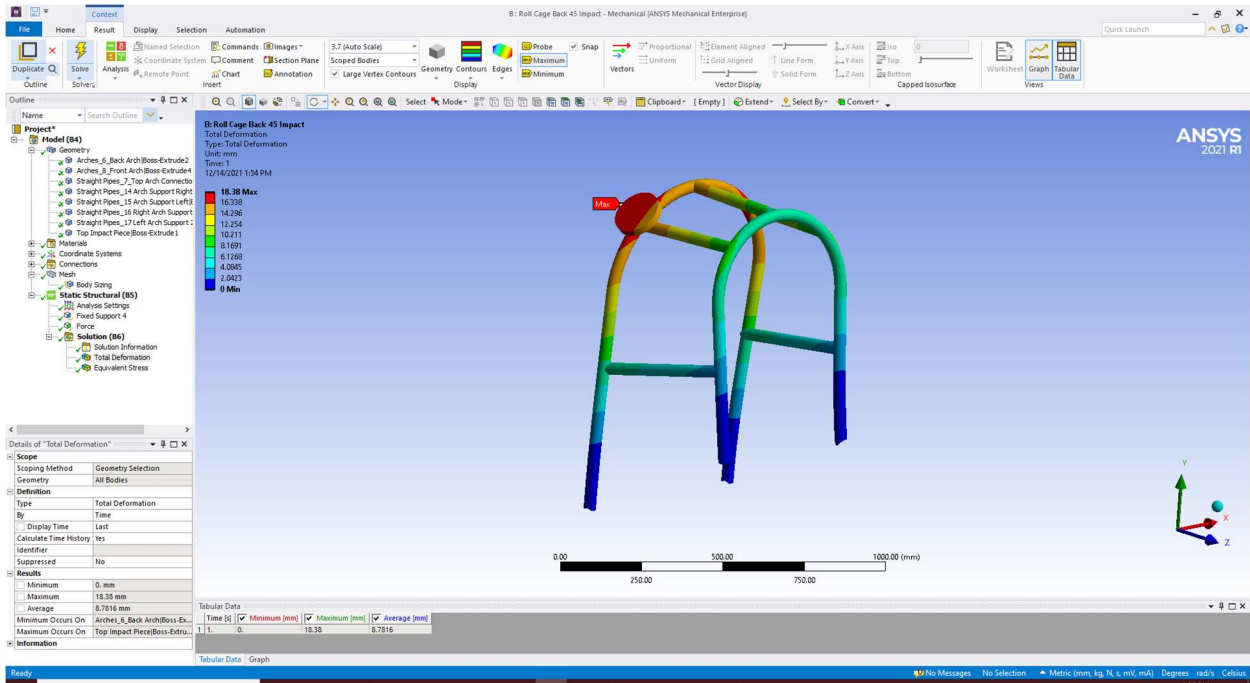


Figure 10. Rear 5g 45 Displacement

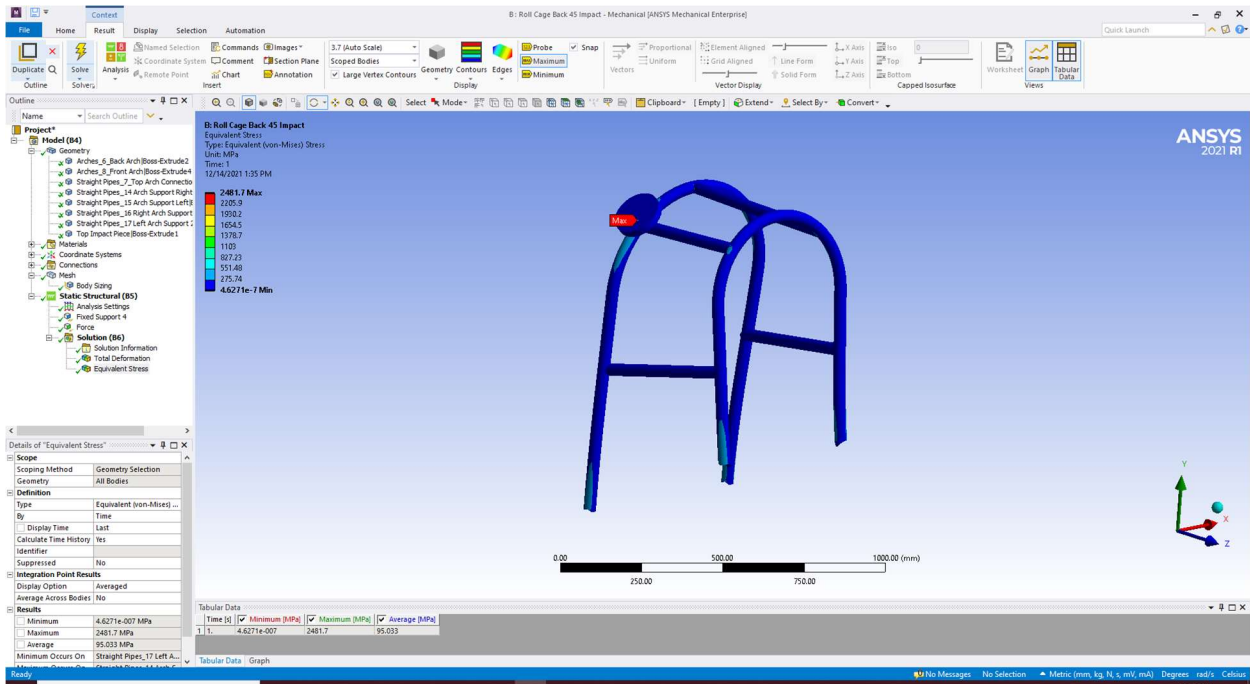


Figure 11. Rear 5g 45 Stress

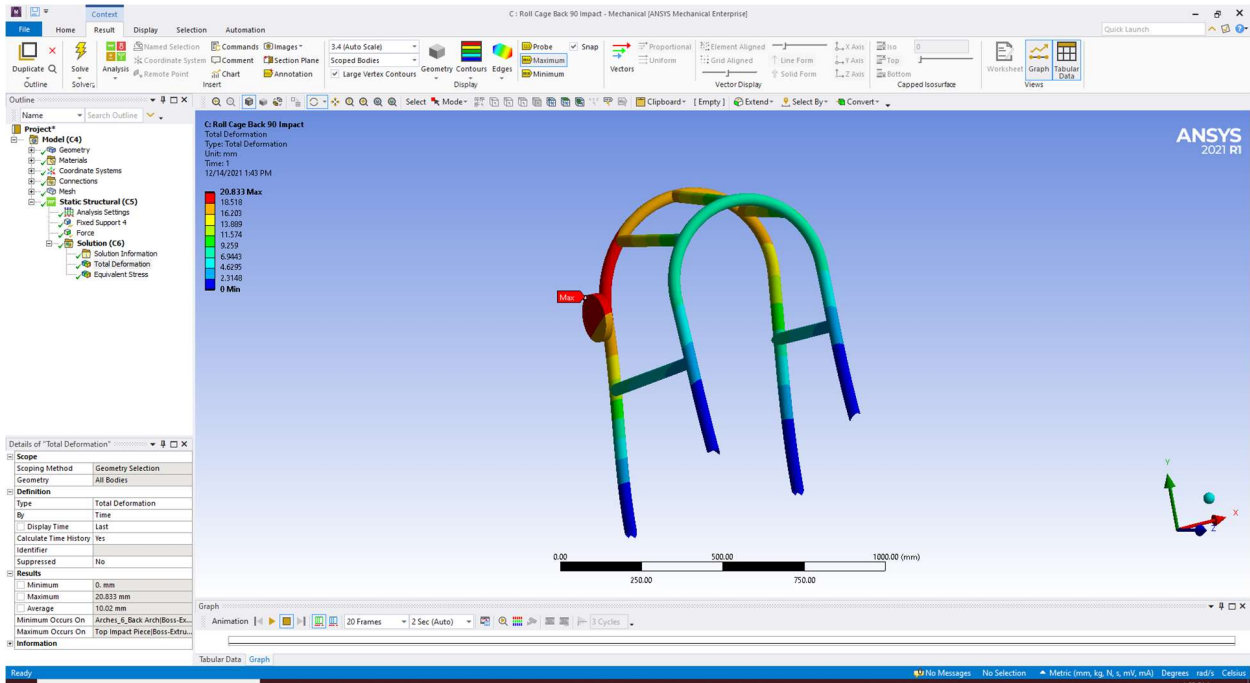


Figure 12. Rear 5g 90 Displacement

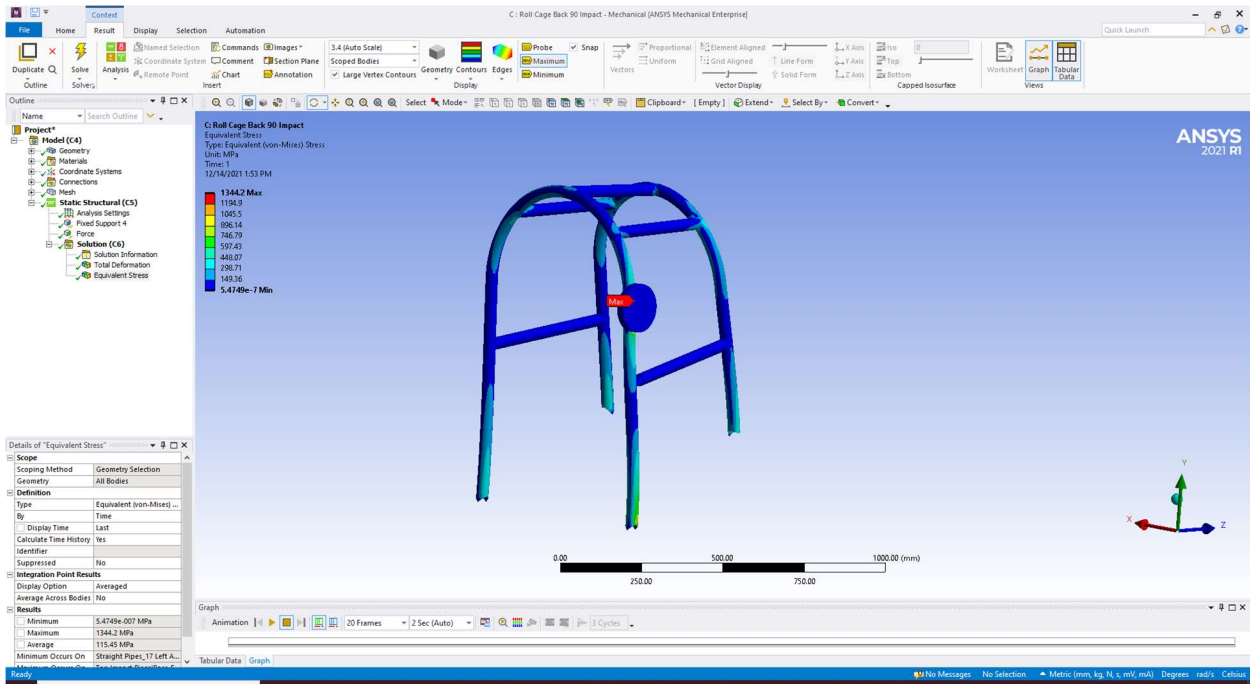


Figure 13. Rear 5g 90 Stress

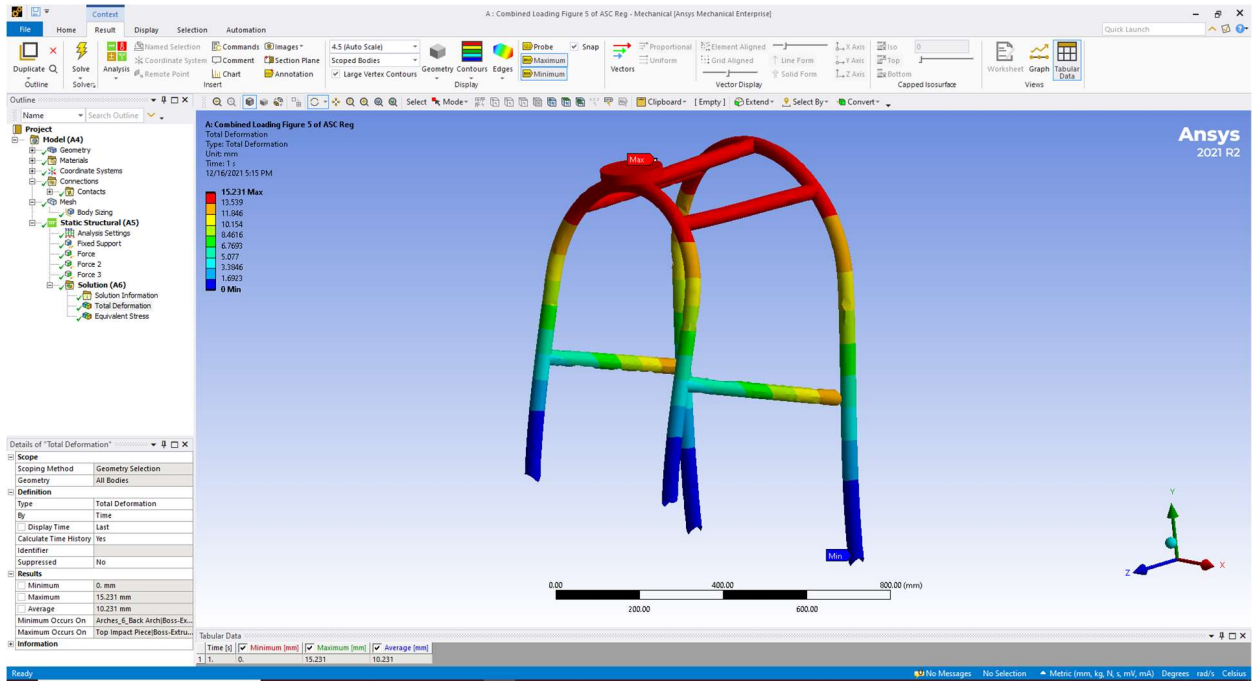


Figure 14. Combined Loading Displacement

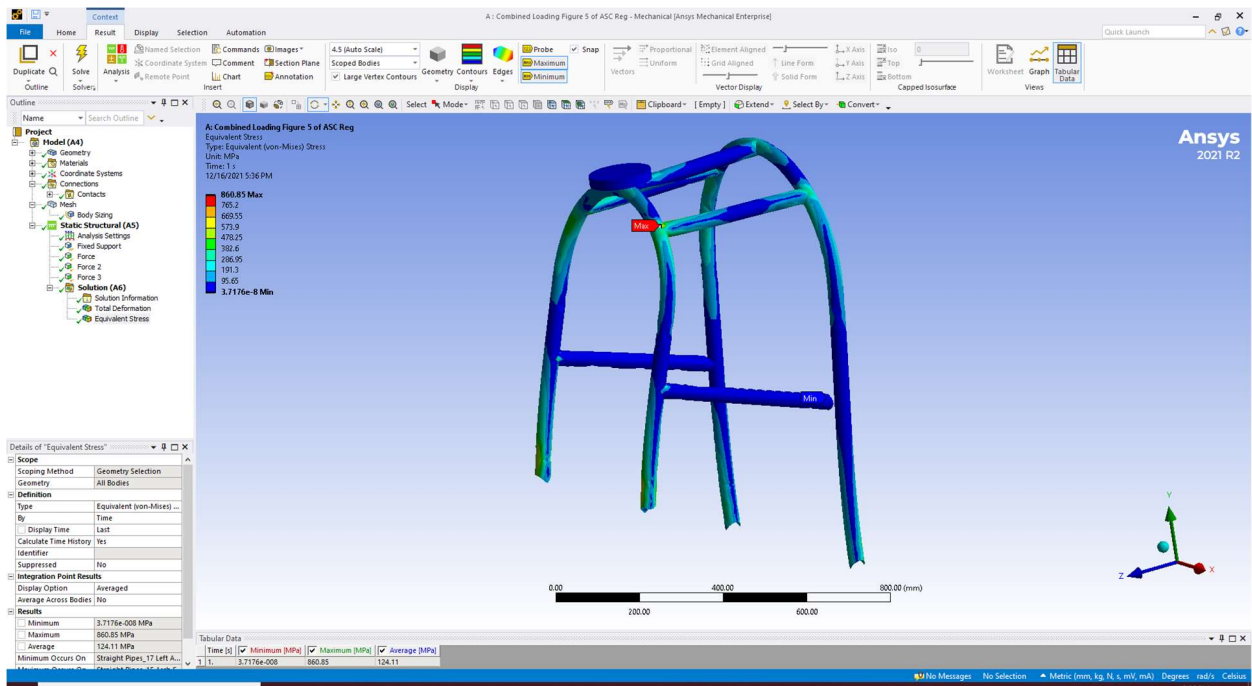


Figure 15. Combined Loading Stress

## 2. Chassis Uprights

Table 2. Simulation results for Chassis Uprights

Axle Simulations:	Stress (Pa)
1G +X	2.996E+08
1G -X	2.995E+08
1G +Z	6.309E+06
1G -Z	6.309E+06
2G +Y	5.683E+08
2G -Y	5.732E+08
Vertical Suspension Arm:	
Stress (MPa)	3.350E+02
Displacement (mm)	0.184

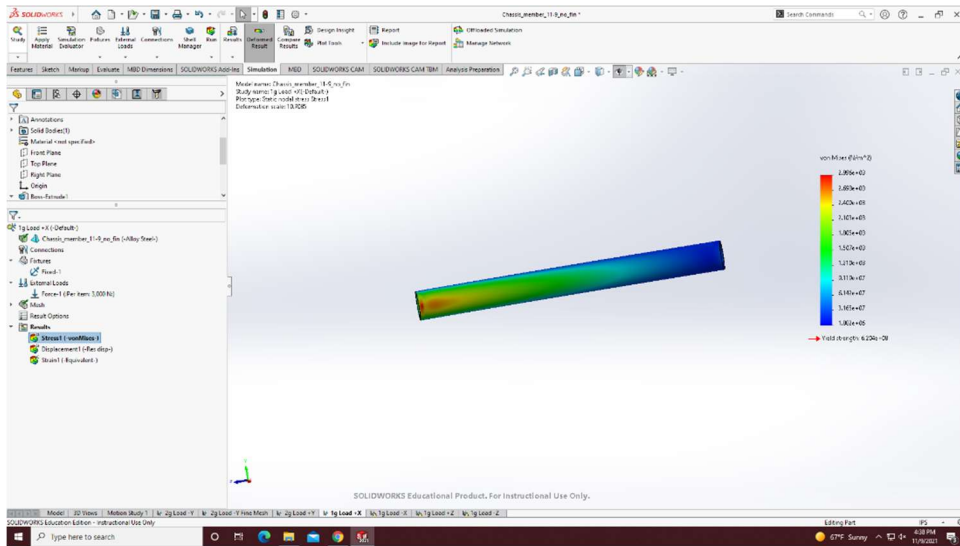


Figure 16. 1g Positive X

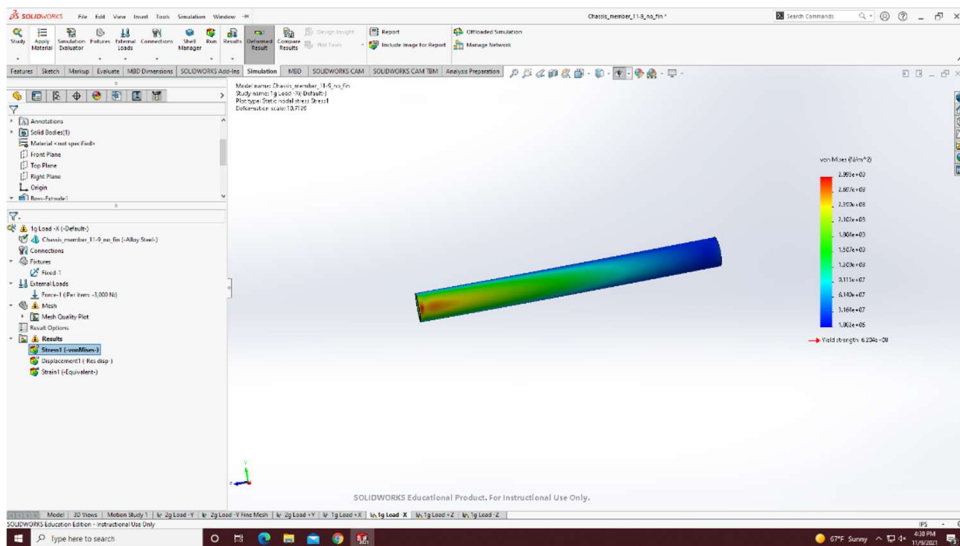


Figure 17. 1g Negative X

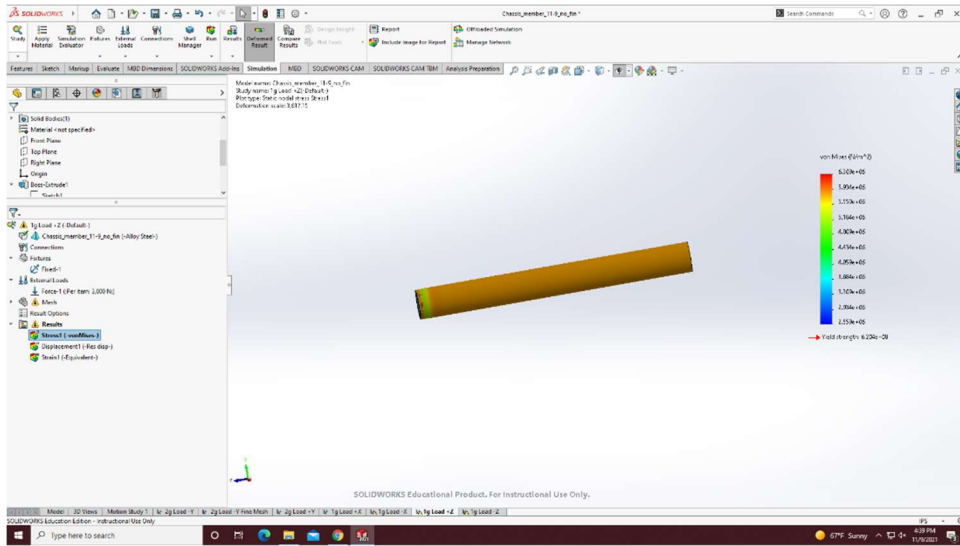


Figure 18. 1G Positive Z

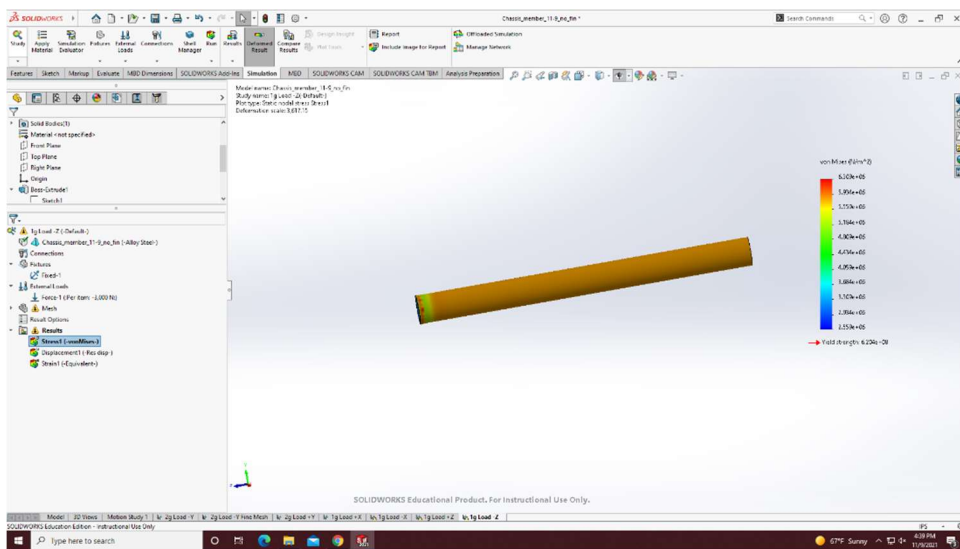


Figure 19. 1G Negative Z

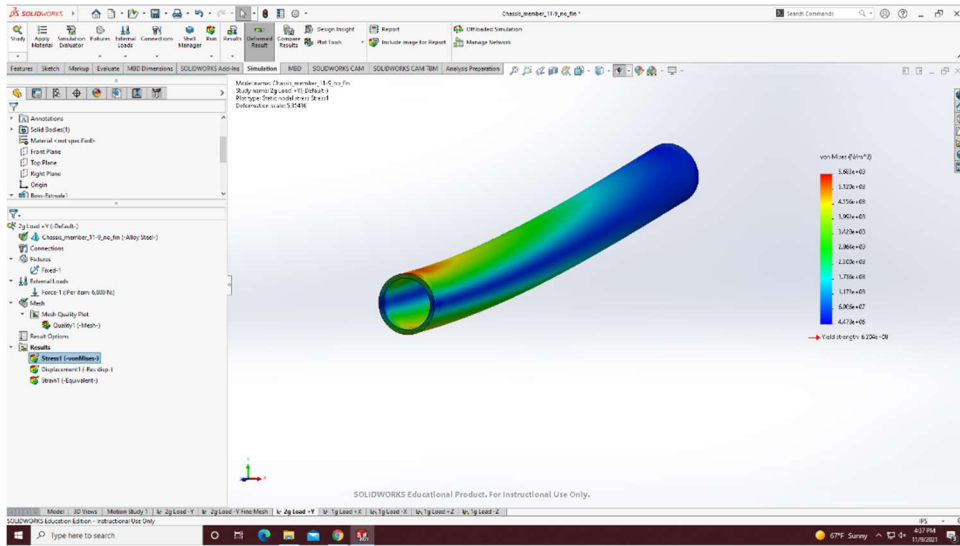


Figure 20. 2G Positive Y

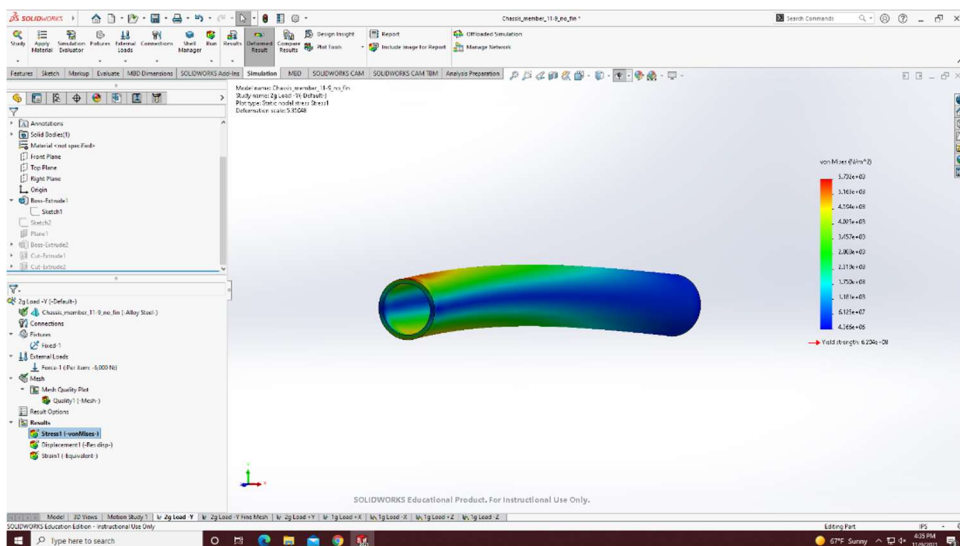


Figure 21. 2G Negative Y

Chassis Pole\_sim1 : Solution 1 Result  
Subcase - Static Loads 1, Static Step 1  
Stress - Elemental, Von-Mises  
Min : 0.27, Max : 334.98, Units = MPa

