Design and Development of a Human Powered Vehicle

Team 17

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Abstract

The NASA Human Exploration Rover Competition starting on March, 30 is a competition that requires two passengers to navigate an extraterrestrial like terrain in the fastest time possible. With many awards available such as featherweight (lightest vehicle) the rookie of the year (best rookie entry) and overall time (fastest time trial), Team 17 has been aggressive in their timetable to get their design done by the end of 2016. With the design of the chassis taking center stage at the beginning of the semester, the group has moved forward to accomplish design in brakes, drive train, joints, hubs, suspension and frame. Metal and parts to start manufacturing have arrived for the frame and manufacturing is being planned to take place in the coming weeks. Future plans are set to finish the details of the drive train, the seats, wheels and steering. With the frame design done, the group can focus more attention on manufacturing while designing the aforementioned components. The idea for designing the parts left is to go simple as to finish a vehicle that can compete in the competition. Depending on time and money left, the group will then begin modifying and upgrading parts. Team 17's goal is to have a prototype of the vehicle done by the end of January as to use February and March to test and modify the vehicle.

Acknowledgements

Team 17 would like to thank everyone who has helped them to this point. Thank you to the local bike shops: University Cycles, Great Bicycle Shop, and Joe's Bike Shop for parts and advice. Thank you to the student machine shop for information on designing for manufacturing. Thank you to FAMU-FSU SAE club for advice on vehicular design. Thank you to team 17's faculty instructors Dr. Chiang Shih, Dr. Nikhil Gupta and Mr. Keith Larson for their advice on design and project management.

1. Introduction

The annual NASA Human Exploration Rover Challenge was started in 1993 under the name of the NASA ‘Moon buggy’ Challenge. The regional collegiate challenge was designed to encourage the development of vehicles and technologies that are up to the task of exploring harsh environments in a similar fashion to the roving vehicles on the NASA Apollo lunar missions. The challenges intent was to foster interest and creativity in young minds interested in further exploration of the universe. Just like the lunar roving vehicle, the competition rovers must abide by specific constraints such as: collapsed vehicle dimensions for storage, and making a vehicle that accommodates two drivers. The main objective of the challenge consists of a time trial around an obstacle course on the grounds of the Marshall Space Flight Center shown in figure 1.

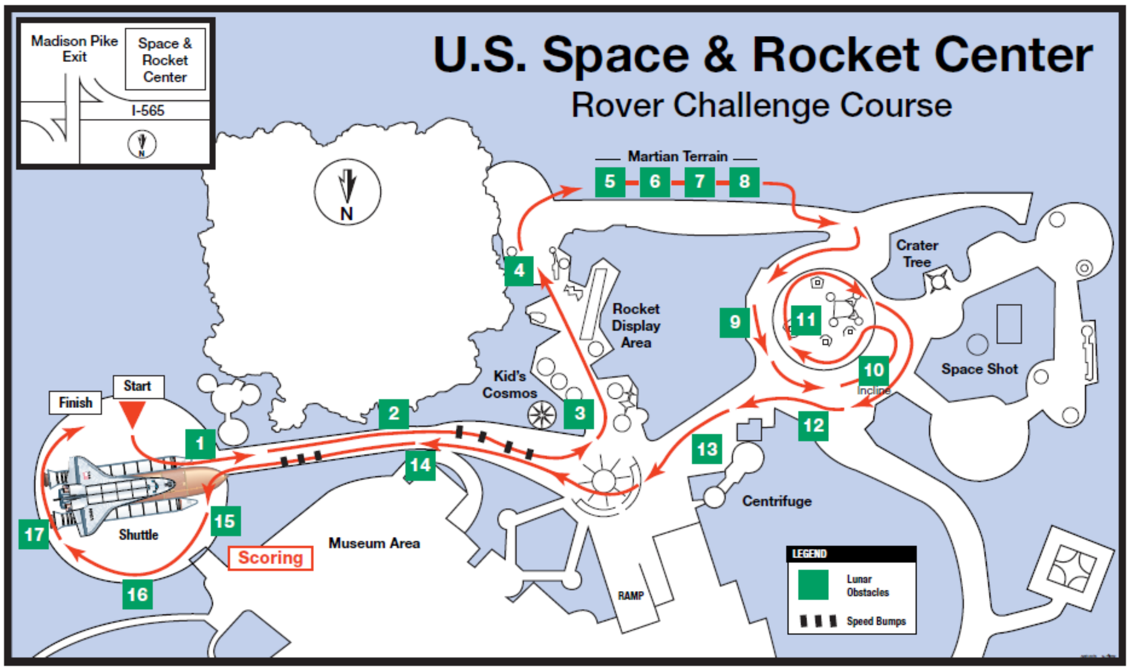


Figure 1: Map of the Course [6]

The course specifics vary by year but are consistent in that they are designed to simulate the terrain of barren planets. The challenge includes optional secondary awards given out for innovations in design, weight, and creativity and so on. The upcoming 2017 challenge features the objectives given by table 1.

Table 1: Available Awards [6]

Awards	Reward ($ amounts)	Details
AIAA Report	250	<12 Page Report Detailing Design
Alternative Drivetrain	500	Vehicle Utilizes drivetrain other than typical chain-sprocket system
Featherweight	none	Lightest Vehicle
Rookie Award	none	Team that posts the fastest 'first year' time, ranked against other first time competing schools
Safety Award	none	Report Detailing measures undertaken to ensure safety before and during competition
Fastest time	none	Post the fastest trial time through the obstacle course

2. Constraints

The following design and competition constraints relevant to FSU's 2017 entry are given by table 2 below. Failure to adhere to any constraint may result in disqualification or a time penalty to the team's trial score.

Table 2: Constraints [6]

Requirement	Description
Occupancy	Vehicle Must carry 1 male and 1 female
Propulsion	Vehicle must not have energy storage devices
Wheel Design	Wheels cannot have any commerical wheel parts except bearings and hubs
Performance	The rover is expected to traverse hills up to 5 ft high at a 30 degree incline
Collapsed Dimensions	Rover must fit within a 5 foot cube in its collapsed form and assembly is apart of the time trial
Weight	The rover must be able to be carried 20 ft by the two riders
Assembled Dimensions	The rover must be no more than 5 ft wide and make at least a 15ft turning radius
Ground Clearance	Any parts in contact with the rider must be greater than 15" from the ground
Occupant Restraints	Seatbelts must be worn by the riders during the race, rovers can be disqualifiedby judges at anytime if they deem a rover unsafe
Flag Display	The US flag and warning stickers must be displayed
Sharp Edges	Sharp edges or protrusions must be covered by padding or dealt with
Fenders	Minimum area of 120 sq.in per fender

3. Needs Statement

The objective of this project is to design, assemble, and drive a vehicle through the 2017 NASA Rover challenge obstacle course in Huntsville, Alabama. The intent is to compete against other vehicles from other institutions in a time trial event. Previous years vehicles will be assessed to determine their weaknesses and strengths in completing the course in order to develop a better vehicle. The main areas of focus will be: structure, weight, power delivery, wheel design, and it must have collapsible configuration.

"There needs to be a ground vehicle that will be operated by a fit male and female driver, capable of competing in the NASA Human Exploration Rover challenge."

4. Methodology

Much of the constraints for this project helped to dictate how we would go about making the choices for the project. Our choice to go for the featherweight award also helped influence many of our choices during this project. The first major hurdle was the chassis that the rest of the rover would be designed off of. When considering strength we went with triangular sections throughout our design. While we were iterating on our frame design we researched other teams in order to get an idea of what the winning teams from previous years used. During this research we came across the Rhode Island School of Design (RISD), who had a similar frame, to the idea that we had started on. We actually liked it enough that we asked them if we could use their great online documentation of their design process to help our team get a jumpstart on the project. Once we received their approval, we started to follow their methods and design a similar frame, which is what we are basing the rest of our components on. They were a big help in keeping our project on track, as it would have been a monumental task to do this project with only five people, compared to the fifteen plus people they had when working on it originally.

5. Concepts: Generation and Selection

5.1 Frame Concepts

The team decided that the best approach to designing the rover would be to tackle the chassis first, and then design the rest of the components based on how they would fit onto the frame. Initial research involving chassis design began by looking at previous teams from the NASA rover competition, as well as other (often motorized) off-road vehicles. From these design concepts we found that there were three main styles of seating orientation, the selection of which has a major impact on how the chassis will be designed. The three styles were side-by-side, tandem, and back-to-back. The team designed basic frame concepts suitable for each type of seating orientation and determined to analyze the advantages of each style in order to decide on the design concept to move forward with.

Figure 2 shows the side by side design, inspired by a dune buggy. In this concept, the two seats would be located in the wide rear section on the left with steering components located in the front on the right of Figure 2. It's simple, solid, and allows components to be integrated into the frame rather than having independent modules welded or bolted onto the sides of the frame.

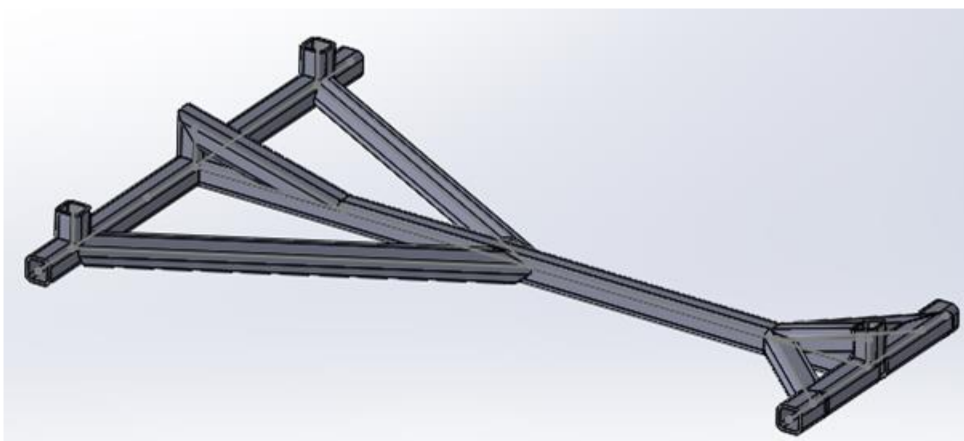


Figure 2: Dune Buggy (Side-by-Side)

The next design, shown in figures 3 and 4, show a single truss as the primary section of the chassis that was typical of previous competition entries, including that of the winning team from the previous year. This design supports both of the two inline types of seat arrangements: tandem and front-to-back. Triangular trusses are an extremely common structure seen in various types of engineering because they can be made extremely strong even with lightweight materials.

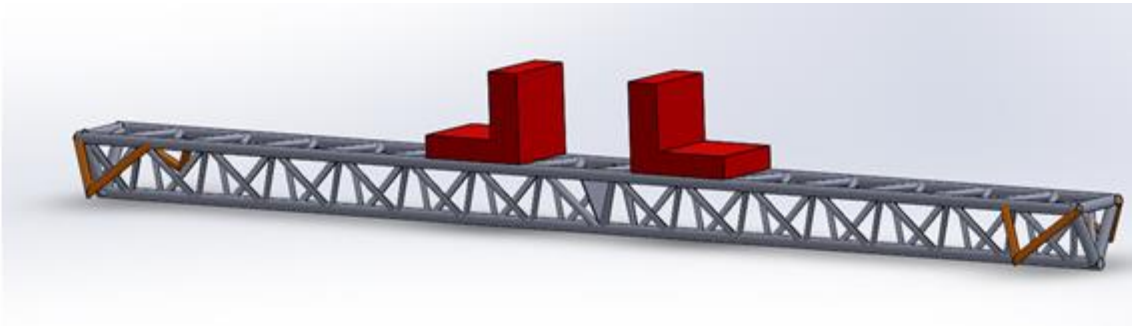


Figure 3: Truss (Back-to-Back)

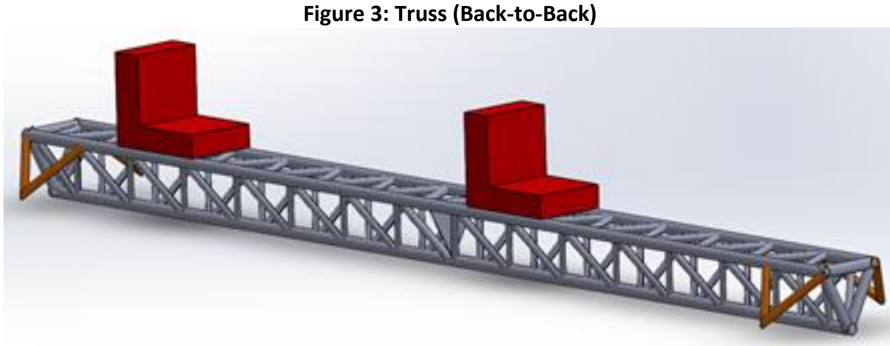


Figure 4: Truss (Tandem)

The final design, shown in Figure 5, is a simple box style frame with sections for seats. It was inspired by the frame for a pickup truck and is also commonly found on soapbox racers. The figure shown is in a tandem configuration, but it could modified by moving the rear (left) seating support closer to the middle and having the rear driver face the opposite direction to accommodate a back-to-back configuration, if desired. This design, like the first concept, allows for a integration of the components onto the frame.

