The University of Akron
College of Engineering

Zips Electric Racing Steering Design
Senior Design Report
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Project Members
Adam Bracken (amb389@zips.uakron.edu)
Jon Roberts (jbr27@zips.uakron.edu)
Sean Zimlich (saz23@zips.uakron.edu)

Advisor
Dr. Daniel Deckler

Abstract

The Zips Electric Racing team hasn't had much success in recent years. After joining the team the goal has been to make a competition-worthy car by designing a functioning steering mechanism. The use of materials that are lightweight and cost-effective, yet durable enough to withstand the rigors of competition are very important when used in the racing setting. This design project is the analysis, development, and manufacture of a steering system that will be used on the 2019 formula electric car. The steering design for the 2019 car needed to fit within the parameters of the frame and include the already purchased steering rack manufactured by KAZ Technologies. After completing the design of the remaining steering components in Solidworks and testing the structural integrity using finite element analysis, the components were manufactured in the university's tool shop. Upon the completion of the manufacturing phase, the components were installed in the car along with the rest of the subsystems. After months and months of hard work, the car is now drivable and is in the testing and tuning phase. The team is scheduled to attend two competitions in the upcoming weeks, one in Canada and one in Lincoln, Nebraska.

Acknowledgements

We would like to offer our special thanks to Dr. Daniel Deckler for introducing us to the team and giving us the opportunity to be part of what should be the first rules compliant formula electric car that The University of Akron has ever had. We would also like to thank Matt Evans from the Zips Racing Combustion team for all his help with welding all of our components and the frame. The car would definitely not be what it is today if it weren't for him. Finally, thank you to the entire Zips Electric Racing team for their assistance and cooperation with us throughout the course of this project and of course our team sponsors. Without the generosity of each and every one of them, none of this would be possible.

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Chapter 1: Introduction

1.1 Background

The Zips Electric Racing team started in 2013 and the team has not yet completed an entirely rules compliant car. The main goal of the team this year is of course to have a rules compliant car, and to compete in all events at the two competitions we plan to attend. The three of us responsible for the steering subsystem and contents within this report are all new to the team as of this academic school year.

1.2 Principles of Operation

The steering system needs to be designed such that it is compatible with other subsystems within the car. In addition, it needs to be manufactured and assembled in such a way that there is minimal free play in the system, as per the Formula Society of Automotive Engineers (FSAE) rulebook. As far as the scope of work, the steering subsystem is responsible for everything from the steering wheel all the way to the tie rod connection point on the steering knuckles. That includes the designing and manufacturing of the steering column, steering column support tubes, tie rods, and the mounting of all components to the car. In addition, standard components needed to be chosen and ordered to fit into the system. This includes universal joints, needle bearings, heim joints, steering wheel quick-disconnect, and mounting hardware.

Chapter 2: Conceptual Design

2.1 Expanded Design Brief

As members of the Formula Electric team at the University of Akron, we have been tasked with designing and manufacturing the steering system for the 2018/2019 academic school year. The system must be compatible with other subsystems within the car. In addition, we are to use the KAZ Technologies steering rack that has already been purchased by the team in the past. The system must be completed and installed in the car by March 20th of 2019. Once the car is ready to be driven, testing can be completed to determine if modifications are to be made.

2.2 Morphological Chart

When designing a new product or system, choosing the final design can be very overwhelming. Instead of trying to come up with a complete and final design from scratch, it is much easier to design individual components or sub-functions. Once you have a few designs for each of the sub-functions, they can then be put into a table called a Morphological Chart. This chart allows the designer to choose multiple final design options by picking individual sub-function designs that work well together. After considering each of the options, a design is chosen as the final solution.

For the steering system of our car, there were a few components that we had many different ideas for and therefore required a morphological chart. The morphological chart that was used can be seen below in Table 1.

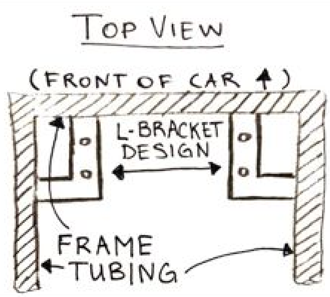
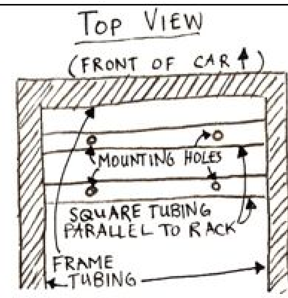
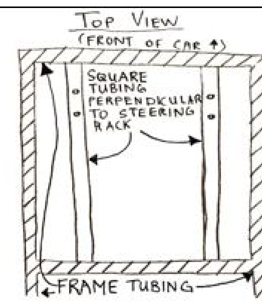
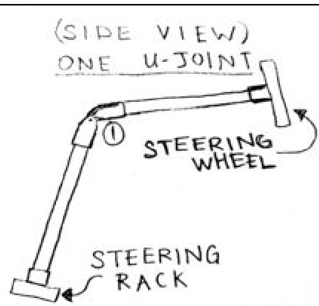
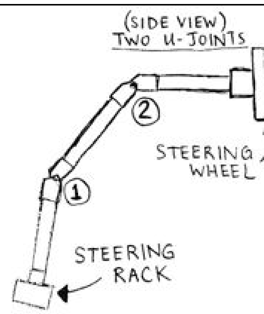
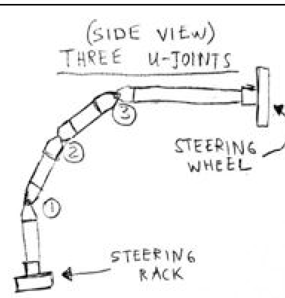
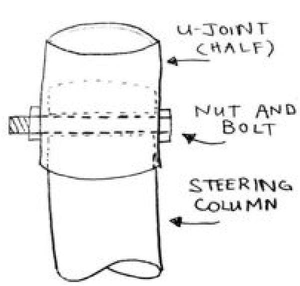
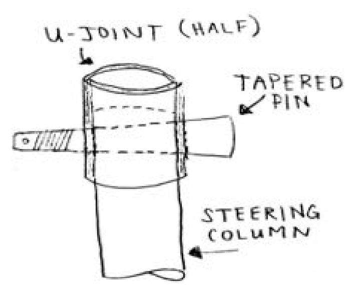
Sub-Functions	Function Solutions		
Rack-to-frame mount			
Number of U-joints			
Connecting U-joints to steering column			

Table 1 - Morphological Chart

The first component that was designed was the steering rack mount that securely attaches the steering rack to the frame of the car. The function solutions can be seen above. The L-bracket ended up being the best design option here as it minimized the amount of tubing compared to the other options in addition to still being strong enough to do the job.

The next sub-function on the list was determining the number of U-joints to have in the assembly. Right away it was apparent that using only one U-joint would be problematic as it would be at too sharp of an angle and not function as needed. Three U-joints gives the most room and minimizes the angles of each of them. The main issue with using a third U-joint is the cost factor. These U-joints were not cheap, and adding an additional U-joint would just result in more leg room for the driver, but this did not outweigh the cost. As a result, the final design ended up incorporating only two and we were able to stay well under the maximum operating angle for the U-joints.

Once the decision had been made to use two U-joints, the next item for consideration was how they would be mounted to the steering column. The simplest and most secure method would be to weld every connection in the whole steering system. The issue with this is the fact that once it is in and welded, the steering column could not be removed from the vehicle. This was a big factor in our decision to weld every other connection, and then connect the other side with hardware. At first, the preliminary decision was to drill a through-hole in the steering column and the U-joint, and connect the two via a nut and bolt with some washers. It wasn't until a few weeks later that members from the Formula Combustion team at the University of Akron mentioned that they highly recommend using tapered pins for this type of connection. After looking into it, the decision was made to go with the tapered pin because it allows for a much tighter connection. In other words, there is less play in the system because as the nut is tightened onto the pin, it jams the taper into each of the two different diameter holes, practically creating an interference fit which helps ensure that there is little to no play in our system.

2.3 Concept Sketches

Now that a final design has been chosen, a rough isometric drawing can be made to illustrate the final product.

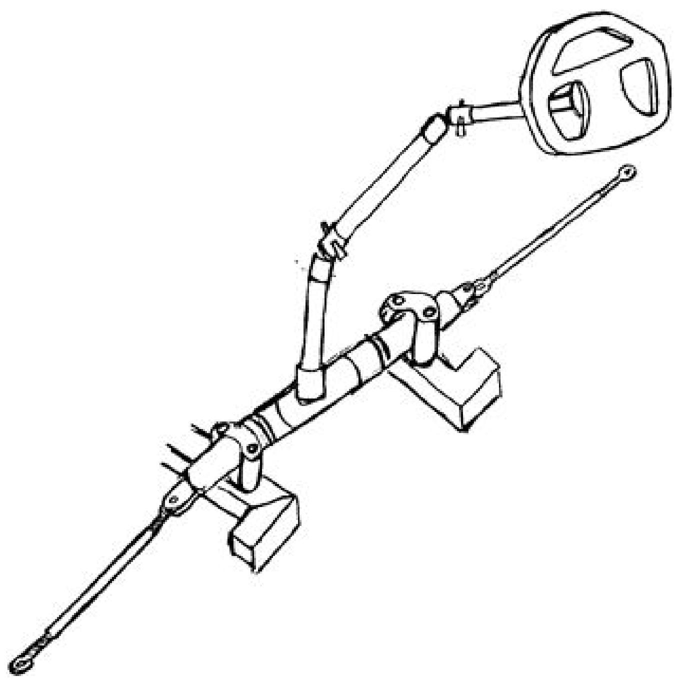


Figure 1 - Concept sketch of the final design

As you can see above in Figure 1, the tapered pins have been methodically placed on the upper side of each of the U-joints while the bottom side is welded to the steering column. The reasoning behind this is so that, if needed, the entire steering column can be disassembled and removed from the vehicle at any time. Also, be sure to note that the drawing is not completely proportional and is not to scale.

2.4 Objective Tree

When designing and manufacturing a product or system, there has to a be a reason for everything that is or isn’t included in the final design. One way to keep track of all the wants/needs is to make an objective tree that details what should make it into the final design, as well as what takes priority over each other. A breakdown of our priorities can be seen below in Figure 2 of our objective tree.

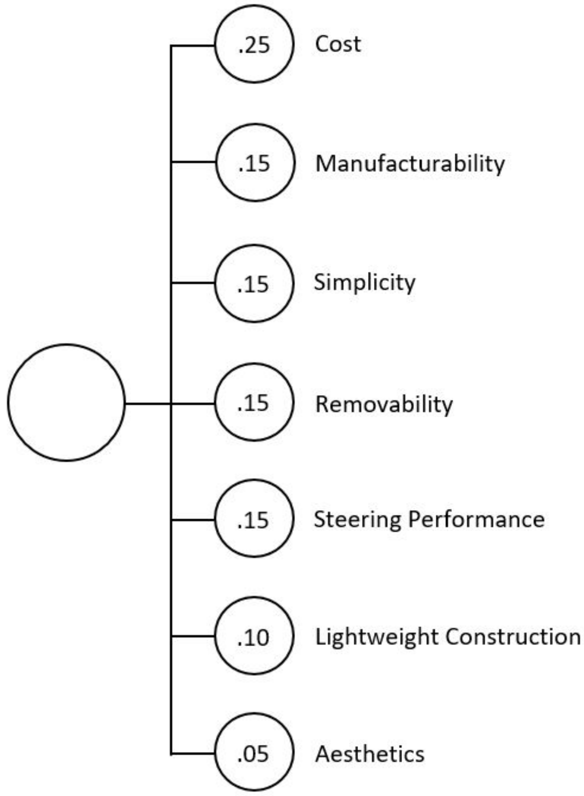


Figure 2 - Objective Tree

At the top of the list is cost with a weighting factor of twenty-five percent. This was the most important thing for us to consider when designing the steering system. The team only has so much money and without having a successful past with our program we did not have an overabundance of sponsors at the beginning of the year. The next two items on our hierarchy of needs were the aspect of manufacturability and simplicity. More importantly, we would need to be able to manufacture any part that we designed. These are important because not having much manufacturing experience between the three of us meant that we tried to avoid crazy, complex designs that would take a lot of time. In addition to time saving here, we were also saving money at the same time because if the design was too elaborate, there was always the chance that an error could be made during the manufacturing that could cost us time and material. Next, of course, was removability of the steering system. One key aspect of our design was that it had to be able to be disassembled and removed from the vehicle if needed for any reason. To accomplish this, we used tapered pins at two different locations on the steering column, whereas the other connection points were made permanent via welding. Equally important is the actual steering performance of the car. By modifying the location of the steering rack, adjusting the length of the tie rods, or moving the connection point on the steering knuckle, the steering performance of the car can be completely altered. This has to do with the geometry within the steering system. Since the main goal of the entire team was to get a rules-compliant race car this year, our team wasn't as focused on having perfect steering performance. Instead, we wanted to make sure that we had a functioning system that would steer the car and hold up to the rigors of competition. In future years, it might be advisable to bump the steering performance up on the priority list. On the same token, we also placed the aspect of having a lightweight construction down the list as well. While it is ideal to minimize weight wherever possible in a formula car, once again, we were more focused on designing and manufacturing a steering system that would be strong enough rather than minimizing weight. One example of this in our design was with the tie rods. At first we were going to go with lightweight 6061 Aluminum tubing, but ended up opting for the stronger, but heavier 4130 steel alternative. Last up on our list of needs was aesthetics. This goes right in stride with the last two points made. We focused more on functionality and strength rather than looks, however, the system needed to be presentable.

