Design and Development of a Human Powered Vehicle

Design Report

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Abstract

The NASA Human Exploration Rover Competition took place on March 30, 2017. This competition requires two passengers to navigate an extraterrestrial like terrain in the fastest time possible. Team 17 decided to take on the design of the chassis at the beginning of the Fall 2016 semester, and then move forward to accomplish design in brakes, drivetrain, joints, hubs, suspension and frame in the Spring of 2017. Overall, the rover was completed in time for the competition but sufficient time for testing was not available to the team and this lead to the majority of the problems experienced at the competition.

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. And lastly, a special thanks to the Florida Space Grant Consortium for funding this project.

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.

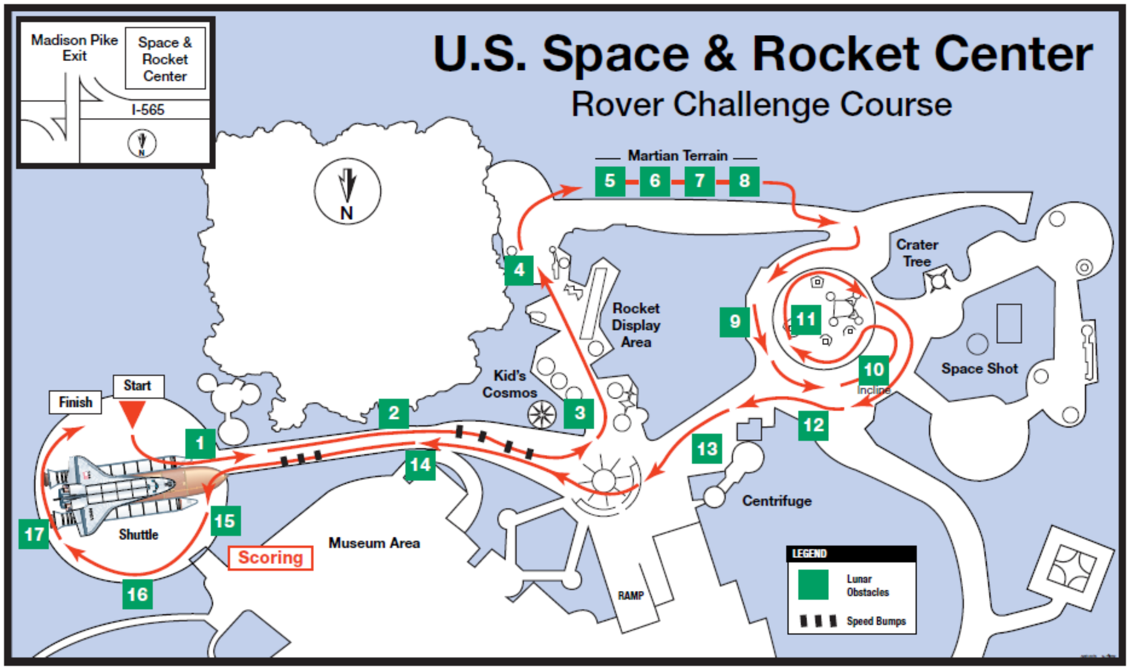


Figure 1: Map of the Course [6]

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.