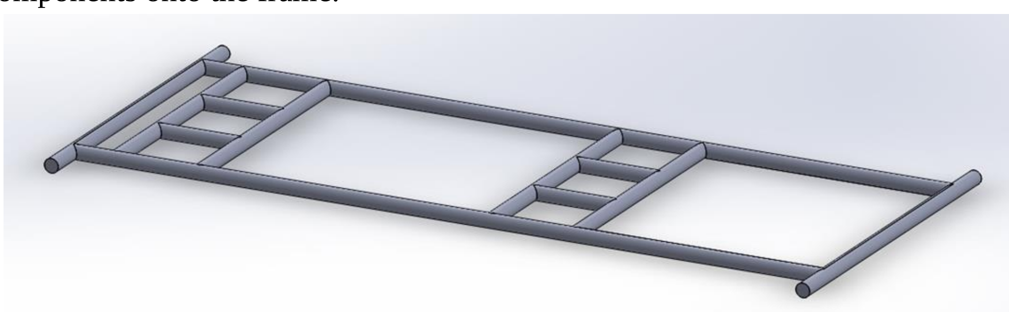


Figure 5: Box Frame (Tandem)

5.2 Frame Concept Selection

The largest obstacle in selecting a design for the chassis was settling on the seating orientation for the drivers: tandem, back-to-back, or side-by-side. Before selecting a design, the team first needed to analyze the strengths and weaknesses of each configuration. If more than one of the design concepts were found to be suitable for the chosen seating orientation, further analysis of each frame would be conducted to decide on a winner. Once one of the frame concepts had been selected, the team could move forward to a detailed design of the chassis.

5.2.1 Tandem

Key features of the tandem configuration were that it would give plenty of seating room for each driver to operate in, each driver sitting at different points along the frame means that their weight is spread along the frame rather than being concentrated at a single point, and it makes assembly relatively simple to design and execute since the team could mimic the methods from previous competition entries. Because each driver is sitting by themselves in this configuration, it also allows the rover to meet the less than five foot width constraint of the competition without sacrificing driver comfort.

This all comes at the cost of an expanded wheelbase, however, since room is needed to fit each driver in their recumbent position as well as the space needed for pedaling. An expanded wheelbase means that the vehicle would need more material and reinforcements for the frame to account for the bending stress from the weight of the drivers. It would also increase the overall turning radius. Perhaps the most complicating factor of choosing an inline style is that it requires the implementation of a folding mechanism in order to meet the pre-assembled requirement of fitting lengthwise inside of a five foot cube. This adds to the overall complexity of the design, however it should be noted that the implementation of such a feature is encouraged by the rules of the competition and so the team could simply use previous competition entries as a guide.

Another issue is power delivery. In a tandem configuration, the driver in each seat powers their respective axle, meaning that front and rear wheels are powered at different rates. This would likely result in one of the drivers bearing a disproportionate share of the load and may lead to premature exhaustion. This is particularly true if the rover is going up an incline, where the weight of the vehicle shifts away from the center and towards the rear wheels, causing the front wheels to lose traction and forcing the rear driver to propel the vehicle almost entirely on their own.

5.2.2 Back-to-Back

A back-to-back configuration has similar strengths and weaknesses to the tandem setup, but there are subtle differences. The drivers can enjoy nearly the same amount of operating space as in the tandem style but because the rear driver’s pedal setup can be allowed to hang off the back end of rover instead of being between the drivers, the wheelbase can be shortened a bit. The weight of the drivers is still spread across the frame, but because they can be seated closer to the wheels the frame itself wouldn’t be under as much bending stress to support their weight.

Some of the drawbacks of the back-to-back configuration were that the rear driver’s pedaling motion runs counter to the direction of the wheels, and so if driven by a belt or chain there would be a greater power loss to those wheels due to the extra gearing that would be required to transmit their torque in the proper direction. The mid-chassis folding joint could also potentially become a problem, because although there’s less bending stress on the overall frame the weight of the drivers would be concentrated closer to its weakest point, increasing the shear force and thus requiring a greater degree of reinforcement around the joint. Also, while each driver would have plenty of room in front of them, there may be a bit of head bumping in a back-to-back configuration. It can also be slightly disorienting for the person in the rear of the vehicle to be facing opposite the direction of motion.

5.2.3 Side-by-Side

The final idea being considered was to have the rover pilots sit side-by-side. This was the most common design found in motorized off-road vehicles but was a rare sight among previous competition entries. The greatest advantage of this setup is that the wheelbase can be made dramatically shorter than with either of the two in-line configurations because it only needed to accommodate the recumbent length of a single driver. In fact, in this configuration it's possible to shorten the overall wheelbase to such an extent that the rover would satisfy the pre-assembled length requirement of less than five feet even without incorporating a folding mechanism. The weight of the drivers would also be concentrated nearly on top of the rear wheels, decreasing the need for supports along most of the length of the frame. Sitting on top of the rear wheels also means that those wheels (which are typically the driving wheels) get increased traction with the ground.

The biggest drawback of the side-by-side configuration is that the drivers are forced to share the same operating space, which could lead to a lot of jostling with each over the course of the track. Delivering power to the rear wheels of a side-by-side manually powered rover may also get a bit tricky because Also, while it is possible to design a side-by-side rover that meets the length requirement without having to implement a fold, if one did need to be added it could complicate the design immensely because it would mean that the space between the sprockets would be different in the folded versus unfolded configurations. Because there were so few side-by-side rovers in previous competitions, any solutions would have to be generated entirely from scratch and would therefore become a potential design bottleneck. Finally, while concentrating the weight at the rear of the vehicle increases the traction at those wheels, it also makes them more likely to sink into any loose sand or other terrain that may be encountered.

In order to come to an informed choice, a decision matrix was set up to help guide the team in selecting a final design. As seen in table 3 below, the results were essentially a wash. However, further research into frame design suggested that the essentially two-dimensional planar frame designs of the dune buggy and box frame styles were not viable without adding additional supports to prevent torsion about their major axes. To make either of these frames rigid would essentially mean doubling the amount of material to transform them from planar to three-dimensional bodies, so the team settled on the truss design because it was both a proven concept in this competition and because it made efficient use of its materials. Specifically, the team selected the truss-inspired concept seen in figure 3 in a back-to-back rider configuration because it was decided that the benefit of the shortened wheelbase far outweighed the minor discomfort to the riders as well as the added complexity of reversing the direction of the rear driving torque.

Table 3: Seating Orientation Pros/Cons Chart

Seating Orientation				
Pros/Cons	**Importance**	**Tandem**	**Back-to-Back**	**Side-by-Side**
Wheelbase	5	1	3	5
Ergonomics	4	5	4	1
Complexity	5	3	2	3
Weight Distribution	3	3	4	4
Turning Radius	3	2	3	4
Assembly Time	4	4	4	2
Power Delivery	4	3	2	3
Score		**83**	**86**	**88**

5.3 Chassis Selection

After selecting the truss-inspired frame, the team set about to determine the specific dimensions that would be used in the final, detailed design. In order to aid this process, the team also began to take a closer look at previous competition entries that had a similar style chassis, which lead to the discovery of the Rhode Island School of Design (RISD). The Rhode Island School of Design has been competing in the NASA Human Exploration Rover Challenge for over 6 years, and in 2016 their tadpole trike style rover (figure 6) came in second place using a modified version (see figure 7) of the triangular truss frame that was common throughout the competition. In addition to finishing second in the main event with a time of 5 minutes and 26 seconds, the RISD rover also picked up the featherweight award (given to the team with the lightest weight design) by weighing in at only 126 lbs. The RISD rover's 2015 incarnation also picked up the Technology Challenge award, given to the team with the best wheel design. In addition to their admirable performance in the main event and their secondary design awards, the RISD team also has a terrific breakdown of their design process detailed online, so we reached out to them and gained their approval to base our frame off of theirs.

Figure 6: RISD Rover [3]

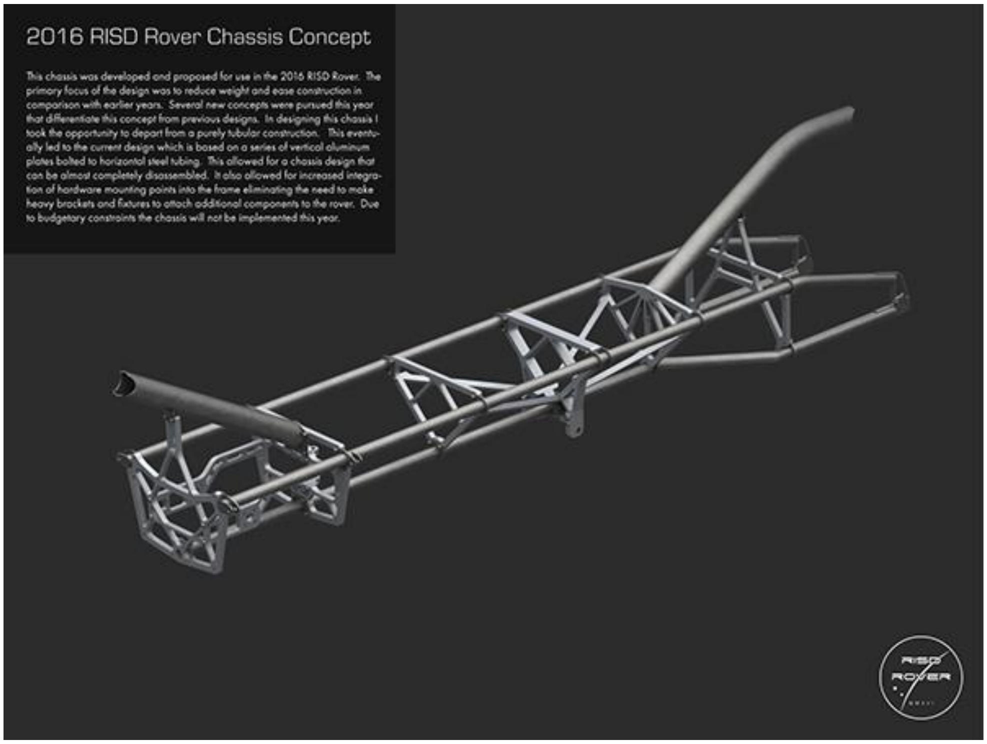


Figure 7: RISD Chassis Concept [3]

With a specific design in mind, the team moved forward with material selection and dimensioning. After consulting with Florida State University's chapter of the Society for Automotive Engineers (SAE), it was decided that AISI 4130 steel (more commonly known as chromoly) would be an ideal material for the frame due to its high strength-to-weight ratio and weldability. Chromoly is a very popular choice for many lightweight vehicle frames, such as Baja racers, and so in addition to being strong, light, and weldable, it has the additional benefit of being readily available and relatively inexpensive.

In order to determine the dimensions of the frame, the team first sought to determine the length of the longest section that could go unsupported and still withstand the weight of the riders without failing. This was accomplished by analyzing the von Mises stress in SolidWorks on various lengths and cross-section thicknesses of chromoly round tubing. Because the only method known to the team for analyzing the von Mises stress involves fixing a single end, rather than both, the von Mises stress was calculated by fixing one end and analyzing a force applied to the other side as shown in figure 8. The length of each trial specimen, therefore, represented half of the total length of the member being analyzed because it was assumed that the greatest stress for a single member would come when the force was applied directly to the middle of the tube. Unfortunately, the team was unable to perform dynamic analysis on the frame or any of its members, so to compensate the force of the weight of each rider was rounded up to 200 lbs despite neither of them weighing over 160 lbs. Using a safety factor of 1.4, which is NASA's standard for metallic structures it was determined that the frame would be made out of 4130 chromoly round tubing with a 0.75-inch outer diameter, 0.065-inch wall, with no member spanning more than 12 inches between supports.

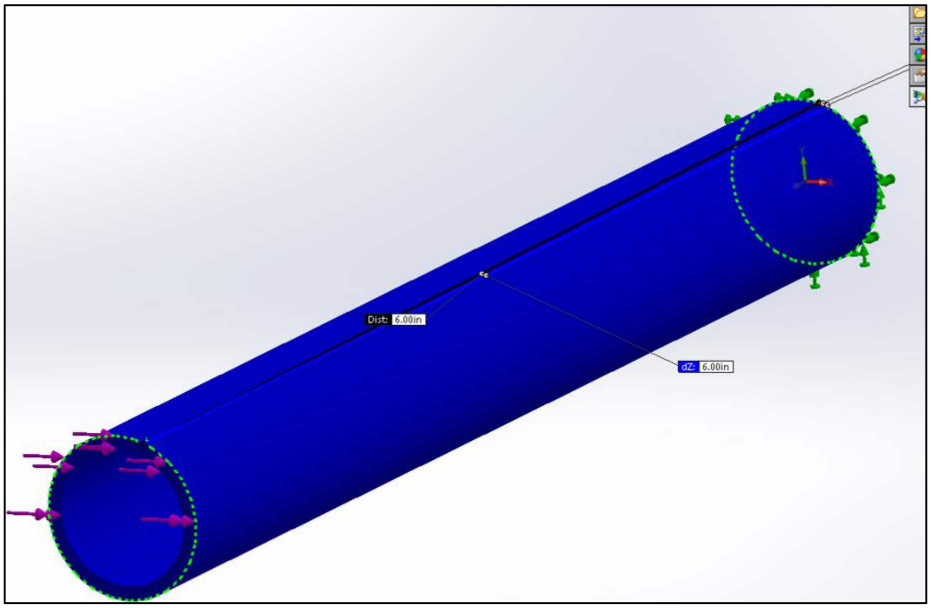


Figure 8: Analysis of Tubing

After measuring the recumbent lengths and widths of the chosen riders, and estimating the wheels to have diameters of no more than 25 inches, it was determined that frame should have a total length of about 96.8 inches (about 8 feet), be just over a foot wide at 12.8 inches, and have a maximum thickness (located in the front drivetrain housing) of 6 inches. Side and top views of the frame at this point showing these major dimensions can be seen in figure 9, below.