Chapter 3: Embodiment Design

3.1 Configuration Design

Throughout this section, the connections discussed and referenced can be seen below in Figures 3 and 4. Most of the connections for the steering system have been welded to ensure a strong bond between different components and to help reduce the overall play in the system. Tapered pins were used to connect the different sections of the steering column together at the U-joints to allow for the steering assembly to be taken apart as well as to reduce play in the system. The tapered pins act as an interference fit with the tubes of the steering column allowing for little to no wiggle at the connection points. This is much better than using a bolted connection here because the fitment with a regular bolt would most likely never be as good unless very low tolerance bolts and drill bits were used, which was not reasonable. Also, the steering rack is mounted to the frame by being bolted to L brackets, which are welded to the frame on both sides. The L brackets also have welded steel inserts to insure the integrity of the bolted connections. The tie rods are affixed to the clevises at either end of the steering rack by way of SAE Grade 8 socket head cap screws with thread deforming or top lock nuts on the other side.

Figure 3 - Steering Rack/Lower Column

Figure 4 - Steering System

3.2 Materials and Manufacturing Processes

After designing the different components for the steering system, large consideration was place on the different materials that could be used. Of course, strength and weight were the two main deciding factors for material. We originally planned to use solid 6061 aluminum stock for the tie rods because we figured that it would be lighter than steel. However, the solid rods were unreasonable and unnecessary so it was decided that thin walled 4130 steel would be used due to its great strength properties. Similarly, the steering column was going to be made with 4130 steel with 0.065" wall thickness, but once we started to manufacture the components it was decided that the 0.095" wall thickness would be better for welding and of course strength and add very little extra weight to the car. After agreeing on materials that were to be used, a purchase request form was filled out and needed to be signed off on by the team's co-captains before any items could be purchased by the treasurer or one of the captains.

After purchasing of materials was complete, it was up to us to manufacture the different steering components in The University of Akron's machine shop. Before we could enter the machine shop, however, each of us had to complete eighteen modules within Tooling U-SME manufacturing education course. The course covered various different machines and safety information that one would need before entering a manufacturing setting such as the machine shop. Also, during the first several times of working the machine shop we were supervised by the machine shop personnel to confirm that we were using proper machine procedures and to help if there were any questions. The L-brackets for mounting the steering rack were manufactured out of 4130, 0.065" wall square steel tube on the CNC mill that can be seen below in Figure 6. Also, the tie rod ends (Figure 5) and steering column support tubes were turned on the lathe to allow for tolerances as low as one thousandth of an inch.

Welding and fitment of all the components together took place after all pieces were machined in reference to sketches made from three dimensional models in Solidworks. All welding done on the car was tungsten inert gas (TIG) welding and was done by Matt Evans from the university's Formula Combustion team. Before welding, all pieces were measured relative to each other and loosely fit together as an assembly to ensure proper fitment. Once fitment was ensured, the parts were sanded using a Scotch Brite pad and then cleaned using acetone. When trying to fit the support tubes for the steering column supports we ended up grinding away small portions of the tube ends at a time, trying to mate them up with the curved frame tubes. We had initially hoped to print out a two dimensional picture of the correct sized tubes with the correct curvature at the ends of the tubes based on our Solidworks model, but after many iterations we were not able to get the scaling to come out correct. In the end we made it work by guessing and checking, but it did take a lot of time and was very tedious.

When assembling the manufactured components for the steering system we referenced the Solidworks model of the steering assembly, however assembling in Solidworks is much different than assembling actual components. As can be expected, many things did not translate perfect from the screen to real life. For instance, when welding the frame, the inside width of the car at the front was approximately half of an inch smaller than what the model stated. So, all of our components had to accommodate this change and were adapted as necessary to work on the car. Also, one of the largest issues we had with assembly of the steering system was with the spline adapter for the steering column. We purchased three spline adapters from three different companies that were all listed as having the same dimensions before we finally received one that had the proper dimensions and fit our steering rack.

Figure 5 - Turning Tie Rod Ends

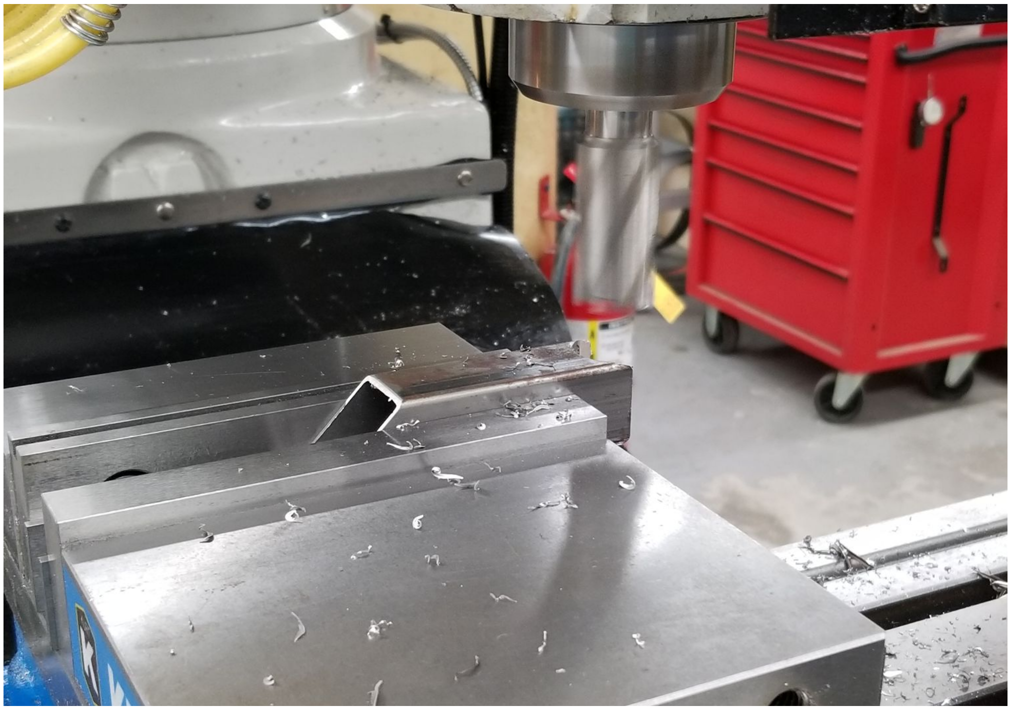


Figure 6 - L-Bracket Milling

Chapter 4: Detail Design

4.1 Steering Calculations

Steer Arm Length

Steer Arm Length is the distance from kingpin axis to center of outer tie rod. Measuring the distance in the model of the full car within SolidWorks we can see that the distance comes out to the following:

$$2.907 \text{ in} = 73.838 \text{ mm}$$

This distance will affect the steering characteristics since the distance plays a role in Ackerman angle. The distance can also be adjusted by drilling multiple holes along the steering knuckle mount to allow for different lengths. The distance we calculated can be found below in Figure 7.

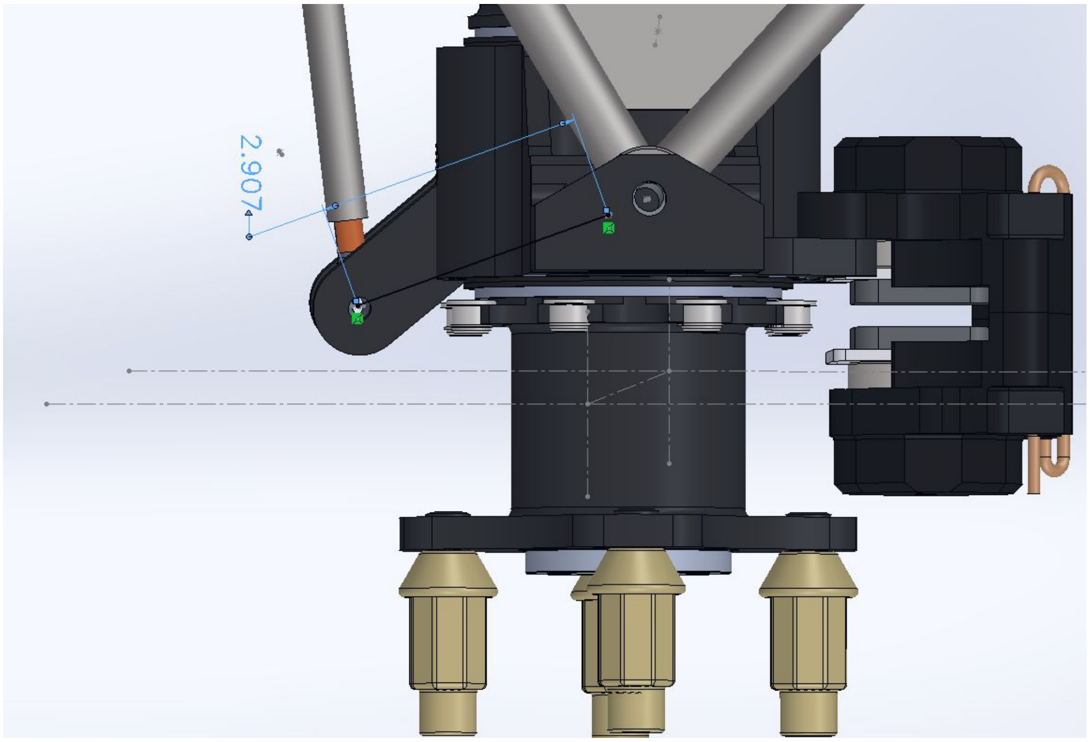


Figure 7 - Steering Arm Distance

C-Factor

C-Factor is the effective steering rack travel (mm) per revolution of the steering input/pinion shaft. We cannot change the C-factor of our system since we purchased our steering rack from KAZ Technologies. The pinion and rack gear teeth were already manufactured to a certain specification and cannot be adjusted as of right now.

$$\frac{travel\ distance}{degrees\ of\ rotation} \times 360 \frac{degrees}{revolution} = \frac{82.55}{248} * 360 = 119.8\ mm$$

Future steering subsystems have a potential to be able to redesign the steering rack if they so wish. If the subsystem designed and manufactured their own rack than they would be able to change all of the gearing inside in order to affect the ratio of rack travel per revolution of input shaft rotation. Since this years steering subsystem used the KAZ Technology steering rack our C-Factor came out to be 119.8 mm per revolution of input shaft.

Steer Ratio

Steer Ratio is the ratio of the steering wheel input angle to road wheel output angle (Average of left and right). This can be calculated by using the model of the steering system while making sure the rack is centered in the model. Once centered then move it a certain distance from center (This would be calculated by picking a steering wheel angle then calculating the distance the rack moves using C-Factor). Once the rack is moved over to the distance of your choice, based off the steering wheel rotation, then the angle of both the left and right wheels can be measured and the average can be calculated. The ratio between these two angles is the Steer Ratio which we calculated to be a ratio of 3.84:1.

Static Ackermann Percentage

There are several different performance characteristic of a steering design for a race car, one of the most important is also one of the harder performance goals to design for especially going into this your first semester on a design team. This performance aspect is called “Ackermann Angle” or the degrees that the inside turning wheel compares to the outside turning wheel. Three different Ackermann performance aspects exist based off of Figure 8: Pro-Ackermann (Ackermann), Parallel Ackermann, and Anti-Ackerman (Reverse Ackermann). When the inside wheel executes a sharper turn than the outside wheel this is called Pro-Ackermann, this form is preferred when driving conditions require sharp/quick maneuvers. On the other hand, when the outside wheel is turning sharper than the inside wheel this form is called Anti-Ackermann, this is preferred when the race vehicle is designed for high speed straights and performance. The last form of Ackermann is just called Parallel, the name is pretty explanatory, both the outside and inside wheels are turning at the same radius. This form is not preferred for racing conditions since one of the wheels will always be dragging when executing corners since they are at the exact same radius.