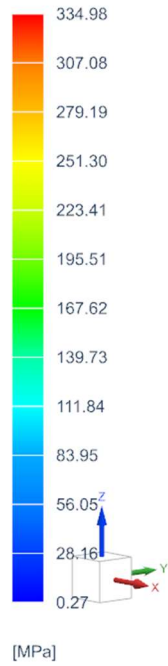


Figure 22. Vertical Arm Stress

Chassis Pole\_sim1 : Solution 1 Result  
Subcase - Static Loads 1, Static Step 1  
Displacement - Nodal, Magnitude  
Min : 0.000E+00, Max : 7.240E-03, Units = in

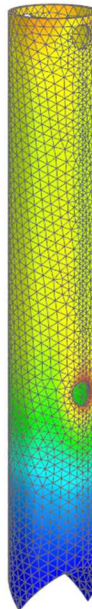


Figure 23. Vertical Arm Displacement

# Chassis Component List

PART NUMBER	DESCRIPTION 1	DESCRIPTION 2	TOP-LEVEL ASSEMBLY	UNIT COST	QTY USED	INVENTORY	SOURCE LINK	Drawing
CS-TUB-150-027-01	Rear Base	Rear base tube	CS		1	0	TW Metals	
CS-TUB-150-061-01	Right Side Base	Right of driver base tube rail	CS		1	0	TW Metals	
CS-TUB-150-061-02	Left Side Base	Left of driver base tube rail	CS		1	0	TW Metals	
CS-TUB-150-020-01	Mid Base	Mid base tube that sits below driver's legs	CS		1	0	TW Metals	
CS-TUB-150-016-01	Top Arch Connection	tube connecting the arches together above drivers head	CS		1	0	TW Metals	
CS-TUB-150-011-01	Right Front Vertical	Right of driver vertical toe box tube	CS		1	0	TW Metals	
CS-TUB-150-011-02	Left Front Vertical	Left of driver vertical toe box tube	CS		1	0	TW Metals	
CS-TUB-150-016-01	Top Front Base	Top of front toe box	CS		1	0	TW Metals	
CS-TUB-150-061-03	Right Side Top	Right of driver top tube rail	CS		1	0	TW Metals	
CS-TUB-150-061-04	Left Side Top	Left of driver top tube rail	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	Arch Support Right	Support between front arch and rear arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	Arch Support Left	Support between front arch and rear arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	Arch Support Right 2	Support between front arch and rear arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	Arch Support Left 2	Support between front arch and rear arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	Main SA Support	Straight tube backwards from Rear arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	SA Support 1	Support between Main SA Support and back arch	CS		1	0	TW Metals	
CS-TUB-150-0XX-XX	SA Support 2	Support between Main SA Support and back arch	CS		1	0	TW Metals	
CS-TUB-SQU-2-1	Dash Bar	Connection between two top rails	CS		1	0	Iron Belle	
CS-TUB-225-XXX-01	Front Axle	Front axle of the Solar Tank	CS		1	0	TW Metals	
CS-TUB-225-XXX-01	Rear Axle	Rear axle of the Solar Tank	CS		1	0	TW Metals	
CS-TUB-225-XXX-01	Vertical Suspension Tube FR	Interfacing between front axle and front right suspension	CS		1	0	TW Metals	
CS-TUB-225-XXX-02	Vertical Suspension Tube FL	Interfacing between front axle and front left suspension	CS		1	0	TW Metals	
CS-TUB-225-XXX-03	Vertical Suspension Tube RR	Interfacing between front axle and rear right suspension	CS		1	0	TW Metals	
CS-TUB-225-XXX-04	Vertical Suspension Tube RL	Interfacing between front axle and rear left suspension	CS		1	0	TW Metals	
CS-TUB-225-XXX-01	Rear Axle Support Right	support between arches and rear axle	CS		1	0	TW Metals	
CS-TUB-225-XXX-02	Rear Axle Support Left	support between arches and rear axle	CS		1	0	TW Metals	
CS-TUB-150-093-01	Back Arch	Rear arch of the roll cage	CS		1	0	TW Metals	
CS-TUB-150-072-01	Front Arch	Front arch of the Roll Cgae	CS		1	0	TW Metals	
CS-SHT-016-BP	Belly Pan	16ga Sheet metal cut to fit undercarage of driver	CS		1	0	VPC	
CS-SHT-016-FW	Fire Wall	16ga Sheet metal that seperates the driver and the batteries	CS		1	0	VPC	
CS-TUB-SCP-RM1	Part of Right M shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-RM2	Part of Right M shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-RM3	Part of Right M shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-RM4	Part of Right M shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-LM1	Part of Left M Shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-LM2	Part of Left M Shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-LM3	Part of Left M Shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-TUB-SCP-LM4	Part of Left M Shape	scrap 1.0" OD steel chassis rail from UTV	CS		1	0	VPC	
CS-SEAT	Seat	Kirkey Racing Aluminium Seat #36500	CS		1	0	Facebook Marketplace	
CS-SEAT-BELT	Seat Belt	Race Quip Seat Belt 711001	CS		1	0	Amazon	
CS-SEAT-BOLT-0.5	Seat Belt Mounting Bolts	1/2" steel bolts to anchoring seat belt	CS		5	0	Becks	
CS-SEAT-NUT-0.5	Seat belt Mounting Nuts	1/2" steel nuts for anchoring seat belt	CS		5	0	Becks	
CS-SEAT-SQU-1-1	Seat Mount	1" x 1" steel square tubing to mount seat to chassis	CS		2	0	Iron Belle	
CS-SEAT-BOLT-0.3125	Seat Mounting Bolts	5/16" x 16 -2" bolts to mount seat to chassis	CS		4	0	Becks	
CS-SEAT-NUT-0.3126	Seat Mounting Nuts	5/16"-16 locking nuts to mount seat to chassis	CS		4	0	Becks	
CS-WELDWIRE	Chromoly weld wire	ER80S-D2 0.035" 11 lb Welding Wire			1		<a href="https://www.mcmaster.com/7678A14/">https://www.mcmaster.com/7678A14/</a>	
CS-SAS-CC-1.5	Cross Connector, 1-1/2 Pipe Socket-Connect Female	SAS cross connector	CS		1	0	<a href="https://www.mcmaster.com/4880K245/">https://www.mcmaster.com/4880K245/</a>	
CS-SAS-LOCKNUT-1.75	Locknut 1.75"	SAS locknut	CS		1	0	<a href="https://www.mcmaster.com/95030A390/">https://www.mcmaster.com/95030A390/</a>	
CS-SAS-RC	Routing Clamp	SAS Clamps	CS		2	0	<a href="https://www.mcmaster.com/3039T18/">https://www.mcmaster.com/3039T18/</a>	
CS-SAS-PVC	1.5" SCH 40 PVC	Pipe sleeve for SAS strcuture	CS		10	0	Becks	
CS-SAS-WOOD	2"x6" x 8'	wood for SAS mounting structure	CS		1	0	Home Depot	





## Supply Chain Log

<u>No</u>	<u>Date</u>	<u>Event</u>	<u>Notes</u>
1	1/13/2022	PO 3007 Moved to UFB Approval	Order placed with UFB office. Out of Hands of student. reliant on UC to purchase the material
2	1/27/2022	Patty Speed Approves PO3007	Patty Speed places order RX15313514 with UC Purchasing
3	2/1/2022	Order Acknoldegment	
4	2/9/2022	Phone Call With Norma	States that tubing will be in by end of week and willship out to cincy "early next week"
5	2/11/2022	Phone Call With Norma	Says tubing is not arriving and doesn't know arrival date
6	2/16/2022	Phone Call With Norma	Acknowledges change of shipping address and still doesn't know delivery date
7	2/23/2022	Phone Call With Norma	Says she has received tubing and it will take 2 weeks to cutt tubes and ship
8	3/2/2022	Phone Call With Norma	Beginning of phone call says she doesn't have tubes then we state yes you do you said last week you had them. She then recalls and says they are in productions hands and she will double check delivery date
9	3/2/2022	Email to Norma asking to confirm tube is in stock	No respone
10	3/3/2022	Email to Norma asking to confirm tube is in stock	No respone
11	3/7/2022	Email to Norma asking to confirm tube is in stock	No repsonse
12	3/7/2022	Call TW Metals	Norma is not in. Talked with Gina. Said he would check on status of tubes
13	3/7/2022	Email from Gina	Gina emails on behalf of Norma - "Looks like they are finally in and you should see them by the end of this week"
14	3/10/2022	Tubes Arrive	Only Receive 60' of 1.5" and 20' of 2.25"
15	3/10/2022	Call with Norma	Tell her that we are 20' short in the 1.5" tube. She says she will find and ship 20' of 4130 1.5" tube to us ASAP
16	3/10/2022	Email From Norma	Receive the quote for the new shipment of tube. Says we need to pay \$234 for 20' of tube.
17	3/10/2022	Drop Off tubes at Harvey Brothers	Drop tubes off at Harvey brothers. "2-7 day lead time"
18	3/15/2022	Call with Norma	Asked to confirm what the \$234 charge was. Norma said we need to pay that because we were only charged for the amount we received (60' 1.5" & 20' 2.25")
19	3/15/2022	Call with Harvey Brothers	Tubes not completed. Expectation to be completed by end of week. Ann Moeller has paid. Confirmed Payement with Zac form Harvey Brothers
20	3/21/2022	Call with Harvey Borthers	Tube Still not compelted. Zac states that tubes will be completed by end of the week.
21	3/23/2022	Call with Harvey Borthers	Tube Still not compelted not started. Zac states that tubes will be completed by end of the week.
22	3/24/2022	Call with Harvey Borthers	Tube Still not compelted nor started . Zac states that tubes will be completed by end of the week.
23	3/28/2022	Call with Harvey Borthers	Tube still not completed nor stated. Zac states that the tubes will be done in 2-3 days. Apologizes and states that shop has been over loaded.
24	3/29/2022	Tubes Bent	Harvey Brothers Tubes are bent and picked up



PH: 800-545-500  
 FX: 800-545-588

\* REPRINT \*

# ORDER ACKNOWLEDGEMENT

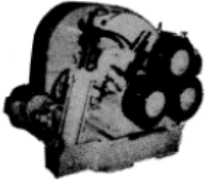
SOLD TO: UNIVERSITY OF CINCINNATI P. O. BOX 210072 CINCINNATI OH 45521 US	<b>Customer PO No.</b> 4600008216
	<b>Order Date</b> 02/01/22
	<b>F.O.B. Point</b> DESTINATION
SHIP TO: BEARCAT SOLAR TEAM 2220 VICTORY PARKWAY ATTN MATT CINCINNATI OH 45206 US	<b>Freight Terms</b> PREPAID
	<b>Ship Via</b> 80-03-LOCAL RELAY
	<b>Terms</b> *CREDIT CARD SALE*
<b>Contact: MATT</b> PH: 513-556-3908 FX: ORIG. QUOTE# 00000000	<b>Customer Acct No.</b> 0304678
	<b>Order No.</b> 80209620

Item #	Qty.	Description	Unit Price	Extended Price	Est Del Date
33689	60 FT	CDS 4130 6736 1-1/2 OD X .120 WA LENGTH 17-24 FT STOCK DUE 3-4 WEELS  CUT 1 @ 96", 1 @ 72", 2 @ 84", 2 @ 60" AND SHIP ALL DROPS.	11.7000 FT	702.00 WGT 106.135	02/18/22
33689	20 FT	CDS 4130 6736 1-1/2 OD X .120 WA LENGTH 17-24 FT  CUT TUBE IN FOURTHS.	11.7000 FT	234.00 WGT 35.378	02/18/22
33919	20 FT	SMLS CD 4130 RD 6736 2-1/4 OD X.120 LENGTH 17-24 FT STOCK DUE 4-5 WEEKS  CUT 1 @ 66", 1 @ 60" AND SHIP DROP	16.9000 FT	338.00 WGT 54.600	02/18/22
SALES TAX					
TOTALS					1,274.00
WEIGHT (LBS)					196.113

This Order Acknowledgement confirms the requirements that you specified when you placed your order with TW Metals. The order is subject to TW Metals' Terms and Conditions of Sale, a copy of which is incorporated herein by reference and available at [www.TWMetals.com](http://www.TWMetals.com), and any conflicting or additional terms and conditions appearing or referred to in your order, shall have no effect.

**YOUR ORDER IS GREATLY APPRECIATED AND WILL RECEIVE OUR PROMPT AND CAREFUL ATTENTION**

<b>By</b> NORMA MARTTINEN	<b>Signature:</b>
---------------------------	-------------------



**Harvey Brothers Incorporated**  
 3492 Spring Grove Avenue  
 Cincinnati, OH 45223 US  
 (513) 541-2622  
 steve.kyle@harveybrothersinc.com  
 http://www.harveybrothersinc.com

**ADDRESS**

University of Cincinnati  
 College of Engineering and  
 Applied Science

**Estimate 8266**

**DATE 02/23/2022**

**CUSTOMER PO #**

BEARCAT SOLAR CAR

**JOB #**

MATT W.

ACTIVITY	QTY	RATE	AMOUNT
<b>Sales:TUBING</b> CS-TUB-150-072-01 1.5" OD X .12" 4130 HR TUBE ROLLED 180° TO 10.15"CLR, W/EQUAL STRAIGHTS ON EACH END LABOR ONLY	1	180.00	180.00
<b>Sales:TUBING</b> CS-TUB-150-093-01 1.5" OD X .12" 4130 HR TUBE ROLLED 180° TO 12.0"CLR, W/EQUAL STRAIGHTS ON EACH END LABOR ONLY	1	180.00	180.00

CONFIRMATION OF COMPLETION UPON RECEIPT  
 OF PO AND MATERIAL

\*\*\*\*\*MUST RECEIVE A SIGNED ESTIMATE TO  
 PROCESS ANY ORDER \*\*\*\*\*

Thank you for the opportunity to quote this job. We look  
 forward to fulfilling this order upon your specific requests!

**TOTAL \$360.00**

Accepted By

Accepted Date  
 INQUIRIES EMAIL, CALL OR FAX

steve.kyle@harveybrothersinc.com  
 513.541.2622 OFFICE  
 513.541.2845 FAX

Benteler Steel/Tube GmbH  
Postfach 13 40  
33043 Paderborn  
Deutschland  
Tel.: +49.5254.81-0 Fax: +49.5254.13666


**BENTELER**   
Steel/Tube

**ABNAHMEPRÜFZEUGNIS EN 10204-3.1**  
INSPECTION CERTIFICATE EN 10204-3.1  
CERTIFICAT DE RECEPTION EN 10204-3.1  
EN 10204:2005-01

Benteler Steel/Tube GmbH - Postfach 1340 - 33043 Paderborn - Deutschland

Benteler Steel & Tube Corporation  
3050 Post Oak Blvd., Suite 1130  
HOUSTON TX 77056  
USA

Dokument-Nr.: 41-1288063/001/E  
Document No.:  
No. du document:  
Kunden-Bestell-Nr.: 46008129 TW M49447023  
Purchase Order No.:  
No. de commande du client:  
Benteler Auftrags-Nr.: 1686461  
Benteler Order No.:  
No. de commande Benteler:  
Versandanzeigen-Nr.: 4174786  
Dispatch Note No.:  
No. d'avis d'expédition:  
Produkt: NAHTLOSE STAHLROHRE  
Product: SEAMLESS STEEL TUBES  
Produit: TUBES D' ACIER SANS SOUDURE

Prüf-Nr.:  
Inspection No.:  
No. du certificat:  
Hersteller: Warmrohrwerk/Zieherei  
Manufacturer: (DIN EN ISO 9001, IATF 16949 CERTIFIED BY TUEV NORD CERT)  
Producteur: (PÉD 2014/68/EU CERTIFIED BY TUEV NORD SYSTEMS)  
Herstellerzeichen:   
Manufacturer's brand:  
Marque du producteur:  
Stempel des Abnahmebeauftragten: WA  
Stamp of the inspection representative:  
Poinçon du contrôleur:  
Stahlerschmelzungsverfahren: ELEKTROSTAHL  
Steelmaking process: ELECTRIC FURNACE  
Procédé d'élaboration de l'acier: FOUR ELECTRIQUE

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Lieferbedingungen: AMS-T-6736B-08 Type 1, MIL-T-6736B-95 Type 1, ASTM-A 519-2017, AMS 6360 rev. P, AMS 2301L, Cold drawn  
Terms of delivery:  
Conditions de livraison:

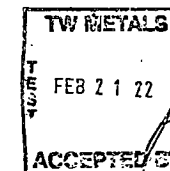
Maße - Toleranzen: AMS 2253F-18, Aircraft Type, Seamless, Cold Finished  
Dimensions-tolerances:  
Dimensions-tolérances:

Stahlsorte: GRADE 4130  
Steel grade:  
Nuance d'acier:

Lieferzustand: Condition N  
Delivery condition:  
État de livraison:

Produktkennzeichnung: FSD: BENTELER AMS 6360P-AMS-T-6736 B 1-MIL-T-6736 B 1-AMS 2301L 4130 Condition NHEAT-NO. CD  
Product marking: AQ S DIMENSIONS WA GERMANY  
Marquage du produit:

AEZ = Ätztintenbeschriftung, Etching ink marking, Gravure à l'encre . FX = Farbkennzeichnung, color marking, marquage par couleur . FS = Farbschablonierung, paint stenciling, marquage par peinture . FSD = Farbstrahlprüfer, Color jet printer, Imprimante à jet d'encre de couleur . FSI = Farbstrahlprüfer Innen, Color jet printer inside, Imprimante à jet d'ancre de couleur intr . LK = Laserkennzeichnung, Laser marking, Marquage laser . PKE = Etikettenkennzeichnung, tag marking, marquage sur étiquette . PS = Prägestempel, die stamp, marquage par poinçonnage . TS = Tintenstrahlkennzeichnung, Ink jet spray marking, imprimante à jet d'encre .



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Benteler Steel/Tube GmbH  
 Postfach 13 40  
 33043 Paderborn  
 Deutschland  
 Tel.: +49.5254.81-0 Fax: +49.5254.13666

**BENTELER**   
 Steel/Tube

**ABNAHMEPRÜFZEUGNIS EN 10204-3.1**  
 INSPECTION CERTIFICATE EN 10204-3.1  
 CERTIFICAT DE RECEPTION EN 10204-3.1

Dokument-Nr.: 41-1288063/001/E  
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Pos.	Stück	Maße	Gesamtlänge	Gewicht	Schmelzen-Nr.	Prüfdruck	Rohr-Nr.-Gruppe	Vielfachlängen
Item	Number	Dimensions	Length total	Weight	Heat No.	Test pressure	Tube number group	Multiple lengths
Poste	Nombre	Dimensions	Longueur totale	Poids	No. de coulée	Pression d'épreuve	Série de no. des tubes	Longueurs multiples
			feet	lbs				
0031	328	1.500" O.D. * 0.120" WT 20 FT - 24 FT	6570,70	11530	291957			

Ort der Stahlherstellung / Country of melt and pour / Lieu de l'élaboration de l'acier  
 BENTELER Steel/Tube GmbH, Lingen, Germany

Schmelzenanalyse [%] / Heat analysis [%] / Analyse sur coulée [%]

Pos.	Schmelzen-Nr.	C	SI	MN	P	S	CR	MO	NI	CU
Item	Heat No.	>=0,2800	>=0,1500	>=0,4000			>=0,8000	>=0,1500		
Poste	No. de coulée	<=0,3300	<=0,3500	<=0,6000	<=0,0250	<=0,0250	<=1,1000	<=0,2500	<=0,2500	<=0,3500
0031	291957	0,315	0,245	0,54	0,007	0,002	0,90	0,18	0,09	0,16

Produktanalyse [%] / Product analysis [%] / Analyse sur produit [%]

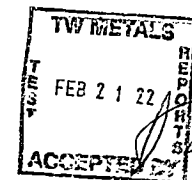
Pos.	Schmelzen-Nr.	C	SI	MN	P	S	CR	MO	NI	CU
Item	Heat No.									
Poste	No. de coulée									
0031	291957	0,320	0,251	0,53	0,007	0,002	0,92	0,17	0,08	0,14

Prüfergebnisse / Test results / Résultats des essais

Die Rohre wurden zerstörungsfrei geprüft: The tubes are non destructive tested: Les tubes ont passé un essai non destructif:	ET-test: acc. to ASTM-A 450; ET - Test method; acc. to ASTM-E 309; for imperfections; ET-test: ET with rotating pancake coils; according to EN 10246-3; imperfections; Notch depth: 0,30 mm; notch width <= notch depth; notch length min. 2 x transducer width (max. 50 mm)	PASSED
Augensichtkontrolle: Visual inspection: Examen visuel:	MATERIALVERWECHSLUNGSPRÜFUNG: Material conformity test: Vérification de la nuance:	PASSED
	MAßKONTROLLE: Dimensions examination: Vérification des dimensions:	PASSED

Ergebnisse der mechanischen Prüfung / Results of mechanical testing / Résultats des essais mécaniques

Die Probennahme erfolgte an Vielfachlängen.  
 The sampling was carried out on multiple lengths.  
 L'échantillonnage était réalisé aux longueurs multiples.