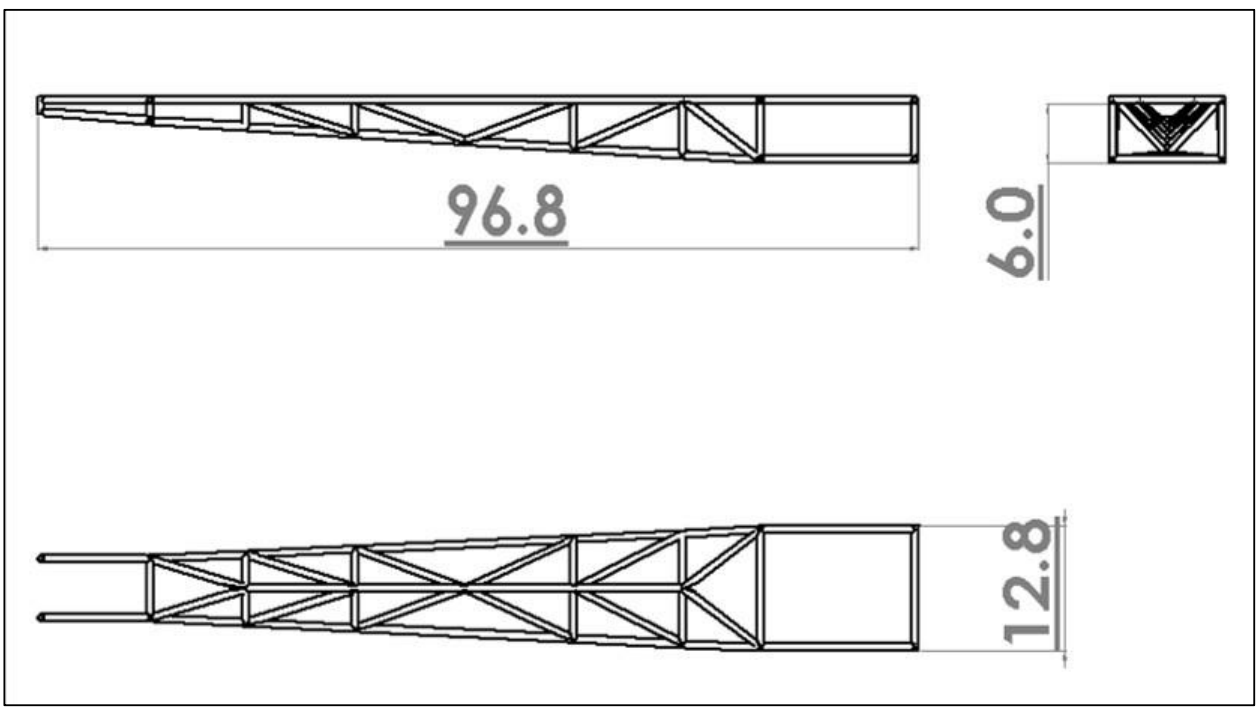


Figure 9: Dimensions of Frame in Feet

Once the frame dimensions and the maximum length of each member had been determined, the team moved on to analyzing the frame as a whole. Unfortunately, the team's familiarity with SolidWorks is not yet to the point where we are able to analyze structural assemblies, and so the frame was analyzed by treating it as a single body. After applying the weight of the riders to the center or the frame, the resulting von Mises stress was compared against our factor of safety of 1.4 to determine if there were any danger areas. As seen in figure 10, the point with the lowest factor of safety was found on the box-like part of the frame meant to house the front drivetrain. However even this weakest point had a factor of safety of 1.8, well above our goal of 1.4.

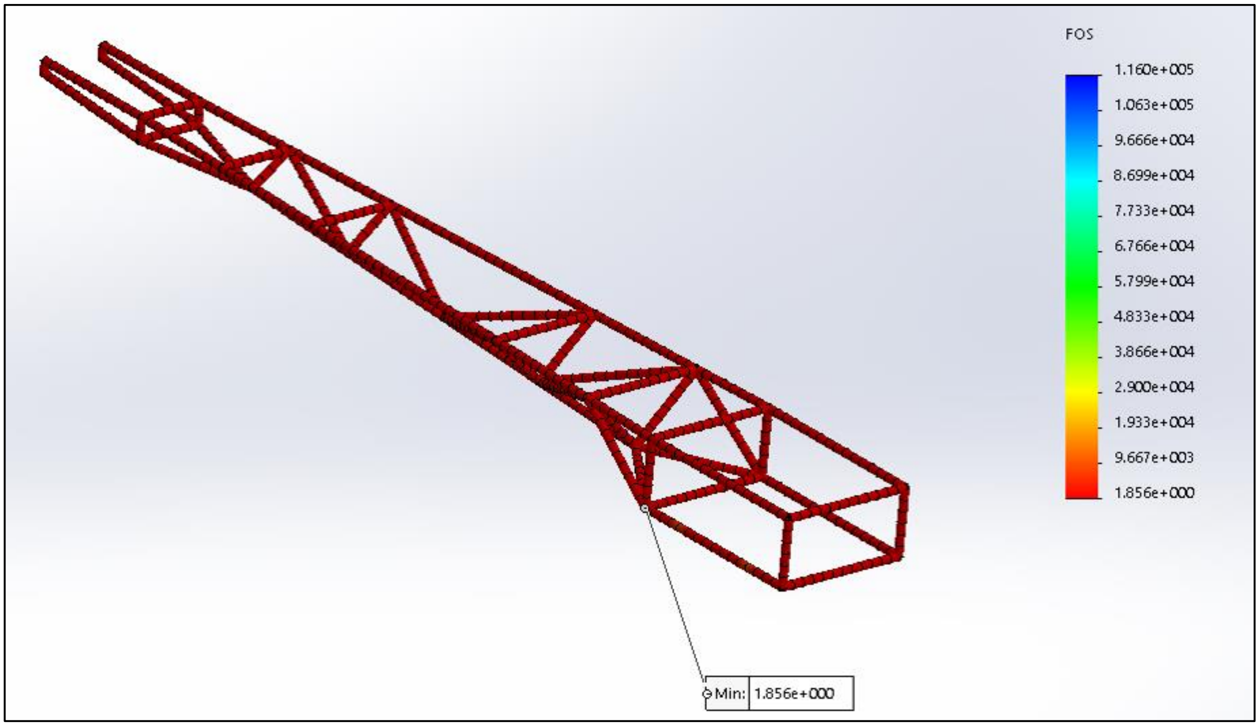


Figure 10: Safety Factor Graphic

Once our factor of safety had been satisfied throughout the entire frame, the same analysis was conducted to determine that actual stresses being felt throughout the frame. Although this is essentially the same as analyzing the factor of safety, the team felt it was important to understand the magnitude of the actual stresses throughout the structure, and the factor of safety plot seen in figure 10 was somewhat unsatisfactory because it did not adequately demonstrate the variations in stress throughout the chassis since the entirety of the frame experienced a factor of safety whose range was insignificant on the scale being used. As figure 11 demonstrates, the point of maximum stress experienced by the frame was only subjected to 248 ksi, well below chromoly's yield strength of 460 ksi. Additionally, the smaller scale used to measure the stress does a better job of illustrating where the stress is most prevalent throughout the body of the frame.

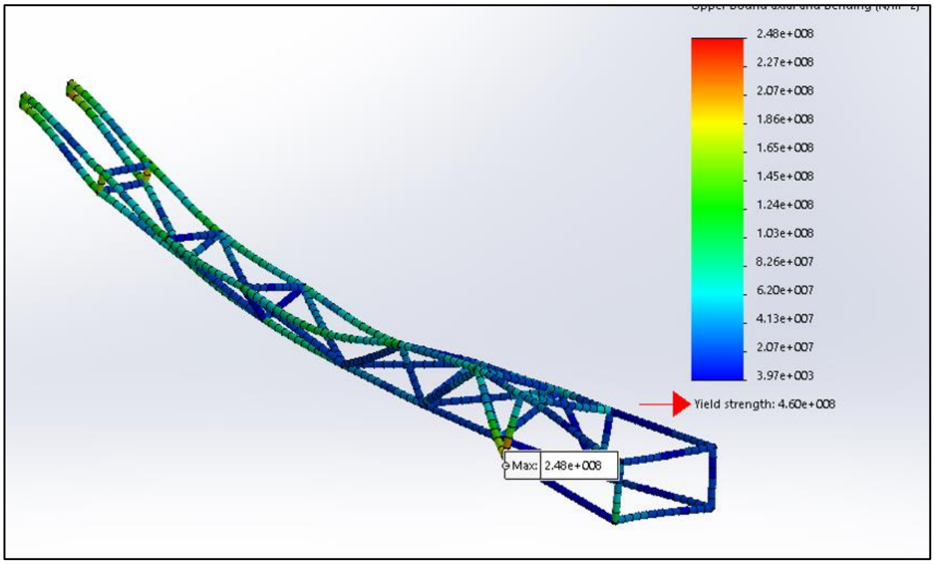


Figure 11: Deflection Chart

Once the team was satisfied that the frame would not undergo loading that would exceed the factor of safety, we set out to explore the rigidity of the frame because even if no permanent deformation was occurring, the team wanted to make sure there would be no significant wobble in the frame as the rover negotiated the track. Using the same von Mises stress used in the previous two analyses, the maximum displacement experienced throughout the 8 foot frame was determined to be only 4.86 mm, or about 0.2 inches.

The frame in its final form requires 52 feet of AISI 4130 steel (chromoly) to assemble. Using OnlineMetals.com, it was determined that 11 sections of 5 foot chromoly round tubing would be enough to construct the entire assembly and leave room for a small margin of error in cutting. Figure 12 shows that using the weight calculator also found on OnlineMetals.com, 55 feet of chromoly tubing with 0.75-in OD and a 0.065-in thick wall only weighs about 26 lbs.

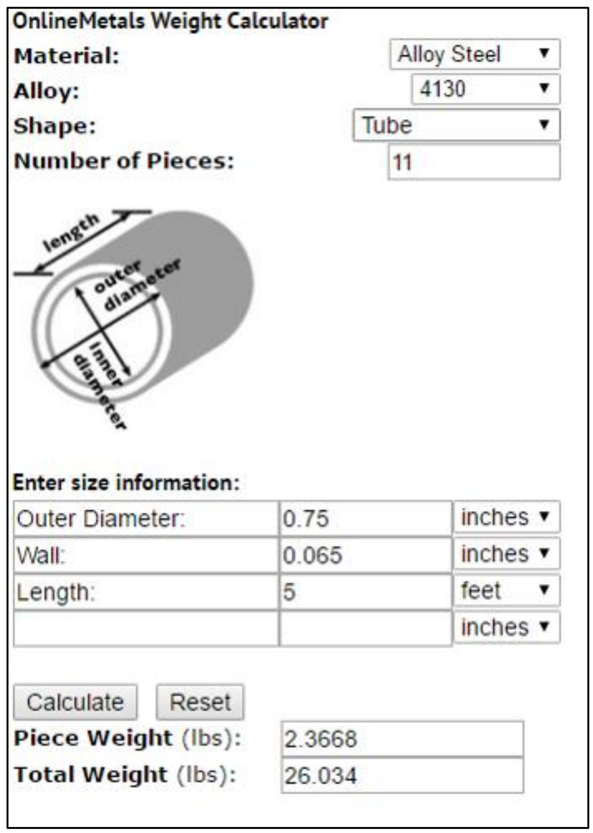


Figure 12: Online Metals Weight Calculator

6. Joint

The joint is a required part due to the constraint put in place by NASA that the rovers in the competition must be able to fit in a 5’x5’x5’ box. While some teams may not have an issue with this constraint based on how they did their design, our team and most others have an issue with the rover being over five feet long in the length direction. The way to solve this issue is some form of joint that allows for the rover to fit inside the constraint. The main two ideas considered were a sliding joint and a hinge joint. Upon consideration of both types, we decided that the hinge joint would be not only effective but also simpler to implement. When looking at most teams from the past years of the competition a hinge joint was implemented by nearly all who needed one, so our decision has some backup from within the competition.