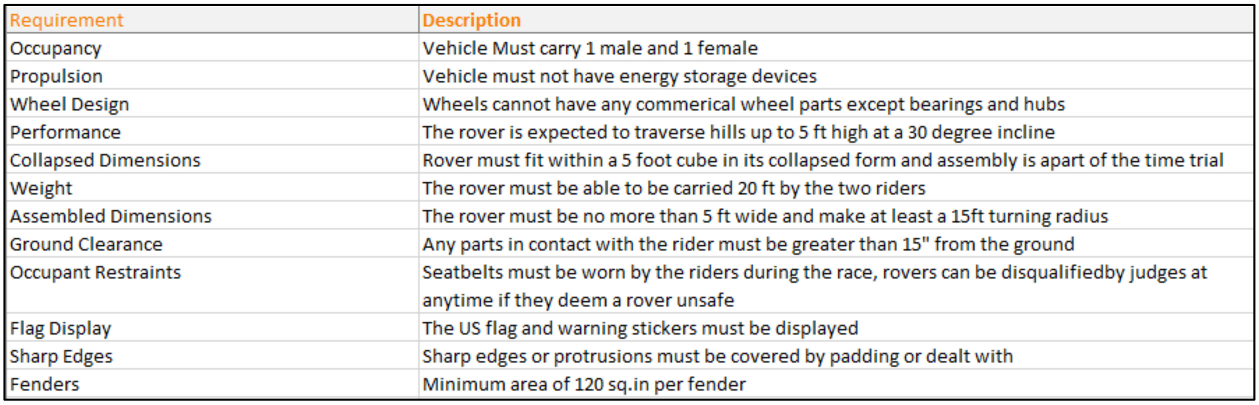
Table 1: Available Awards [6]

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

1. 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

2. 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."

3. 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.

4. Design for Manufacturing

The easiest way to assemble the rover's components is to assemble both front and rear halves of the frame independently and then attach both halves with the hinge pin. The following steps assumes that the welded attachments on the frame are already complete. In reality, most subsystems had to be painstaking aligned and set up when welding to the frame to ensure accuracy.

The rover assembles in the following subassemblies:

Front Drivetrain

1. Mount the freewheel and its adapter hub to the central drive shaft with its key and set screws, mind the orientation of the freewheel as it is a ratcheting mechanism. Assemble the brake rotor and hub and place on shaft. Place two shaft collars on either end of the shaft. Place both flange bearings onto the ends of the shafts with the bronze bearing surface facing inward.
2. Mount aluminum drivetrain brackets onto the exterior of the front drivetrain box with the provided U-bolts and locknuts, do not tighten yet. Position drive shaft assembly from step 1 into the through-holes centered on either plate. Lock each bearing into each plate with 2 3/8" bolts.
3. Attach a pin-block universal joint onto the ends of the fabricated 'Double-D' shafts with roller pins provided. Apply a small amount of heavy grease into the double-d coupler and insert the other half of the double-d shaft, attach the needle-bearing universal joints on to the opposite end of the double d shaft with a key and set screw to complete the CV joint.
4. Attach both CV joint assemblies (step 3) onto the ends of the central drive shaft assembly with roller pins.
5. Assemble pedals, crank arms, chain ring into pedal bracket. All components are bicycle components and only have one orientation to be assembled. Take care not to cross thread left handed/right handed threads
6. Attach derailleur to tab on lower front crossbar with 3/8" bolt and route chain through pedal assembly, chain ring and output sprocket, connect chain with chain tool
7. Position brake caliper to encompass brake rotor and secure to frame mount with 10-24 screws
8. Route brake lines to handlebar

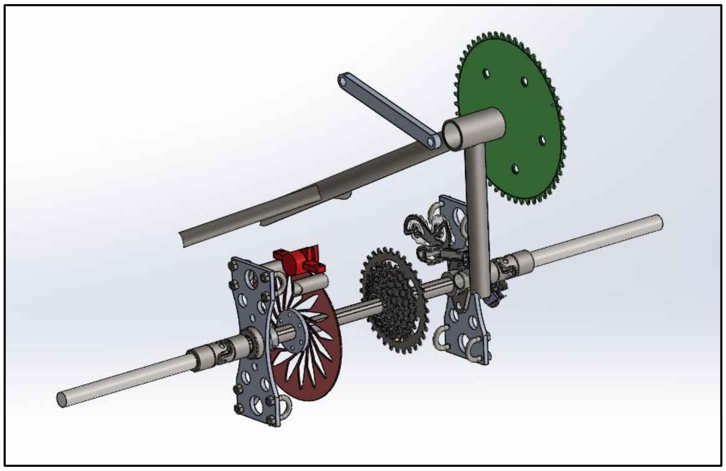


Figure 2: Front Drive Train

Suspension

1. Screw 2 heim joints into each control ‘A- arm’ and a ball joint into the opposing end of each arm.
2. Mount each arm to the corresponding tabs on either side of the frame with 3/8” bolts. The arms with the cross bars are the lower arms. Press single-row roller bearings into each side of the spindles (2 total). Screw the ball joints into either end of the spindles. Attach the shock assemblies to the frame and lower control arm tabs with 3/8” bolts to complete the suspension assembly.
3. Attach wheel hubs to corresponding keyed shafts with key and set screws, insert through spindle bearings and attach to CV joint with key and set screws.
4. Mount wheels on to 3 lugs on wheel hubs in a similar fashion to an automobile.