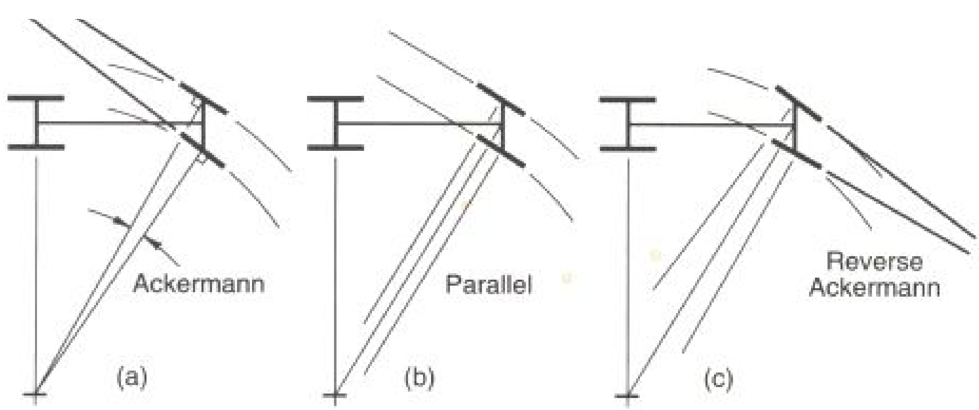


Figure 8 - Different Ackermann Configurations

During our Spring 2018 semester of school or main tasks was solely designing the steering system to these performance characteristics. After sitting down for hours doing research off the internet and the manuals provided by the team we were starting to get an idea of what needed to be accomplished but still fuzzy on some aspects. We expressed our concern with Adam K. and he gave us the contact information of Jeff DiSante, the suspension lead for the combustion team. We all sat down with Jeff after one of the meetings and discussed out ideas of how to design the steering system and position our rack onto the car correctly. He gave us several tips, suggestions of documents to look over, and his cell phone in case we needed to contact him any further. After several hours of design iterations we came up with a design that we believed suited our needs and performance goals. Using our SolidWorks model we determined the position of the rack and tie roads based on the location of the steering knuckles. It was determined at maximum steering lock that we would have roughly 7 degrees of Pro-Ackermann (Determined by taking the different between the outside and inside wheel angle). Our next step was to move onto the manufacturing of the entire car and mate everything to the frame.

We successfully machined and assembled the entire system and completed it during the week of March 18th. The group went to the weekly meeting where we met up with suspension to discuss the integration of our two systems since they were close to being done also. Adam Kuhar physically measured the Ackermann number when the frame was sitting up on the welding table and came up with a numbers that was actually Anti-Ackermann. We were shocked to hear this since we designed it to have Pro-Ackermann, this could have came about from the small difference in the actual frame and model or our numbers could have just been slightly off. We sat down and discussed our options with suspension and came to the conclusion that our subsystems would need to create longer tie rods and machine new steering knuckle mounts. Fortunately even before this meeting, suspension was ahead of the game and already planned this out and was ready to machine new tie rods and knuckle mounts in the following week. The steering and suspension groups worked together several hours to overcome this design challenge and have successfully engineered a new design that now meets all of our requirements. Looking at Figure 9 below we can see that the car is currently running 30 percent static Ackermann at 5.19 degrees of Pro-Ackermann, perfect for all the tight turns in the autocross events. After completing brick road testing, Mary Gladwin parking lot testing, and FCA both steering and suspension groups are very happy with the results of all our hard work and look forward to pushing the car to its limits at competition.

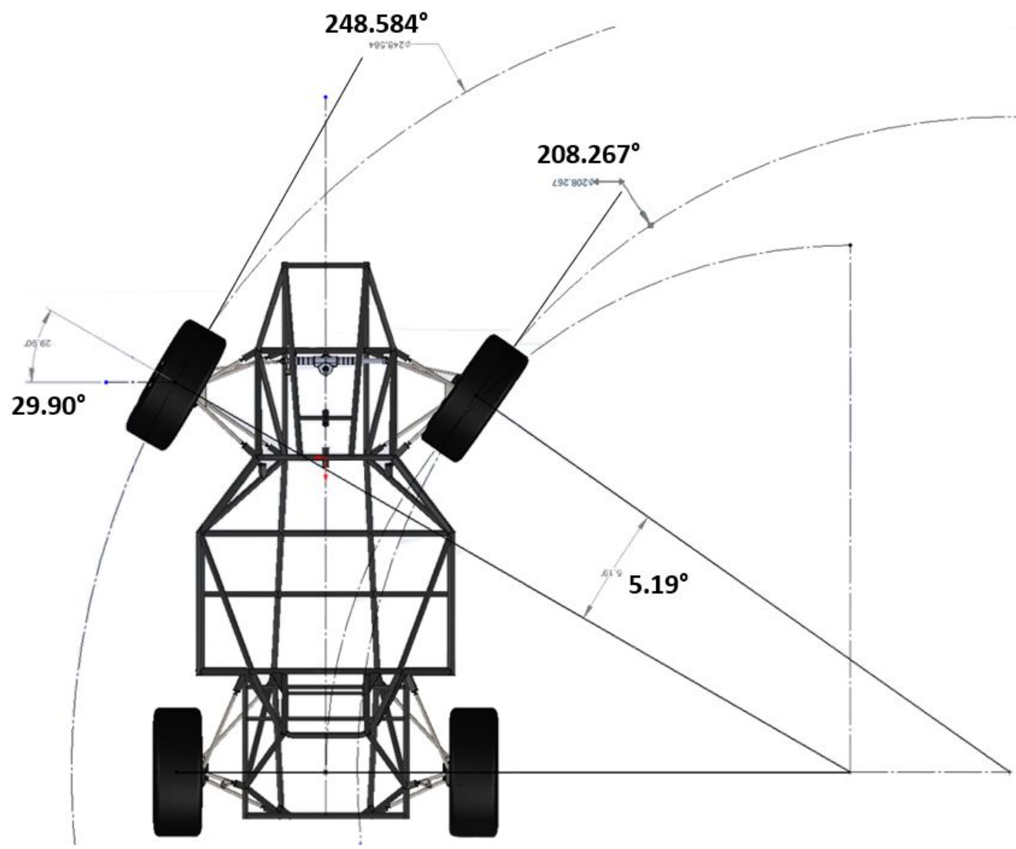


Figure 9 - Ackermann SolidWorks Model

<u>Finite Element Analysis (FEA)</u>

When designing complex components for large projects you want to make sure you are using the correct materials and dimensions in order to be confident in your margin of safety. One of the resources an engineer has at their disposal is Finite Element Analysis (FEA), this is where you can simulate different loads and stresses on a part within a CAD software and understand the different deformations that come from it. Throughout the design process of the steering system students have used SolidWorks to design all of their components, SolidWorks as a matter of fact as their own built in FEA program to run different simulations. The two highest risk components on our system are the mounting points of the steering rack and the tie rods that control the wheels of the car. We wanted to make sure to run both of these through a quick FEA test. Both of the simulations were set-up using the proper materials from the SolidWorks database and both experienced loads of 1000 lbfs. The tie rods load was directed axially along the length of the tube while one end was fixed to load the tube in compression. The steering rack mount was placed in torsion located directly at the welded insert points.

6061 Aluminum Tie Rods - FEA Results
Von Mises Stress: Yield Strength at 5.515e+07 (N/m^2)
Displacement: Max of 0.2494 mm

4130 Steel L-Bracket Steering Rack Mounts - FEA Results
Von Mises Stress: Yield Strength at 4.600e+08 (N/m^2)
Displacement: Max of 0.04998 mm

After compiling the results from the two seperate FEA tests the steering group determined that we were well within safety qualifications and that our dimensions and material choice met all of our requirements. Figures 16 and 17 are the screenshots from the FEA simulations from SolidWorks and they are located in Appendix sections 7.1 and 7.2.

4.2 Standard Components Used

Throughout the manufacturing of the steering system, many standard components were purchased for use from various different companies. The most important component that we bought from a manufacturer was that of the KAZ Technologies steering rack, which, is specifically made for FSAE use. The U-joints that are being used in the system are from Apex and we chose to use their single universal joints because they are considered to be some of the highest quality joints that are available. Also, spherical rod ends were purchased from Aurora Bearing for use with our tie rods because they are well known in the Formula SAE community as being some of the best heim joints that money can buy. Needle bearings were used in either end of both the column support tubes to allow the steering column to effortlessly rotate within the support and ensure that the steering column is centered relative to the car. The quick release spline as well as the quick release were also purchased from a manufacturer because of the high level of machining that would be needed to create such pieces. Similarly, we purchased a spline adapter to allow for proper connection to the steering rack that would have been difficult to manufacture. Finally, all of the fasteners such as nuts, bolts and pins were purchased from Fastenal because they are a sponsor of the team.

4.3 Part Drawings

For all manufactured pieces part drawings were created and dimensioned using Solidworks. When thinking of dimensioning, one of the most important things to keep in mind is the tolerances required for each individual dimension. Certain measurements simply are not as important as others and therefore can have greater tolerance. One example of tolerance mattering a lot with the steering system is that of the tubes for the column supports that have needle bearings press-fit into either end of the tube. If we didn't hold tolerance to within several thousandths of an inch above or below the specified target, the bearings would have either not fit, or become damaged upon press fitting. All of the drawings for the parts we manufactured can be found in section 8.4 of the appendix.

4.4 Steering Assembly Drawing

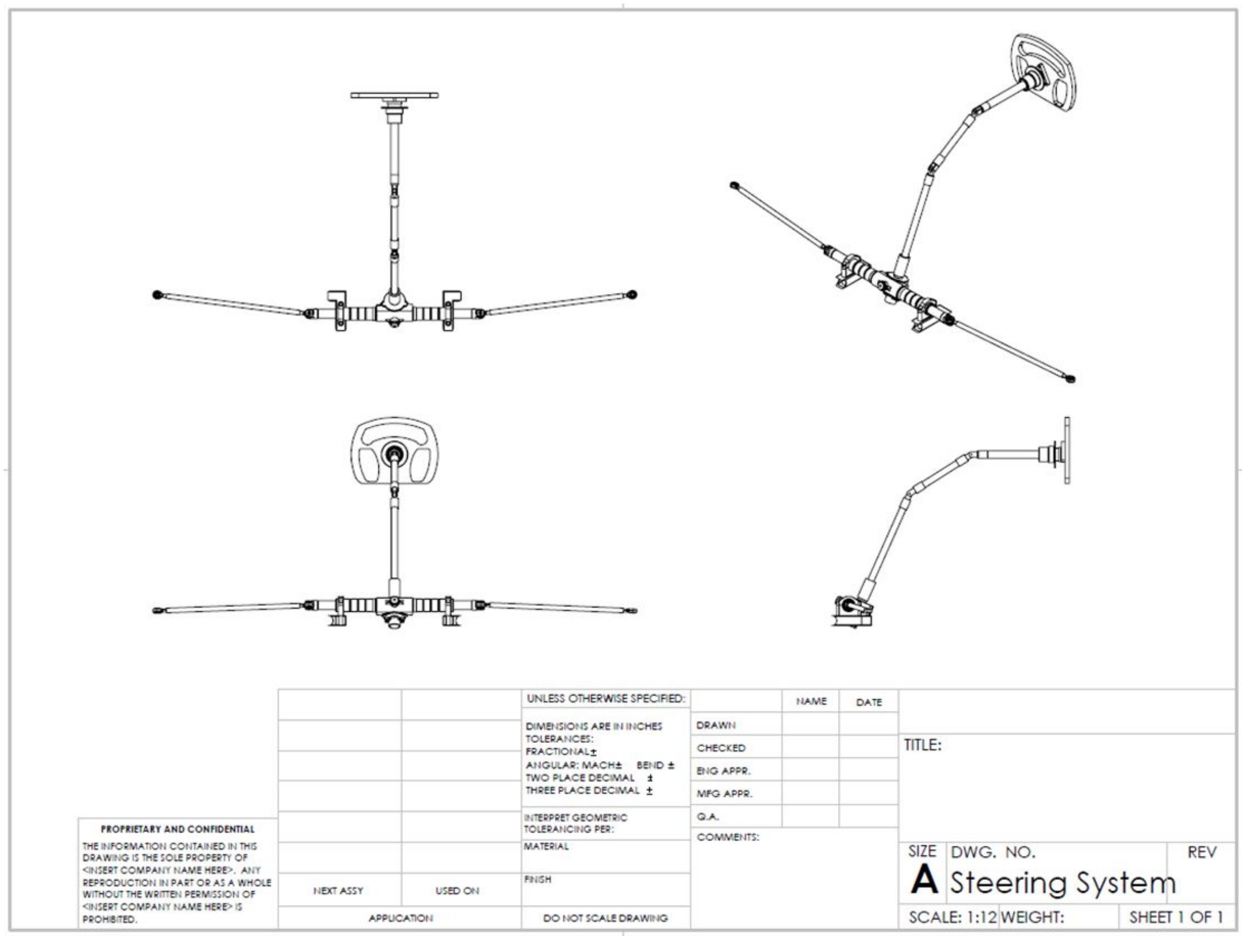


Figure 10 - Final Steering Assembly

4.5 Exploded View

Looking at the exploded views of the different models used in the steering system more detail can be seen on the necessary construction of each mating part. In Figure 11 below, the entire steering system is modeled with simplified construction and for this reason fasteners are not included.