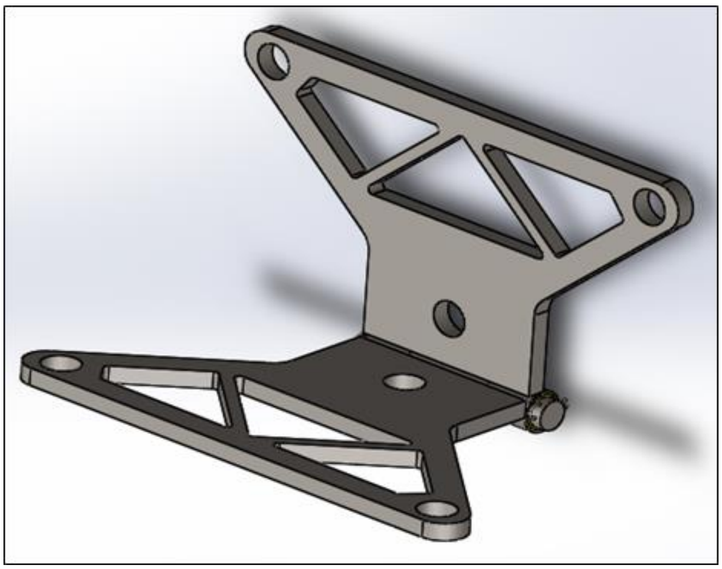


Figure 13: CAD of Joint

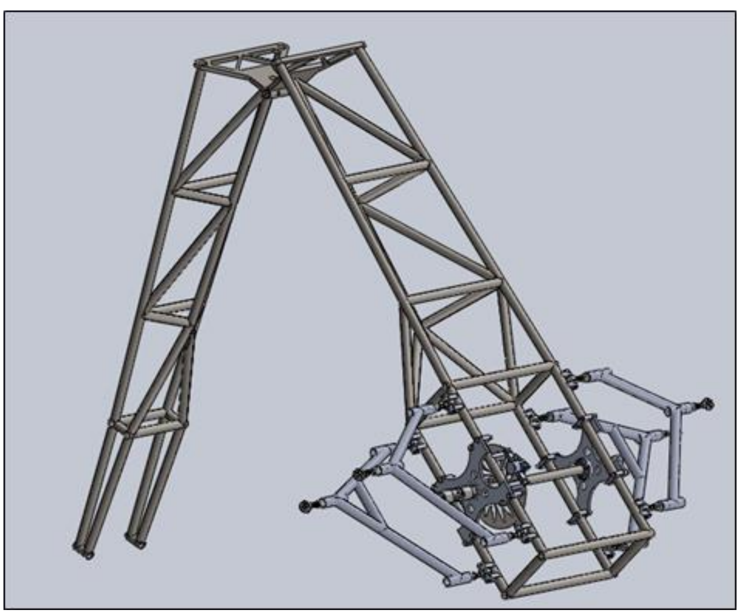


Figure 14: Assembled Frame with Joint

Figure 13 shows a close view of the joint that we design for this hinge as well as the joint being used in the chassis itself (figure 14). This allows the rover to fit within the constraint and then return to full length and be used for the rest of the competition. The triangles cut out are to reduce weight and a water jet cutter will be used to achieve this result. During analysis of this joint, the most stress was found to be at the hinge itself at the bottom. While the weight did apply a high amount of stress to the hinge itself, once the pin has been installed with cotter pins on both sides to hold that in place, it will be able to handle the load.

7. Tabs

The tabs were designed to attach components that require mechanical mobility. The outside pieces that can be seen in figure 15 below will be water jetted. The ends will be welded onto the frame. There is a Heim joint attached using a standard bolt and washer. One side of the tab will be threaded to keep the bolt in place. Heim joints allow for 360 degrees of movement in the parallel direction and only about 10-20 degrees of freedom in the perpendicular direction. These tabs will be used primarily to attach the suspension a-arms and in other places that require mobility. The tabs will be made out of Chromalloy and can be seen in figure 15 below.

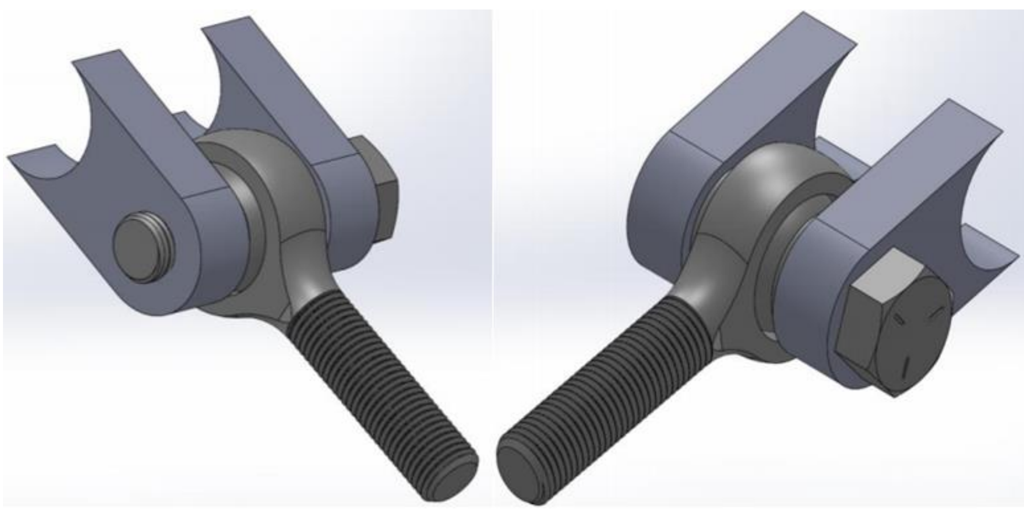


Figure 15: Tab Assembly

8. Suspension

Using the RISD website as a guide, the suspension chosen was the popular wishbone suspension. The suspension system is simple and therefore easy to manufacture and design. It is a simple design using two a-arms. Figure 17 shows the upper a-arm that will attach to the top bar of the frame. Figure 16 shows the lower a-arm that is slightly different to accommodate a place to attach the shock seen in figure 18.

Figure 17: Upper A-Arm

Figure 16: Lower A-Arm

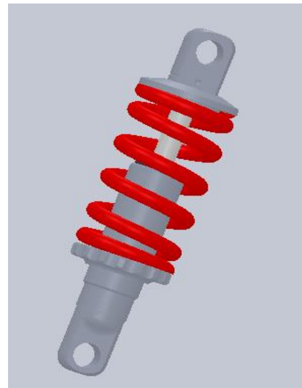


Figure 18: Bicycle Shock

The upper a-arm attaches to the top of the hub that will be discussed later in the report. The lower a-arm attaches to the bottom of the hub. The Heim joints attached at the end allow for 360 degrees of freedom in the parallel position and about 10-20 degrees of movement in the perpendicular position. The bicycle shock in figure 18, was donated from University Cycles. It has a spring tension of 650lb/in. This will attach on one end directly to the frame, and the other end to the bar that comes across in the lower a-arm.

The a-arms will be constructed out of the same material as the frame which is Chromalloy. On each tube ends a bung will be welded into it. Bungs are threaded inside and are created so that it can be welded into a tube to allow for connections. Those ends will be attached to the tabs seen in the previous sections.

Table 4 below indicates the amount of clearance that will be gained depending on the a-arm angle from the frame. The larger the angle, the greater the clearance gained. The more clearance gained means the smaller the wheel size that can be designed. This is important because the size of the wheel impacts how much torque and power is required from the drive train to power the vehicle.

Table 4: Maintaining 15" Clearance using Angle vs Wheel Size

A-Arm Angle	Clearance Gained	Minimum Wheel Size
10°	1.6 inches	26.8 inches
15°	2.3 inches	25.4 inches
20°	3.1 inches	23.8 inches
25°	3.8 inches	22.4 inches
30°	4.5 inches	21.0 inches
35°	5.2 inches	19.6 inches
40°	5.8 inches	18.4 inches
45°	6.4 inches	17.3 inches

Overall, a simple suspension system was designed to help maintain the safety of the vehicle as it navigates the course. Since there are only three wheels, there will only be a suspension system in the front. The desire is that the front will be able to accommodate any terrain and keep the vehicle upright. Based on talks with the FAMU-FSU SAE club and faculty member Mr. Keith Larson, they both indicated that the wishbone suspension is a simple and proven suspension system that should succeed.

9. Drive Train

New to the NASA Rover Challenge in 2017 is the optional Drive Train Technology Challenge, whereby the team which can get the best performance from a rover driven by something other than a chain will receive a $500 award. One of the team's goals for this competition was to pick up as many secondary awards as possible, and this one in particular seemed intriguing. However, the main goal was still to win the main event, so the team set out to compare and contrast different drivetrain concepts in order to see which one would be the most viable. The three concepts being considered where chain drives, belt drives, and shaft drives.

9.1 Chains

Chain drives were the most popular choice among previous rover entries. In fact, the team did not observe a single team in any of the previous year's powering their rovers with anything else, and they are popular for a reason. Transmitting power across a chain between two gears is possibly the single most efficient way of doing so, which is why they are so common amongst other human-powered vehicles (such as bicycles) where having an efficient power delivery system is far more valuable than having one with extreme reliability. Linking a pair of gears via a chain is also among the simplest ways of transmitting power, with the added bonus of the chain's symmetry about its central axis meaning that it can be looped and redirected in almost any fashion because either side of the chain is capable of meshing with the gears.

The biggest drawback to using a chain, at least for this competition, is that it disqualifies the team from competing for the optional drivetrain award. However, chains have disadvantages beyond their eligibility to win the team awards, which is the reason why NASA is encouraging the development of different systems. Chains are not very durable. Compared to the other two systems being considered, chains require far more maintenance (mostly in the form of periodic lubrication) and are liable to fail far earlier than the relatively maintenance free and durable belt and shaft drives.

9.2 Belts

One option for powering the rover that satisfies the innovative drivetrain challenge was to simply replace the chain with a v-belt. This would allow the team to compete for the award without radically deviating from the simplicity offered by a chain-and-sprocket system. Modern v-belts offer many of the same advantages as chains do, without the slippage that plagued their earlier incarnations. V-belts deliver power efficiently, although still slightly behind the level of a chain due the chain's rigidity. Belt drives as a whole are also a bit lighter than chain drives. Where they really shine, however, is in their improved durability. Belts do not need to be oiled, and although they will also fail eventually it happens on a completely different time scale than with a chain.

Belts, however, remain a bit of a niche market as the propulsion system for a vehicle. Finding and installing parts for a belt drive is likely to prove costlier and more difficult than a standard chain-and-sprocket system due to lack of availability of parts. They are also, as mentioned, slightly less efficient for delivering power than chains are.

9.3 Shafts

The final option being considered as a power delivery system for the rover was to run a solid shaft between the pedals and the wheels. Shafts are the method of choice for automobiles and many other vehicles because they are essentially maintenance free and often last the lifetime of the vehicle. A solid shaft would also put the team squarely in the running to win the drivetrain award.

However, there's a reason why solid shafts are a popular choice for automobiles yet are practically nonexistent for human-powered vehicles, and that reason is power loss. The drive shaft and the wheels each rotate about axes that are perpendicular with one another, and the point where the torque from the drive shaft is transmitted 90° to the wheels is a source of a great degree of lost power. This is acceptable an automobile because having a drivetrain that essentially never fails is far more important than having one that can deliver power more effectively from the engine, but a vehicle powered by a human being needs to prioritize efficiency or the driver will tire. Furthermore, the 90° transmission in a car only needs to happen once, and only if the vehicle is rear-wheel drive, because the motor can be oriented to rotate in the same direction as the drive shaft. The same cannot be said of a human-powered vehicle like the rover. The drivers of the rover pedal about an axis perpendicular to the drive shaft, and so if using a shaft the power would need to be transmitted at 90° not just once but twice: first, to transmit the motion of the pedals 90° to allow the shaft to rotate about its axis between the pedals and the wheels, then again at the wheels so that the torque propels them to rotate in the driving direction. That is a very large amount of power lost, and it is unlikely that it would be worth the lone benefit that a shaft provides: extreme durability. Add in the facts that solid shafts are generally heavier and more expensive than belts or chains and shafts appear to have very little going for them in this competition.

9.4 Drive Train Concept Selection

As before, the characteristics of each system under consideration were entered into a decision matrix to help guide the team to a solution. As seen in table 5, the choice here is clearly between chains and belts, with shafts coming in a distant third. This is especially true if one ignores the eligibility requirement of not using chains to win the Drive Train Challenge, in which case chains would have a slight edge over belts and shafts would fall even further into irrelevance. That being said, winning the drive train award is something that the team is interested in, and the added durability of belts was seen by the team as secondary but non-trivial. It was decided that if belts could be implemented in place of chains without significantly detracting from the overall performance, the team would do so.

Table 5: Transmission System Pros/Cons

Transmission System				
Pros/Cons	**Importance**	**Chain**	**Belt**	**Shaft**
Complexity	1	3	2	1
Power Loss	3	3	2	1
Innovative	2	0	3	3
Weight	2	2	3	1
Durability	1	1	2	3
Price	1	3	2	1
Score		**20**	**24**	**16**

9.5 Front Drive Train

The front portion of the frame itself is simplified to a rectangular box to house the front drivetrain and steering mechanisms. The right angles of the tubing simplify mounting of the drivetrain plates.