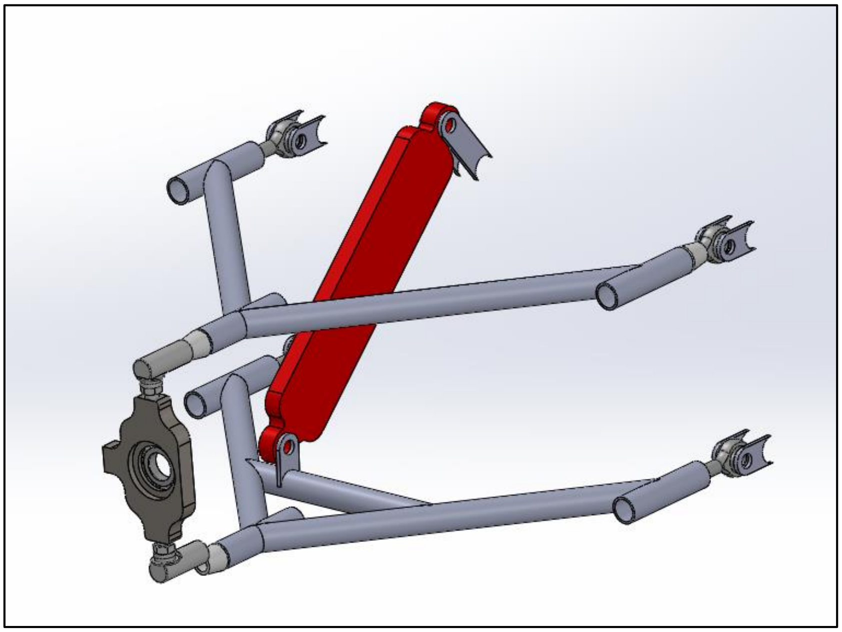


Figure 3: Suspension

Steering

1. Attach handlebars to steering plate pivot with u bolts, do not tighten down
2. Attach heim joints to either end of each tie rod and fasten each end of the tie rod to the steering pivot plate with 3/8” bolts
3. Screw in steering bent rods with locknuts into each spindle, making sure each spindle is facing the rear of the rover.
4. Attach the heim joints to the steering bent rods to complete the steering