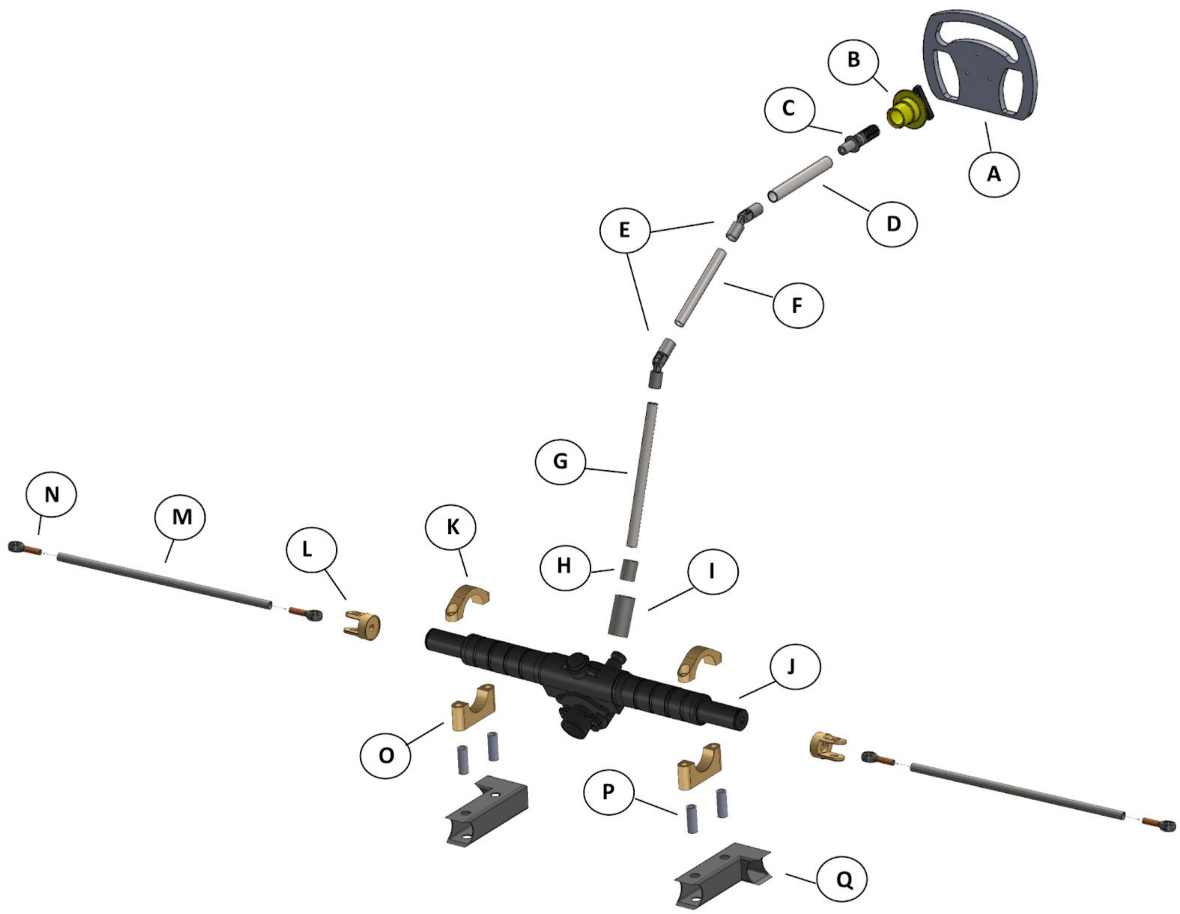


Figure 11 - Exploded Steering Assembly

A) Aluminum Steering Wheel
B) Quick Release
C) Spline Adapter (Column to Release)
D) Upper Column Tube
E) ⅝" Universal Joints (x2)
F) Middle Column Tube
G) Lower Column Tube
H) ⅝" to ¾" Adapter
I) Spline Coupler Adapter
J) KAZ Steering Rack
K) Upper Rack Collar (x2)
L) Clevis for Steering Rack (x2)
M) Tie Rod (x2)
N) Rod End Bearing / Heim Joint (x4)
O) Lower Rack Collar (x2)
P) Tube Insert (Structural Support) (x4)
Q) Steering Rack Frame Mounts (x2)

4.6 Bill of Materials

The table below was constructed based on all of the components used to create the steering subsystem. This Bill of Materials does not accurately represent the actual costs of the materials/parts used to build the 2019 Zips Electric Racing car, instead it represents the theoretical costs based on the Formula SAE Cost Report system. The table below was generated using this years cost report that was submitted for the Formula North competition. In this case students are supposed to imagine they are a company that needs to generate prototypes of these cars and begin to mass produce them. This takes into account material, tooling, and, manufacturing cost to generate the below table based on cost standards created by the Society of Automotive Engineers (SAE). Actual costs to create the steering subsystem were higher than the total created by SAE and this is to be expected when it is solely used as theoretical mass production values.

Area of Commodity	Assembly	Component	Unit Cost	Quantity	Material Cost	Process Cost	Fastener Cost	Tooling Cost	Total Cost
Steering System	Steering Wheel Quick Release		$6.77	1.00	$1.46	$5.17	$0.14	$0.00	$6.77
Steering System	Steering Wheel		$17.69	1.00	$1.41	$16.09	$0.19	$0.00	$17.69
Steering System	Tie Rods		$33.12	1.00	$29.84	$3.28	$0.00	$0.00	$33.12
Steering System	Steering Column		$135.85	1.00	$60.74	$70.08	$5.03	$0.00	$135.85
Steering System	Steering Rack		$59.45	1.00	$12.87	$41.69	$4.89	$0.00	$59.45
Steering System		Quick Release Hub	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Tie Rod Tube	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Steering Rack Body	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Spline Adapter for Upper Column	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Lower Column	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Middle Column	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Quick Release System	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Steering Wheel	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Tie Rod Ends - Left Hand	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Rack Rod	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Spline Adapter	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Tie Rod Ends - Right Hand	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Pinion Gear	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Upper Column	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Clevis Ends	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Steering Wheel Support	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Rod Ends - Left Hand	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Rod Ends - Right Hand	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Column Support	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Rack Ring Mounts	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		U-Joints	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Steering Rack Frame Mounts	$0.00	2.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Spline Coupler	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Lower Column Adapter	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Upper Column Adapter	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Needle Bearings	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
Steering System		Mounting Tubes	$0.00	1.00	$0.00	$0.00	$0.00	$0.00	$0.00
		[Area Total:]			**$106.32**	**$136.31**	**$10.25**	**$0.00**	**$252.88**

Table 2 - Bill of Materials

Chapter 5: Discussion

5.1 Compliance with SAE Rules

Listed below are all of the rules pertaining to the steering subsystem within the 2019 FSAE rule book version 2.1 and what we did in order for the steering assembly to obey the rules in order to pass any and all inspections at competition.

T.1.6.1 The steering wheel must be mechanically connected to the front wheels.

- The front wheels had to be the main source of steering for the car and therefore the steering wheel must be connected to the front wheels by way of mechanical connections that also adhere to the SAE rules.

T.1.6.2 Electrically actuated steering of the front wheels is prohibited.
T.1.6.3 Steering systems using cables or belts for actuation are not permitted

- The steering of the front tires must occur manually with driver input to the steering wheel with no driver aids such as power steering or any other electrical means of steering. The steering of the front tires must be purely mechanical in nature and we accomplished this with the use of a rack and pinion gear that is turned with the use of a steering column connected to the pinion gear at one end and a steering wheel at the other. Once the wheel is turned, the tie rods that are connected on either side of the rack and pinion and also connected to the steering knuckles on the hub assemblies then move linearly with the pinion gear to effectively turn the car left and right.

T.1.6.4 The steering system must have positive steering stops that prevent the steering linkages from locking up (the inversion of a four bar linkage at one of the pivots). The stops may be placed on the uprights or on the rack and must prevent the wheels and tires from contacting suspension, body, or frame members during the track events.

- To stop any steering components from coming in contact with the suspension, body or the frame of the car, nylon spacers were placed on our steering rack at either side. This ensures that we do not steer at an angle that is greater than what is reasonable, helping reduce the possibility of locking up the front tires when steering as much as is possible to one side.

T.1.6.5 Allowable steering system free play is limited to seven degrees (7°) total measured at the steering wheel.

- Free play refers to the play in the steering system at a stop and it is measured by lightly rotating the steering wheel to one side or the other to show how much slop or take up is in the assembly. The rules allow a maximum of seven degrees of play and our system easily passes with a maximum play of approximately two degrees.

T.1.6.6 The steering wheel must be attached to the column with a quick disconnect. The driver must be able to operate the quick disconnect while in the normal driving position with gloves on.

- The steering wheel must be able to be removed quickly and without the use of any tools by the driver while seated inside of the vehicle. We accomplished this by welding a quick release spline to the top end of our steering column that mates up with a quick release that is mounted on the back side of our steering wheel.

T.1.6.7 The steering wheel must have a continuous perimeter that is near circular or near oval. The outer perimeter profile may have some straight sections, but no concave sections. “H”, “Figure 8”, or cutout wheels are not allowed.

T.1.6.8 In any angular position, the top of the steering wheel must be no higher than the top-most surface of the Front Hoop. See T.2.13.4

- The steering wheel could not have any cutouts or concave sections and when rotated, the steering wheel could not extend higher than the front roll hoop in case of an accident. Our steering wheel is made of aluminum and resembles an oval racetrack with cutouts on either side to allow for gripping of the steering wheel at three and nine when thinking of a clock. Also, the steering wheel is well under the front roll hoop to ensure that even if the drivers hands are at either end of the steering wheel, the drivers hands will be lower than the front roll hoop so their hands will not be crushed in a crash that results in an overturned car.

T.1.6.9 The steering rack must be mechanically attached to the frame

- Since the steering rack must be attached to the frame in some mechanical fashion, we machined L brackets that were then welded to the frame. Once the L brackets were welded, we used SAE Grade 8 Hex headed bolts with thread deforming nuts to secure the steering rack to the welded L brackets.

T.1.6.10 Joints between all components attaching the steering wheel to the steering rack must be mechanical and be visible at Technical Inspection. Bonded joints without a mechanical backup are not permitted.

- All components that comprise the steering assembly are connected in accordance with the FSAE rules and are visible and therefore able to be inspected prior to competition.

Also, we have no bonded joints in the steering system that would require a mechanical backup.

T.1.6.11 Fasteners in the steering system are Critical Fasteners, see T.10.2 and T.10.3
T.1.6.12 Spherical rod ends and spherical bearings in the steering must meet T.1.5.5 above

- All fasteners that were used in the steering system were SAE Grade 8 nuts and bolts when FSAE rules require at least SAE Grade 5. Also, our spherical rod ends are mounted in double shear which meets the criteria of T.1.5.5. The section of the rules that refers to critical fasteners also states that a minimum of two full threads must protrude from any lock nut and this has also been accomplished with all of our connections.

T.1.6.13 Rear wheel steering may be used. a. Rear wheel steering must incorporate mechanical stops to limit the range of angular movement of the rear wheels to a maximum of six degrees (6°). b. The team must provide the ability for the steering angle range to be verified at Technical Inspection with a driver in the vehicle. c. Rear wheel steering may be electrically actuated.

- Although rear wheel steering is allowed, we decided not to pursue it this year in order to keep things simplified to make sure the car was completely rules compliant and able to compete.

5.2 Recommendations for Future Steering Subsystem

Over the course of an entire project life-cycle, certain things are going to become apparent that could have been done better. On the contrary, there will also be some things that were done very well and shouldn't be changed in future designs.

For our system, one thing that we would recommend that does not change in future designs is the use of the tapered pins. We could not believe how tight these pins held the entire steering column together once installed. The tapered pins are a large part of why the total steering system has approximately only two degrees of play.