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Zugversuch längs bei RT, Vollprobe / Tensile test longitudinal at RT, Full section test specimen / Essai de traction longitudinale à TA, Eprouvette a section complete

Pos. Item Poste	Proben-Nr. Specimen No. No. de l'éprouv.	Schmelzen-Nr. Heat No. No. de coulée	Probenabmessung Specimen dimensions Dimensions de l'éprouv.	Streckgrenze Yield strength Limite élastique	Zugfestigkeit Tensile strength Résistance à la traction	Dehnung Elongation Allongement
<b>Anforderungen</b> Requirements Exigences				Rp 0,2 % KSI MIN 75	Rm KSI MIN 95	A2" % MIN 12.00
			mm			1. Formel 1. Formula 1. Formule
0031	000001	291957	38,10 X 2,95	98	125	26,00
0031	000002	291957	38,10 X 2,95	98	125	26,00
0031	000003	291957	38,10 X 2,95	100	124	26,00
0031	000004	291957	38,10 X 2,95	100	124	26,00
0031	000005	291957	38,10 X 2,95	99	125	26,00
0031	000006	291957	38,10 X 2,95	99	125	26,00
0031	000007	291957	38,10 X 2,95	99	125	26,00

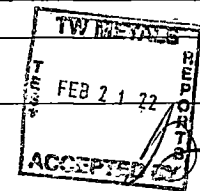
Korngröße / Grain size / Grosseur de grain

nach ASTM-E 112, Längsschliff, am Vormaterial / acc. to ASTM-E 112, Longitudinal structure micrography, on prematerial / svt. ASTM-E 112, Micrographie longitudinale, sur prematériel

Pos. Item Poste	Proben-Nr. Specimen No. No. de l'éprouv.	Schmelzen-Nr. Heat No. No. de coulée	Korngröße Grain size Grosseur de grain
			MIN 5
0031	000001	291957	9,0

Randentkühlung / Surface decarburization / Décarburation superficielle

acc. to AMS-6360, acc. to ASTM-E 1077, partial decarburization outside max. 0.017 in, partial decarburization inside max. 0.017 in, partial decarburization outside and inside max. 0.022 in, without total decarburization; partial decarb. out. max.: 0,432 mm; partial decarb. ins. max.: 0,432 mm; partial decarb. out. + ins.max: 0,559 mm



Vermerk / Remark / Remarque

Certificate remarks: The steel grade corresponds to MIL-6736B, AMS 6360P, material free from mercury contamination, FAR BAA: 52.225-1 CANNOT COMPLY, DFARS BAA: 252.225-7001 CAN COMPLY, FAR TAA: 52.225-5 CAN COMPLY, No weld repair has been carried out, Country of origin of the material and heat: Germany, All materials provided under this purchase order are free of conflict minerals in accordance with the Dodd-Frank Act Section 1502, Aircraft quality steel acc. to AMS 2301L; Semi finished product examination see appendix page 1 of 1

Benteler Steel/Tube GmbH  
Postfach 13 40  
33043 Paderborn  
Deutschland  
Tel.: +49.5254.81-0 Fax: +49.5254.13666

**BENTELER**   
Steel/Tube

**ABNAHMEPRÜFZEUGNIS EN 10204-3.1**  
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41-1288063/001/E

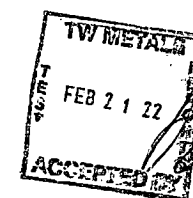
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Macroscopic examination: acc. to ASTM-E 381

Magnetic particle inspec.: acc. to AMS 2301L/ASTM-E 1444, on prematerial

Verkäufer(in) / Sales Personnel / Personne chargée : Mrs Sehrbrock, Tel.: 05254 81-204276, Fax: 204279



Werk 41, Marienloher Str., 33104 Paderborn, 03.11.2021, TEL.: 05254.81-201765

Abnahmebeauftragter  
Inspection representative  
Contrôleur

i. A. THOMAS GOLLAN / WIE

Es wird bestätigt, dass die gelieferten Erzeugnisse den techn. Lieferbedingungen des Auftrages entsprechen. Dieses Dokument wurde mittels EDV erstellt und ist ohne Unterschrift rechtsgültig.  
We certify that the supplied products comply with the order specifications. This document was prepared by means of electronic data processing and is valid without signature.  
Nous attestons que les produits livrés sont conformes aux stipulations de la commande. Ce document a été établi par traitement électronique de l'information et est valide sans signature.

Benteler Steel/Tube GmbH  
 Residenzstraße 1  
 33104 Paderborn  
 Germany  
 Tel.:49.5254.81-0 Fax: 49.5254.13666

**BENTELER**   
 Steel/Tube

Abnahmeprüfzeugnis EN 10204-3.1 / Anhang  
**Inspection Certificate EN 10204.3.1 / appendix**  
 Certificat de réception EN 10204-3.1 / appendice

Dokument-Nr.  
**Document No.:** 41-1288063/001/E  
 No. de document:

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**Page:** 1 of 1  
 Page: de

Halbzeuguntersuchung: Stahlsorte 4130A / **Semi finished product examination: grade 4130A** / Produit semi-fini: nuance 4130A

Schmelzen-Nr. Heat No. Coulée No.	Position Item Poste	Korngröße Grain size Grosseur de grain (ASTM-E 112)	Härtbarkeit (min. Anforderungen) Hardenability (min. requirements) Trepabilité (exigence min.) (ASTM-A 255)		Magnetpulverprüfung Magnetic particle inspection Essai à la poudre magnétique (AMS 2301)		Makroätzung Macrostructure test Essai de macrostructure (ASTM-E 381)		
		min. 5	J(5/16") min. 35 HRC	J(8/16") min. 28 HRC	F max. 0,34	S max. 0,25	max. S 2	max. R 1	max. C 2
291957	031	9	42	35	0,020	0,015	S 2	R 1	C 2
Decarburization Depth		Outside 0,000 mm	Inside 0,000 mm						

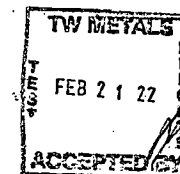
Der Stahl ist frei von Quecksilberverunreinigungen. / **The steel is free of mercury contamination.** / L'acier est libre des contaminations de mercure.

Paderborn Schloß Neuhaus, 03.11.2021  
 Tel.: (0)5254.81-201760 Fax: (0)5254.81-201752

Abnahmebeauftragter  
**Inspection representative**  
 Contrôleur

Thomas Gollan

restricted



800 74740



# TEST REPORT

400 McMunn St.  
South Lyon, MI 48178



Date : 01/11/2022  
Page : 1  
Job : MJ00007458  
Order : MS00010788

Truck# : MT06411  
Pick# : 57645

Heat : 74124034  
Ship# :

<b>Ship To :</b> TW METALS 235 TUBEWAY CAROL STREAM IL 60188	<b>Sold To :</b> TW METALS INC P O BOX 644 CAROL STREAM EXTON PA 19341 USA
--	--

<b>FD No :</b> M49448751	<b>Cust Item :</b> 33919	<b>Shape :</b> Round Round	<b>Wt/ft :</b> 2.730
<b>OD Size :</b> 2.250 IN	<b>ID Size :</b>	<b>Wall Size :</b> 0.120 IN (Average)	<b>Grade :</b> 4130-3
<b>Surface :</b> OIL	<b>Anneal :</b> Per Spec		

**Specifications :** AMS-6360-Rev. P,AMS-6371-Rev. L,AMS-T-6736 B-N,MIL-T-6736B-N,MST Customer-CP49-7.4.2-005-Rev. 10  
**Oil :** PRODUCE TO AMS-T-6736BN, MIL-T-6736BN, AMS-6360P, TW SPEC CP49-7.4.2-005/R10. DECARB LEVELS TO AMS-6371L. T/R TO INCL-PHYS & COUNTRY OF ORIGIN & MFG. DFARS COMPLIANT. MARK W/MST, SIZE, GRADE, HEAT#, SPECS & PO#. 5000# MAX BUNDLES. FORKLIFT REAR UNLOAD. \*RTG-EMAIL BOL, P/L, MTR TO MIKE.MHULEC@TWMETALS.COM WHEN READY FOR PICK UP.

Heat	Furnace	Melted Source	Feet	Weight (lbs)
74124034	EAF	USA,GERDAU - FORT SMITH, AR	2076	5667

Chemistry Analysis - L (Ladle), P1/P2 (Product Analysis) - %																						ppm			
C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	Sn	Nb	SB	As	Ti	Zr	N	Ca	CO	W	B	H2	CE		
L	0.30	0.50	0.009	0.013	0.240	0.230	0.19	0.02	0.16	0.018	0.003	0.009	0.001	0.002	0.005	0.001	0.009	0.001	0.008		0.00				

**Grain Size:** 7      **Decarb:** OK

Tensile Properties - PSI															Hardness	
Yield															HRc Mid	
000107																
<b>Tensile</b>	<b>0.2%</b>															
121825	95297														23.5	25.0
123256	104025														23.5	25.0
128531	106286														23.5	25.0

Additional Testing							
Hydro (Tested 100% Length)	Ultrasonic %	Eddy Current	Flatten	Flare	Bend	Expansion	
		PASS					

**Magnetic Particle Inspection**  
**Frequency :** 0.00      **Severity :** 0.00

TW METALS  
 FEB 15 2022  
 ACCEPTED BY

DFAR 252.225.7014, FAR BAA, DFARS BAA & FAR TAA COMPLIANT

Lot Details			
Bundle	Footage	Pcs	Length
ms0001078801001	1038	53	Rand 17' 0.000" - 24' 0.000"
ms0001078801002	1038	53	Rand 17' 0.000" - 24' 0.000"

TW METALS  
 TEST REPORT  
 JAN 19 22  
 ACCEPTED BY



400 McMunn St.  
South Lyon, MI 48178

# TEST REPORT



Date : 01/11/2022  
Page : 2  
Job : MJ00007458  
Order : MS00010788

Truck# : MT06411

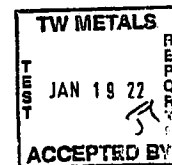
Heat : 74124034

Pick# : 57645

Ship# :

- Material has not been exposed to metallic mercury, lead or asbestos so as to cause contamination. Material is free from radioactive contamination. Cold Drawn Seamless. No weld repair. 100% Manufactured USA.
- Michigan Seamless Tube LLC, South Lyon MI is a division of Specialty Steel Works, Inc.
- Certificate of Conformance Statement: This certificate asserts that the tubing listed above has been manufactured, inspected and approved in accordance with all specifications, requirements and the customer's purchase order.

Jacob Gorkowski  
Quality Assurance Manager



### 13.3 Steering

4

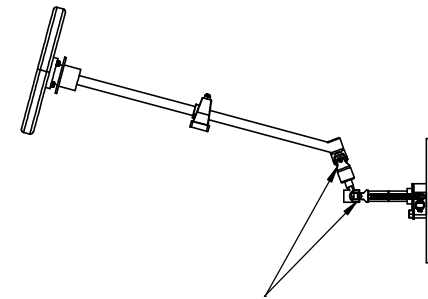
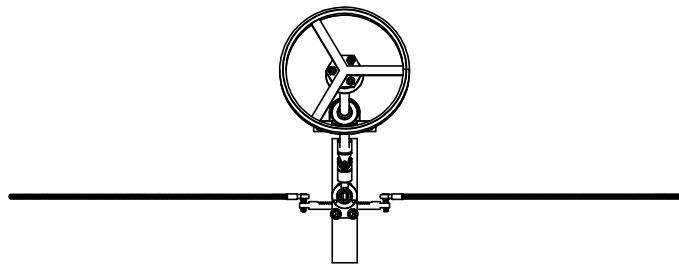
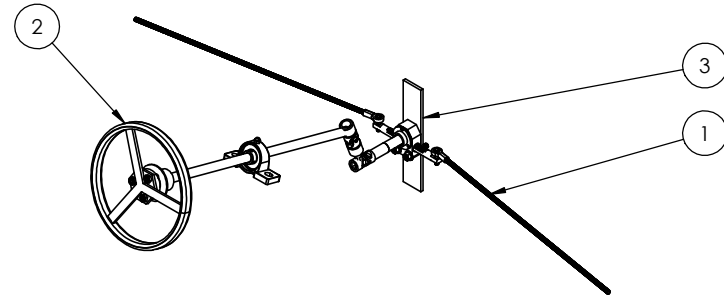
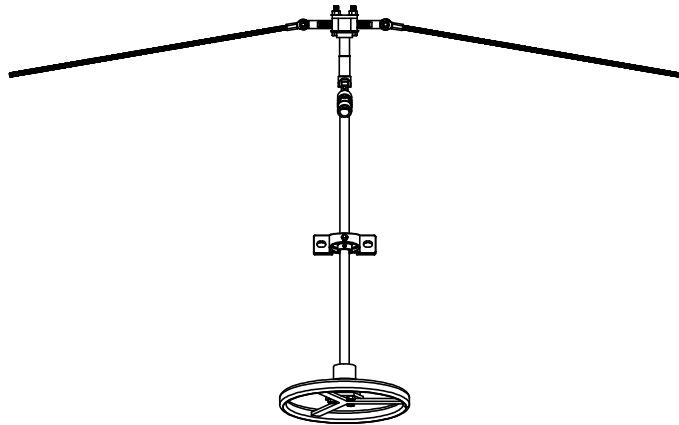
3

DO NOT SCALE DRAWING

2

1

ITEM NO.	DESCRIPTION	QTY.
1	Lower Steering Rack	1
2	Upper Column	1
3	20"X2"X.25" ASTM A510 STEEL PLATE	1



NOTE: THESE JOINTS ARE NOT IN THE BENT CONFIGURATION  
SHAFT ANGLES ARE CORRECT

DRAWN BY: BAM	SIZE	MATERIAL
APPROVED BY: MRB	<b>B</b>	FINISH
DATE: 04/20/2022		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± .XXX ANGULAR: ± 2°	TITLE: <b>FULL SYSTEM ASSEMBLY</b>	
<b>Bearcat Solar Car Team</b>	DWG. NO. <b>BCSC-ST-003</b>	
	SCALE: 1:10 WEIGHT:	SHEET 1 OF 1

4

3

2

1

4

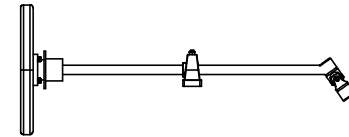
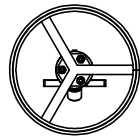
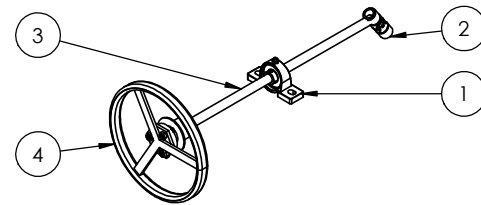
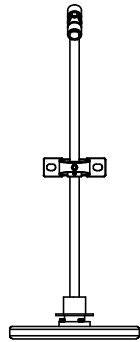
3

DO NOT SCALE DRAWING

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6494K13 - MCMMASTER CARR	Mounted Ball Bearing with Nickel-Plated Iron Housing	1
2	6443K39 - MCMMASTER CARR	Single U-Joint	1
3	1346K32 - MCMMASTER CARR	Rotary Shaft	1
4	Steering Wheel		1



DRAWN BY: BAM	SIZE	MATERIAL
APPROVED BY: MRB	<b>B</b>	
DATE: 04/20/2022	FINISH	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± .XXX ANGULAR: ± 2°	TITLE:	UPPER COLUMN
<b>Bearcat</b> <b>Solar Car Team</b>	DWG. NO.	BCSC-ST-003
	SCALE: 1:10 WEIGHT:	SHEET 2 OF 4

4

3

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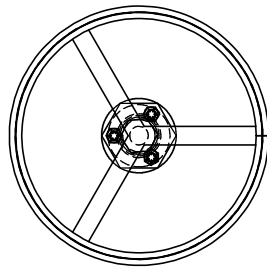
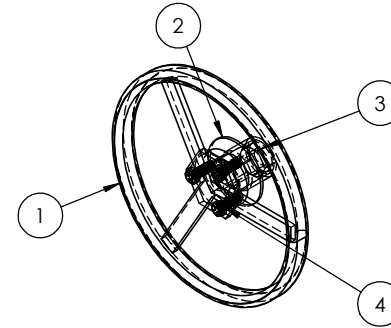
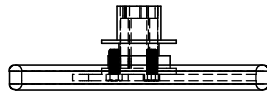
3

DO NOT SCALE DRAWING

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1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Wheel	1/2" TUBE BENT INTO A 10" CIRCLE, 1" WIDE 1/2" THK PLATE IN CENTER	1
2	3400-3/4ALU PEGASUS AUTO RACING	QUICK RELEASE HUB	1
3	3400-3/4ALU PEGASUS AUTO RACING	HUB SHAFT CONNECTOR	1
4	92620A655 MCMASTER CARR	Zinc Yellow-Chromate Plated Hex Head Screw	3



DRAWN BY: BAM	SIZE	MATERIAL
APPROVED BY: MRB	<b>B</b>	FINISH
DATE: 04/20/2022		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± .XXX ANGULAR: ± 2°	TITLE:	STEERING WHEEL
<b>Bearcat</b> <b>Solar Car Team</b>	DWG. NO.	BCSC-ST-003
	SCALE: 1:5	WEIGHT: SHEET 3 OF 4

4

3

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1

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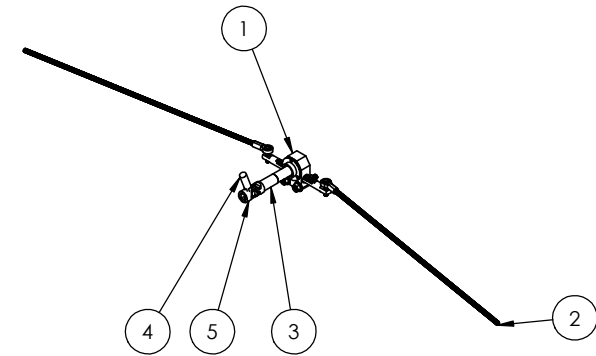
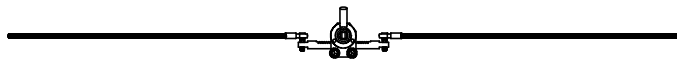
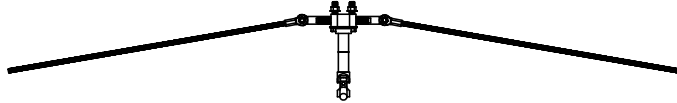
3

DO NOT SCALE DRAWING

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1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ARC Steering Rack Assembly	9/16" INPUT SHAFT	1
2	98957A131 - MCMASTER CARR	Grade B7 Medium-Strength Steel Threaded Rod	2
3	5545A72 - MCMASTER CARR	12-Point Deep Socket	1
4	8920K528 - MCMASTER CARR	Low-Carbon Steel Rod	1
5	5523A19 - MCMASTER CARR	1/2" Square Drive Flex Socket Adapter	1



DRAWN BY: BAM	SIZE	MATERIAL
APPROVED BY: MRB	<b>B</b>	FINISH
DATE: 04/20/2022		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: ± .XXX ANGULAR: ± 2°		TITLE: <b>LOWER COLUMN</b>
<b>Bearcat Solar Car Team</b>		DWG. NO.: <b>BCSC-ST-003</b>
SCALE: 1:10 WEIGHT:		SHEET 4 OF 4

4

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1

### 13.2.2 Logs

Major Events	
Event	Date
Joined Team	3/30/2021
Outlined Official Problem Statement	6/6/2021
Senior Design Proposal Approved	6/14/2021
Preliminary Design CAD Completed	6/20/2021
Senior Design Proposal approved by Dr. Huston	9/7/2021
Second Design Iteration CAD Completed	10/5/2021
Rack from SMC scrapped, design updated to incorporate it	11/11/2021
Advisor Meeting	12/2/2021
Master CAD (entire car) Created	1/10/2022
First FEA Run to validate design choices	1/23/2022
Third Design Iteration CAD Completed	2/11/2022
Initial Parts Order Placed	2/9/2022
Initial Parts Order Arrives	2/13/2022
Fabrication Begins	3/28/2022
Minor Changes to Final CAD Iteration due to fab constraints	4/5/2022
Second FEA run to verify viability of changes	4/7/2022
Remaining Parts Order Placed	4/8/2022
Remaining Parts Order Arrives	4/10/2022
Fabrication and Testing Completed	4/13/2022
Successful performance at CEAS Expo	4/14/2022

Weekly progress	
Progress	Date
Note: Weekly updates were not kept as a team requirement until the week of 10/18/2022	
Cal's performed to set design parameters, initial cost assessment of \$1800 made	10/18/2021
Began cost trimming, interfacing, and became aware of SMC parts	10/25/2021
Made decisions in cost reduction	11/1/2021
Confirmed SMC parts could work in theory, need greenlight from Dean Arthur to use	11/8/2021
Officially incorporated SMC rack into design, CAD updated, parts list updated, cost updated	11/15/2021
Steering work hit a lull, began CAD assistance to incorporate SMC parts for chassis team	11/22/2021
No progress - Holiday	11/29/2021
Break in work due finals and Christmas break	
Finished Master CAD of entire car, began CAD and interfacing management role, created team CAD naming convention	1/10/2022
Finalized parts list with treasurer Matt Wiegandt	1/20/2022
Ran first set of FEA on confirmed parts	1/27/2022
Waiting on confirmation to order parts	2/3/2022
All (initial) items purchased, CAD updated accordingly, Second Master CAD rev completed	2/10/2022
All (initial) items arrived	2/17/2022
Holding pattern until chassis fabrication progresses, maintained CAD updates for team	2/24/2022
Due to lack of work on wheel hubs/braking these were reassigned from Will Name to Trevor Crumley and Ben Morrow	3/3/2022
After deliberation Will Name was allowed to resume on wheel hubs/brakes, Ben Morrow ceased work on these	3/10/2022
Holding pattern until chassis fabrication progresses, maintained CAD updates for team	3/17/2022
Fabrication plan finalized, ready when chassis was finished at weld shop and sent to VPC	3/24/2022
Fabrication begins, specific parts machined and ready for assembly	3/31/2022
Minor CAD Changes due to fabrication, 3rd Master CAD Rev, Second FEA ran to check fabrication choices	4/7/2022
Remaining parts arrive, all components installed and properly functioning, assisted others in fabrication, went to CEAS Expo	4/14/2022
ME Senior Design Presentation Completed, final report in progress	4/21/2022

### 13.2.3 Engineering Background

#### Turning radius calculations for minimum as specified by the regulations (16m):

$$R = \text{Turning radius} = 16m$$

$$W = \text{wheel base} = 2.1m$$

$$\alpha = \text{angle of front wheel}$$

$$R = \frac{W}{\sin(\alpha)} \quad [ref]$$

$$16 = \frac{2.1}{\sin(\alpha)}$$

$$\sin(\alpha) = \frac{2.1}{16}$$

$$\alpha = \sin^{-1}\left(\frac{2.1}{16}\right)$$

$$\alpha = 7.5^\circ$$

$$\% \text{ of full rotation} = \frac{\alpha}{360^\circ}$$

$$\% \text{ of full rotation} = \frac{7.5^\circ}{360^\circ}$$

$r = \text{radius of suspension rotation}$

$t = \text{linear translation of tie rods} = 1''$

$C = \text{Circumference of suspension rotation} = 2\pi r$

$$C = 2\pi(r)$$

$\% \text{ of circumference of suspension rotation} = \% \text{ of full rotation} = t/C$

$$\% \text{ of circumference of suspension rotation} = \frac{1''}{2\pi r}$$

$$2\pi r * 2.094\% = 1''$$

$$r = \frac{1''}{2\pi * 2.049\%}$$

$$r = 7.6''$$

Tie rods must be 7.6" from the center of suspension rotation to achieve front wheel angle of 7.5° to achieve minimum turning radius of 16m.

#### Turning radius calculations for desired (8m or less):

$R = \text{Turning radius} = 8m$

$W = \text{wheel base} = 2.1m$

$\alpha = \text{angle of front wheel}$

$$R = \frac{W^{[ref]}}{\sin(\alpha)}$$

$$8 = \frac{2.1}{\sin(\alpha)}$$

$$\sin(\alpha) = \frac{2.1}{8}$$

$$\alpha = \sin^{-1}\left(\frac{2.1}{8}\right)$$

$$\alpha = 15^\circ$$

$$\% \text{ of full rotation} = \frac{\alpha}{360^\circ}$$

$$\% \text{ of full rotation} = \frac{15^\circ}{360^\circ}$$

$r = \text{radius of suspension rotation}$

$t = \text{linear translation of tie rods} = 1''$

$C = \text{Circumference of suspension rotation} = 2\pi r$

$$C = 2\pi(r)$$

$\% \text{ of circumference of suspension rotation} = \% \text{ of full rotation} = t/C$

$$\% \text{ of circumference of suspension rotation} = \frac{1''}{2\pi r}$$

$$2\pi r * 4.22\% = 1''$$

$$r = \frac{1''}{2\pi * 4.22\%}$$

$$r = 3.76''$$

Tie rods must be 3.76" from the center of suspension rotation or closer to achieve a minimum front wheel angle of 15° to achieve minimum turning radius of 8m or less.