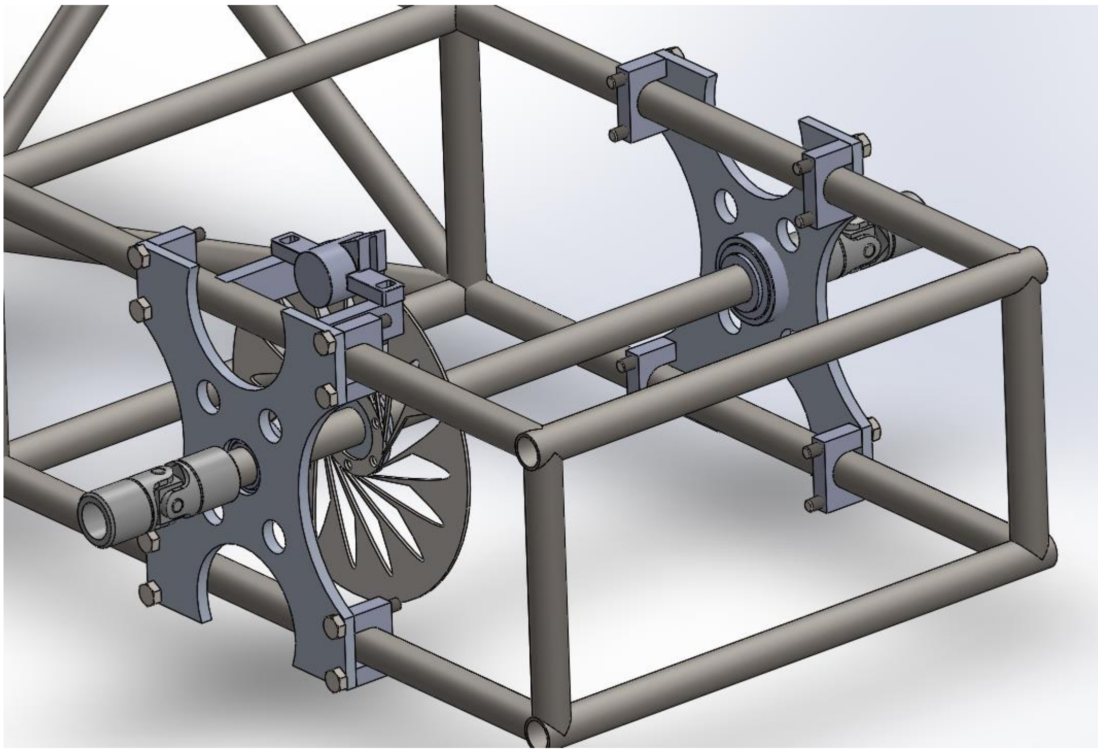


Figure 19: Front Drive Train Assembly

A major design change from RISDs vehicle is the braking system in the front. Shown in figure 19, the disc brake and caliper is mounted directly to the drive shaft and frame itself. The original design from RISD had a disc brake mounted to each front wheel, typical of cars or motorcycles.

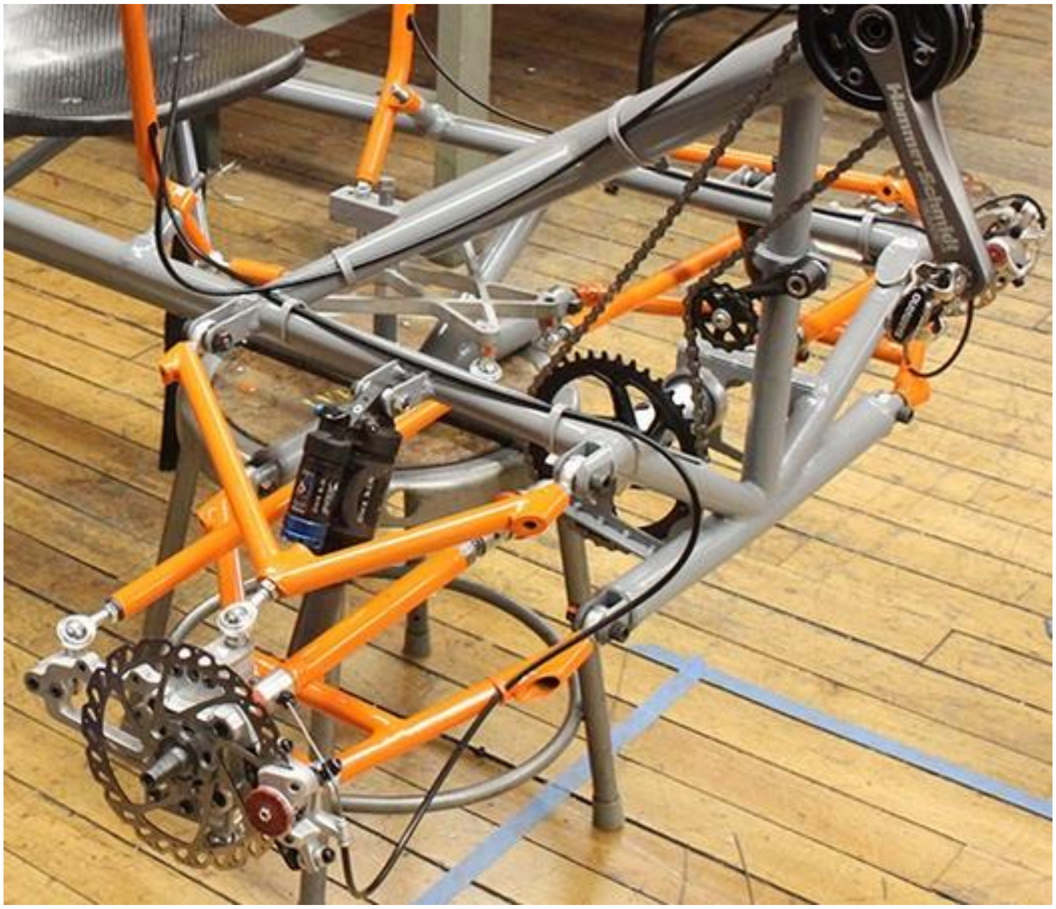


Figure 20: RISD Front Drive Train [3]

However, this means that in the likely event that the rider brakes harder to one side, the vehicle will skid to that side, losing stability. This change will not only allow even braking, but will reduce the overall weight and reduce the amount of parts associated with the design.

The front drivetrain will be chain and sprocket driven with a fixed gearing. The decision to go with a typical chain-sprocket set up is due to the donated bicycle parts which included chains and sprockets. The fixed gearing will be set for higher speeds as a derailleur to change gears would critically fail or jam as it has for other teams in the past. The final drive sprocket (not shown) will be mounted to the shaft with a keyed hub. The bearings used for the driveshaft are opposed conical roller bearings that will be press-fit into the x-shaped mounting plates on either side of the frame. The driveshaft itself will be press-fit with the interior portion of either conical bearing and will fit into the plates when they are bolted on the exterior of the frame. The plates and mounting tabs will be water jet and tapped accordingly. The plates themselves were chosen to be aluminum 7075 due to the fact that the strength to weight ratio is higher than that of the mild steel plating used on the rest of the frame. The mountings were statically analyzed where they were subjected to axial and radial forces from the drive shaft as well as forces due to the torsion of the frame. A figure for the analysis is given below by figure 21.

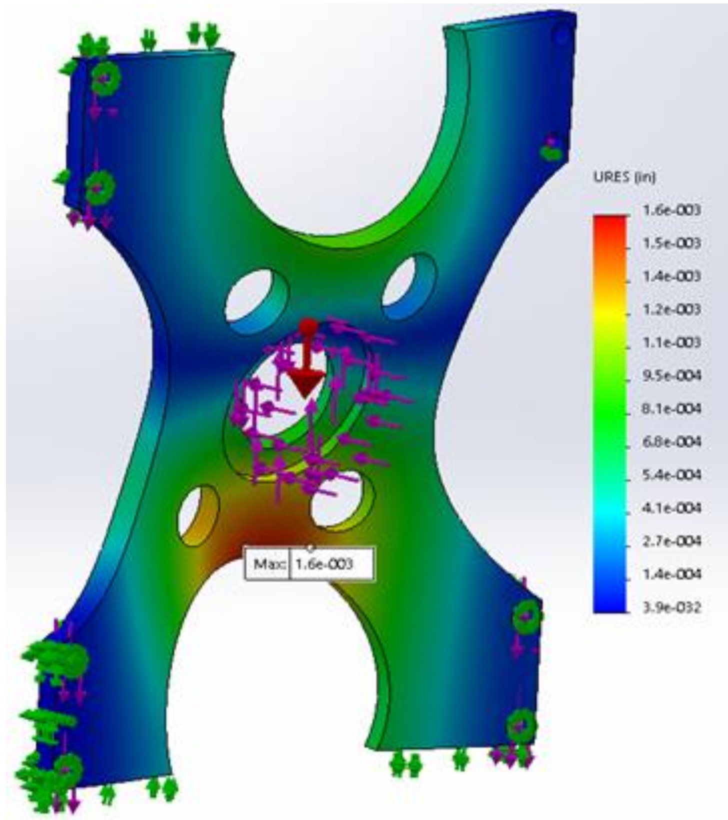


Figure 21: Mounting Plate Stress Analysis

To compensate for the lacking of a transient analysis, again the expected forces in the static test were doubled, meaning that the magnitude of the forces shown were multiples of 100 lbs. Shown in figure 21, the maximum deformation of the plates occur at the cut out portions on the bottom and tops of the arcs, with a maximum deformation of approximately 0.0013”. This has been deemed suitable for the purposes of the vehicle.

The universal joints, conical roller bearings and 1/4-20 bolts shown have their specifications and load ratings detailed below.

Table 6: Parts List [5]

Name	Material	Load Rating
1/4-28 Steel Hex Bolts	Steel	150 KSI tensile
3/4” Universal Joints	Zinc	500 in-lbs. torque (15 deg.)
Steel Tapered-Roller Bearing for 3/4" Shaft Diameter	Steel	8000lbs. combined radial/thrust

9.6 Rear Drive Train

One of the challenges to choosing a back-to-back driver configuration is that the rear driver's pedaling motions runs counter to the direction of the wheel's rotation, as seen in the RISD rover, below. Generally speaking, there are two solutions to this problem: the rear-facing driver can learn to pedal backwards, or the team can devise an engineering solution to reverse the direction of the torque to match the wheel rotation. It was determined that finding an engineering solution would be preferred to being dependent on the power to the rear wheels coming from the rear driver performing an unnatural motion.

Figure 22: RISD Back to back configuration [3]

Because the RISD rover that the team was using for inspiration also featured riders in a back-to-back configuration, the team first analyzed their solution to the same problem. As seen in both figure 22, above, and figure 23, to the right, the RISD team reversed the chain's driving direction through the use of idler pulleys, one sharing an axle with the driven gear on the wheel and other located near the driving sprocket. The resulting chain line follows a path that is non-planar, which leads to losses in power due to the chain pulling on the gears not just in the direction of rotation but also normal to their faces. The rear chain-and-sprocket was an area of the RISD rover that we felt we could improve upon.

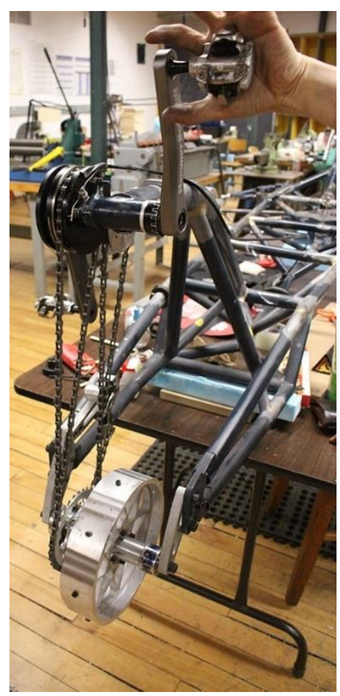


Figure 23: RISD Rear Drivetrain [3]

After both researching and brainstorming ways to reverse the chain direction while maintaining a planar path of motion, the team discovered a configuration involving a driving gear, a driven gear, and two idler pulleys (shown below in figure 24) that achieved this and that the team believes may be adapted to the rover. All that remains is to work out the exact dimensions and a satisfactory system for mounting the supports for the idlers onto the frame. Unfortunately, the team was unable to come up with a design that satisfies the need to remain coplanar that could be executed using a v-belt in place of a chain. It is unlikely that powering the front of the vehicle with a belt while using a chain in the rear would satisfy the Drive Train Technology award requirements, and so choosing to maximize efficiency in the rear drivetrain also has the unfortunate side effect of removing us from contention for that particular award.