One thing that wasn't necessarily done wrong by us per se, but something that could be improved upon in future designs, is the steering performance and characteristics. As mentioned in Chapter 2, we were more focused on creating a rules-compliant car for the first time in the team's history. In that regard, we didn't focus as much on making sure that we had perfect steering performance. Instead, we made sure that we made a system that was functional and followed all of the rules laid out by FSAE. So, this allows for future teams to take a deeper dive into the vehicle dynamics behind steering a race-car and hopefully edge the university closer to coming home with a gold medal from competition.

If we had more time, I think it would have been beneficial for us to design a new steering wheel. The one we used was made in the past by one of the previous teams. It does the job but lacks heavily in ergonomics and is much heavier than it needs to be. The overall shape and design could lead to hand soreness and fatigue for some of the longer events. Since the wheel was manufactured from aluminum future teams can reduce weight by switching over to a carbon fiber design or even a more sleek aluminum design with more weight reduction techniques taken.

Another thing that could have been improved upon was time management. There were a few deadlines that were almost missed due to lack of planning ahead on our part. Although we were quoted normal lead times on most items without any surprises, some items did take a lot longer than expected and caused us to come down to the wire on a couple of the team deadlines. With this, it should be noted that any part that needs to be ordered from an outside vendor should be done so as soon as possible. People within those companies are human and are capable of making mistakes just like any one of us. There is no worse feeling than missing a deadline and holding up the rest of the team because someone sent the wrong part. Things happen, but if ordered well in advance, most of these scenarios are not a big deal because there is plenty of time to take corrective actions.

5.3 Slack Communication with Team

Trying to build a formula electric student design race car without communication between the subgroups is near impossible to accomplish. There are several meetings throughout the week in order for the groups to come together and communicate ideas on the development and design of the car, but outside of these meetings there still needs to be a strong source of discussion to ask questions and update team leaders. Luckily for the team there is an easy and free solution to the problem, this is where Slack comes in. Slack is a team collaboration tool that can be used by any member of the team as long as they own a computer or smartphone.

Figure 12 - Slack Logo

Within the application each subgroup has their own “channel” where they can post messages, videos, photos, and even different files from their computer. Students from one subgroup can join other groups and there are even channels dedicated for the entire team incase you want to get everyone's opinion or make announcements. The fact that the team can share important information like event dates, project statuses, testing information, design changes, and lots of other crucial information is very valuable to have at our disposal. We personally recommend that all new members of the team download the application on their phones and personal laptops that stay in the loop and keep up to date with what is happening outside of the design center.

5.4 Brick Road and Parking Lot Testing

After two semesters of working hard on the car it was a sight to behold to finally watch it drive down the brick road on its own power in front of the Goodyear Polymer Center building. Getting to this point required hours upon hours of design work, manufacturing, and assembling subsystems together to form a functional vehicle. After successfully helping the team complete on-stand testing in the design center we were able to move onto fully functioning road tests. Since this involved driving the high voltage car on campus where the public would be walking between classes everyone needed to make sure we closed down a section of the road and had safety equipment close by. With the help of the combustion team at either ends of the road we were easily able to accomplish this and proceed with testing. Adam Kuhar successfully drove the car up and down the road, the team discovered several coding errors that needed to be tweaked in the system to get the performance characteristics we needed for further testings.

Once the team was happy with the results from the brick roads tests it was determined that further testing on a larger scale needed to take place. Our captain, Adam K. agreed and asked Daniel Deckler if we would be able to reserve the parking lot in front of Mary Gladwin for a full day of testing with our team and combustions. Dr. Deckler was successfully able to secure this lot for both teams on a Saturday, everyone was excited this was about to happen. At least one member from every subgroup was able to attend the event to spectate and also gather information about our designs and any changes that needed to be done before the Fiat Chrysler Automotive (FCA) event. The car was driven for several hours Saturday, finding kinks in designs, gathering information for programming, and bringing multiple smiles to everyone's faces for seeing Akron’s first fully functional electric car speed across the pavement. The entire team learned how to work together to fix minor problems, transport the car to a different site, and how to check their respective subsystem after each run for any damage. Figure 13 below captures a moment of the team working together to overcome a challenge.

Figure 13 - Team Practicing in Mary Gladwin Parking Lot on Campus

Chapter 6: Conclusions

After almost 9 months of hard work, we have finally put wheels on the ground and the pedal to the metal so to speak. Not only did the steering team complete their design as expected, the entire team and all of the subsystems involved managed to overcome hurdle after hurdle and finally have something to show for it. We are looking forward to the team going to competition and we are proud to part of something that is being done for the first time in The University of Akron's history. After initial testing, it seems that the steering system is functioning as it was supposed to and very few changes were needing to be made. Replacement tie rods were also made in case of an accident or if the main set were somehow misplaced at competition so the team could still compete. In future years, the team could continue to use the KAZ steering rack that was purchased for the 2019 car due to it being completely removable, or the team could do what most others do and design and build their own steering rack to exactly fit the teams requirements and specifications.

Figure 14 - Team Photo at ZIPS Electric / Combustion Racing Reveal Event

We want to thank The University of Akron for hosting the unveiling event and letting us show off our long hours of work!

Chapter 7: Appendices

7.1 Steering Rack L-Bracket SolidWorks Models/FEA

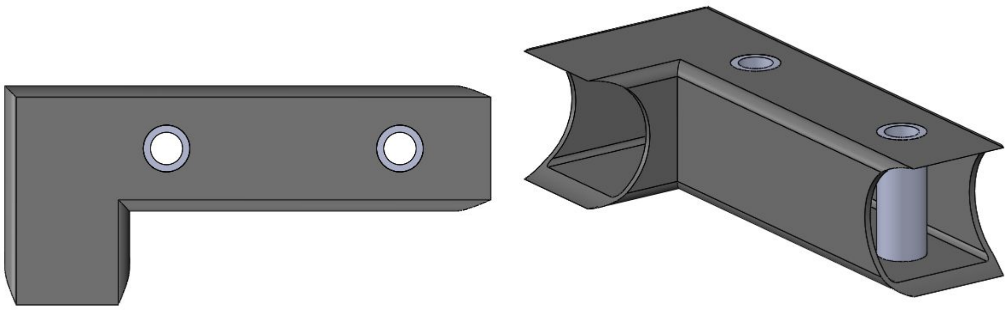
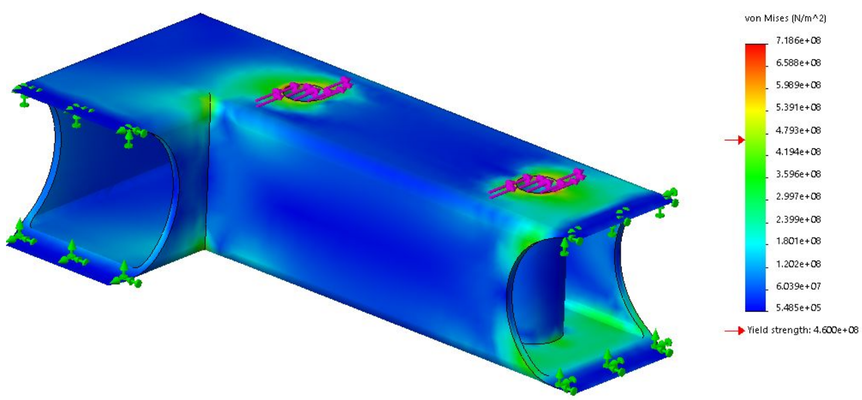
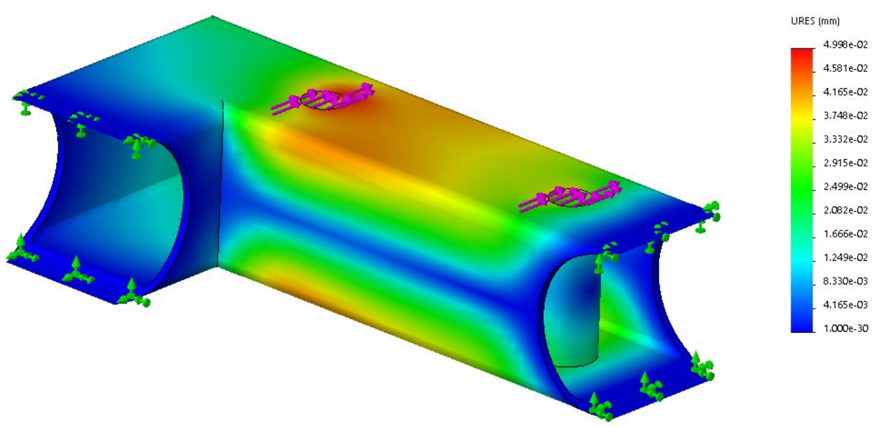


Figure 15 - Final L-Bracket Design



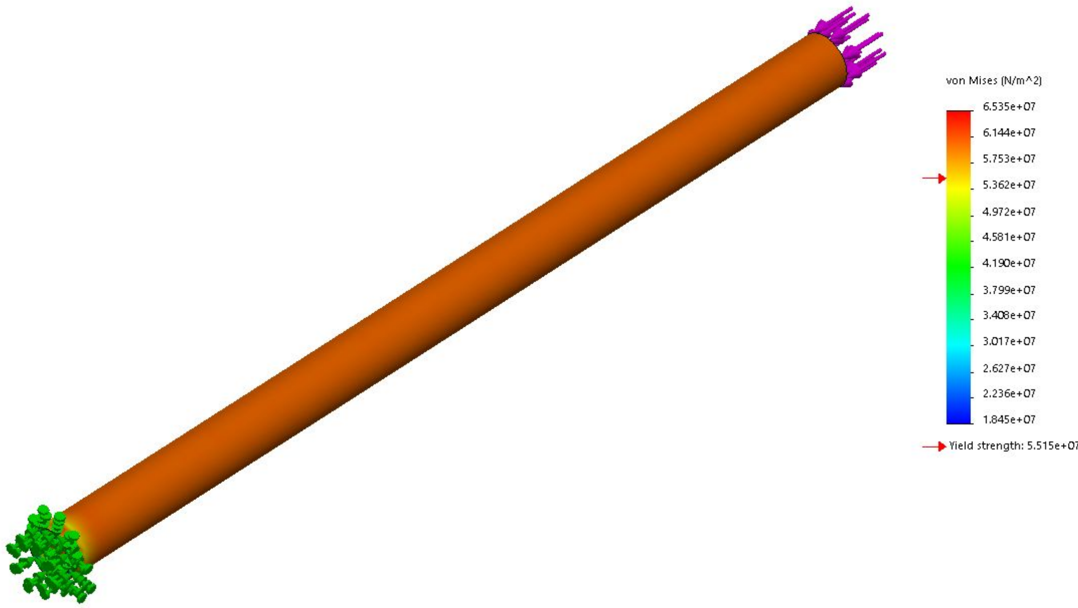
Stress - von Mises (N/m^2)



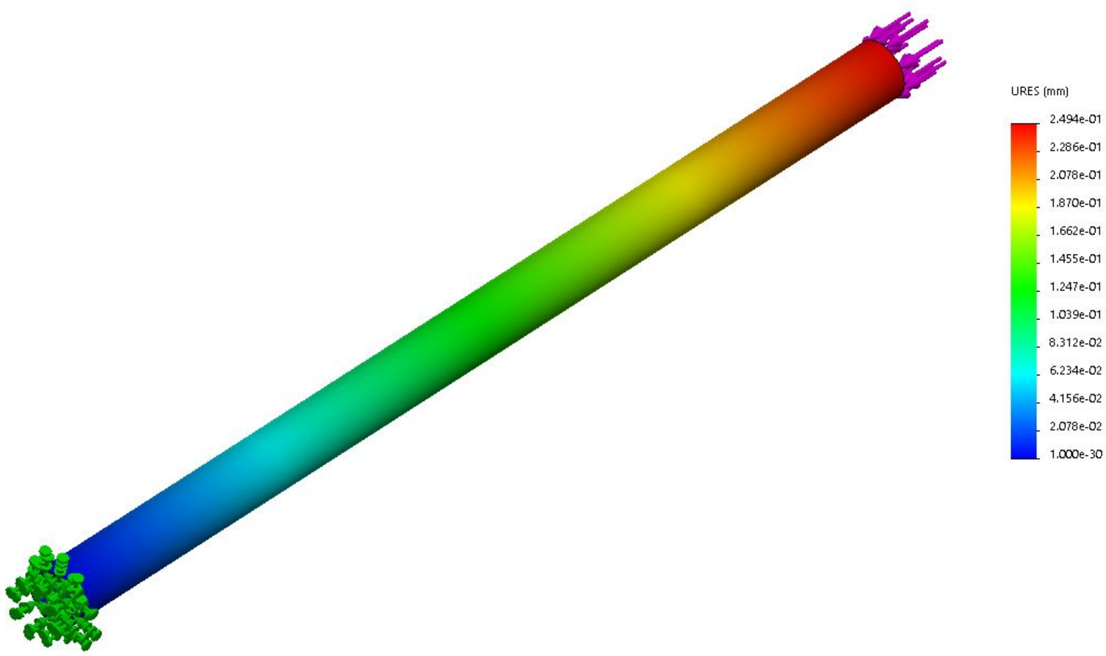
Displacement (mm)