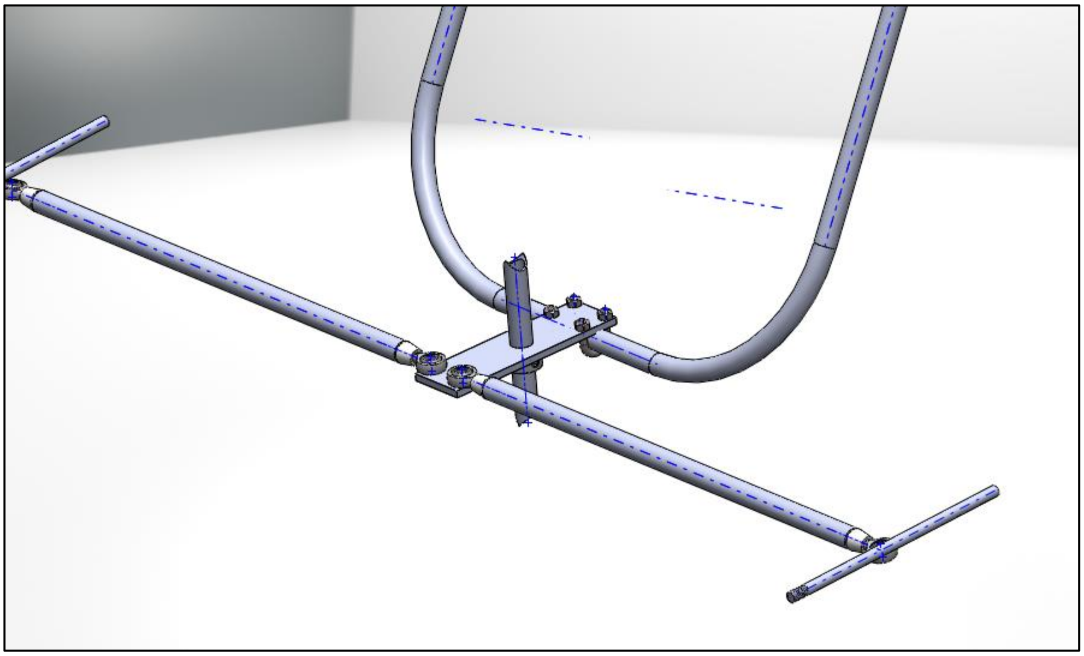


Figure 4: Steering Assembly

Seating

1. Both front and rear seating attaches in the same fashion
2. Secure bucket seats to angled mounting bracket with 4 10-24 bolts and corresponding locknuts.
3. Based upon preference, secure seat and bracket to mounting rail with at least 4 1/4-20 bolts and locknuts

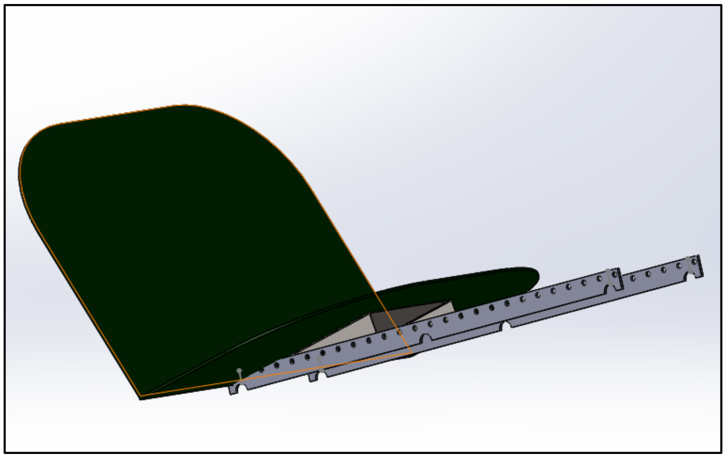


Figure 5: Seat Assembly

Rear Drivetrain

1. Attach pedals and bicycle components to rear boom in the same fashion listed in step 5
2. Attach seat in same fashion listed in step 17-19
3. Fit rear wheel hub onto wheel with provided lug nuts and slide onto rear driveshaft.
4. Fit freewheel adapter to freewheel sprocket and slide onto driveshaft, note direction of ratchet and position of chain ring
5. Fit two shaft collars onto either end of the driveshaft
6. Fit two flange bearings onto either end of the driveshaft following the shaft collars
7. Lift entire rear drive assembly into steel bracket slot and secure flange bearings into mounting holes with 3/8” bolts
8. Attach derailleur onto same 3/8” mounting bolt and secure with locknut
9. Route chain through chain ring, derailleur, and drive sprocket and join with chain tool