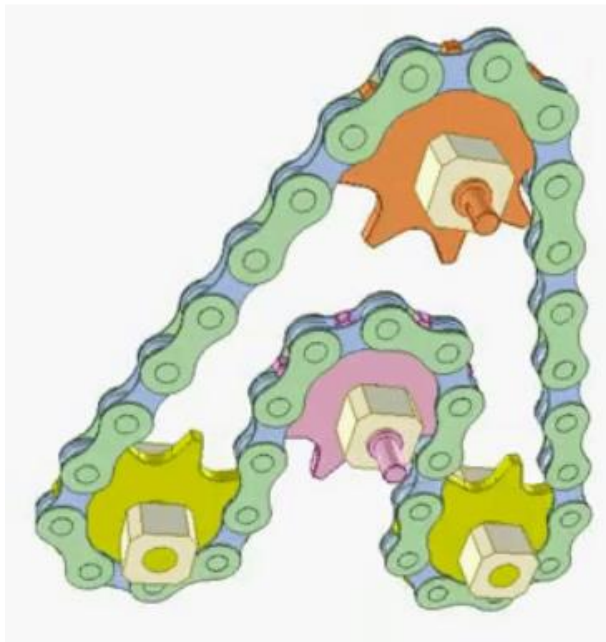


Figure 24: Team 17's Rear Drivetrain

10. Hubs

The hub that was deigned was made as simple as possible due to other choices made during the design process. By moving the brakes to the center driveshaft in the front of the rover, the hubs became primarily about connecting the suspension, steering, and wheel together. Figure 25 shows the hub that we will use, with Heim joints being used on the top and bottom for the connection to the suspension and a ball joint on the horizontal section to connect the steering. The size of the driveshaft was dictated by the free ball bearing we received and plan on using in the rover. This hub will be made of steel, a strong material that will not add too much weight as the hub is not very large. The analysis showed that not much stress would be put on the hub itself since it is designed to move with turning of the wheel. The primary section could because issue is where the steering connection attaches to the circular section of the hub.

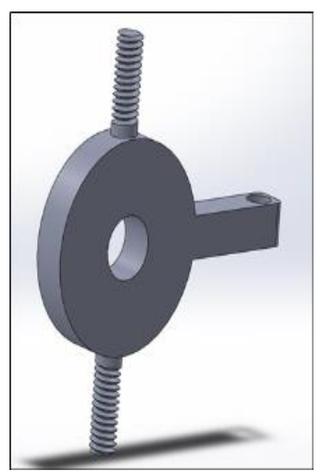


Figure 25: Hub

11. Gantt chart and Future Plans

The Gantt chart below indicates Team 17's timeline and what they intend to get done by January. As can be noted below, Team 17 is a little behind on manufacturing. However, parts are being ordered and coming in. The goal is to have a bulk of manufacturing done by the end of December with iterations coming in January. The conceptual designs are coming to an end. The project is phasing into more and more manufacturing rather than design.

Table 7: Gantt chart

Task Name	Duration	Start	Finish
Fundraising	47 days	Sat 10/1/16	Mon 12/5/16
Conceptual Design	17 days	Sat 10/1/16	Sun 10/23/16
Chassis	11 days	Tue 10/11/16	Tue 10/25/16
Part Selection	7 days	Fri 10/21/16	Mon 10/31/16
Drivetrain	10 days	Tue 10/25/16	Sat 11/5/16
Suspension	7 days	Tue 10/25/16	Wed 11/2/16
Steering	7 days	Fri 10/28/16	Sat 11/5/16
Purchasing	10 days	Tue 11/1/16	Mon 11/14/16
Wheels	11 days	Thu 11/3/16	Thu 11/17/16
Manufacturing	15 days	Mon 11/7/16	Fri 11/25/16
Brakes	5 days	Thu 11/17/16	Wed 11/23/16
Revisiting Design	4 days	Fri 11/25/16	Wed 11/30/16
Finalize Design	17 days	Thu 12/1/16	Fri 12/23/16
Refine Reports	14 days	Wed 12/14/16	Sat 12/31/16
Continue Manufacturing	15 days	Wed 12/21/16	Tue 1/10/17
Tweek Design	14 days	Sun 1/1/17	Wed 1/18/17
Testing	17 days	Mon 1/9/17	Tue 1/31/17

11.1 Wheels

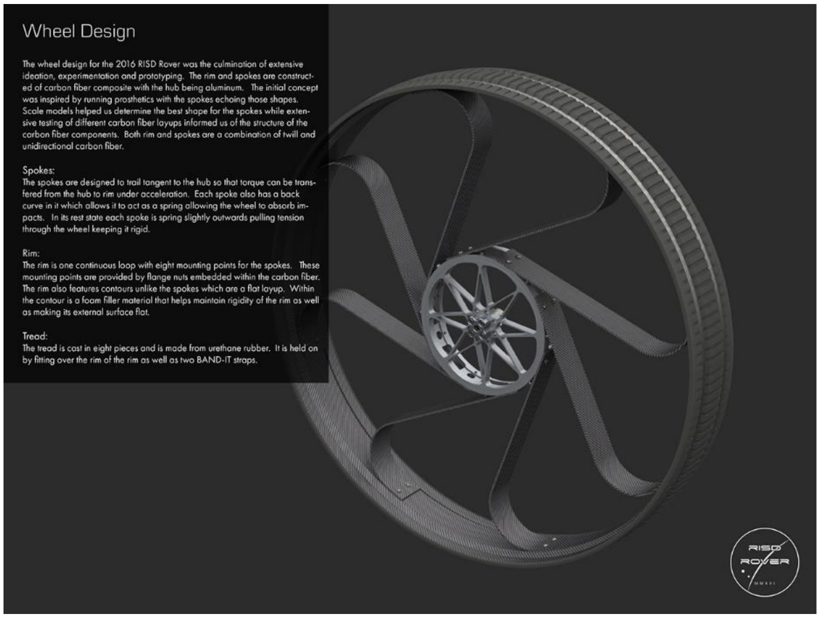


Figure 26: RISD Wheel Design [3]

Shown in figure X, RISD focused heavily on optimizing their wheel design as the rim and spoke sections were custom fabricated carbon fiber and the tread was custom molded silicon. Due to time and financial constraints, Team 17's final design will not feature carbon fiber and instead opt for a design similar to one of RISD's earlier concepts featuring an all-aluminum rim and spokes shown below by figure X.

Figure 27: RISD Spoke Design Iteration [3]

11.2 Seats

There are many options for seating, but also some elements to keep in mind. Weight is a key element in the design of the seat. Since the lightest vehicle in the competition receives a featherweight award, the last place needed to add weight is in the seats. With that being said, manufacturing seats may be the best way to make that happen. The problem comes to finding a material that is going to be light and easily manufactured to be a comfortable seat. Money is also an issue. A cost analysis is going to be done to determine if it is better to manufacture a seat or to buy a seat and fabricate it to attach to the frame. A new tab is going to be designed to allow for horizontal movement on the frame to accommodate different heights of drivers. The angle of which the seat is going to be at will also impact the comfort and amount of torque the driver can apply to the pedals. With that in mind, the angle of the seat will ideally be adjustable. The seat will be one of the last things that are designed because it is also impacted by the location of the pedals. Depending on the height of the pedals will impact the kind of seat needed. Other necessities of the seat include a seat belt. The seats are on pace to be done by the end of December to allow time for ordering of the parts.

11.3 Steering

The steering system is critical to the functionality of the vehicle. One of the biggest challenges we will face in the upcoming weeks is designing a steering system that will allow us to preserve our existing frame design without structurally weakening it. Other factors affecting our steering system include our rider configuration, and braking system. The chosen back to back configuration lead to the decision of having only one rider take on the responsibility of guiding the vehicle. Also, since the seating of the vehicle somewhat shadows that of a recumbent bicycle, it is best to design a steering system that can match the seating angle of the driver in order to keep him or her comfortable during the competition. After conducting extensive research, it was decided that the steering system should be composed of two steering levers, two steering arms and a steering plate that will connect these components together directly at the steering pivot point. All three components will most likely be made out of aluminum. Moreover, cold connections will be the preferable method of joining these components together in order to avoid any sort of deformation. The diagram below shows the components of the steering system designed by Thomas Brenner of the Rhode Island School of Design[3].

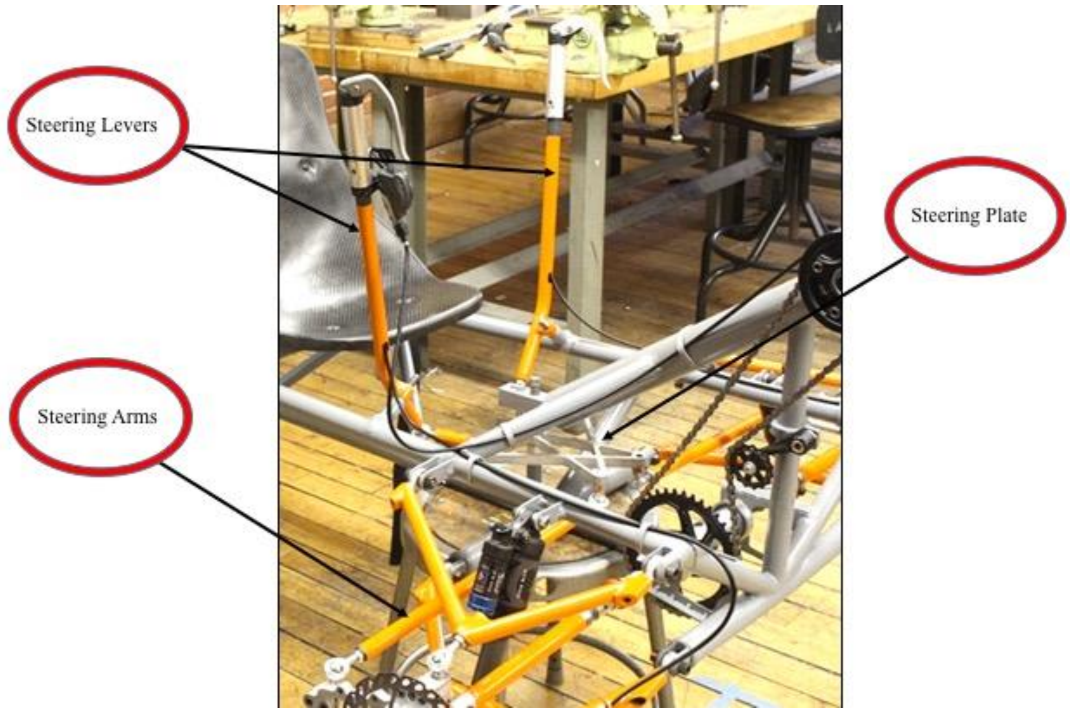


Figure 28: RISD Steering Mechanism [3]

The steering levers will be positioned at the sides in order to achieve an aerodynamic profile and a comfortable ride position. The terrain that will be driven over is very uneven, so it is important to note that the steering levers will be a wide width apart in order to improve handling and control.

11.3.1 Connecting the Brakes to the Steering System

It was decided that a mechanical disc brake cable and lever assembly would work best with the steering system mentioned above. Research suggests that discs provide more powerful and reliable braking in all types of weather and terrain, and are not compromised if the wheel bends after a hard landing [2], making it ideal for this type of competition. Moreover, a standard brake cable offers many advantages. They are: simple to install and adjust, light weight, inexpensive and offer less complicated maintenance [2]. Since the braking system is so critical, it will be tested repeatedly weeks before the race. Below is an example of a disc brake, cable and brake lever assembly.

Figure 29: Disc Brake, Cable, and Lever Assembly

12. Financials

The allowed budget for this project is $2000 from the aero propulsion, Mechatronics and Energy (AME) center in Tallahassee, FL. The only purchase completed thus far is for the chassis tubing and A-arms for the suspension. A detailed expense report for the required bill of materials designed and analyzed so far is as follows from online metals and Mcmaster Carr:

Table 8: Expense Chart from Online Metals [4]

Expense	Unit price	Quantity	total	Vendor	Component
0.75" OD X 0.065" WALL 4130 ALLOY STEEL TUBE	24.38	12	292.56	Online Metals	Frame/sus
ALLOY STEEL SHEET 4130 NORMALIZED 0.19" 12X12	58.83	1	58.83	Online Metals	joint
0.875" OD X 0.065" WALL 4130 ALLOY STEEL TUBE 10"	8.21	1	8.21	Online Metals	joint
COLD FINISH ALUMINUM BARE ROUND 7075 T651 10"	5.19	1	5.19	Online Metals	joint
Zinc-Plated Steel Reusable Cotter Pin	5.42	1	5.42	McMaster Carr	joint
Oil-Embedded Sleeve Bearing	1.55	2	3.1	McMaster Carr	joint
Medium-Strength Grade 5 Steel Hex Head Screw 3/8-24	5.56	1	5.56	McMaster Carr	tabs
Steel Ball Joint Rod End	3.78	20	75.6	McMaster Carr	tabs
18-8 Stainless Steel Washer	5.45	1	5.45	McMaster Carr	tabs
HOT ROLLED MILD STEEL PLATE A36 0.375" 12X12	58.08	1	58.08	Online Metals	tabs
inc Yellow-Chromate Plated Hex Head Screw 1/4"-28	8.52	1	8.52	McMaster Carr	general
Low-Speed Pin-and-Block U-Join	20.16	4	80.64	McMaster Carr	F DT
ALUMINUM PLATE 7075 T651 "0.25 7X7	22.05	2	44.1	Online Metals	F DT
EXTRUDED ALUMINUM BARE ROUND 6061 T6511 10"	16.73	1	16.73	Online Metals	F DT
Tube-End Weld Nut	5.3	15	79.5	McMaster Carr	suspension
Subtotal			**747.49**		
tax approx			82.2239		
shipping est			149.498		
Estimated total			979.2119		
Budget			2000		
Remaining Funds for other assemblies and competition			1020.788		

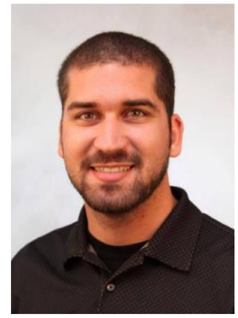
This estimate is on the higher end of pricing. General purpose items like washers, bolts and possibly scrap for attachment tabs can be sourced locally to greatly reduce prices. This list does not include the donated bicycle parts, donated components, or machining time. The materials included in the list are also exaggerated in their quantity to allow for small mistakes in machining and assembly. The upcoming component assemblies: Wheels, Rear Drivetrain, Seating and Steering will ideally occupy 80% of the remaining budget, leaving the remainder for travel and unforeseen expenses.