Figure 16 - L Bracket FEA

7.2 Tie Rod SolidWorks FEA



Stress - von Mises (N/m^2)



Displacement (mm)

Figure 17 - Tie Rod FEA

7.3 Purchasing Request Form

Purchase Request Form											Approval		Post Purchase
Requester	Item	Description	Supplier	Link*	Cost/unit	Discount %	Units	Total Cost	Date Requested	Needed By	Adam Kuhar	David Streen	Fulfill Date
Sean Zimlich	(1/4" Ball) 5/16" Right Hand Heim	Tie rod heim joints	Aurora Bearing	#1	$65.34	50%	4	$130.68	2/2/2019	2/7/2019	✓	Ordered	2/27/2019
Sean Zimlich	(1/4" Ball) 5/16" Left Hand Heim	Tie rod heim joints	Aurora Bearing	#2	$65.34	50%	4	$130.68	2/2/2019	2/7/2019	✓	Ordered	2/27/2019
Sean Zimlich	5/8" Apex U-Joints	U-joints for steering column	Taylor Racing	#3	$109.99	0%	2	$219.98	1/17/2019	1/24/2019	✓	Ordered	1/19/2019
Sean Zimlich	Bolts (1/4-20) Socket Head	Bolts to secure steering rack	Fastenal	#4	$0.62	0%	6	$3.74	1/17/2019	1/24/2019	✓	Ordered	2/8/2019
Sean Zimlich	Nylon Locknuts (1/4-20)	Nylon nuts to secure rack	McMaster-Carr	#5	$3.56	0%	1	$3.56	1/17/2019	1/24/2019	-	Currently Own	-
Adam Bracken	5/8" 6061 Aluminum Tubing (4 ft)	Tie rods	McMaster-Carr	#6	$26.79	0%	1	$26.79	1/24/2019	1/28/2019	✓	Ordered	2/7/2019
Sean Zimlich	6061 Aluminum 5/8" Dia. Rod	Tie rod ends	McMaster-Carr	#7	$3.40	0%	1	$3.40	1/24/2019	1/28/2019	✓	Ordered	2/7/2019
Adam Bracken	5/8" - 36 Spline Coupler	Spline Coupler	Speedway Motors	#8	$39.99	0%	1	$39.99	1/24/2019	1/28/2019	✓	Ordered	1/30/2019
Adam Bracken	3/4" OD x 1 ft 4130 Steel Rod	Steering Column Coupler Adapter	McMaster-Carr	#9	$12.13	0%	1	$12.13	1/29/2019	2/4/2019	✓	Ordered	1/29/2019
Adam Bracken	Needle Bearing 5/8 ID x 13/16 OD x 5/8 L	Column Bearings	McMaster-Carr	#10	$7.05	0%	4	$28.20	2/2/2019	2/5/2019	✓	Ordered	2/7/2019
Sean Zimlich	Needle Bearing 3/4 ID x 1 OD x 1/2 L	Column Bearings	McMaster-Carr	#11	$6.26	0%	4	$25.04	2/7/2019	2/11/2019	✓	Ordered	2/7/2019
Adam Bracken	1" OD x 0.095" Wall 4130 Steel Tube (2 ft)	Steering Column Support Tubes	Online Metals	#12	$24.73	0%	1	$24.73	2/2/2019	2/5/2019	-	Currently Own	-
Sean Zimlich	3/8" 4130 Alloy Steel Rod	Rod for welded inserts (3 ft)	McMaster-Carr	#13	$9.40	0%	1	$9.40	2/4/2019	2/6/2019	✓	Ordered	2/8/2019
Sean Zimlich	Steering Wheel Quick Release Spline	Spline for quick release	SPA Technique	#14	$76.00	0%	1	$76.00	2/4/2019	2/7/2019	✓	Ordered	2/14/2019
Sean Zimlich	4130 Alloy Steel 3/4" OD x 0.065" Wall Tube (1 ft)	Upper Column Tube	McMaster-Carr	#15	$13.64	0%	1	$13.64	2/7/2019	2/9/2019	✓	Ordered	2/7/2019
Sean Zimlich	Threaded Taper Pins	Taper Pins for the Steering Column	Military Fasteners	#16	$13.64	0%	3	$40.92	2/25/2019	3/4/2019	✓	Ordered	2/25/2019
David Streen	Steering Shaft Coupler	Spline Coupler for Rack	KAZ Technologies	#17	$35.00	0%	1	$35.00	2/26/2019	3/4/2019	✓	Ordered	2/26/2019
Sean Zimlich	5/16"-24 Grade 18-8 Stainless Steel Jam Nut	Lock nuts for heim joints	Fastenal	#18	$0.30	0%	5	$1.48	3/10/2019	3/15/2019	✓	Ordered	Corey
Sean Zimlich	5/16"-24 Grade 18-8 Stainless Steel Jam Nut - Left Hand	Lock nuts for heim joints	Fastenal	#19	$1.45	0%	5	$7.25	3/10/2019	3/15/2019	✓	Ordered	Corey

<u>*List of Website Links:</u>

#1 http://cad.aurorabearing.com/item/h-performance-rod-ends-spherical-bearings-rod-ends/prxm-t-prxb-b-series-male-rod-ends-ptfe-lined/prxm-4t-2?plpver=10
#2 http://cad.aurorabearing.com/item/h-performance-rod-ends-spherical-bearings-rod-ends/prxm-t-prxb-b-series-male-rod-ends-ptfe-lined/prxb-4t-2?plpver=10
#3 https://www.taylor-race.com/apex-universal-joint-58-bore
#4 https://www.fastenal.com/products/details/11587960
#5 https://www.mcmaster.com/97135a210
#6 https://www.mcmaster.com/9056K68
#7 https://www.mcmaster.com/8974K48
#8 https://www.speedwaymotors.com/Flaming-River-FR1943-Steering-Coupler-5-8-36-Spline-to-3-4-Round,52471.html
#9 https://www.mcmaster.com/6673t25
#10 https://www.mcmaster.com/5905K25
#11 https://www.mcmaster.com/5905K26
#12 https://www.onlinemetals.com//merchant.cfm?pid=7559&step=4&showunits=inches&id=250&top_cat=0
#13 https://www.mcmaster.com/6673t39
#14 http://www.spatechnique.com/store/itemDetail.cfm?prodID=767&catID=9
#15 https://www.mcmaster.com/89955k599
#16 https://military-fasteners.com/pins/threaded-tapered-pins/AN386-1-10
#17 https://kaz-technologies.myshopify.com/collections/steering-rack/products/steering-shaft-coupler-5-8-36-spline-x-3-4-id
#18 https://www.fastenal.com/product?query=70831+&fsi=1
#19 https://www.fastenal.com/product?query=0175071&fsi=1