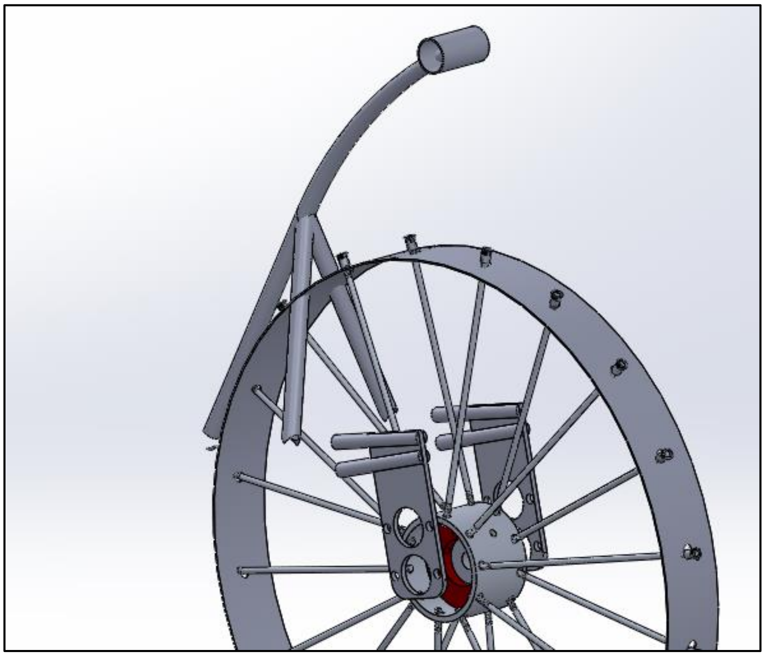


Figure 6: Rear Drive Train

Final Assembly

1. Align rear and front frame sections at identical hinge plates and pass hinge pin through hinge tubing.
2. Lower entire assembly, front and rear axles rolling away from each other until fully assembled.

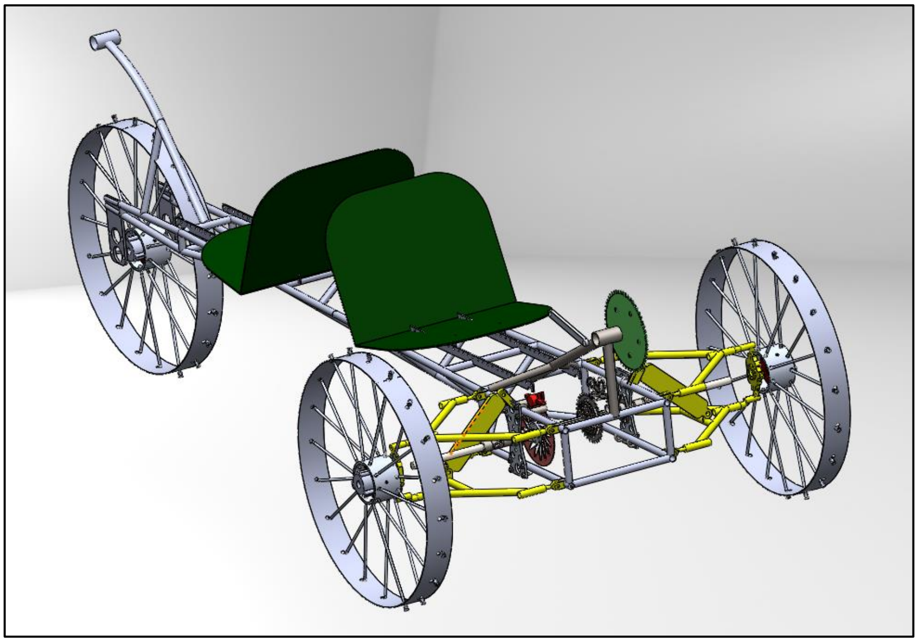


Figure 7: Final Assembly

Adjustment

1. Adjust chain tension in both front and rear by loosening and rotating derailleurs until desired chain tension is achieved
2. Adjust steering alignment and camber by changing tie rod length, and amount of thread inserted into spindle respectively
3. Adjust seat position by repositioning mounting bolts to a different mounting location
4. Adjust Steering handle position by loosening U-bolts and retightening

Manufacture Time

The actual assembly of the rover listed previously in steps 1-34 takes about 2 hours to complete with alignment and adjustment included. Total manufacture time took approximately 4 months to complete, most of which was spent on the frame. Notching and welding tubing for accuracy proved to be more difficult than expected, and many modifications had to be made. The amount of manufacture time was expected but inadequately budgeted for. Setbacks in the machine shop with technician availability, material order arrivals and personal conflicts pushed back the manufacture finalization to the week of competition. Testing phase was incredibly short and troublesome.