13.Conclusion

With the NASA Rover Competition being the goal of this project, constraints and objectives were easily laid out. Working within these constraints we began to work through different ideas to build a vehicle that would make it through the NASA course and hopefully win some awards along the way. When we slowed down at trying to select the correct chassis design, we looked for inspiration from past competition participants and found RISD. This lead us to use an eight foot long frame of a triangular design, made with chromoly. With the base structure decided on we moved into the other major components such as the drivetrain, suspension, drivetrains, hubs, and braking. Also important but not yet completed are the wheels, seats, and steering though all have been considered at a basic level. With the goal of getting a competitive time at the NASA competition, we are on track to finish the rover manufacturing and conduct tests before the actual competition takes place at the end of March.

14.Biography

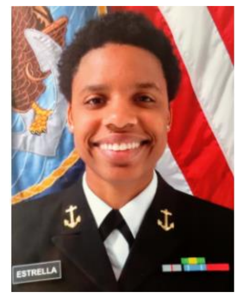
Garrett Rady



Team Leader

Born and raised in Tallahassee FL, Garrett came to the Florida State University as an exploratory major. Trying such majors as Actuarial Science, Statistics, and Finance he didn’t find his true passion until he found Mechanical Engineering. After graduating in May, 2017, with an Engineering degree and a business minor, he plans on using his vast supervisory experience to obtain a project management position in a related field.

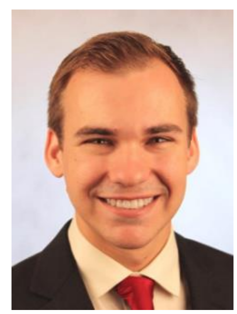
Katherine Estrella



Communications/Webmaster

Born in the Dominican Republic and moving to the United States at the age of 12, Katherine is on track to graduate with a Mechanical Engineering degree from the Florida State University in December, 2017. She has research experience in synthesis and characterization of carbon nanotubes. She is currently on track to become a Navy Nuclear Submarine Officer.

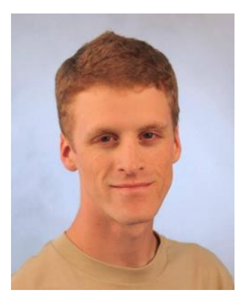
Luke Maeder



Lead Mechanical Engineer

Luke is an Eagle Scout from Rockville, MD. His focus in Mechanical Engineering is Sustainability and Power Generation, and has experience in manufacturing and mechatronics. He is applying for the Navy's Officer Candidate School and graduate programs after he graduates with a Mechanical Engineering Degree in May, 2017.

Jacob Van Dusen



Design

Jacob is an Eagle Scout who grew up by the space coast in Cocoa, Florida. He is on track to graduate with a Mechanical Engineering degree in May, 2017. After graduation Jacob is going to enlist into the United States Air Force with a job lined up as a Combat Systems Officer.

Quentin Hardwick

Design

Coming to Florida State University from Tampa, FL, Quentin originally majored in pure mathematics before finding a passion for physics. With this newfound passion, Quentin changed his major to Mechanical Engineering where he is on track to graduate in May, 2017. Quentin's focus is in Dynamics where he can use his love of ODE's and motion equations. After graduation, he plans to make a difference as a civilian contractor for the D.O.D.

15. References

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[2] H. Ventures, "Disc brake basics," 1999. [Online]. Available: http://mikesbikes.com/how-to/disc-brake-basics-pg158.htm. Accessed: Dec. 4, 2016.

[3] P. C. Info, "RISD: DTC moon buggy parts on RISD portfolios," 2015. [Online]. Available: http://portfolios.risd.edu/gallery/23181693/RISD-DTC-Moon-Buggy-Parts. Accessed: Dec. 4, 2016.

[4] Online Metals. 2016 [Online]. http://www.onlinemetals.com/. Accessed: Dec. 4, 2016.

[5] McMaster. 2016 [Online]. https://www.mcmaster.com/. Accessed: Dec 4, 2016.

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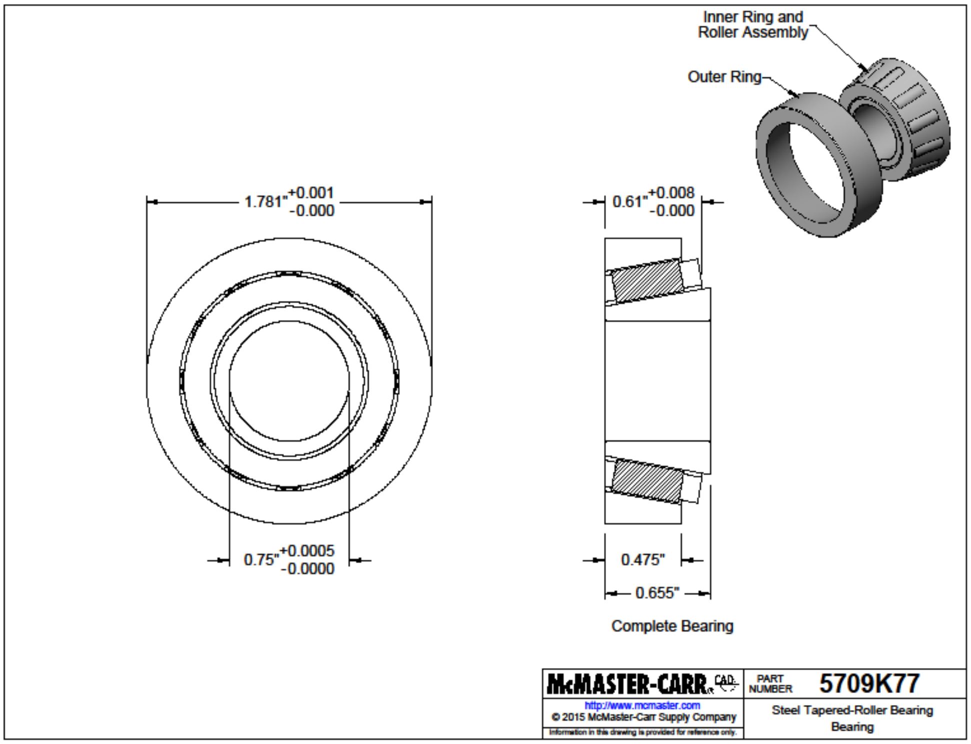
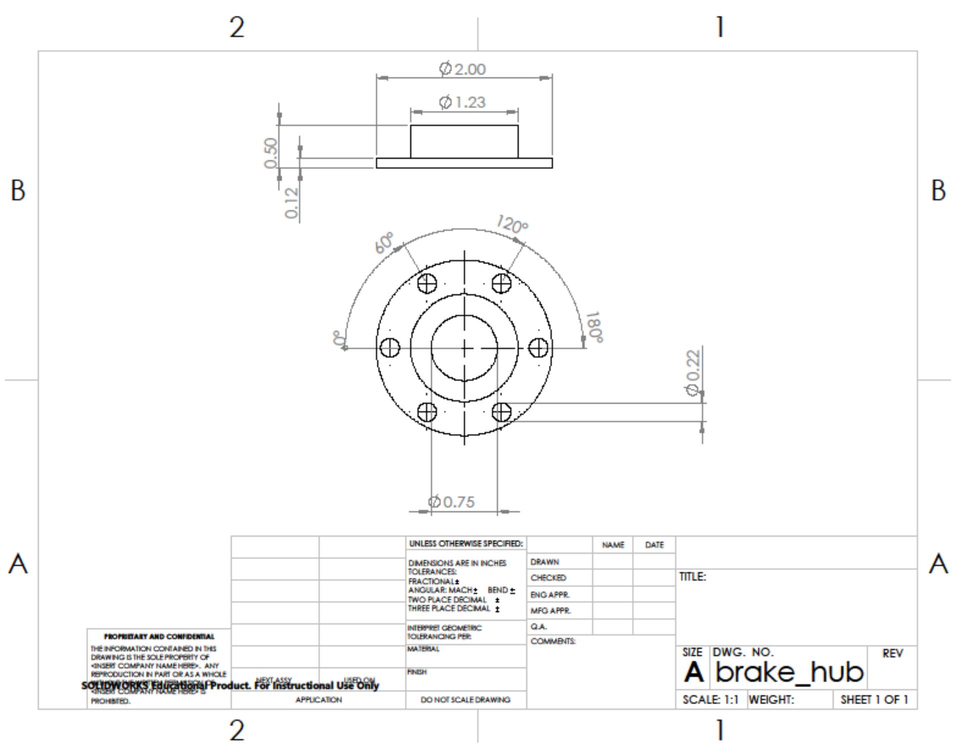
Appendix