Figure 18 - Purchasing Request Form

7.4 SolidWorks Models/Drawings

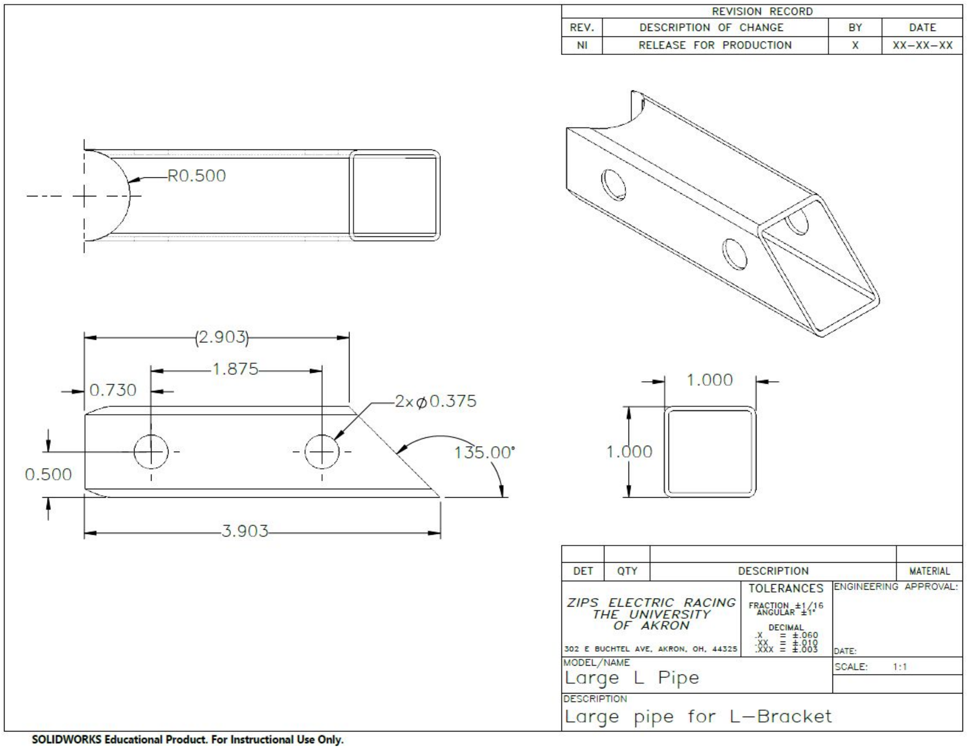


Figure 19 - Long Side of L-Bracket

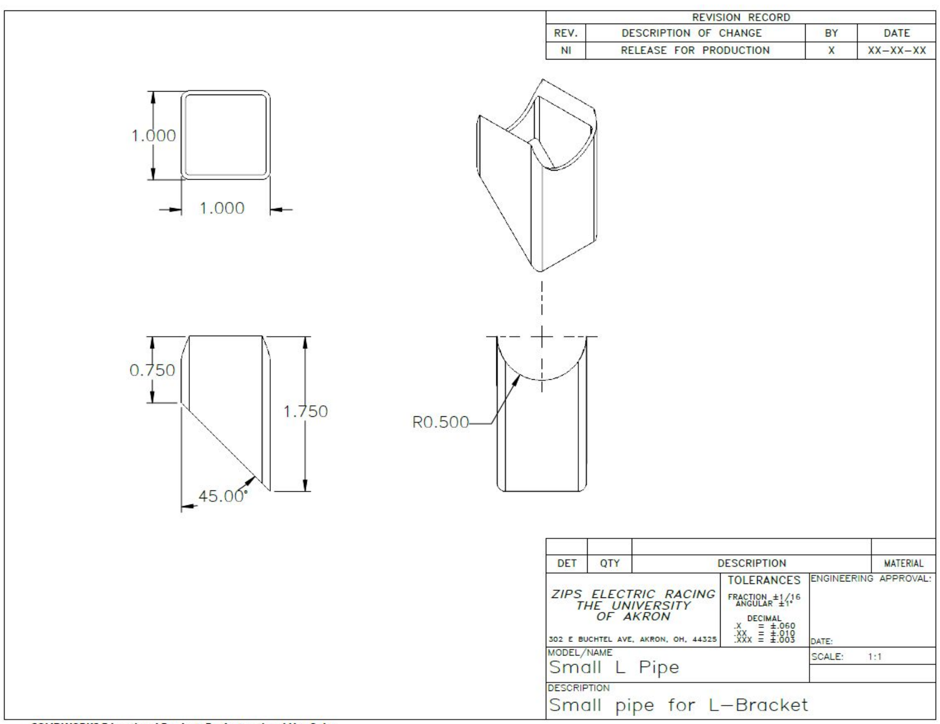


Figure 20 - Short Side of L-Bracket

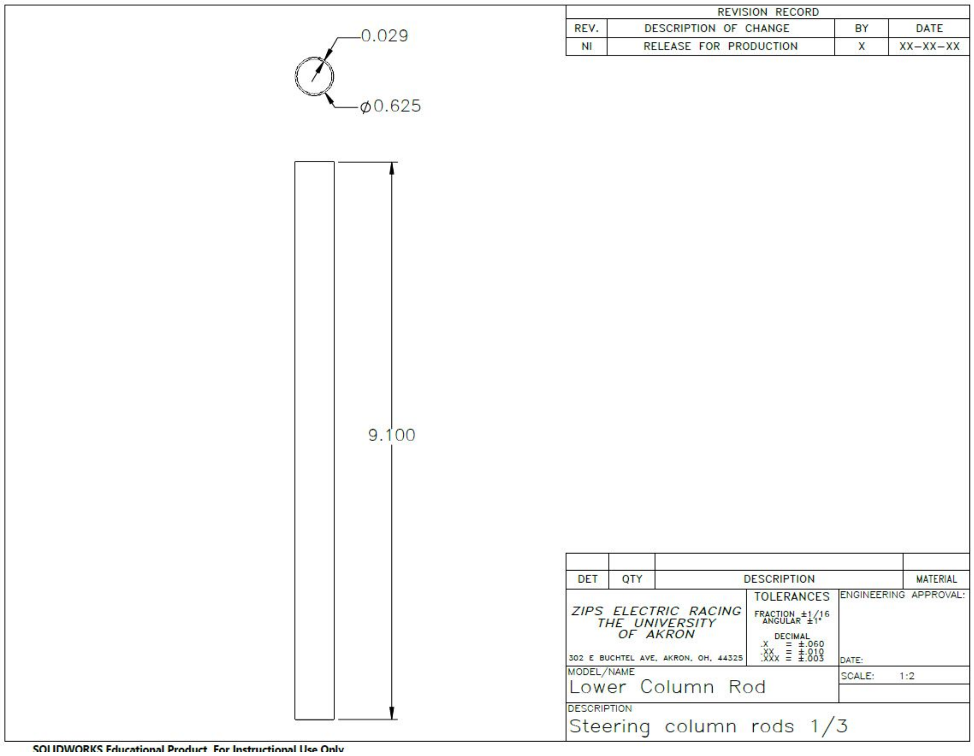


Figure 21 - Lower Column Rod

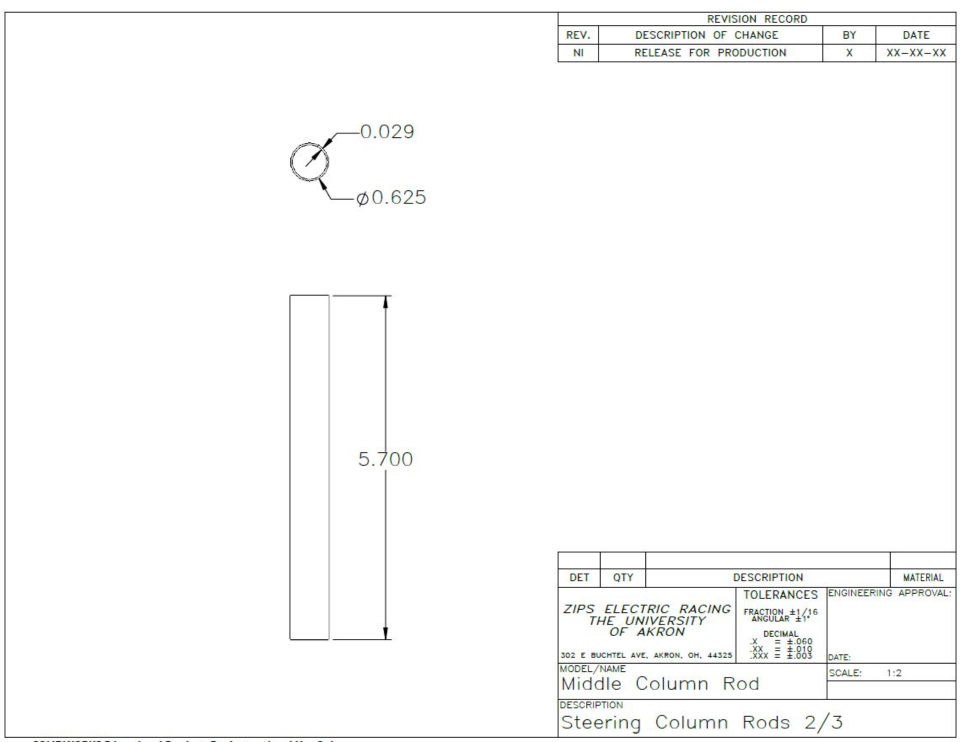


Figure 22 - Middle Column Rod

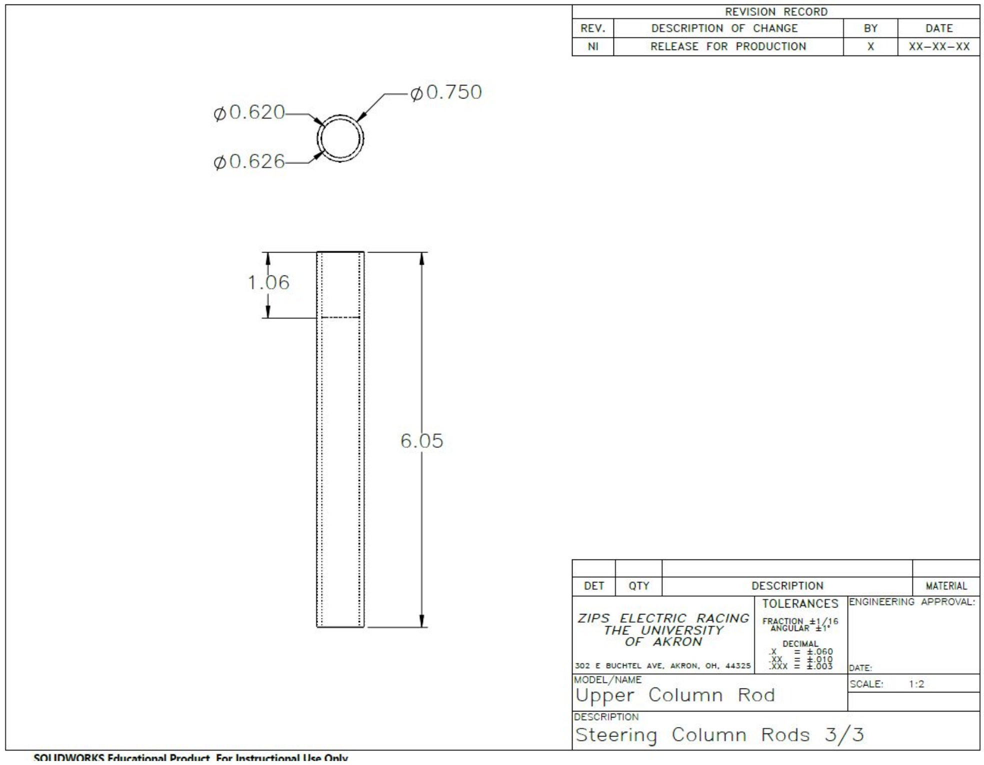


Figure 23 - Upper Column Rod

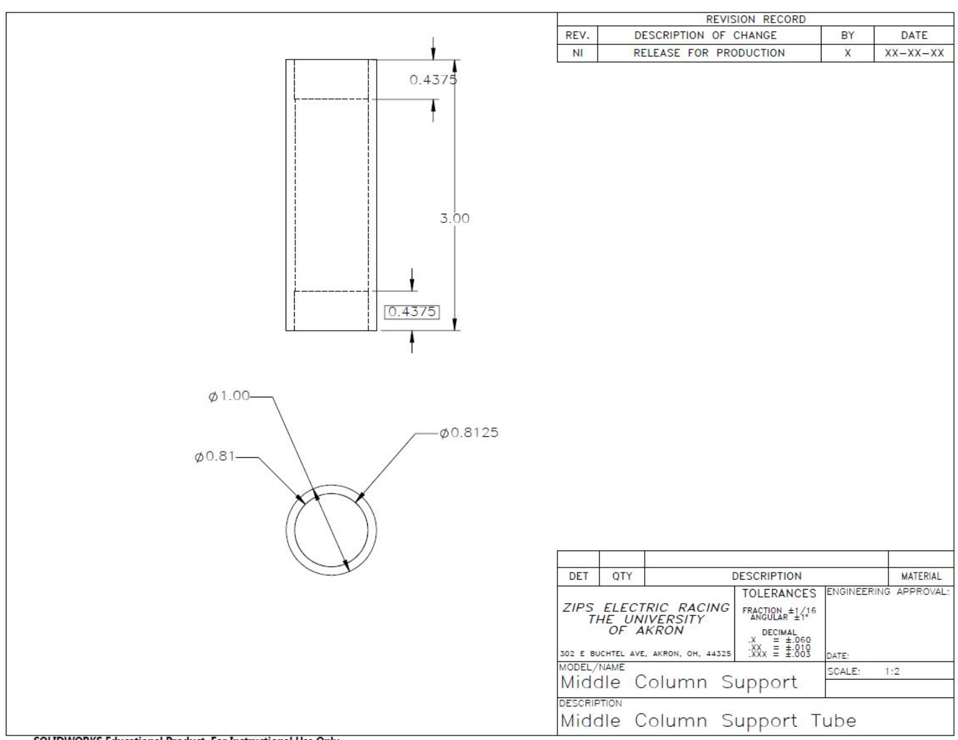


Figure 24 - Middle Column Support Tube

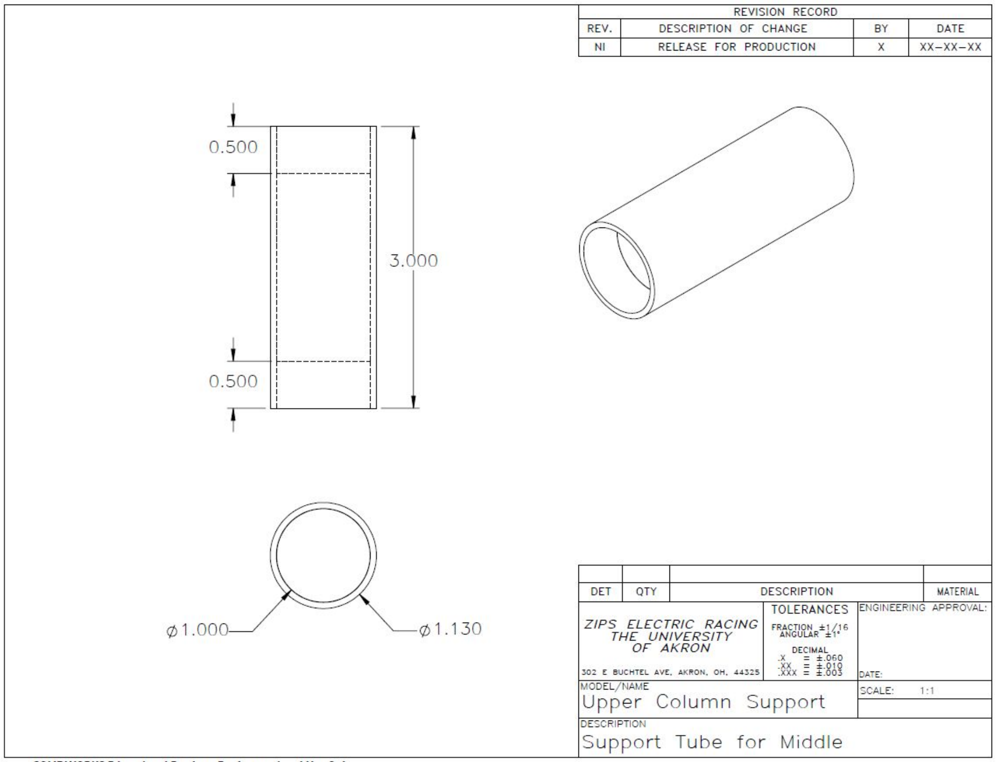