#### **Translational force to turn the wheels (compressive/tensile load on tie rods):**

$m = \text{mass of car full load} = 678 - 810\text{lbs}/307.5 - 367.4\text{kg}$  (see weight chart reference)

$k = \text{coefficient of friction between tire and road} = 0.7 - 1$

$$F = k * m * g^{[ref]}$$

Divide by 4 for load per tire.

$$F_{low\_imperial} = \frac{0.7 * 678 * 1}{4} = 118.65\text{lb}f$$

$$F_{low\_metric} = \frac{0.7 * 307.5 * 9.81}{4} = 527.9\text{N}$$

$$F_{high\_imperial} = \frac{1 * 810 * 1}{4} = 202.5\text{lb}f$$

$$F_{high\_metric} = \frac{1 * 367.4 * 9.81}{4} = 901\text{N}$$

#### **Driver input to turn wheels based on translational force to turn the wheels:**

$F = \text{translational force}$

$d = \text{diameter of pinion} = 1''$

$T = \text{required input torque}$

$$F = 2 * \frac{T^{[ref]}}{d}$$

$$118.65\text{ lbf} = 2 * \frac{T_{\text{low imperial}}}{1}$$

$$527.9\text{ N} = 2 * \frac{T_{\text{low metric}}}{0.0254}$$

$$202.5\text{ lbf} = 2 * \frac{T_{\text{high imperial}}}{1}$$

$$901\text{ N} = 2 * \frac{T_{\text{high metric}}}{0.0254}$$

$$\frac{1 * 118.65\text{ lbf}}{2} = T_{\text{low imperial}} = 59.325\text{ in} * \text{ lbs}$$

$$\frac{0.0254 * 527.9\text{ N}}{2} = T_{\text{low metric}} = 6.704\text{ N} * \text{ m}$$

$$\frac{1 * 202.5\text{ lbf}}{2} = T_{\text{high imperial}} = 101.25\text{ in} * \text{ lbs}$$

$$\frac{0.0254 * 901\text{ N}}{2} = T_{\text{high metric}} = 11.44\text{ N} * \text{ m}$$

**Tangential force on the 10" steering wheel to induce required torques above:**

$$T = F * r^{[ref]}$$

$$r = 5" = 0.127\text{ m}$$

$$\frac{59.325}{5} = F_{\text{low imperial}} = 11.8\text{ lbf}$$

$$\frac{6.704}{0.127} = F_{\text{low metric}} = 52.8\text{ N}$$

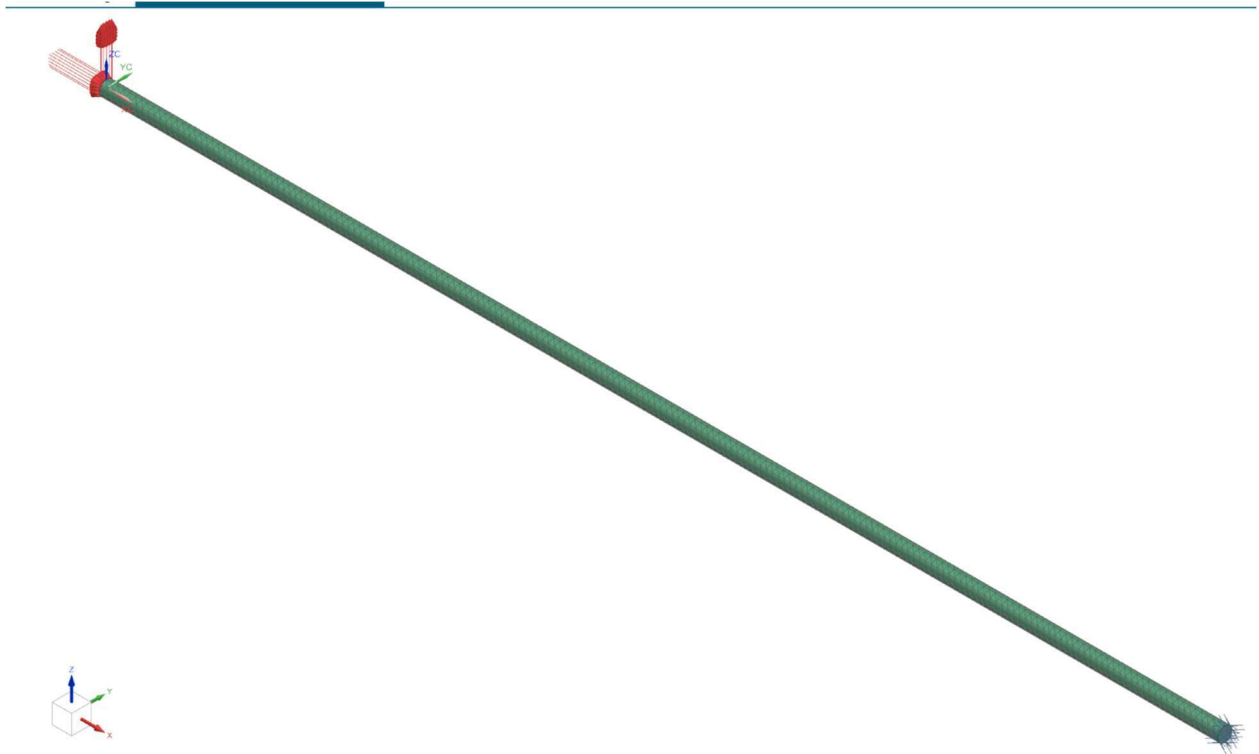
$$\frac{101.25}{5} = F_{\text{high imperial}} = 20.25\text{ lbf}$$

$$\frac{11.44}{0.127} = F_{\text{high metric}} = 90.1\text{ N}$$

#### 13.2.4 Simulation Results

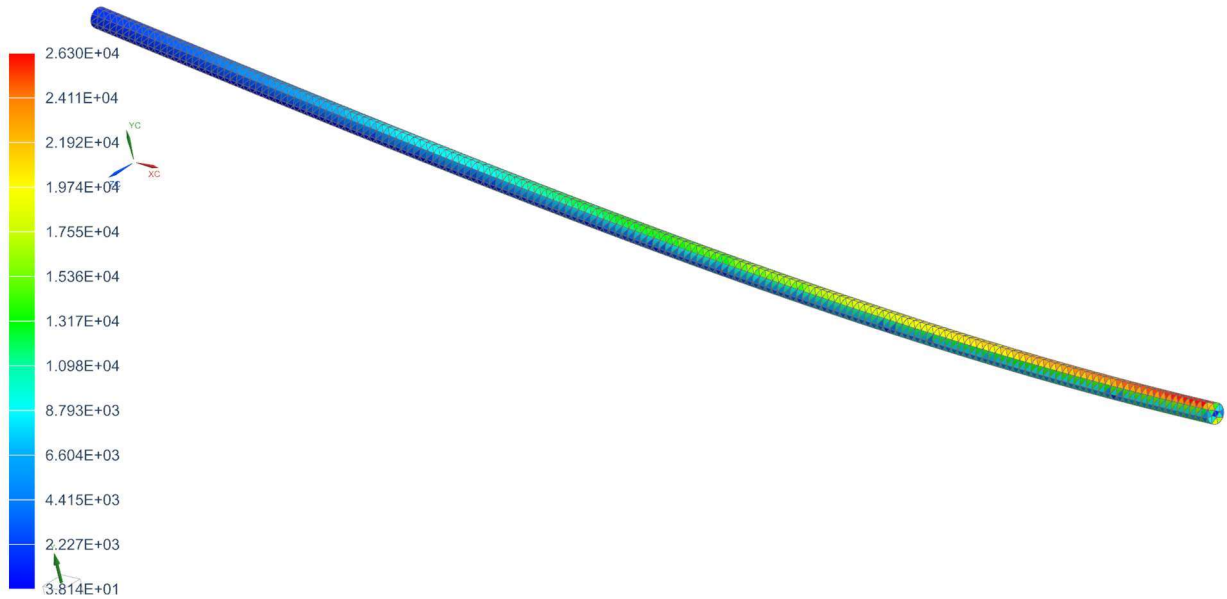
Two main simulations were ran: forces on the tie rods and torsion on the upper steering column. These were selected because of concerns in design choices for both. The tie rods were much longer and thinner than preferred due to the rack that was used. Likewise, the rack input shaft size reduced the diameter of the upper column, causing concern being able to carry the torsion. The input forces/torques are outlined in above Section 13.2.3, specifically the high imperial forces and torques were chosen to give an absolute worst case scenario conservative estimate.

**Tie rod simulation:**



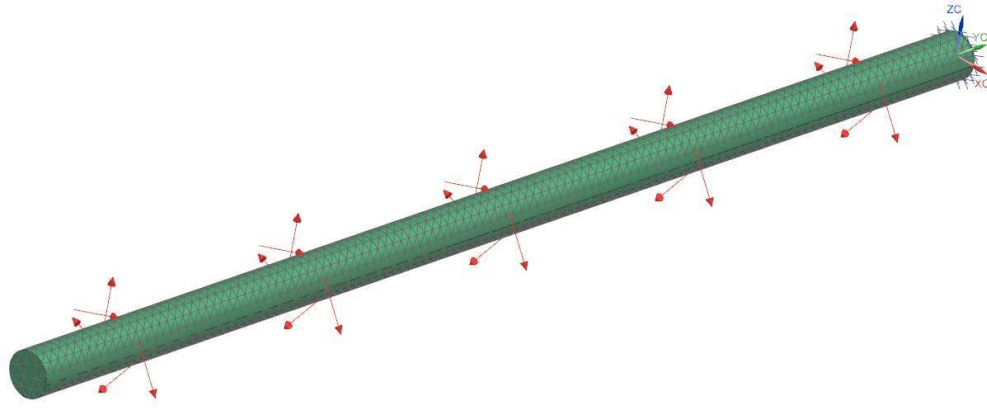
202.5lbf of compression induced at a 5 degree angle (split into component vectors) the other end is fixed.  
 A 1/4" mesh was used.

model5\_sim1 : Solution 1 Result  
 Subcase - Static Loads 1, Static Step 1  
 Stress - Elemental, Von-Mises  
 Min : 3.814E+01, Max : 2.630E+04, Units = lbf/in<sup>2</sup>  
 Deformation : Displacement - Nodal Magnitude

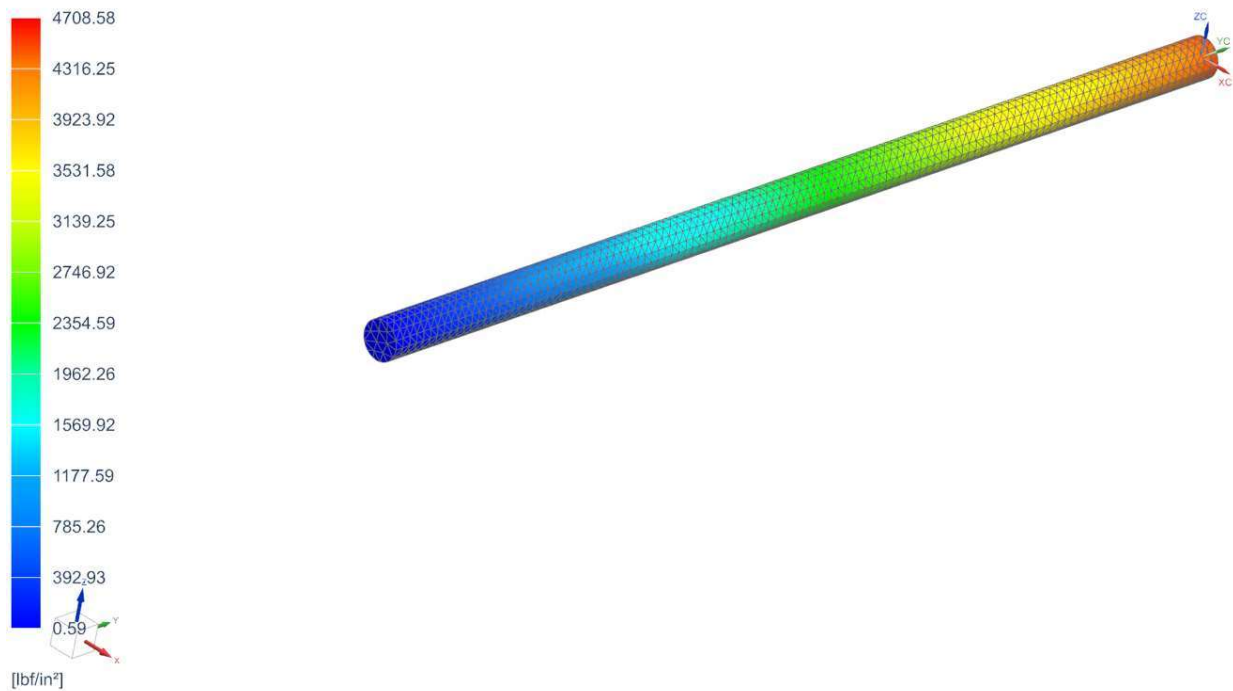


The resulting stresses on the rod are shown above. The highest stress is below that of the yield strength of steel, so even in a conservative worst case scenario, the rods will not yield.

## Upper Column Simulation



101.25 in-lbs of torque induced along the shaft, the other end is fixed. A  $\frac{1}{4}$ " mesh was used.



The resulting stresses on the rod are shown above. The highest stress is well below that of the yield strength of steel, so even in a conservative worst case scenario, the column will carry the loads fine.