Complexity

Our design was fairly simple, all of our components were either minimally required by the competition or for basic functionality. An area in particular what needed more complexity was the steering. In an attempt to simplify the design and reduce weight, the steering lost functionality and robustness in its simplification. A lever acumen should have been implemented with more points of contact and pivoting points.

5. Design for Reliability

The purpose of the prototype is to compete in a time trial event meant to simulate the hostile terrain of an alien body. Due to the intense nature of the obstacles on the track and the fact that the event is a competitive race against the clock, designing a vehicle capable of completing more than a handful of runs without experiencing some sort of failure would likely be overly time-consuming and cost prohibitive. Increased durability also typically comes with a cost in the weight and handling of a vehicle, and so maximizing durability to the point where the vehicle is capable of completing the course multiple times without needing maintenance would not only be expensive but likely detrimental to the project goal.

Some ruggedness is needed, however. In its current state, the prototype rover experiences breakdowns every time it is used to the point where it is incapable of successfully navigating the course. In particular, both the front and rear drivetrains are prone to failure. In the front, the primary culprits are the zinc pin-and-block universal joints responsible for allowing the drive shaft to pivot up and down with the suspension. The total driveshaft assembly contains a total of four U-joints in series, each allowing some degree of play before transmitting power to the next component. This leads to all of the torque being delivered through a single joint before the shaft rotates enough to eliminate the dead space in each of the joints, and while the lower cast ductile iron U-joints that transmit power to the wheels are durable enough to handle the load, the upper zinc U-joints are not. Specifically, the spring pins used to transmit power from the joints to the drive shaft are prone to shearing when torque is applied. The joints are also only rated for a maximum angle of 15° between the shafts, a limit that may be exceeded when negotiating the obstacle course. Exceeding this limit causes the shoulder portion of the joints themselves to shear off. The upper U-joints on the drivetrain are a weak point in the design that need to be replaced with ones that offer both a higher torque rating and a greater degree of rotation between the shafts.

Another design flaw in the front was the use of aluminum spindles in the suspension system. Each spindle acts as a concentration point for the suspension and orientation of the wheels, so all of the force acting on the wheels flows through them. The 6061 aluminum used to create the spindles was unable to handle the force from the suspension system, however, and ought to be replaced with a stronger material (such as steel).

In the rear section of the vehicle, the supports for the pedal assembly boom were installed too close to the base of the arm. The boom acts as a cantilevered beam, and when torque is transmitted from the pedals to the wheels the force from the chain pulls down on the tip of the boom, causing it to flex downwards. This flexion reduces the distance between the input and output sprockets, causing the chain to go slack when pedaling despite the presence of a tensioner. This slack causes the chain to slip on the gears and, in the worst case, fall off of the chain ring entirely. To compensate, a fin was welded along the top of the boom arm to change its geometry in a way that increases its moment of inertia, however this by itself was insufficient to stop the flexion. At least one more support post will need to be added further down the length of the boom to eliminate the problem.

Another potential issue with the rear drivetrain was the method used to reverse the output direction from the motion of the rear-facing driver’s pedal input. The idea was to mount a pair of idlers below the output chain ring to act as tensioners and run the chain over the top of the output gear. This was accomplished by mounting a derailleur underneath the chain ring, a decision made in part because it already possessed the geometry needed for the design but also as a cost cutting measure: the derailleur was donated from a local bike shop, eliminating the need to purchase idler sprockets and the components needed to mount them. However, after consulting with a team of

NASA engineers it was decided that the plastic gears on the derailleur may not be strong enough to be used in this manner and so the mechanism was removed in favor of having the rear driver pedal backwards as a last-minute fix in order to avoid the potential of experiencing a catastrophic breakdown on the course. Having the rider pedal backwards is undesirable, however, and replacing the derailleur with a pair of metal idler sprockets would make the rear drivetrain both more efficient and more reliable.

FEA

Extensive static FEA was done on most manufactured components that were under loading. Purchased components were taken at their manufacturer's load rating and over specified for simplicity. The focus of this section will be on the wheel construction in particular to emphasize the fact that total remanufacture was required by the competition. The wheels also included the most elemental complexities and offer more to discuss.