Figure 25 - Upper Column Support Tube

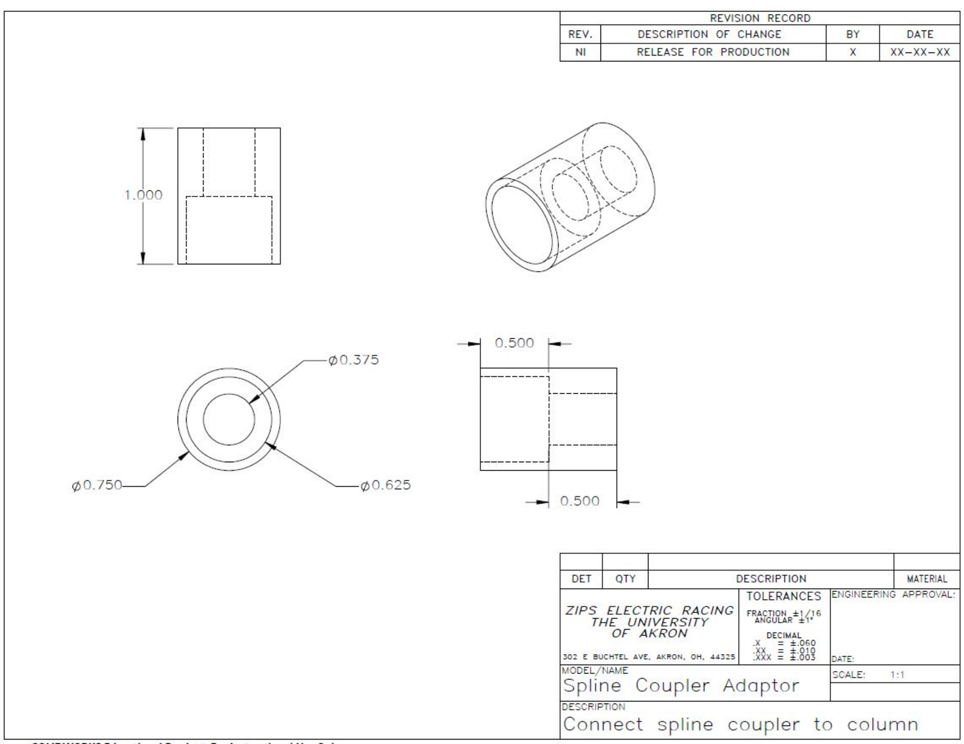


Figure 26 - Adapter for Spline Coupler

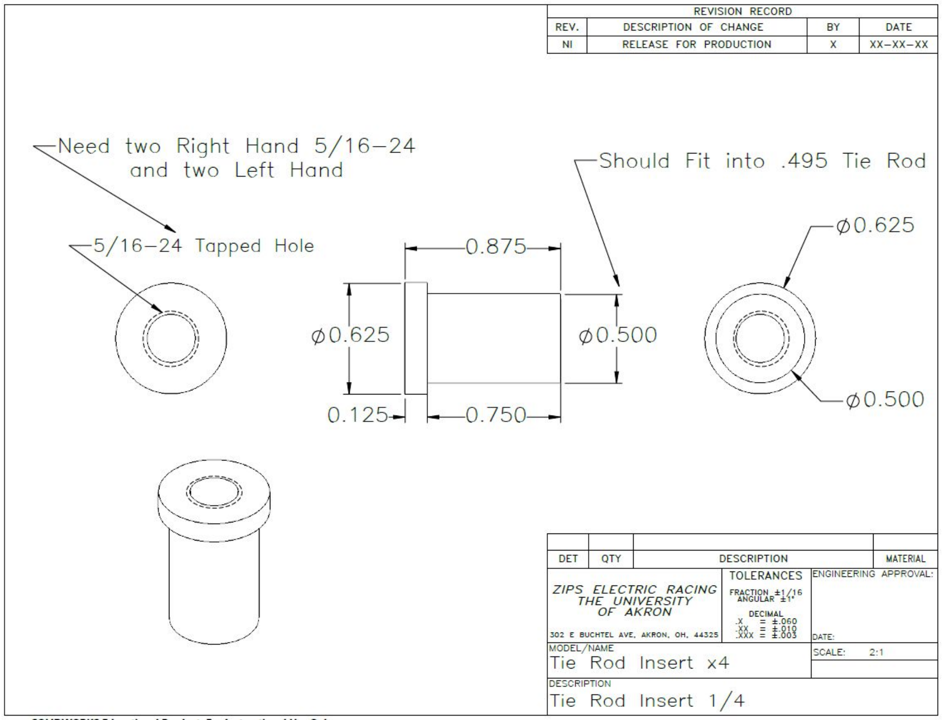


Figure 27 - Tie Rod Threaded Inserts

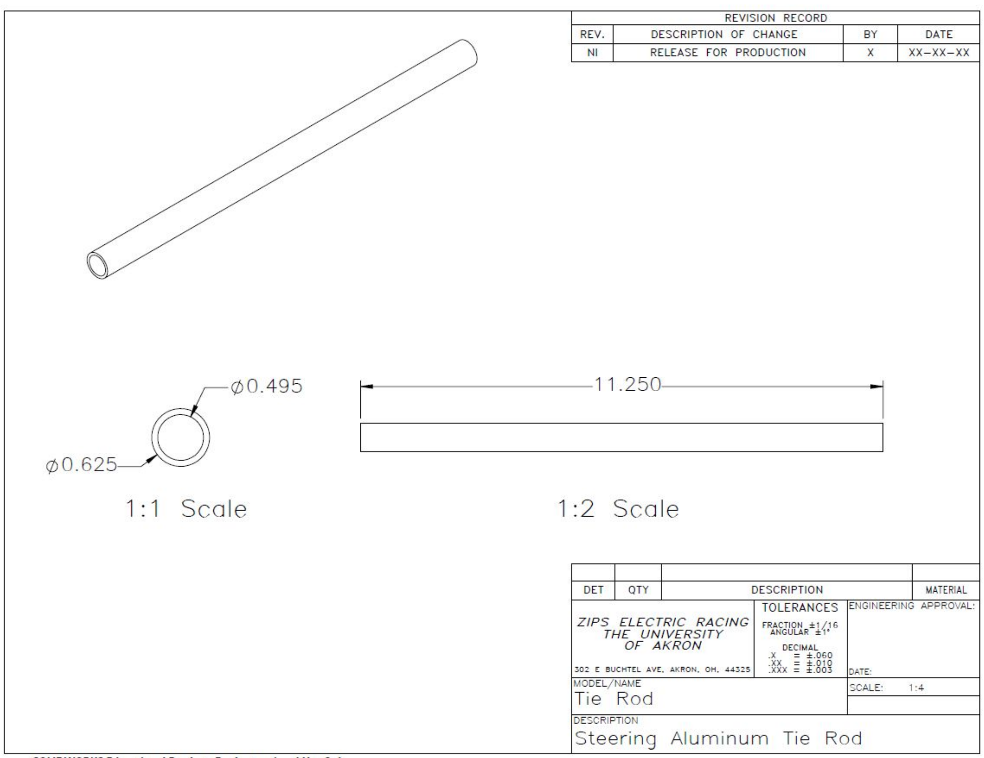


Figure 28 - Tie Rod

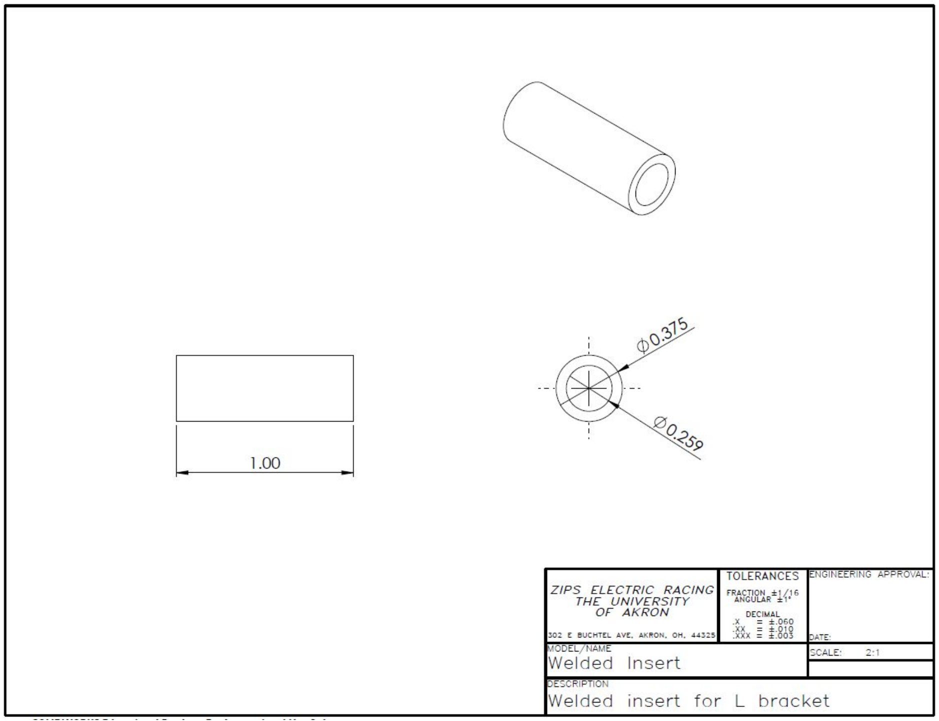


Figure 29 - Welded Insert

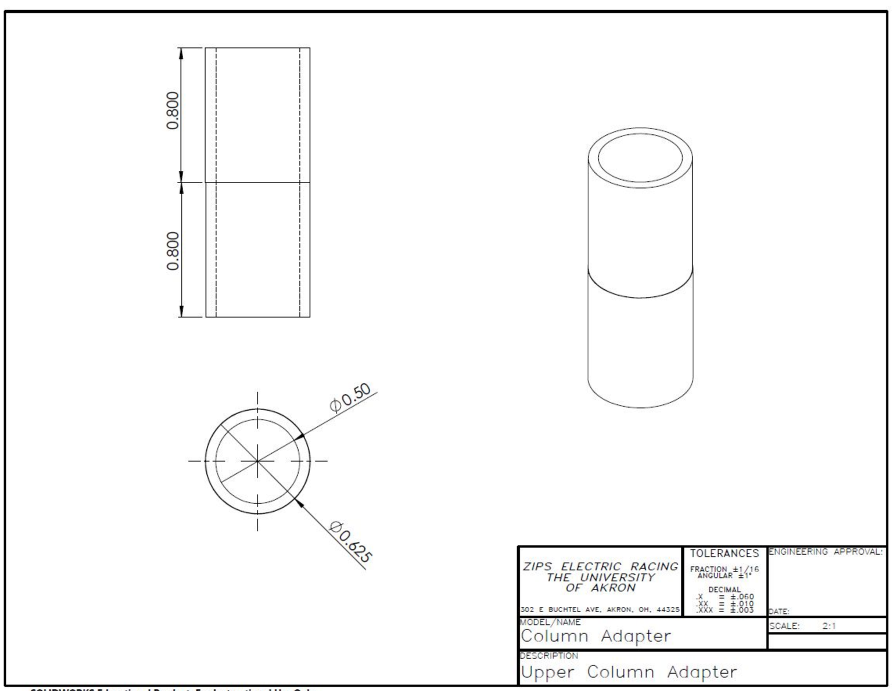


Figure 30 - Upper Column Adaptor

7.5 Actual Photos of Build/Testing

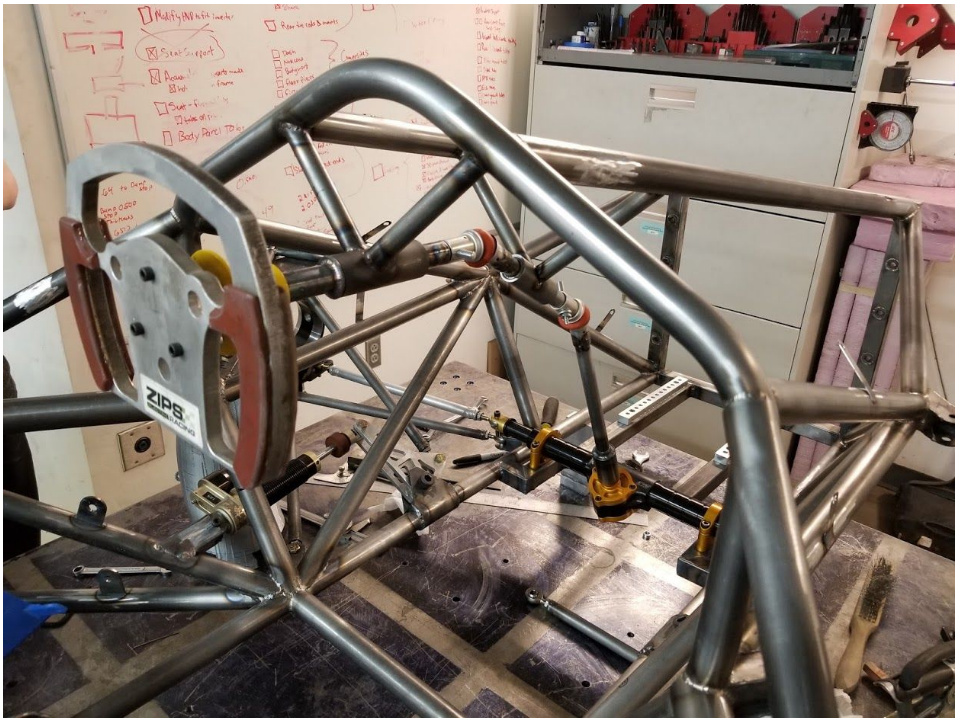


Figure 31 - Completed Steering System

Figure 32 - Mary Gladwin Parking Lot Testing