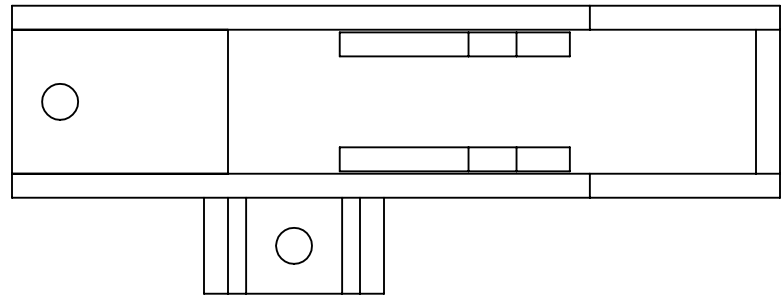
## 13.4 Suspension

2

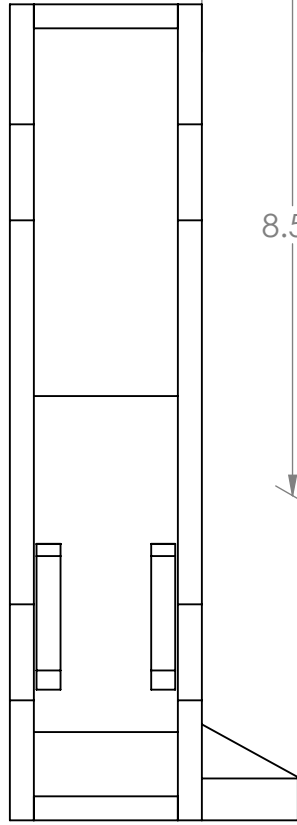
1

B

B



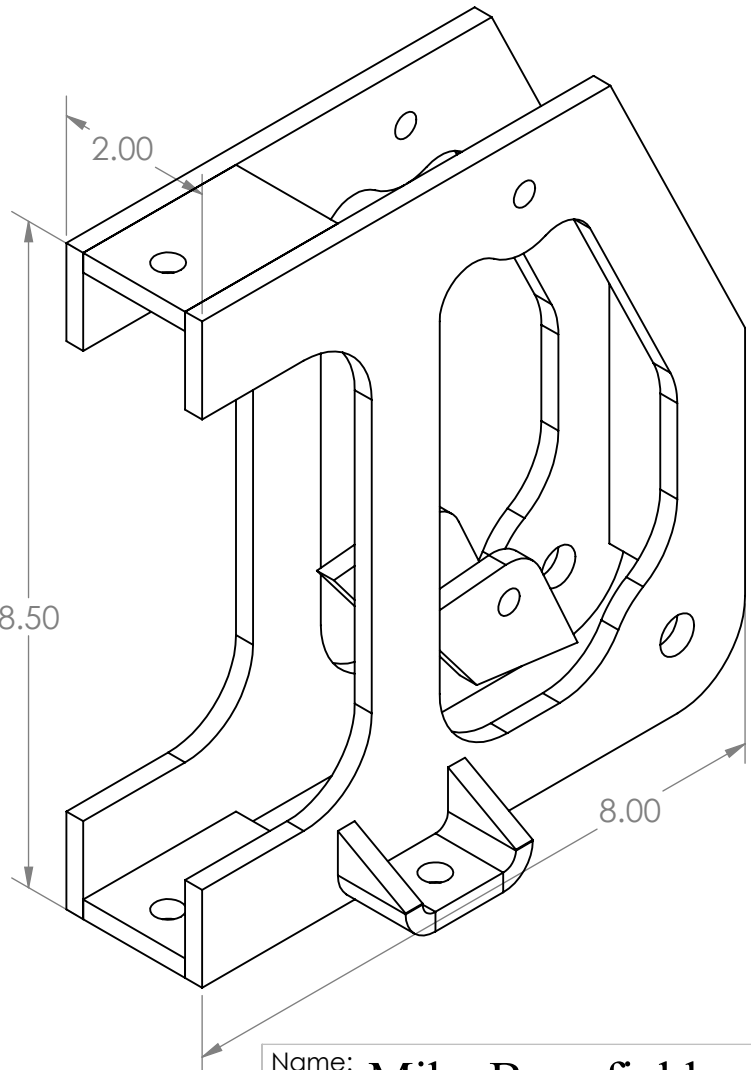
.25



8.50

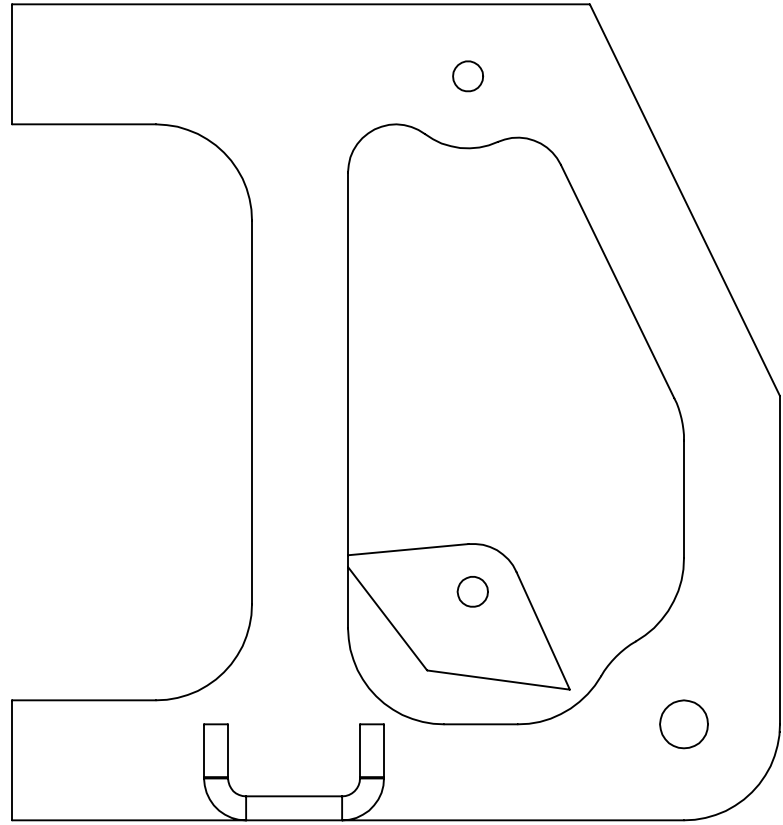
2.00

8.00



A

A



2

1

COMMENTS:  
Dimensions are in Inches

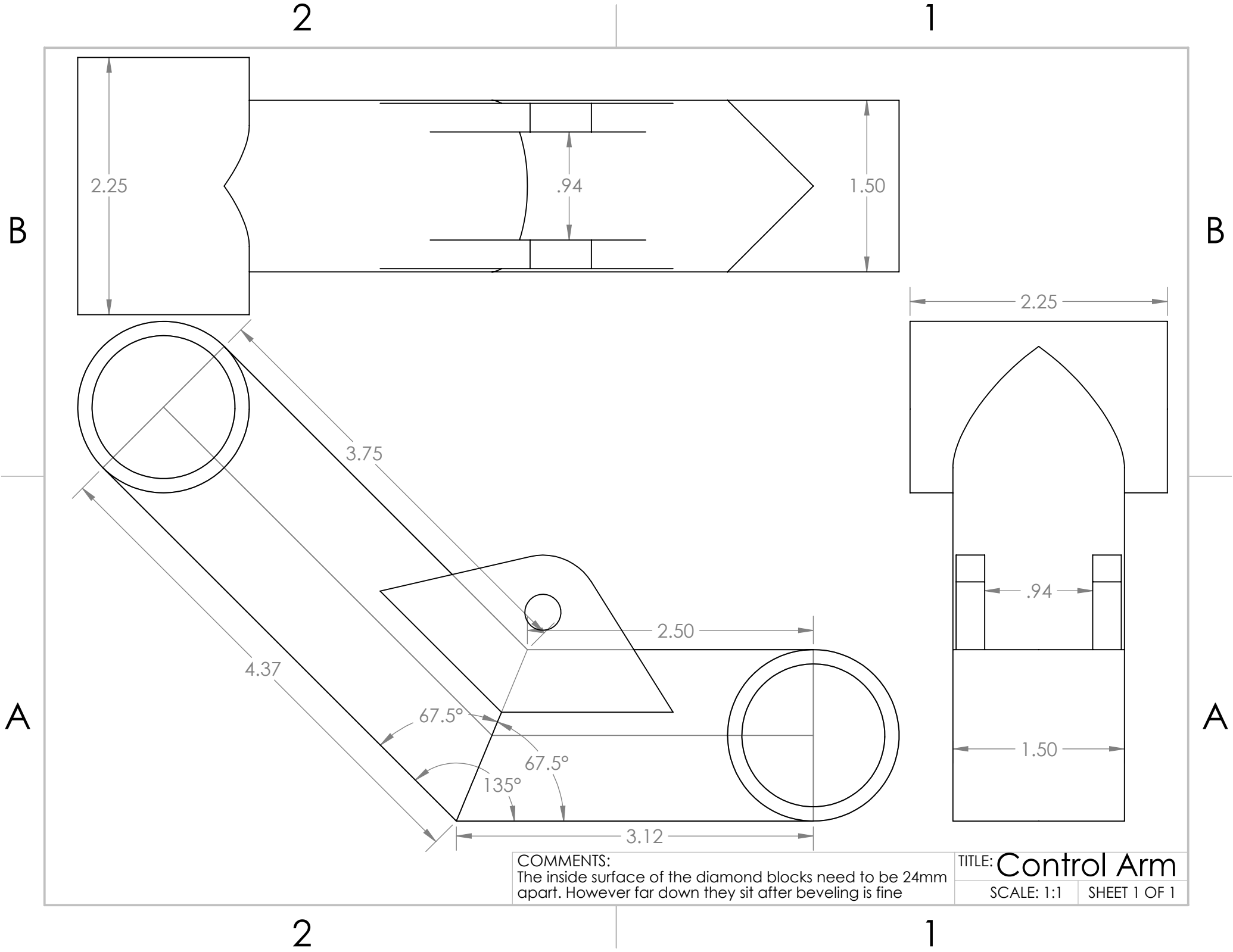
Material:  
0.25" Steel plate

Name: **Mike Brassfield**

TITLE:  
**Beracat Solar Car  
Suspension**

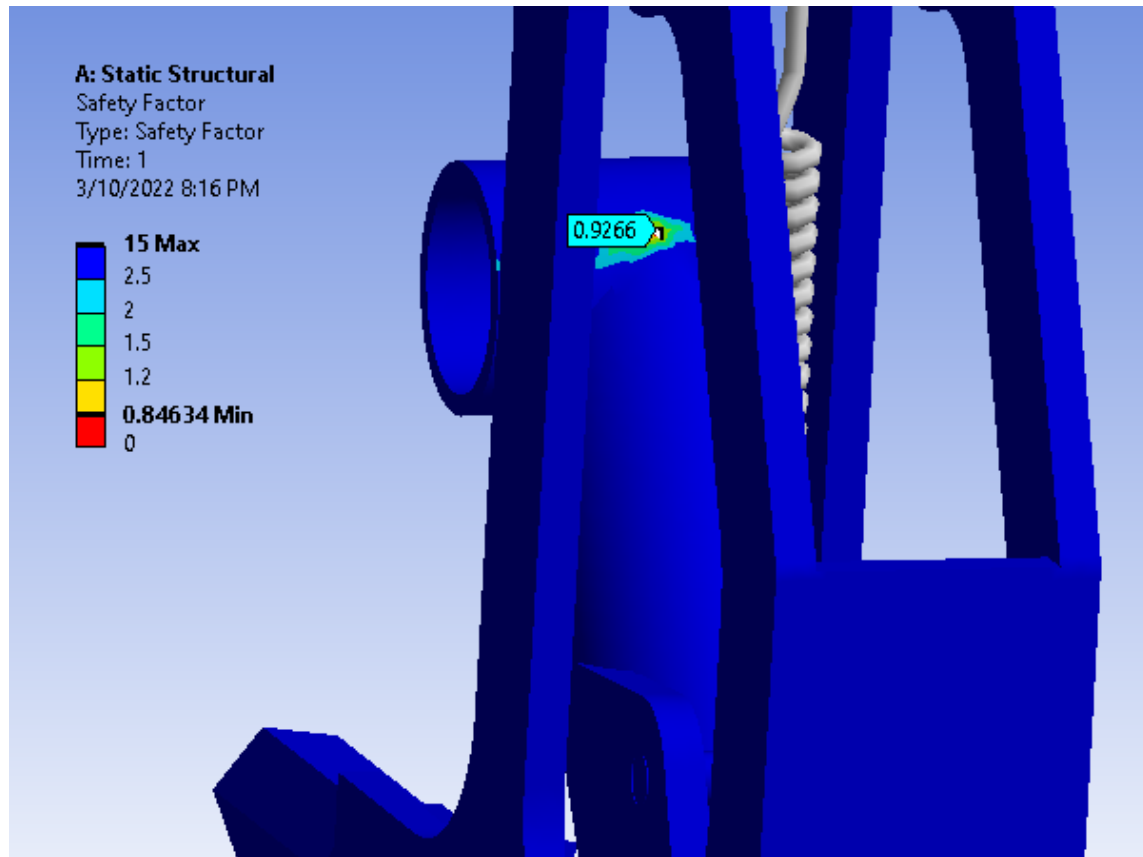
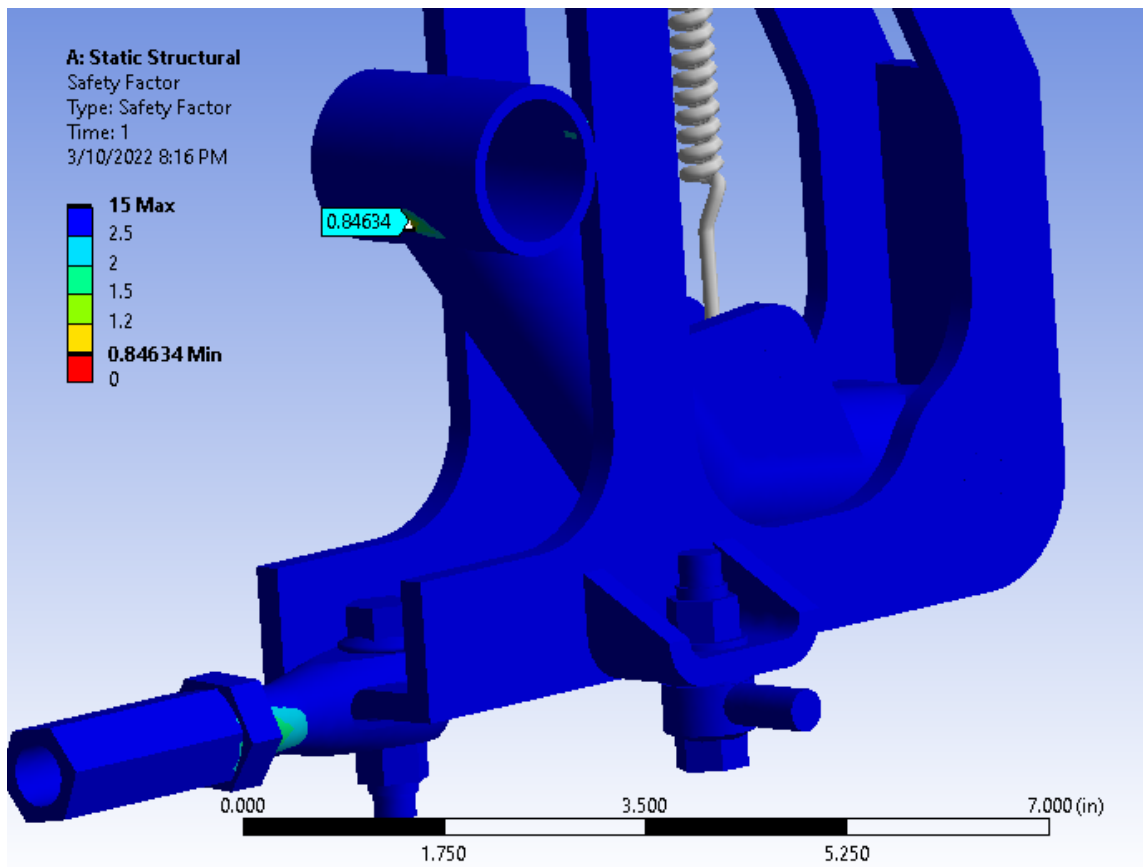
SIZE	DWG. NO.	REV
<b>A</b>	<b>Mk IV</b>	

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1
------------	---------	--------------



COMMENTS:  
 The inside surface of the diamond blocks need to be 24mm apart. However far down they sit after beveling is fine

TITLE: **Control Arm**  
 SCALE: 1:1 | SHEET 1 OF 1



## 13.5 Aerodynamics

## Aerodynamics

The following setup was used for the CFD.

- Inlet velocity: 10 m/s (22.34 miles per hour)
- Zero pressure condition at far-field behind the car.
- Boundary layer mesh thickness:  $3.08 \times 10^{-2}$  m.
- Turbulence model: k-omega SST
- Error between CFD and experiments: 7.095%

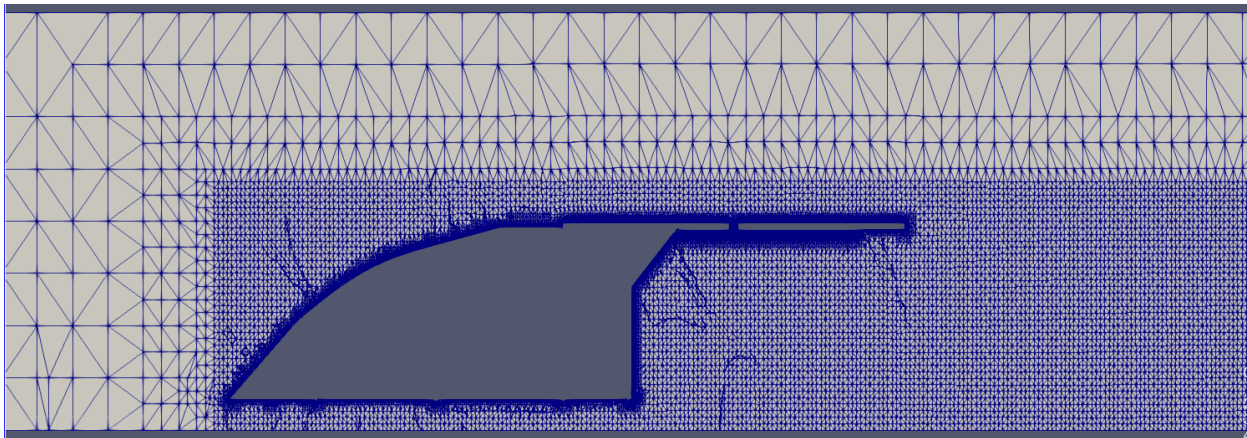
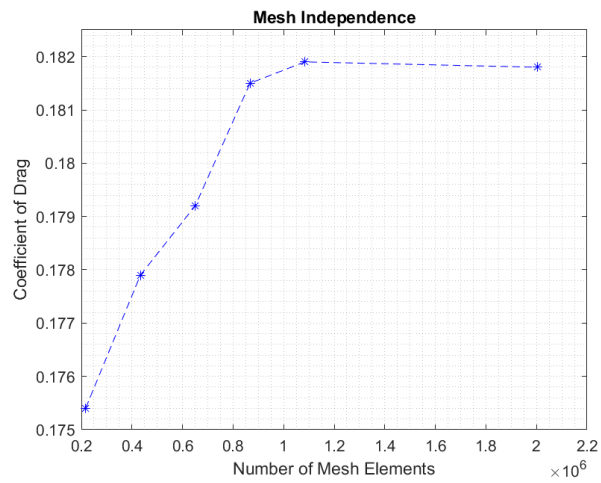


Figure 1 Sample Mesh

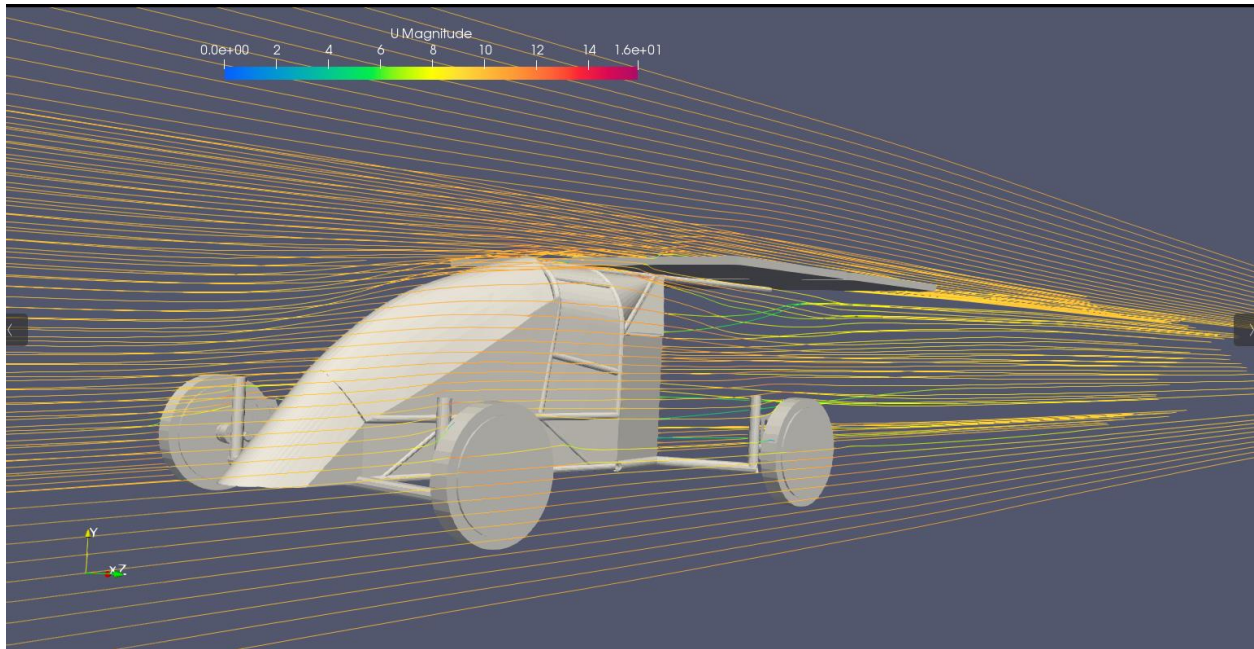


Figure 2 Flow Velocity

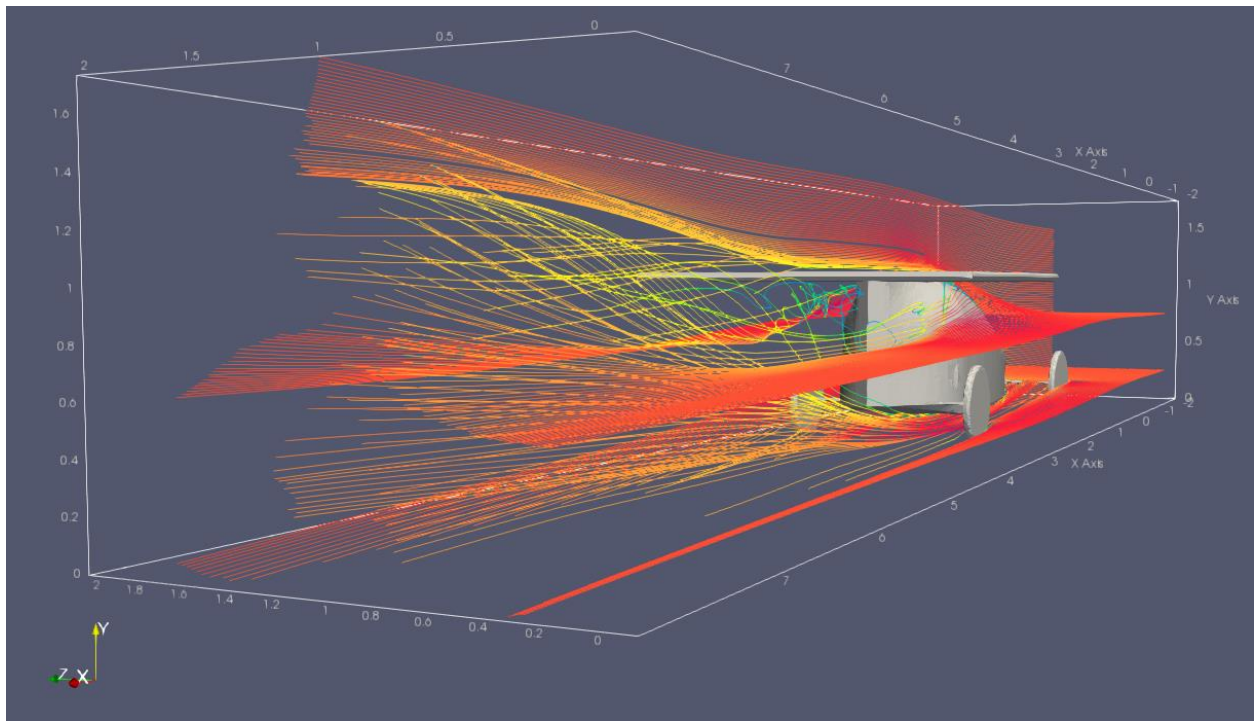


Figure 3 Vortex Shedding Behind the Car

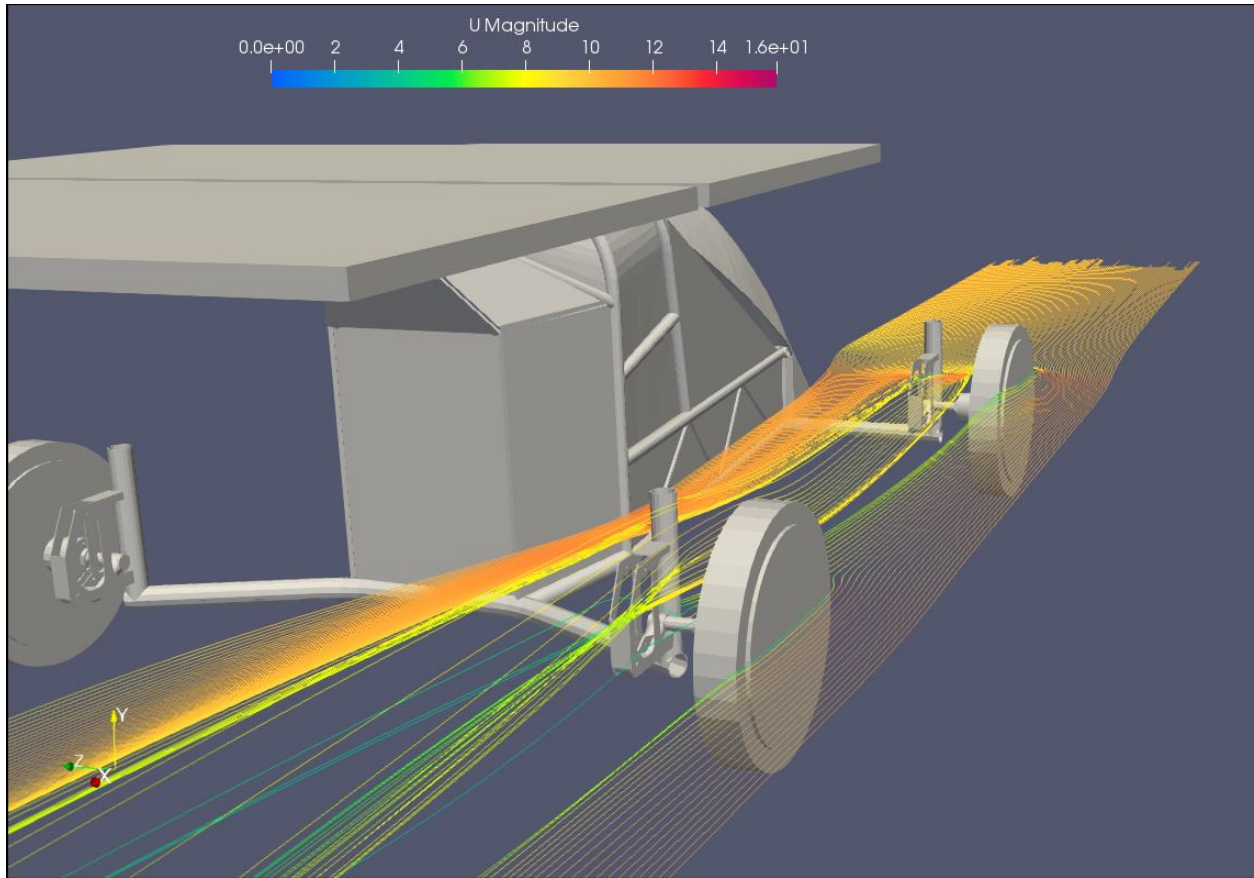


Figure 4 Flow Over the Suspension and Wheels

## 13.6 Motor/Motor Hub

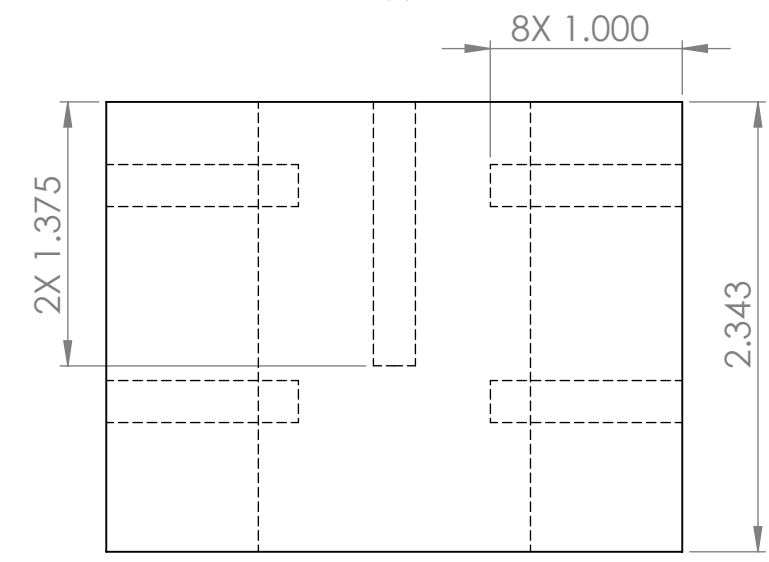
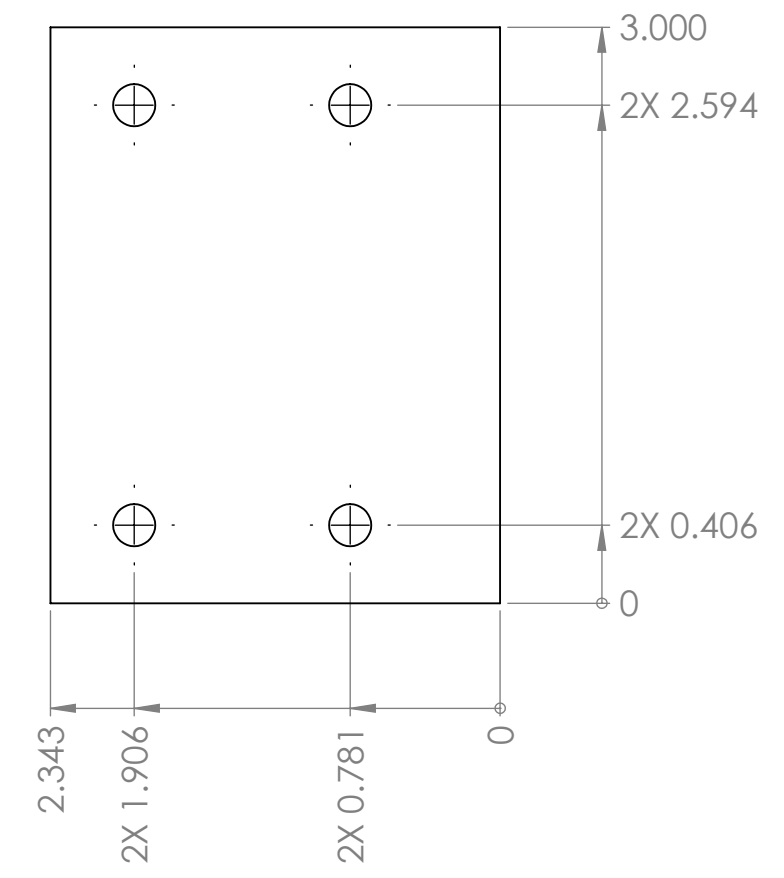
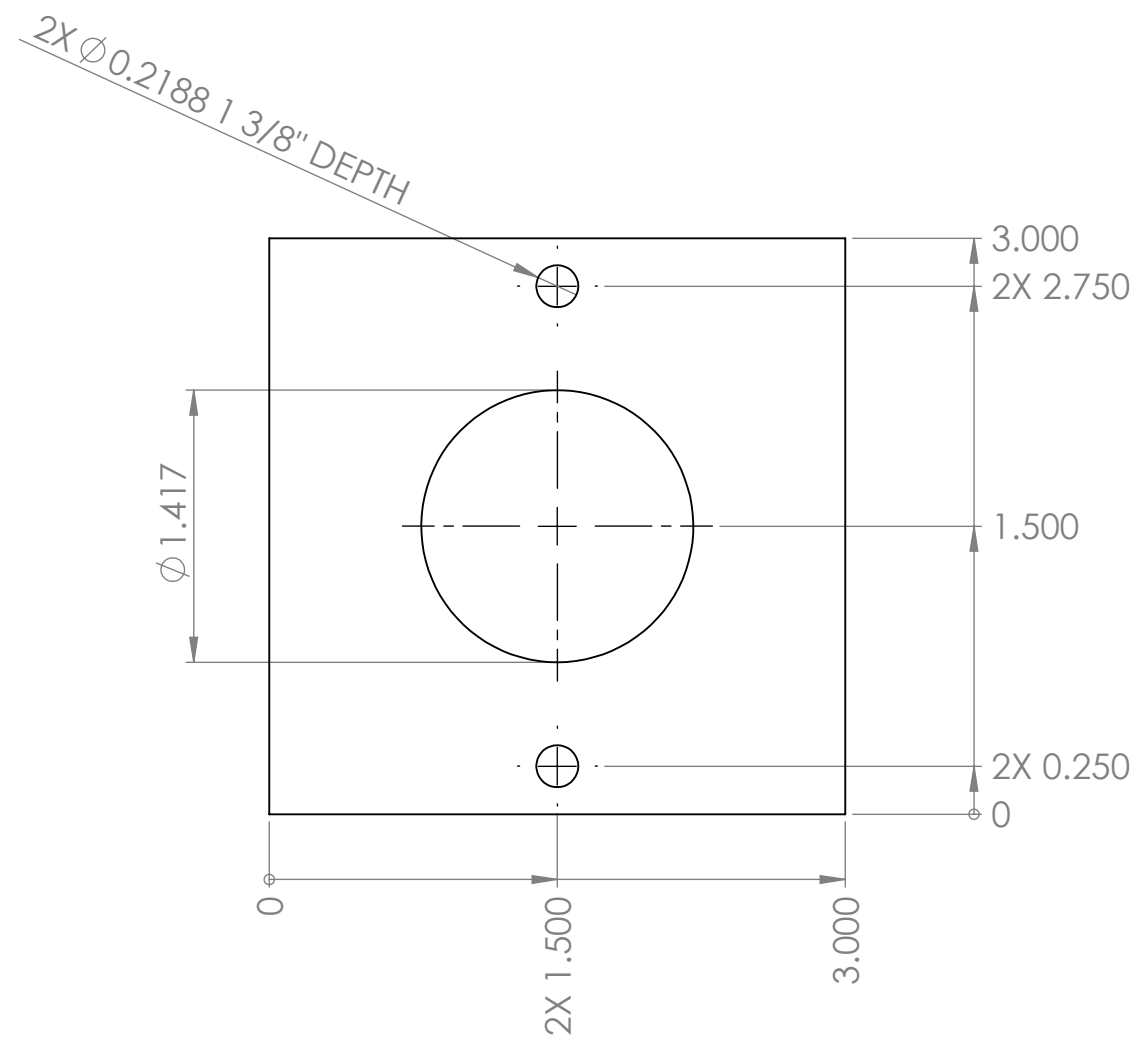
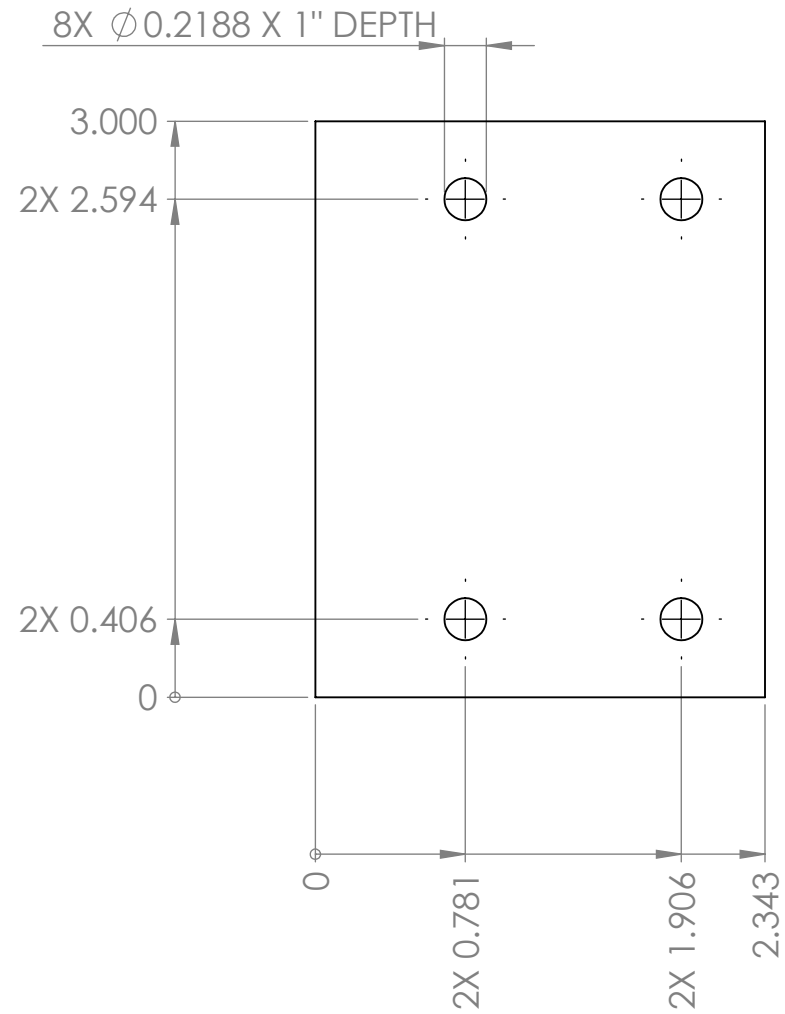
4

3

DO NOT SCALE DRAWING

2

1



**Notes**

1. Cut Raw Material down to size (2.34 in.)
2. Cut 8x .20 inch diameter holes to length of 1" depth (To then tap 1/4"-20 x 3/4" for bolts)
3. Cut 2x .20 inch diameter holes to length of 1.375" depth (To then tap 1/4"-20 x 1" for bolts).