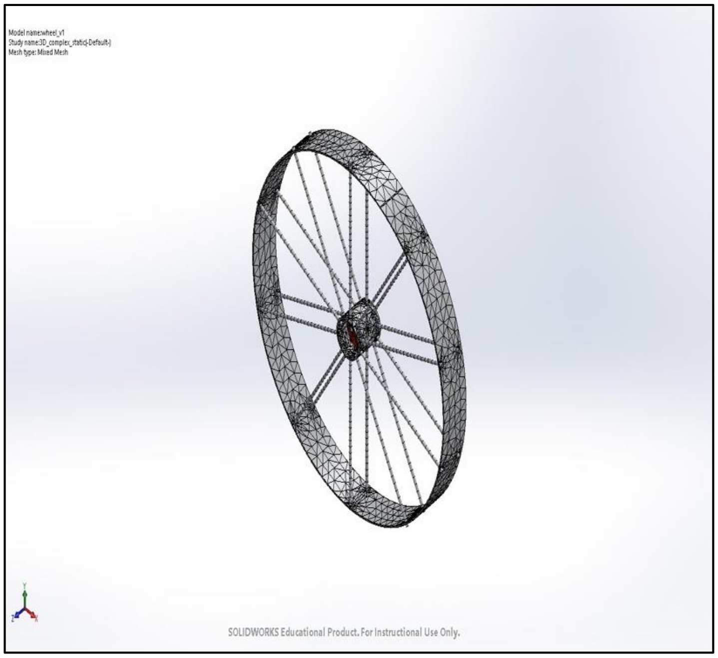


Figure 8: Wheel FEA

The weight of the vehicle as well as the payload (two passengers) was assumed to be 450 lbs. A static test was used in place of a buckling or transient to simplify the process of iterating, to compensate the full weight was applied at the axle and the material assumed to be Aluminum 6061-T6. With the addition of a 100 ft-lb moment about the center axis representing the moment exerted on a wheel from the offset mass of the vehicle. In addition, a 500 in-lbs. torque on the mounting holes was applied. This represents the input driving torque and was chosen due to the mechanical limitations of the universal joints in the drivetrain leading up to the wheel. Logically, the 500 in-lbs. of torque, the joint would fail before the wheel.

To simplify the model for analysis, the spokes were treated as beam elements and the solid rim components meshed with a relatively coarse mesh shown. The mounting hardware (nuts, washers, bolts) were excluded from the analysis to simplify meshing. The meshed model is shown in figure X.

Table 3: Wheel Analysis Results

Result	Value (unit)
Weight (total combined)	4.54 (lb.)
Maximum Axial/bending combined stress (Beams)	3.28 (ksi)
Maximum Von Misses Stress (Solid components)	19.6 (ksi)
Minimum Factor of Safety(throughout)	1.55

6. Design for Economics

The rover that was designed for this project can be compared to a modern day recumbent tricycle (figure X). This style of seating allows the rider to be in a laid-back or reclining position instead of an upright position. Like the rover, most tricycles allow the user to adjust the seat by sliding it forward or back along a rail. A reclined rider with their legs forward, legs-forward creates a smaller frontal profile, increasing efficiency and maximizing speed. Additionally, having three wheels adds to the overall stability of this product.

Figure 9: 2011 Catrike Villager

A recumbent trike in today’s market can cost anywhere between $1,300 and $2,000. The total cost of the rover was roughly $1,778, nearly $300 under the original $2000 budget. The breakdown of component costs can be seen in the pie chart below (Figure x). From this chart, one can conclude that the metal components were collectively the most expensive at a total cost of $735 (36.7 percent of total budget). Nuts, bolts, and bearings were collectively the second most expensive items on the list, and took nearly 15 percent of the total budget.