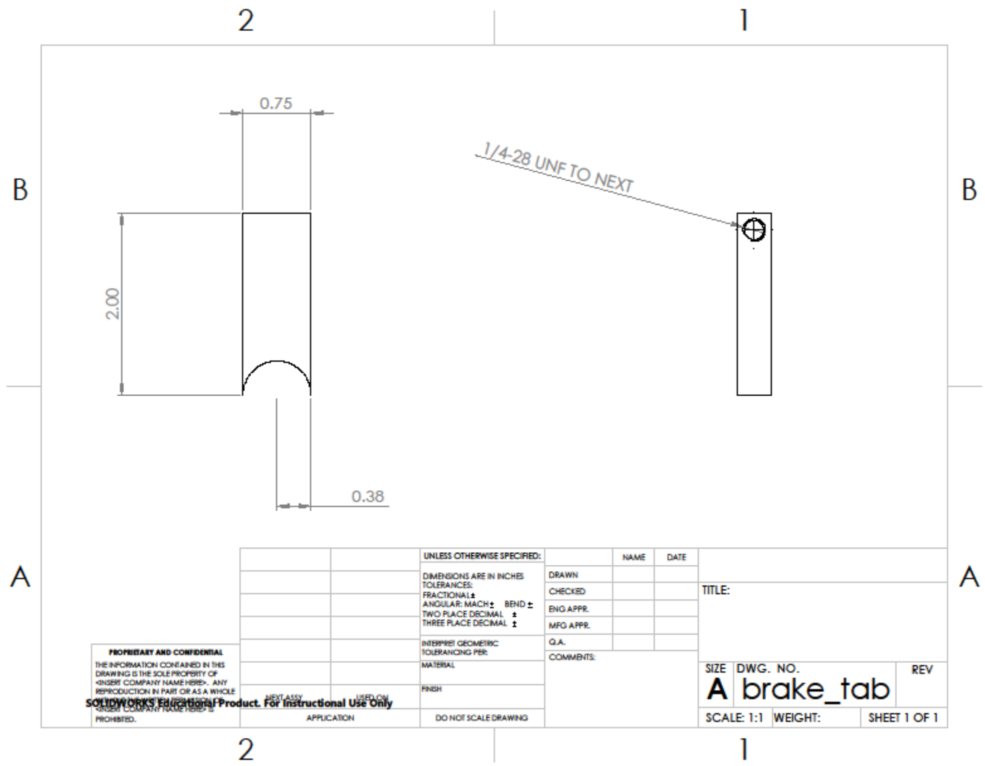
A-1 Steel Tapered-Roller Bearing



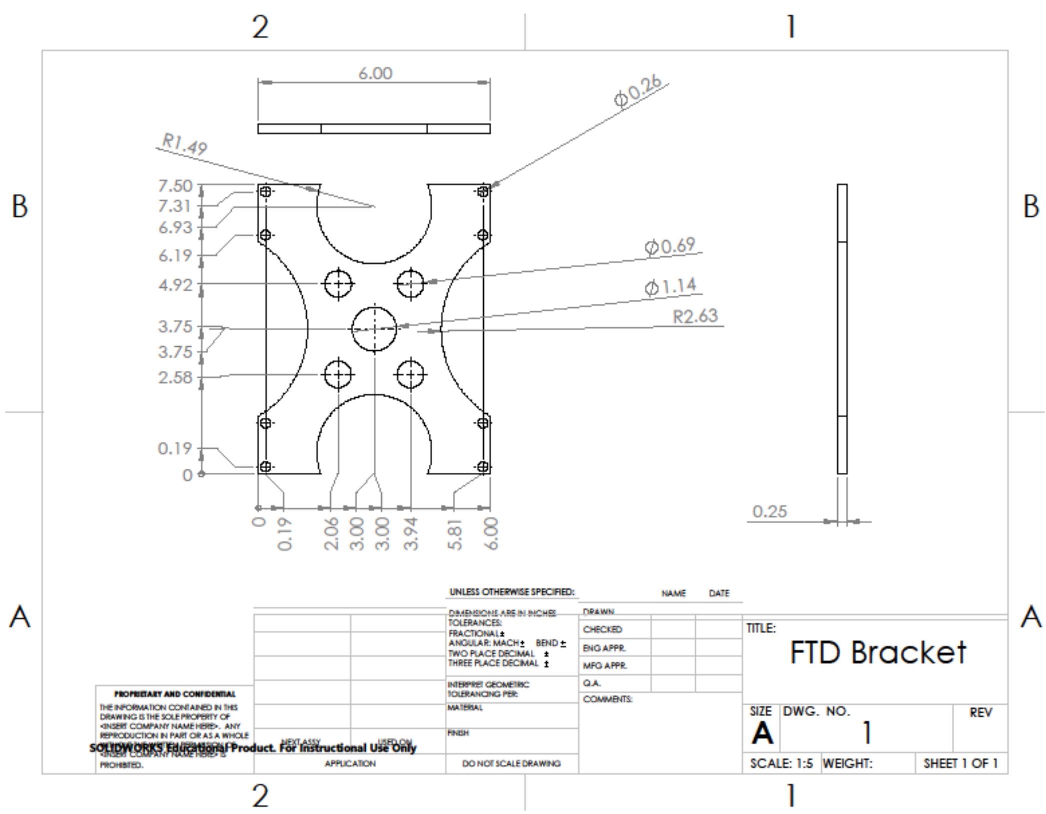
A-2 Brake Hub



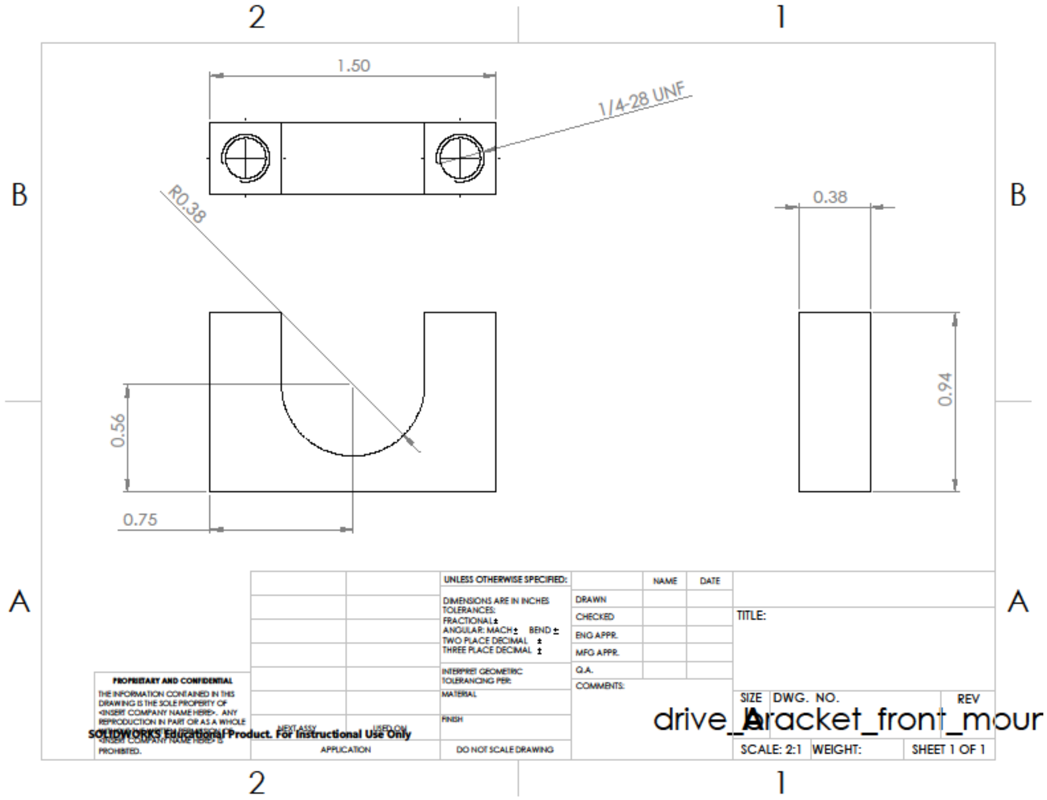
A-3 Brake Tab



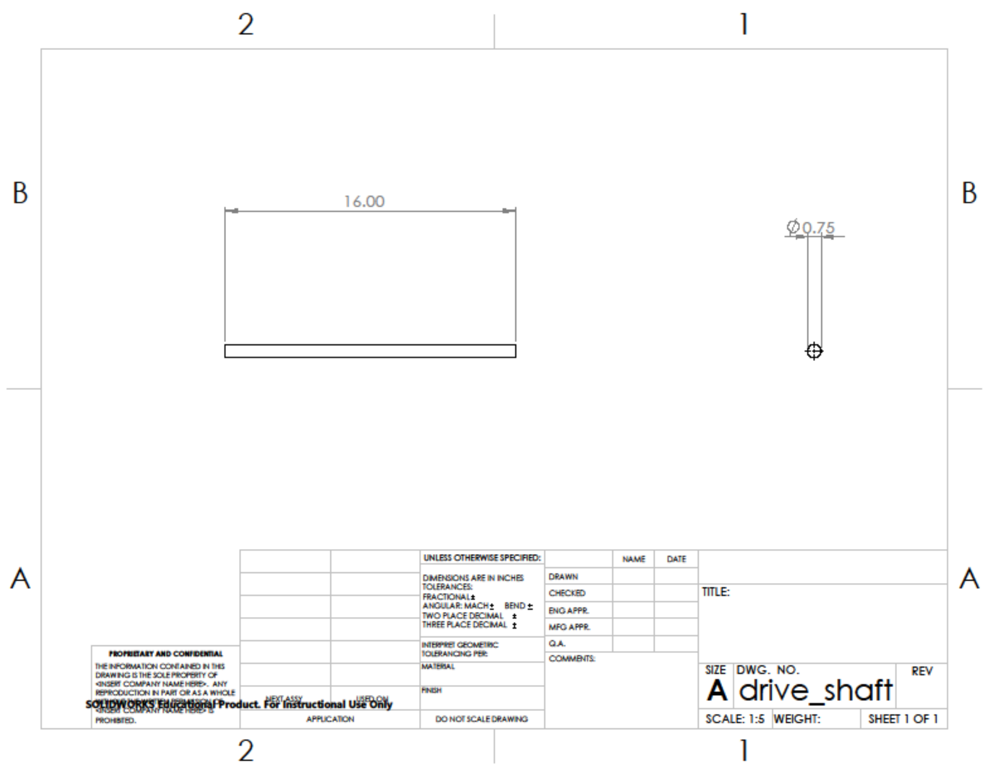
A-4 Front Drive Train Bracket



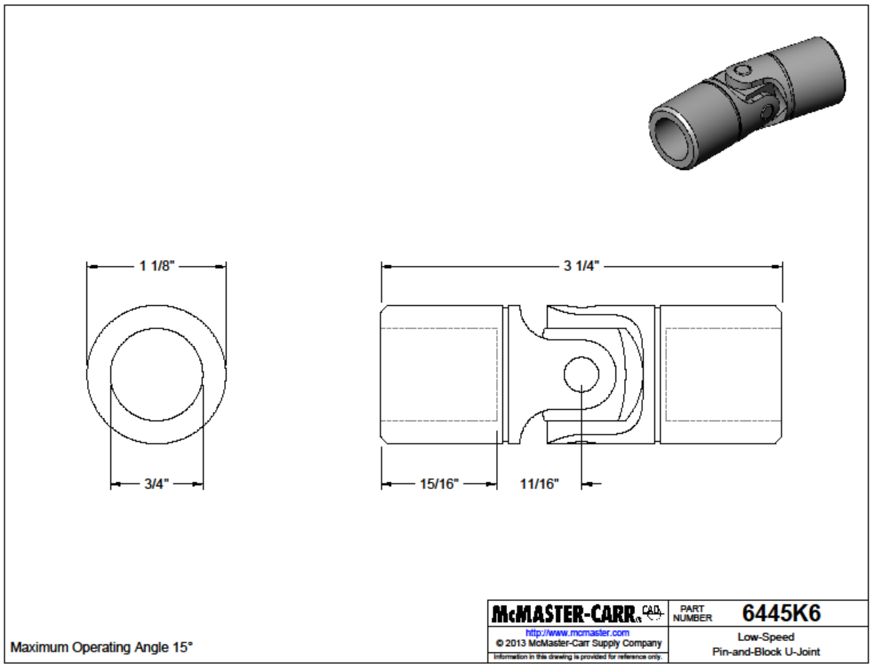
A-5 Drive Train Front Bracket Mount



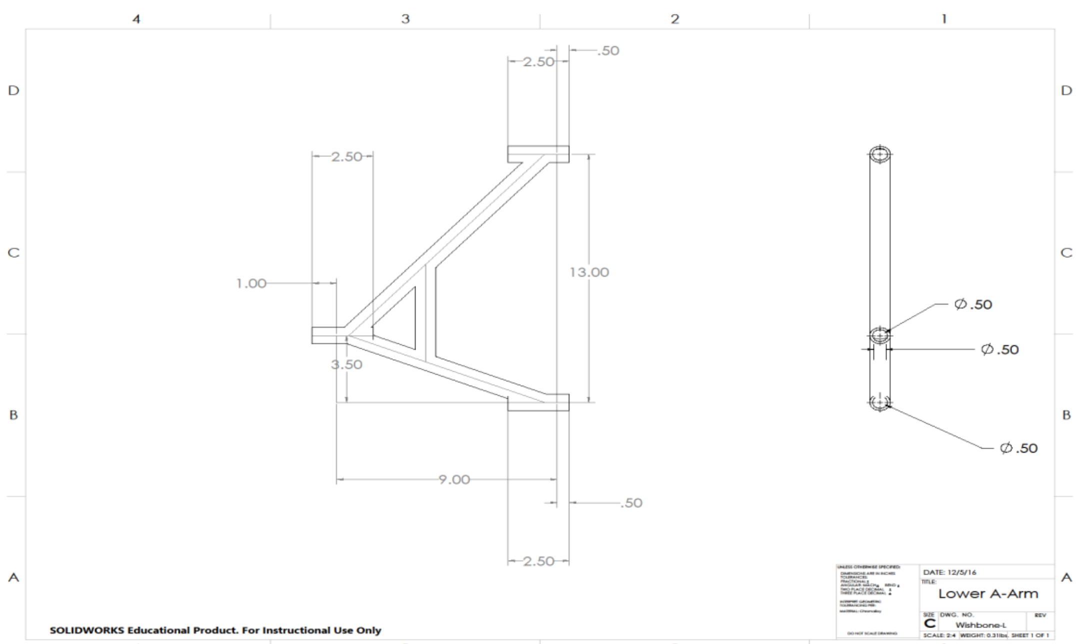
A-6 Drive Shaft



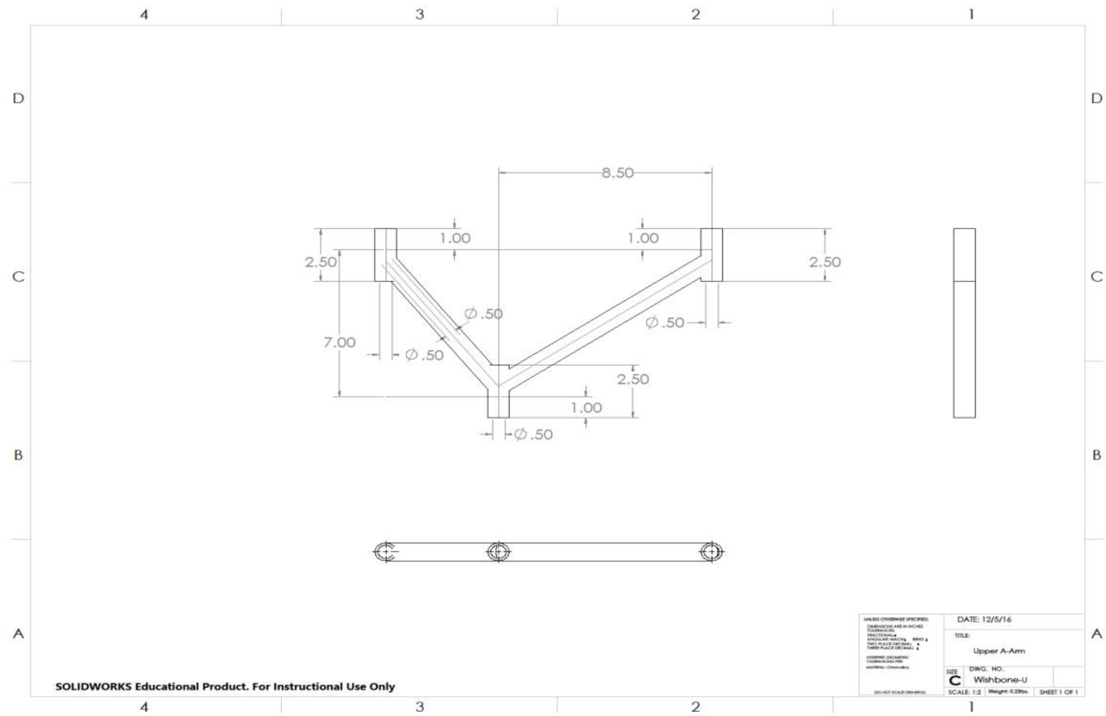
A-7 Low Speed Pinned Block Universal Joint



A-8 Lower A-Arm



A-9 Upper A-Arm



A-10 Tab Assembly