DRAWN BY: DKM	SIZE	MATERIAL
APPROVED BY: JPB	<b>B</b>	3" x 3" Square 1018 Steel
DATE: 03/31/2022		FINISH
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES, LINEAR: $\pm 1/64$ ANGULAR: $\pm 2^\circ$		TITLE:
		Motor Hub Connection
DWG. NO.		BCSC-MOTOR-HUB-002
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

3

2

1

B

B

A

A

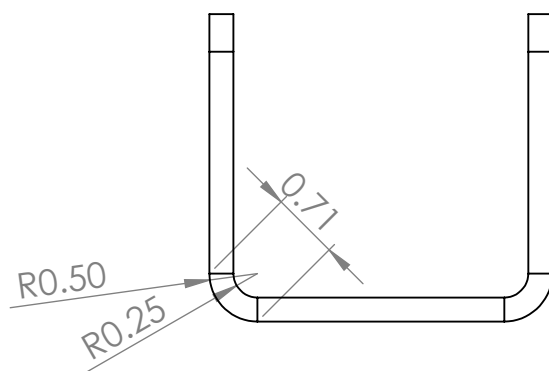
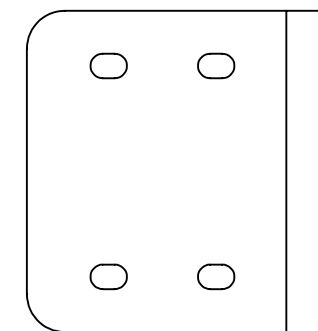
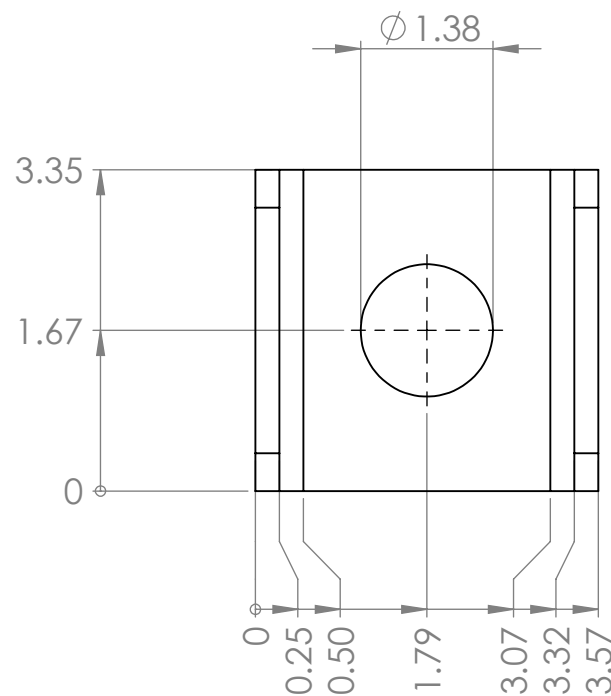
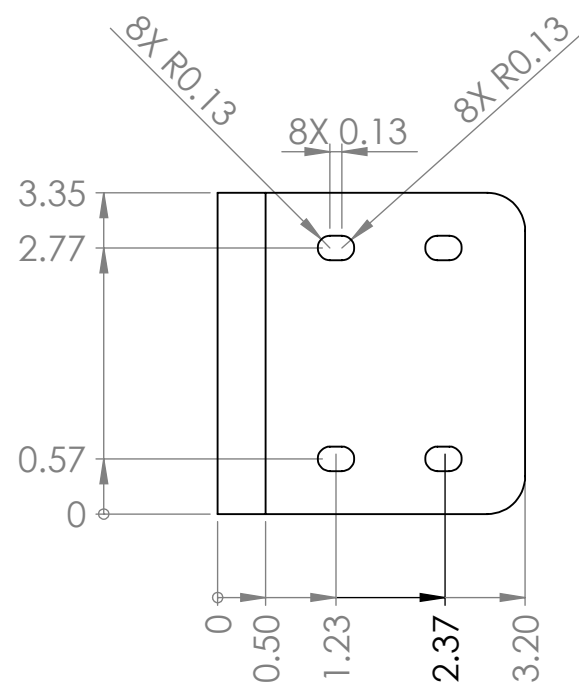
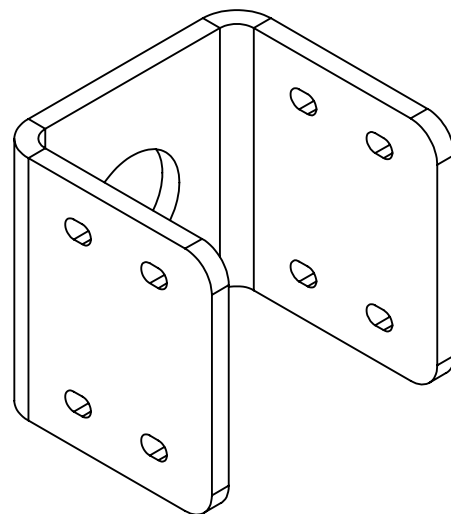
4

3

DO NOT SCALE DRAWING

2

1



DRAWN BY: DKM	SIZE	MATERIAL	Steel
APPROVED BY: JFB	<b>B</b>	FINISH	
DATE: 03/31/2022		TITLE:	BCSC- C-Channel
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES, LINEAR: ± XXX ANGULAR: ± 2°		DWG. NO.	outer c channel
<b>Bearcat</b> <b>Solar Car Team</b>		SCALE: 1:2	WEIGHT: SHEET 1 OF 1

4

3

2

1



4

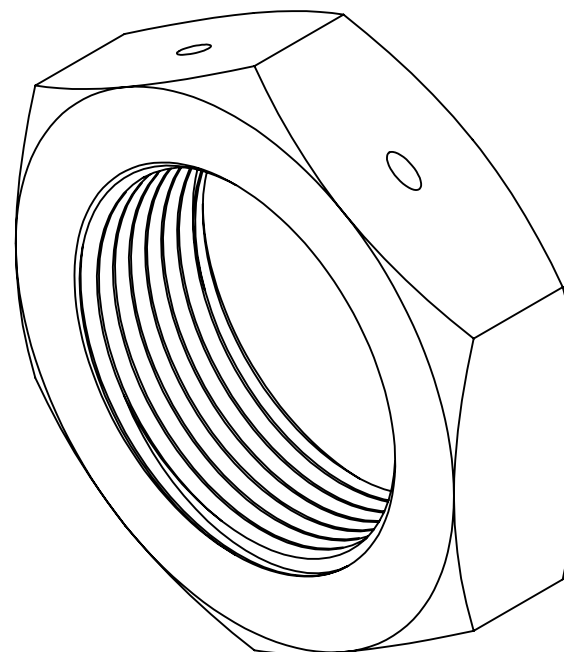
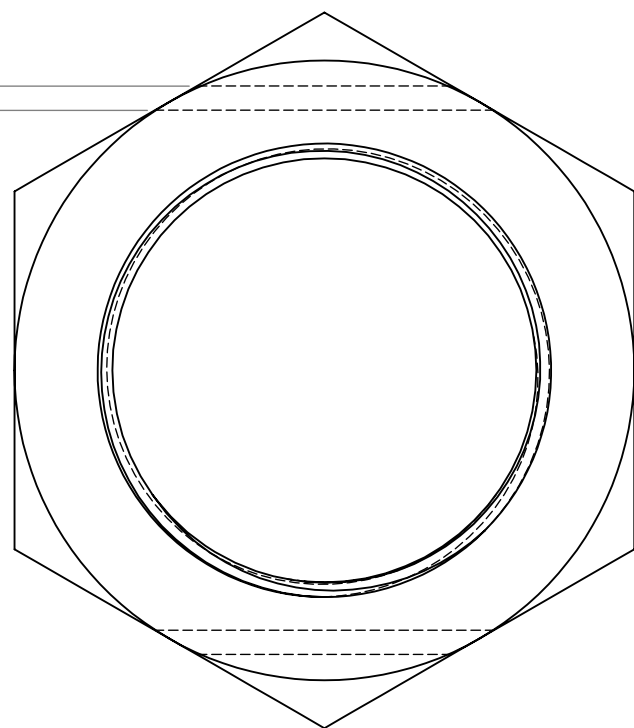
3

DO NOT SCALE DRAWING

2

1

$\phi 0.06$



DRAWN BY: XXX	SIZE <b>B</b>	MATERIAL Steel
APPROVED BY: XXX		FINISH
DATE: XX/XX/XXXX		TITLE: Fine-Thread Medium-Strength Steel Thin Hex Nut
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES, LINEAR: $\pm$ XXX ANGULAR: $\pm$ 2°		DWG. NO. Fine-Thread Medium-Strength Steel Thin Hex Nut
<b>Bearcat</b> <b>Solar Car Team</b>		SCALE: 2:1 WEIGHT: SHEET 1 OF 1

3

2

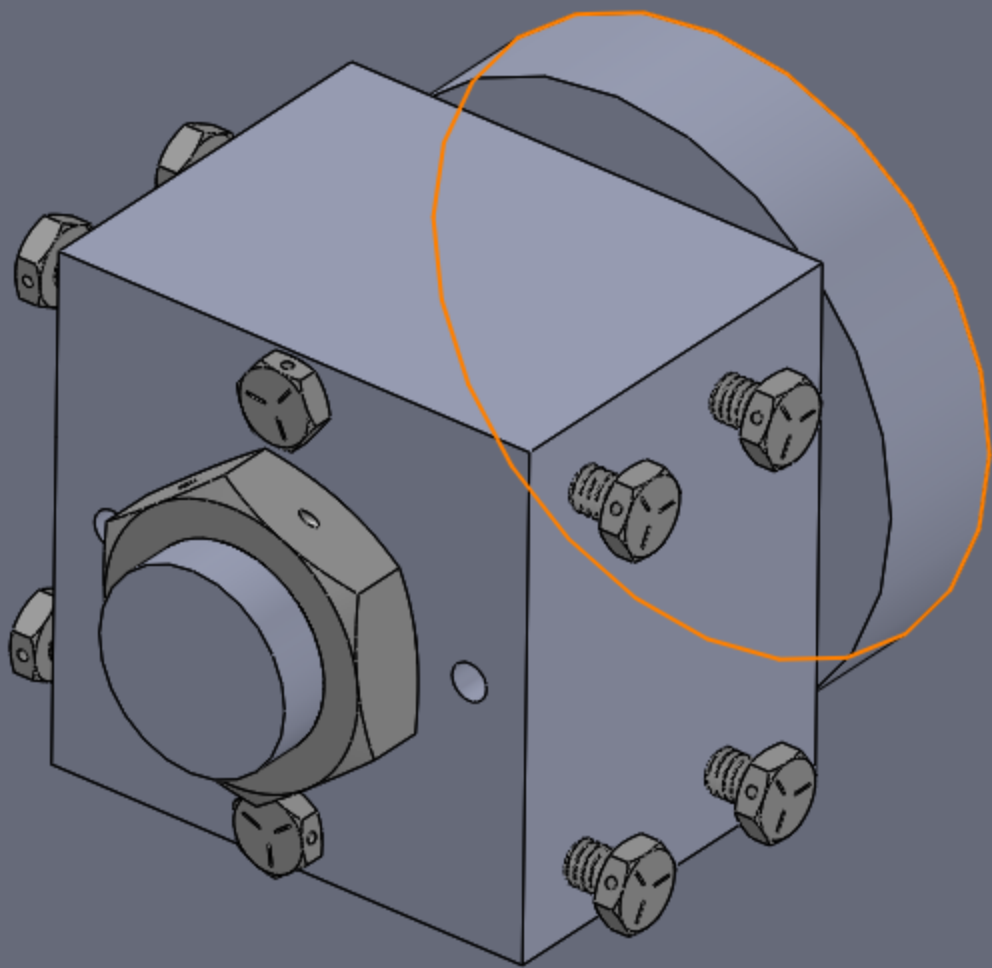
1

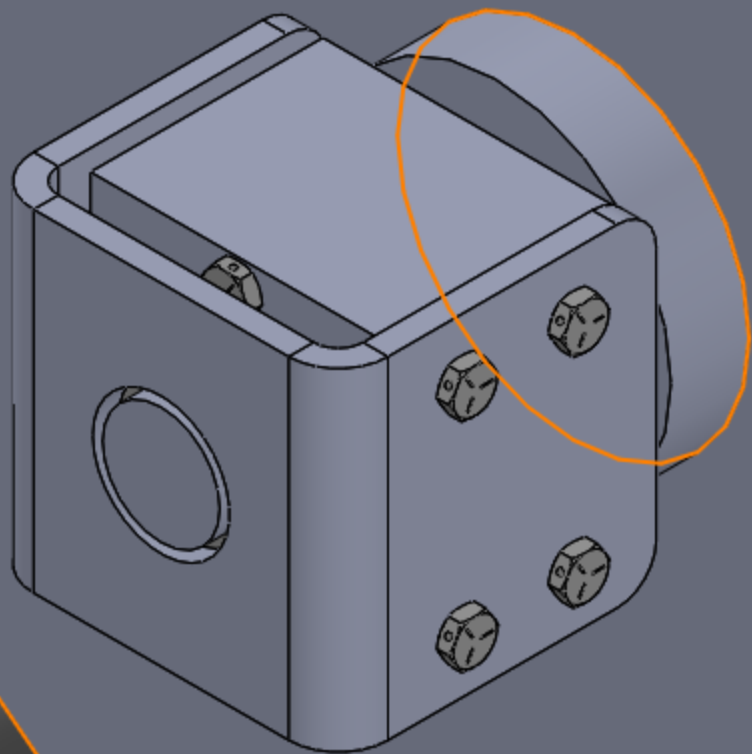
B

B

A

A



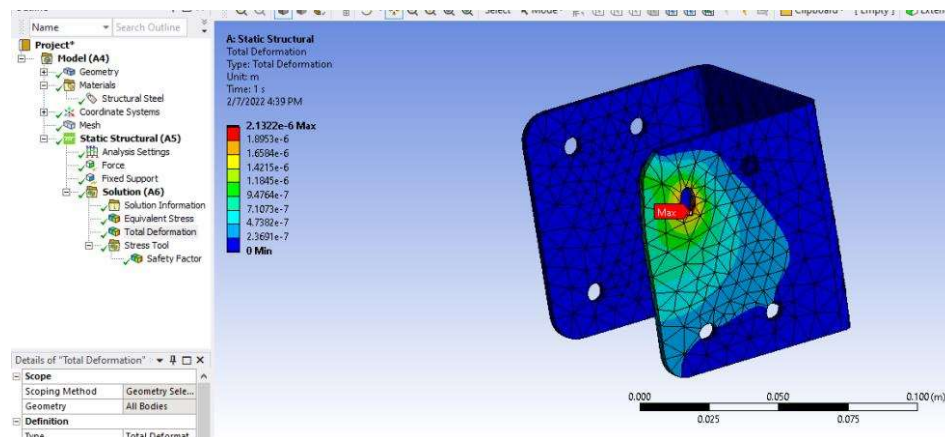
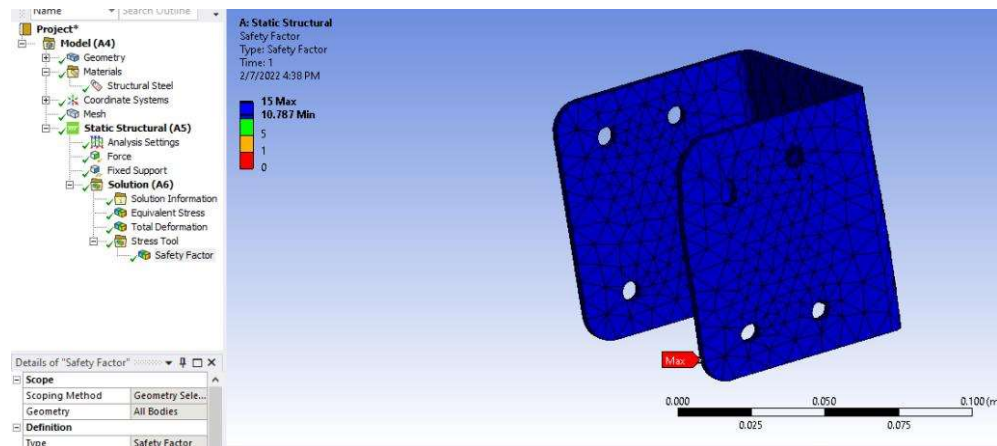


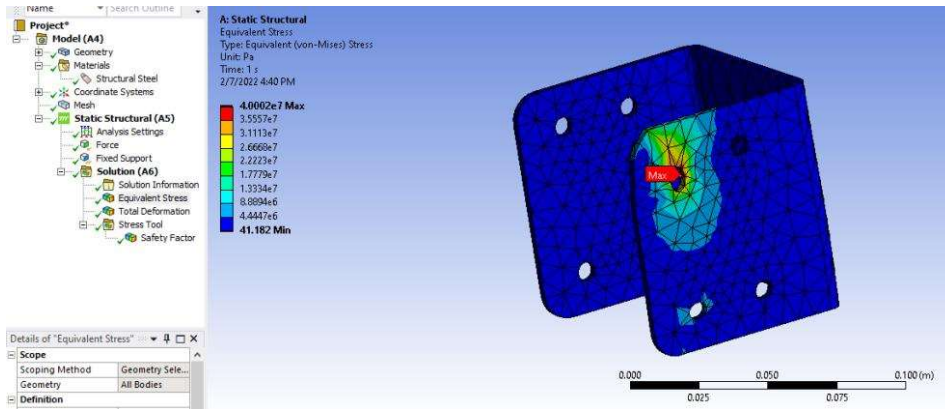
## Screw Calculations

Steel Wire-Lockable Hex Head Screw Black-Oxide, 1/4"-20 Thread Size, 1" Long

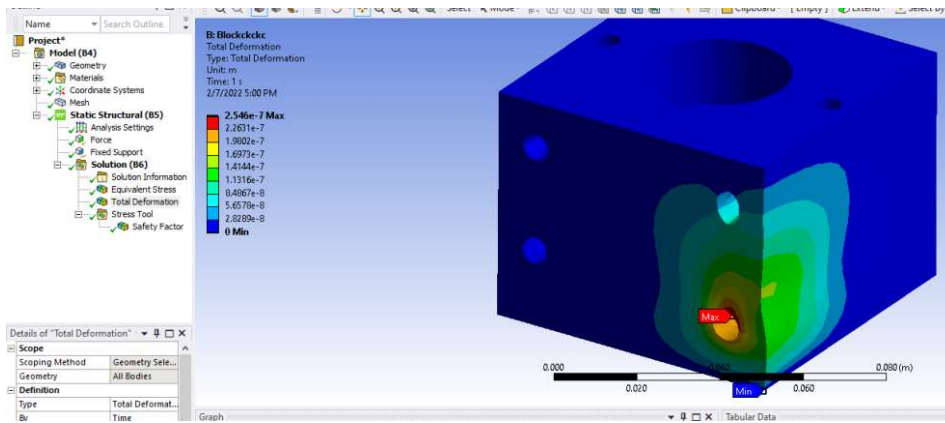
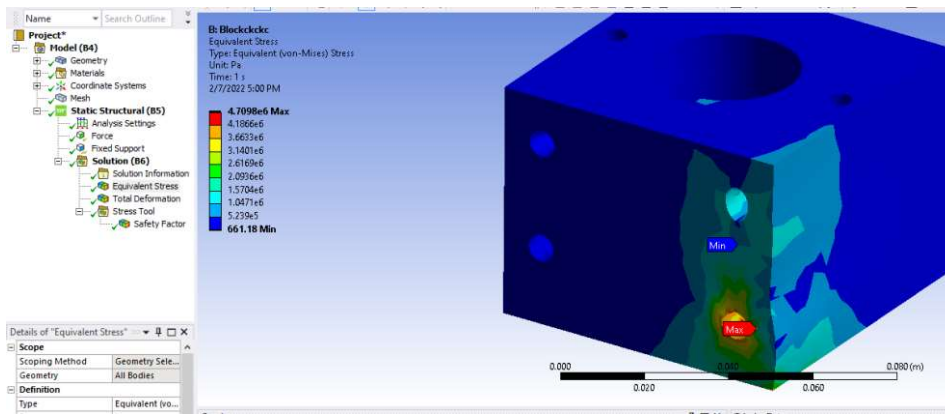
- <https://www.mcmaster.com/90124A314/>
- Tensile Strength - 120,000 psi = 827.371 MPa
- Hole Diameter – 0.063” (For Safety Wire)
- Right Hand – 1/4"-20 Thread Size
- 4x on each side of C-Chanel (8x total) holding to 1/8” material
- 2G Bump = Max Force = 2 kN
- 2 kN/8 screws = 250 N per screw
  - 250 N per 66.81 mm<sup>2</sup> (Area of one hole)
  - 3,741,954.8 pascals (3.7419548 MPa)
  - If 2 kN per 33.41 mm<sup>2</sup> (Full Sim on half hole)
  - 59,862,316.7 pascals (59.8623167 MPa)
  - FOS Min = 13.8
- Need 10 for Design
  - \$9.86 per pack of 5

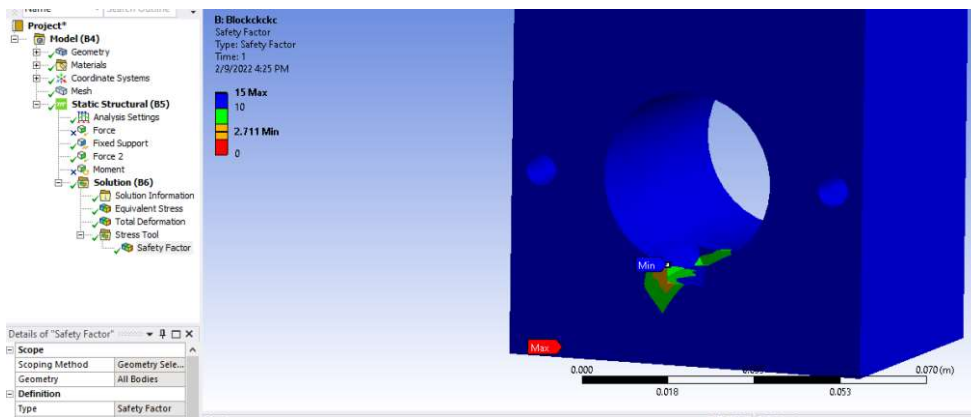
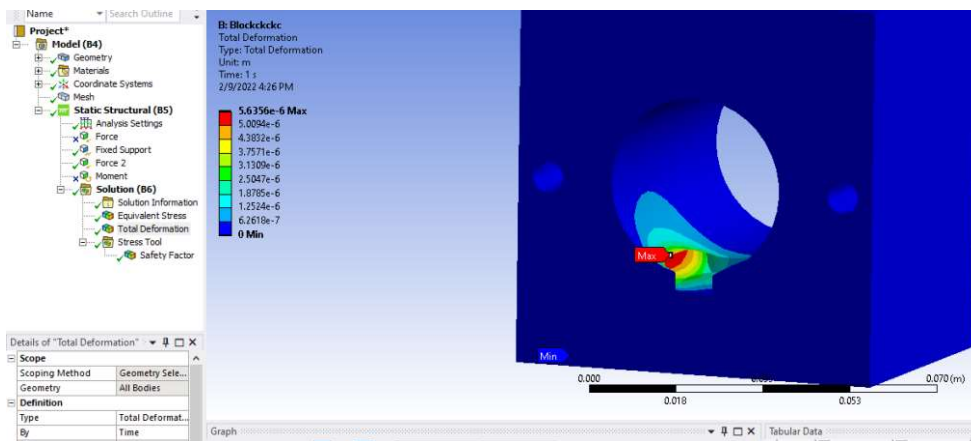
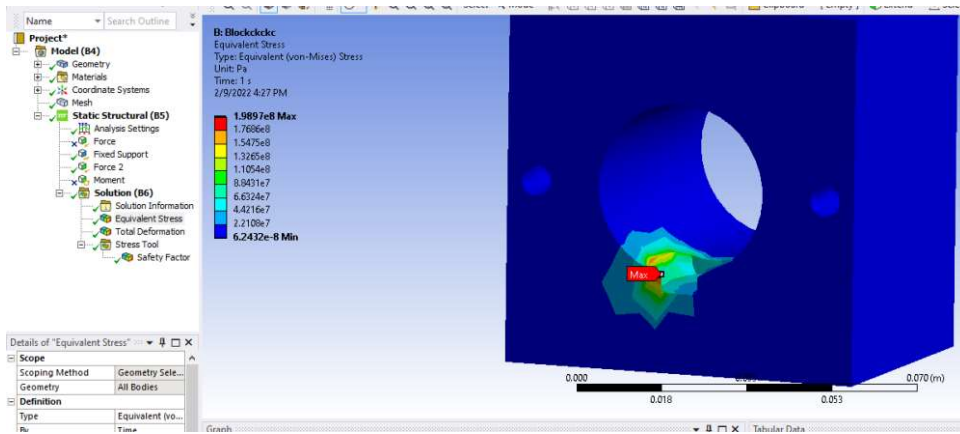
## 1/8” FEA For C Chanel (Safety Factor, Deformation, Equivalent Stress)



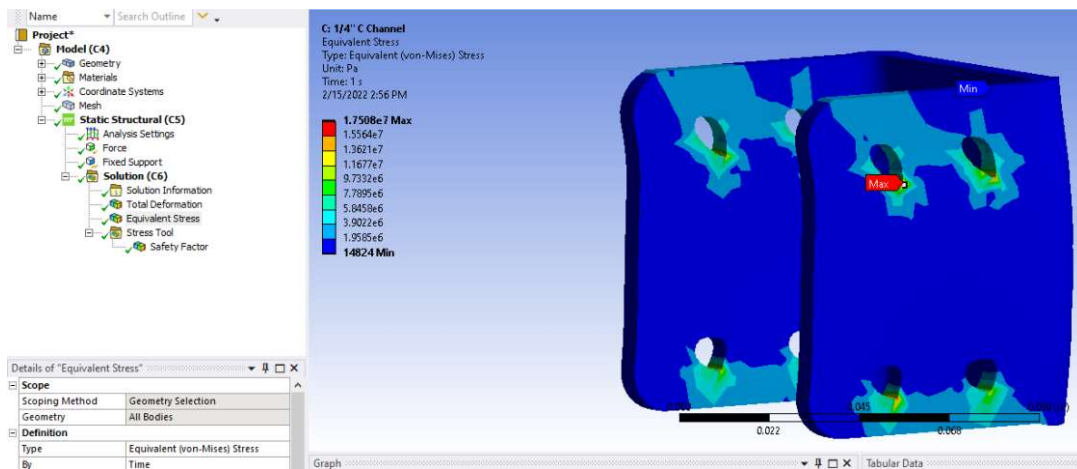
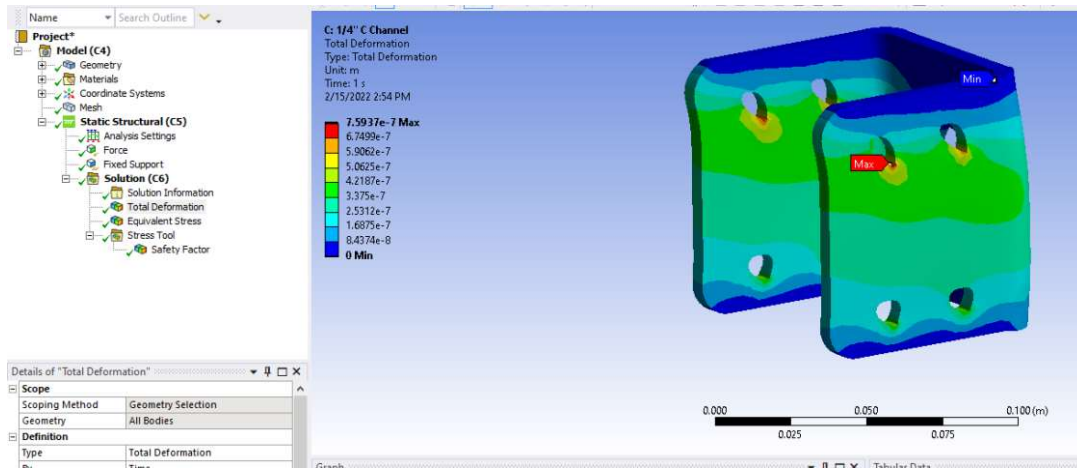


**FEA For Hub Connection Block (equivalent stress, Deformation, Safety Factor)**





# 1/4" FEA For C Channel (Deformation, Equivalent Stress)





**Alibaba.com Singapore E-Commerce Private Ltd.**  
GST Reg. No. : M90371710Y  
8 Shenton Way, #45-01 AXA Tower, Singapore 068811

## Invoice

### Customer Information

Customer Name: -  
Customer Address : US

Invoice No. : 130779751501020830\_100148294704  
Invoice Date: 2022-01-19

### Order Information

Order Number : 130779751501020830

Order Create Time : 2022-01-11

Description	Payment Amount	Transaction Service Fee
Transaction Service Fee	786.16 USD	23.51 USD
Amount Due		809.67 USD

E. & O. E.

### Note:

1. Alibaba.com Singapore E-Commerce Private Limited reserves all rights to determine and conclude all items and amounts set out in this invoice and all services and products defined herein.
2. This is a computer-generated document and no signature is required.
3. The price payable includes Singapore GST, but is quoted exclusive of any other applicable taxes.



# TAIZHOU SIA SCIENCE AND TECHNOLOGY CO.,LTD.

4F, Building 8,188 Kaifa east Road, Development Zone,Taizhou City, Zhejiang Province, China

Contact:Vincent WeChat/Phone Number:+86 13676668276 E-mail:Vincent@siaecosys.com Tel:+86 88551619 Skype:Vincent Xu



## Taizhou Quanshun Electric Drive Technology Co.,Ltd. (Powered By SIA ECOSYS)

No. 2555, Shugang Road Section, Pengjie Town, Luqiao District, Taizhou City, Zhejiang Province, P.R China

### PROFORMA INVOICE

To: David Meiners

Attention:

Address:

Phone:

Email: @gmail.com

Postcode:



Quo. No.: XY11220112024

Date: 12 January 2022

Client code.: UNITED STATES4245

Version: V1.0

PO No.:

S/N	Descriptions	Qty (piece)	U/p (USD)	T/p (USD)	Remarks
1	<b>QS SS273-17*3.5-2000-28-V3-72 2000W V3 17*3.5 Inch 273 Single shaft E-Scooter Hub Motor</b> Volt & Speed:Logo: With"QSMOTOR"logo Powered by SIA ECOSYS	1	\$356.16	\$356.16	 QS MOTOR 
<b>EXW</b>				\$356.16	
<b>Shipping Cost</b>				\$430.00	
<b>Total Amount, CNF</b>				\$786.16	

Payment term: Bank Transfer (T/T) Money Gram or Western Union/Paypal 100% in advance

Producing Time: 10-13 working days after receiving payment

Warranty: 15months (since the date of producing), not include destructive test/abusing usage due to test purpose. For mass production, offer 1% hall sensor set as spare part.

Packing: Stand packing with proper protection to the goods during the transportaion.

Delivery Address: same as above

Products Quotation Validity: 30 days.

The quotation is based on the exchange rate between 6.5-6.8.If the exchange rate is lower than 6.35, please contact our sales representative for a new quotation.

Shipping Quotation (by sea & air) Validity: 7 days. Check again before delivery, retreat more fill less.

TAIZHOU SIA SCIENCE AND TECHNOLOGY CO.,LTD. is our own exporting system, and the foreign exchange account information below:

BANK INFO(USD account):

BANK INFO(USD account):

BENEFICIARY: TAIZHOU SIA SCIENCE AND TECHNOLOGY CO.,LTD.

BEN'S ACCOUNT: 394877174621

BEN'S BANK: BANK OF CHINA TAIZHOU BR JIAOJIANG SUB BR ZHEJIANG CHINA

BANK'S ADDRESS: 269 ZHONGXIN RD JIAOJIANG TAIZHOU ZHEJIANG CHINA

SWIFT: BKCHCNBJ92J

P.S.: Please note Beneficiary is TAIZHOU SIA SCIENCE AND TECHNOLOGY CO.,LTD. , and to place the order asap, could you please send your bank slip after payment(there maybe 2-3 working days to received the payment), Thank you for your understanding in advance.

Remark: We will not change our bank information without any formal documentary advising.

If any suspicious documents with different bank account, please contact us by telephone for confirmation.

For custom duties, it needs to be paid by customer himself, the seller doesn't bear the duty.

For bulk orders, there is storage charge USD 3.5/m<sup>2</sup> for the goods exceeds one month since produced and QC passed.

Date	Motor History Log	Personel
10/21/2021	Initial inquiry into purchasing motor (Asking about the specifications of the motor to get a better understanding if the motor would work for our application.)	Di Shi
10/22/2021	We received initial specifications on the motor	Di Shi
11/9/2021	We reached out with more questions on specific dimensions and more pictures/3D models (Response on 12/2)	Di Shi
12/2/2021	We asked about the price of shipping (Quick response)	Di Shi
12/16/2021	We sent purchase request through campuslink	Patty Speed
12/16/2021	Purchase request approved by treasurer	Matt Wiegandt
12/16/2021	Purchase request approved by advisor	Muthar
1/6/2022	Patty notified us that she would not order the motor and we would have to do this on our own	Patty Speed
1/7/2022	We initiated contact to purchase a motor	Di Shi
1/7/2022	We were told production time is about 14 days and shipping before Feb. 1st	Di Shi
1/8/2022	Information given for purchase of the order	Di Shi
1/10/2022	We inquire about when the order will be ready to purchase	Di Shi
1/11/2022	We inquire about when the order will be ready to purchase again	Di Shi
1/11/2022	Vincent Sent order information to us	Vincent Xu
1/12/2022	We notified Vincent of errors on the invoice	Vincent Xu
1/12/2022	We received the new invoice	Vincent Xu
1/12/2022	Purchased Motor (Have invoice)	Vincent Xu
1/18/2022	We were notified shipping will be arranged after the Chinese new year (Feb 10 - feb 15), ETA end of February	Di Shi
2/15/2022	We were told shipping will be arranged soon	Di Shi
2/21/2022	We reached out about when shipping will be arranged	Di Shi
2/21/2022	We were told parcel was packed and waiting to be picked up	Di Shi
2/23/2022	We asked if the piece has been shipped yet	Di Shi
2/28/2022	We asked if the piece has been shipped yet, again	Di Shi
2/28/2022	We were told the item will be shipped this week	Di Shi
3/1/2022	We asked for the arrival date of the motor	Di Shi
3/1/2022	We were told it depends on our local shipping but that it should arrive soon	Di Shi
3/2/2022	We asked again when the motor will be shipped	Di Shi
3/2/2022	We asked if the piece will be shipped by air	Di Shi
3/7/2022	We asked if the motor was shipped	Di Shi
3/9/2022	We asked if the motor was shipped again	Di Shi
3/10/2022	We were told parcel was picked up	Vincent Xu
3/18/2022	We were told the motor will be shipped by air	Vincent Xu
3/20/2022	We were told the piece will be held for a week at "the station" and will take 3 days to arrive after the week, ETA Beginning of April	Vincent Xu
3/24/2022	We asked when the piece will arrive again	Vincent Xu
3/29/2022	Piece stuck in shanghai due to lockdown	Vincent Xu
4/7/2022	Asked when the lockdown will not longer be in effect.	Vincent Xu
4/21/2022	Asked if the piece was still in Shanghai	Vincent Xu

Metric Tap & Clearance Drill Sizes		Tap Drill				Clearance Drill			
		75% Thread for Aluminum, Brass, & Plastics		50% Thread for Steel, Stainless, & Iron		Close Fit		Standard Fit	
Screw Size (mm)	Thread Pitch (mm)	Drill Size (mm)	Closest American Drill	Drill Size (mm)	Closest American Drill	Drill Size (mm)	Closest American Drill	Drill Size (mm)	Closest American Drill
M1.5	0.35	1.15	56	1.25	55	1.60	1/16	1.65	52
M1.6	0.35	1.25	55	1.35	54	1.70	51	1.75	50
M 1.8	0.35	1.45	53	1.55	1/16	1.90	49	2.00	5/64
M 2	0.45	1.55	1/16	1.70	51	2.10	45	2.20	44
	0.40	1.60	52	1.75	50				
M 2.2	0.45	1.75	50	1.90	48	2.30	3/32	2.40	41
M 2.5	0.45	2.05	46	2.20	44	2.65	37	2.75	7/64
M 3	0.60	2.40	41	2.60	37	3.15	1/8	3.30	30
	0.50	2.50	39	2.70	36				
M 3.5	0.60	2.90	32	3.10	31	3.70	27	3.85	24
M 4	0.75	3.25	30	3.50	28	4.20	19	4.40	17
	0.70	3.30	30	3.50	28				
M 4.5	0.75	3.75	25	4.00	22	4.75	13	5.00	9
M 5	1.00	4.00	21	4.40	11/64	5.25	5	5.50	7/32
	0.90	4.10	20	4.40	17				
	0.80	4.20	19	4.50	16				
M 5.5	0.90	4.60	14	4.90	10	5.80	1	6.10	B
M 6	1.00	5.00	8	5.40	4	6.30	E	6.60	G
	0.75	5.25	4	5.50	7/32				
M 7	1.00	6.00	B	6.40	E	7.40	L	7.70	N
	0.75	6.25	D	6.50	F				
M 8	1.25	6.80	H	7.20	J	8.40	Q	8.80	S
	1.00	7.00	J	7.40	L				
M 9	1.25	7.80	N	8.20	P	9.50	3/8	9.90	25/64
	1.00	8.00	O	8.40	21/64				
M 10	1.50	8.50	R	9.00	T	10.50	Z	11.00	7/16
	1.25	8.80	11/32	9.20	23/64				
	1.00	9.00	T	9.40	U				
M 11	1.50	9.50	3/8	10.00	X	11.60	29/64	12.10	15/32
M 12	1.75	10.30	13/32	10.90	27/64	12.60	1/2	13.20	33/64
	1.50	10.50	Z	11.00	7/16				
	1.25	10.80	27/64	11.20	7/16				
M 14	2.00	12.10	15/32	12.70	1/2	14.75	37/64	15.50	39/64
	1.50	12.50	1/2	13.00	33/64				
	1.25	12.80	1/2	13.20	33/64				
M 15	1.50	13.50	17/32	14.00	35/64	15.75	5/8	16.50	21/32
M 16	2.00	14.00	35/64	14.75	37/64	16.75	21/32	17.50	11/16
	1.50	14.50	37/64	15.00	19/32				
M 17	1.50	15.50	39/64	16.00	5/8	18.00	45/64	18.50	47/64
M 18	2.50	15.50	39/64	16.50	41/64	19.00	3/4	20.00	25/32
	2.00	16.00	5/8	16.75	21/32				
	1.50	16.50	21/32	17.00	43/64				
M 19	2.50	16.50	21/32	17.50	11/16	20.00	25/32	21.00	53/64
M 20	2.50	17.50	11/16	18.50	23/32	21.00	53/64	22.00	55/64
	2.00	18.00	45/64	18.50	47/64				
	1.50	18.50	47/64	19.00	3/4				

Tap & Clearance Drill Sizes				Tap Drill				Clearance Drill			
Screw Size	Major Diameter	Threads Per Inch	Minor Diameter	75% Thread for Aluminum, Brass, & Plastics		50% Thread for Steel, Stainless, & Iron		Close Fit		Free Fit	
				Drill Size	Dec. Eq.	Drill Size	Dec. Eq.	Drill Size	Dec. Eq.	Drill Size	Dec. Eq.
0	.0600	80	.0447	3/64	.0469	55	.0520	52	.0635	50	.0700
1	.0730	64	.0538	53	.0595	1/16	.0625	48	.0760	46	.0810
		72	.0560	53	.0595	52	.0635				
2	.0860	56	.0641	50	.0700	49	.0730	43	.0890	41	.0960
		64	.0668	50	.0700	48	.0760				
3	.0990	48	.0734	47	.0785	44	.0860	37	.1040	35	.1100
		56	.0771	45	.0820	43	.0890				
4	.1120	40	.0813	43	.0890	41	.0960	32	.1160	30	.1285
		48	.0864	42	.0935	40	.0980				
5	.125	40	.0943	38	.1015	7/64	.1094	30	.1285	29	.1360
		44	.0971	37	.1040	35	.1100				
6	.138	32	.0997	36	.1065	32	.1160	27	.1440	25	.1495
		40	.1073	33	.1130	31	.1200				
8	.1640	32	.1257	29	.1360	27	.1440	18	.1695	16	.1770
		36	.1299	29	.1360	26	.1470				
10	.1900	24	.1389	25	.1495	20	.1610	9	.1960	7	.2010
		32	.1517	21	.1590	18	.1695				
12	.2160	24	.1649	16	.1770	12	.1890	2	.2210	1	.2280
		28	.1722	14	.1820	10	.1935				
		32	.1777	13	.1850	9	.1960				
1/4	.2500	20	.1887	7	.2010	7/32	.2188	F	.2570	H	.2660
		28	.2062	3	.2130	1	.2280				
		32	.2117	7/32	.2188	1	.2280				
5/16	.3125	18	.2443	F	.2570	J	.2770	P	.3230	Q	.3320
		24	.2614	I	.2720	9/32	.2812				
		32	.2742	9/32	.2812	L	.2900				
3/8	.3750	16	.2983	5/16	.3125	Q	.3320	W	.3860	X	.3970
		24	.3239	Q	.3320	S	.3480				
		32	.3367	11/32	.3438	T	.3580				
7/16	.4375	14	.3499	U	.3680	25/64	.3906	29/64	.4531	15/32	.4687
		20	.3762	25/64	.3906	13/32	.4062				
		28	.3937	Y	.4040	Z	.4130				
1/2	.5000	13	.4056	27/64	.4219	29/64	.4531	33/64	.5156	17/32	.5312
		20	.4387	29/64	.4531	15/32	.4688				
		28	.4562	15/32	.4688	15/32	.4688				
9/16	.5625	12	.4603	31/64	.4844	33/64	.5156	37/64	.5781	19/32	.5938
		18	.4943	33/64	.5156	17/32	.5312				
		24	.5114	33/64	.5156	17/32	.5312				
5/8	.6250	11	.5135	17/32	.5312	9/16	.5625	41/64	.6406	21/32	.6562
		18	.5568	37/64	.5781	19/32	.5938				
		24	.5739	37/64	.5781	19/32	.5938				
11/16	.6875	24	.6364	41/64	.6406	21/32	.6562	45/64	.7031	23/32	.7188
3/4	.7500	10	.6273	21/32	.6562	11/16	.6875	49/64	.7656	25/32	.7812
		16	.6733	11/16	.6875	45/64	.7031				
		20	.6887	45/64	.7031	23/32	.7188				
13/16	.8125	20	.7512	49/64	.7656	25/32	.7812	53/64	.8281	27/32	.8438
7/8	.8750	9	.7387	49/64	.7656	51/64	.7969	57/64	.8906	29/32	.9062
		14	.7874	13/16	.8125	53/64	.8281				
		20	.8137	53/64	.8281	27/32	.8438				
15/16	.9375	20	.8762	57/64	.8906	29/32	.9062	61/64	.9531	31/32	.9688
1	1.000	8	.8466	7/8	.8750	59/64	.9219	1-1/64	1.0156	1-1/32	1.0313
		12	.8978	15/16	.9375	61/64	.9531				
		20	.9387	61/64	.9531	31/32	.9688				

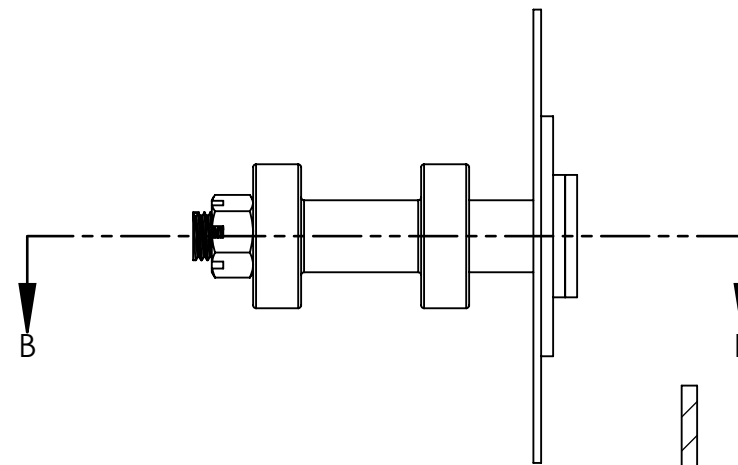
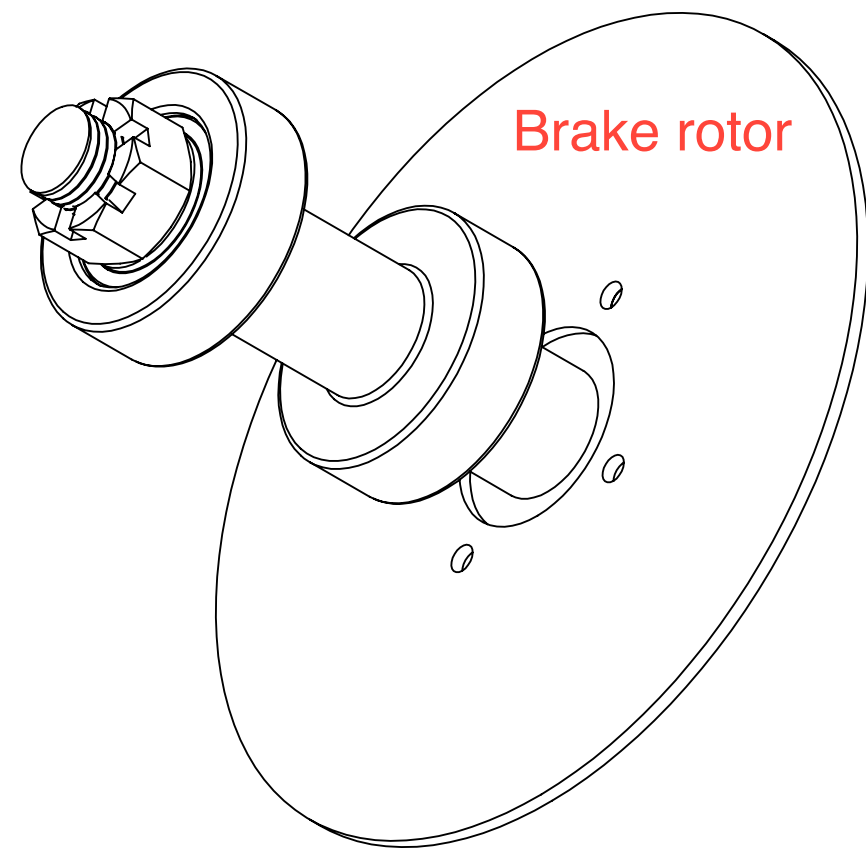
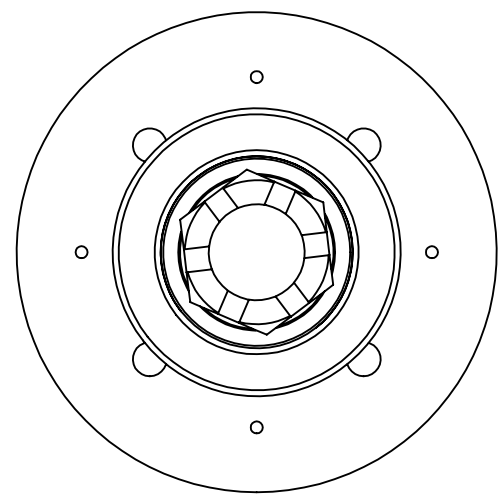
## 13.7 Wheel Hub & Brakes

4

3

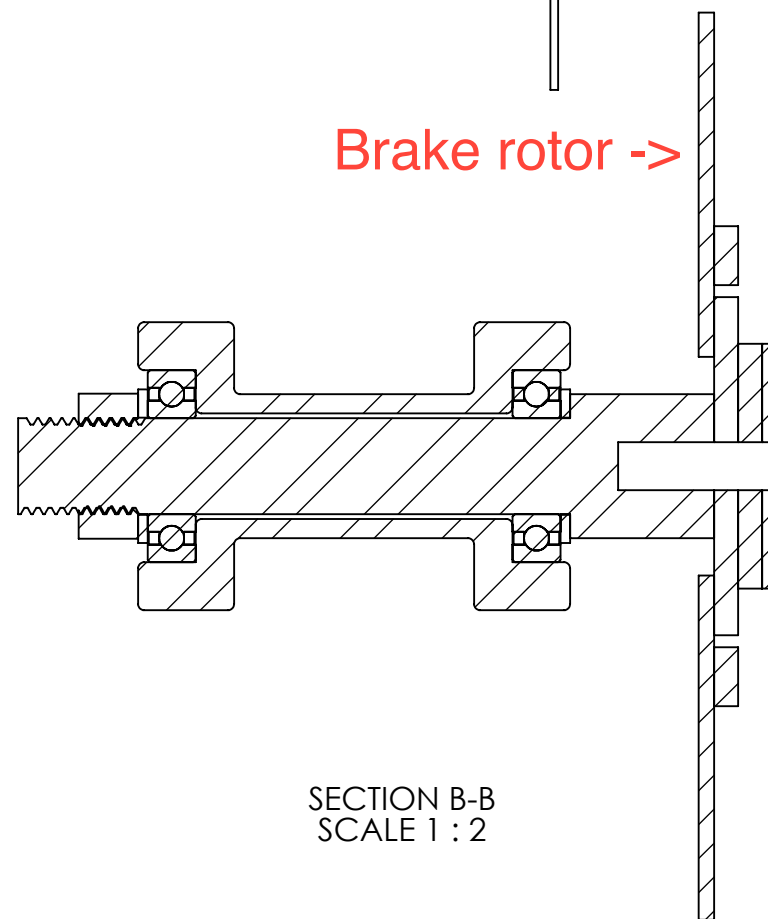
2

1



Brake rotor ->

<- wheel adapter



Disks that are machined to fit the hub bore. "cookies"

SECTION B-B  
SCALE 1 : 2

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		DIMENSIONS ARE IN INCHES		DRAWN		TITLE:	
		TOLERANCES:		CHECKED			
		FRACTIONAL ±		ENG APPR.			
		ANGULAR: MACH ± BEND ±		MFG APPR.			
		TWO PLACE DECIMAL ±		Q.A.			
		THREE PLACE DECIMAL ±		COMMENTS:			
		INTERPRET GEOMETRIC TOLERANCING PER:				SIZE	DWG. NO.
		MATERIAL					REV
NEXT ASSY	USED ON	FINISH				Hub and Bearing Assembly Drawing for	
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4	WEIGHT:
						SHEET 1 OF 1	

4

3

2

1

B

B

A

A

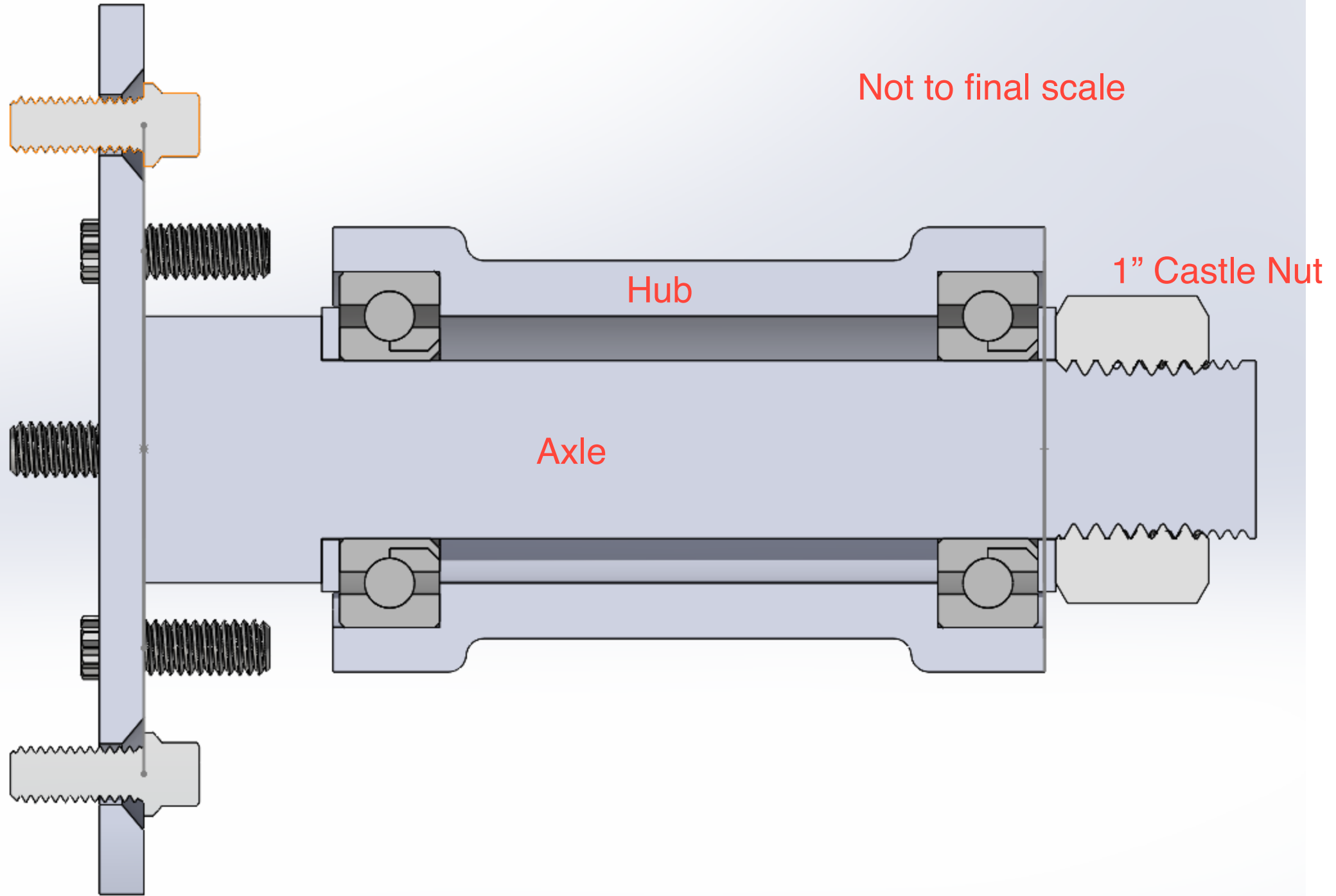
Adapter Plate

Not to final scale

Hub

1" Castle Nut

Axle

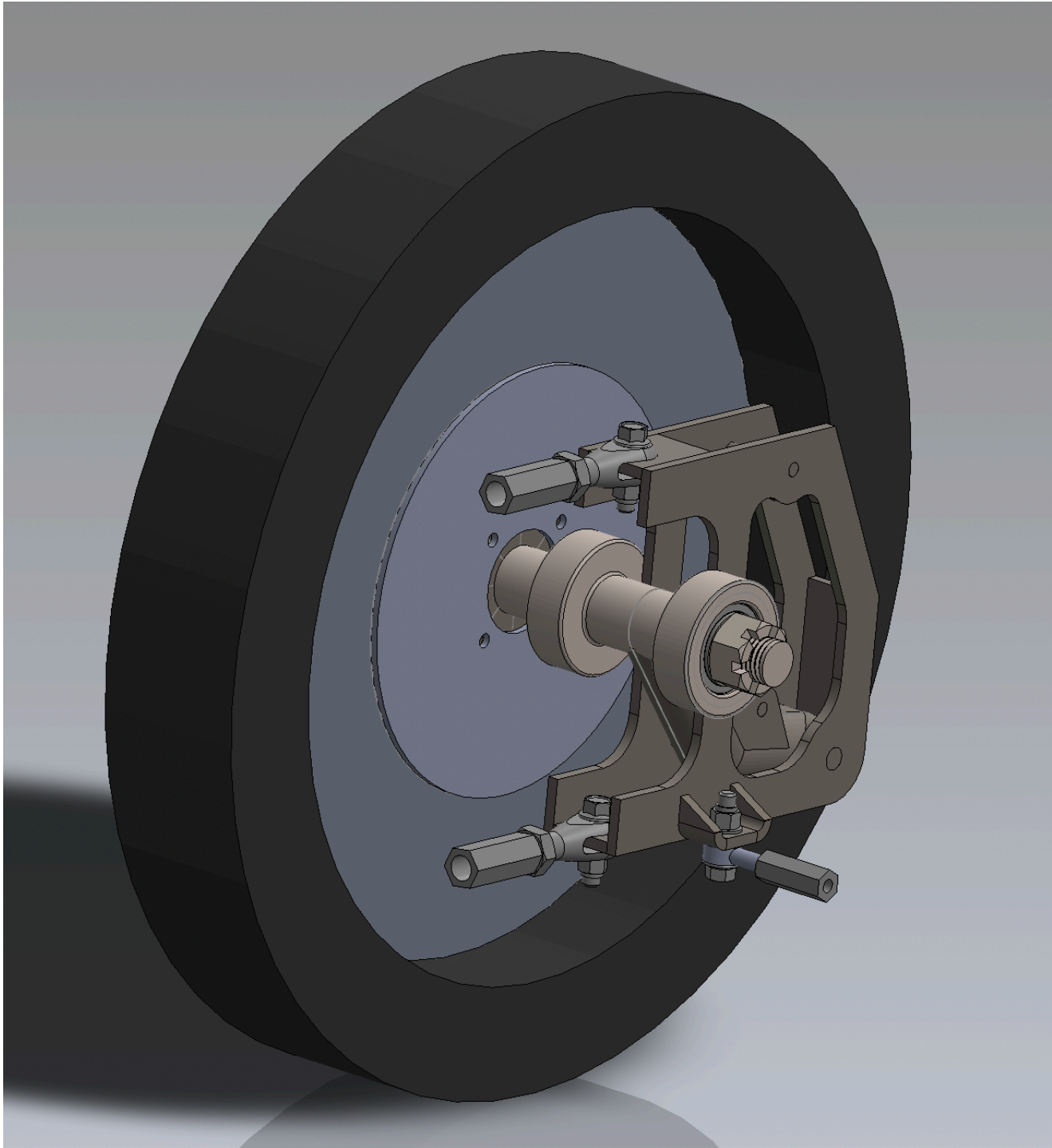


Axle welded up, before machining. The cookies were turned down to 59.99 mm (metric mm). The wheel adapter plate was machined flat. The rest was cleaned up for aesthetics and to reduce weight imbalance.



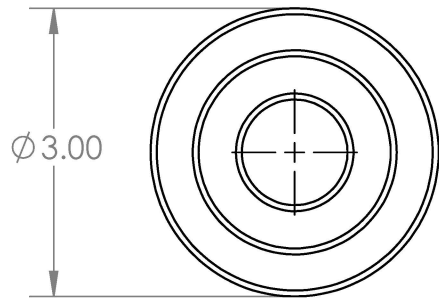
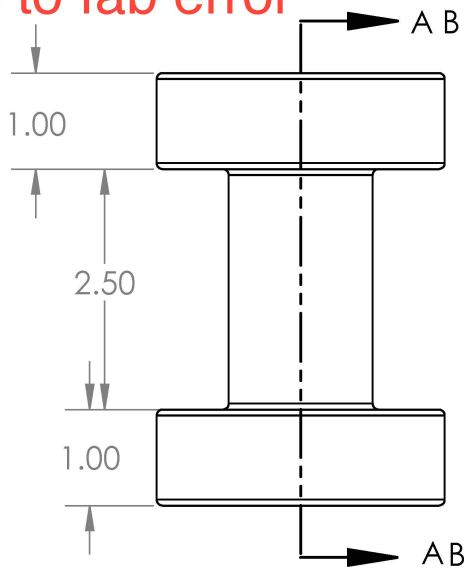
← 60mm “cookies” that slot into wheel bore before machining down to 60 mm exact

← Wheel and rotor adapter plate



Two of the hubs 2  
were 5" in length  
due to fab error

B

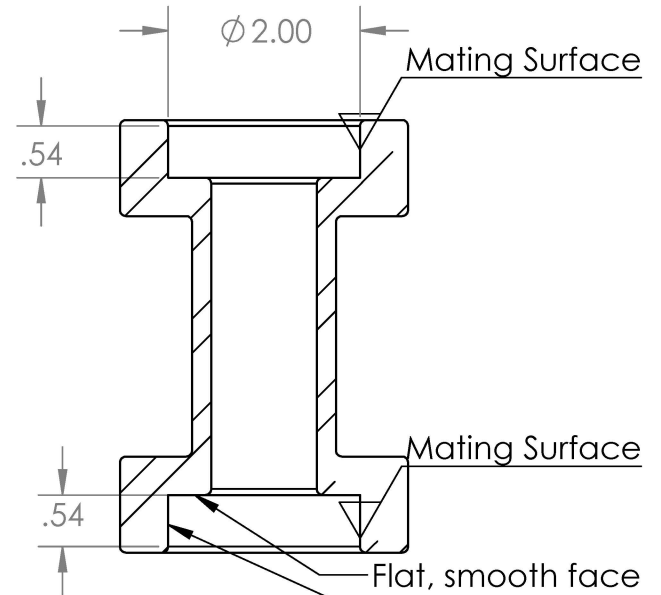


NO fillet allowed

NO fillet allowed

All fillets 1/16  
approx to  
smooth corners

1



Round, smooth surface  
for bearing. Depth must be  
>0.51 inches

B

A

A

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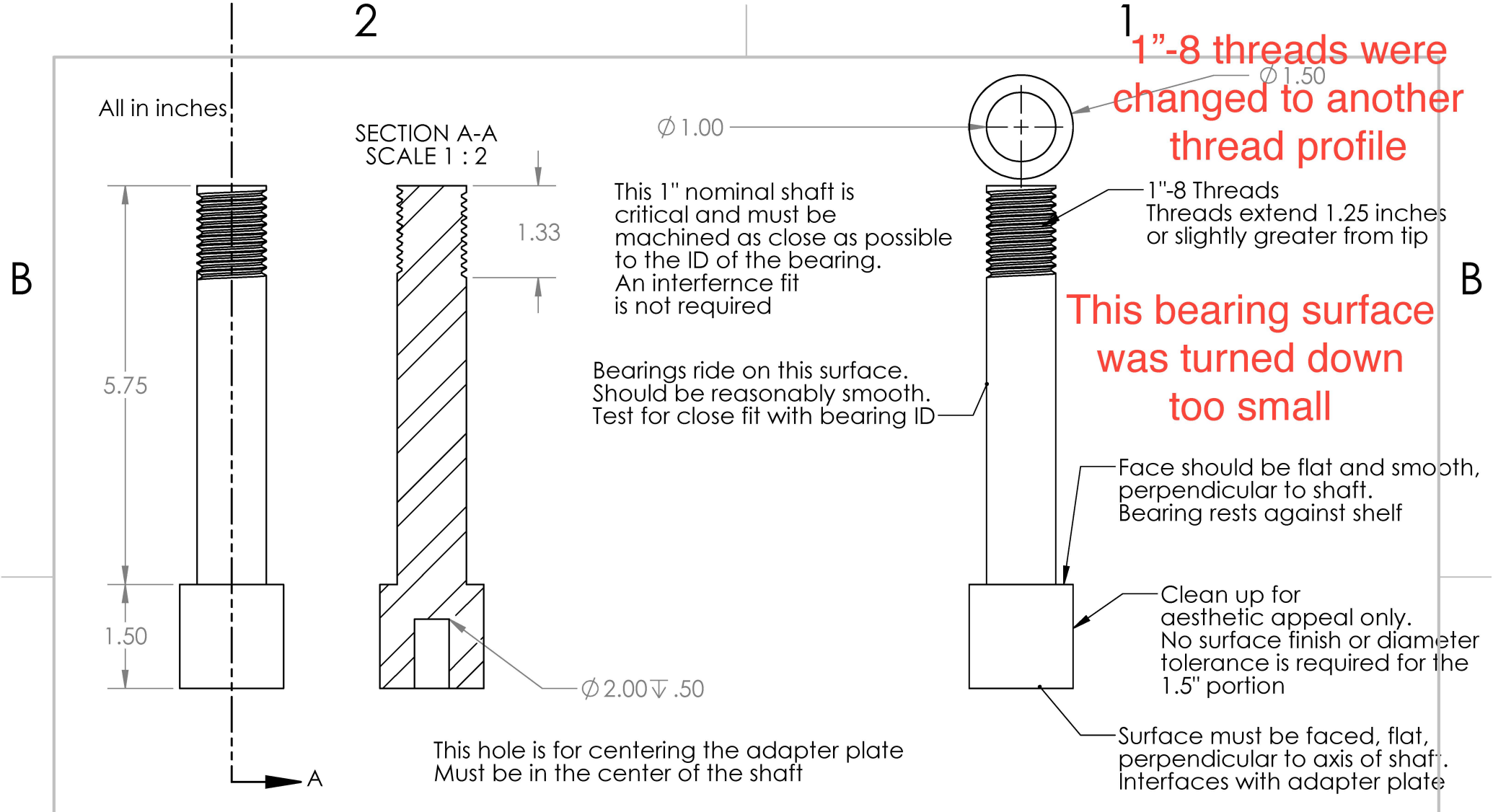
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES	DRAWN		
		TOLERANCES:	CHECKED		
		FRACTIONAL ±	ENG APPR.		
		ANGULAR: MACH ± BEND ±	MFG APPR.		
		TWO PLACE DECIMAL ±	Q.A.		
		THREE PLACE DECIMAL ±	COMMENTS:		
		INTERPRET GEOMETRIC TOLERANCING PER:			
		MATERIAL			
		FINISH			
NEXT ASSY	USED ON				
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE DWG. NO. REV

**A-Hub Drawing**

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

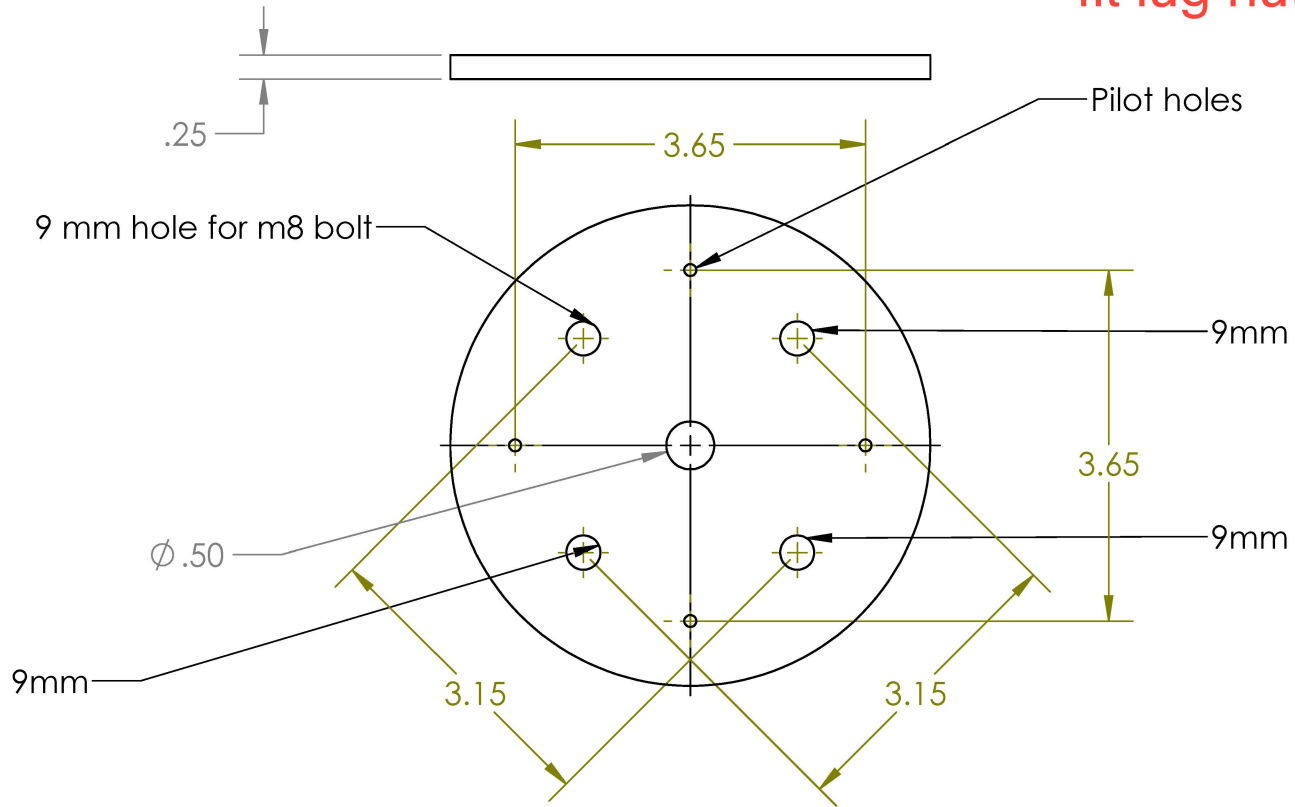


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			DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN					
			INTERPRET GEOMETRIC TOLERANCING PER:	CHECKED					
			MATERIAL	ENG APPR.					
	NEXT ASSY	USED ON	FINISH	MFG APPR.					
APPLICATION		DO NOT SCALE DRAWING		Q.A.			SIZE	DWG. NO.	REV
				COMMENTS:			<h1>Stab Axle Drawing</h1>		
					SCALE: 1:4	WEIGHT:	SHEET 1 OF 1		

2

1

Pilot holes were enlarged to fit lug nuts



B

B

A

A

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		DIMENSIONS ARE IN INCHES	DRAWN		
		TOLERANCES:	CHECKED		
		FRACTIONAL $\pm$	ENG APPR.		
		ANGULAR: MACH $\pm$ BEND $\pm$	MFG APPR.		
		TWO PLACE DECIMAL $\pm$	Q.A.		
		THREE PLACE DECIMAL $\pm$	COMMENTS:		
		INTERPRET GEOMETRIC TOLERANCING PER:			
		MATERIAL			
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:		
SIZE	DWG. NO.	REV
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

Wheel and Rotor Adapter Drawing

2

1