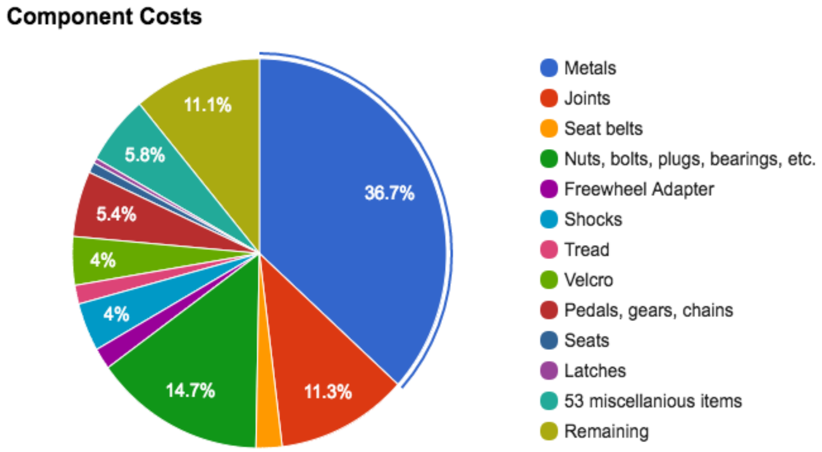


Figure 10: Component Costs

The bar graph below shows how the Team 17 Rover compares to a popular recumbent trike on the market, the 2011 Catrike Villager. This trike is superior in almost all aspects. Overall, the “Villager” is more comfortable, versatile, and faster than the Team 17 Rover. The seat recline is adjustable from 35 to 55 degrees making the Villager more ergonomic than the rover, which has no adjustability in seating other than its ability to shift the seat back and forth. Besides similar pricing, both tricycles have a wide design to keep them stable with or without the rider. In comparison to the rover, which does not allow the rider to shift gears, the Villager is available with 9 speeds or 27 speeds; depending on how much speed the customer desires.

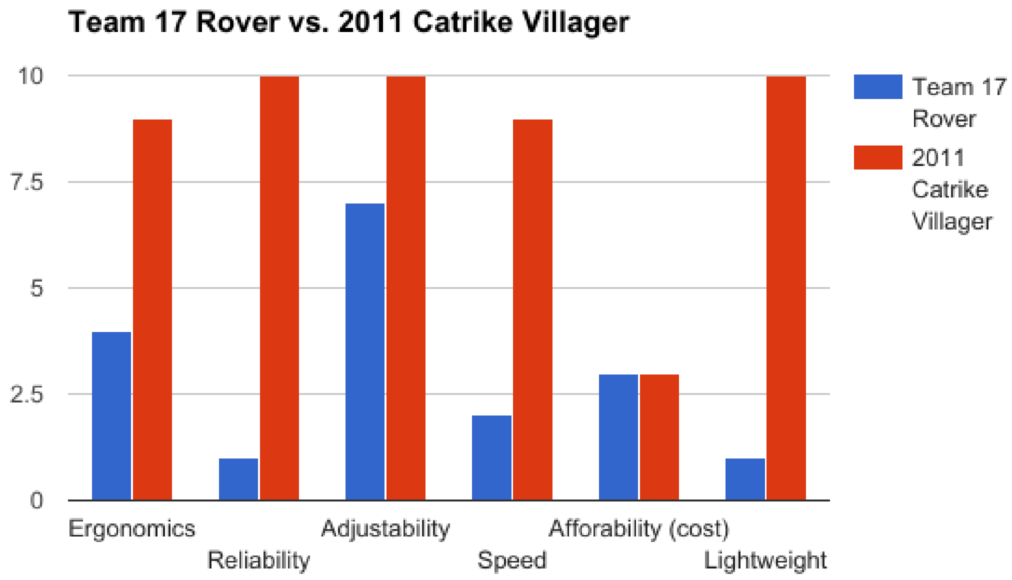


Figure 11: Team 17 Rover and 2011 Catrike Villager tricycle compared

7. Conclusion

With the NASA Rover Competition being the goal of this project, constraints and objectives were easily laid out. Working within these constraints, Team 17 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 trying to select the correct chassis design, the process was simplified by looking for inspiration from past competition participants and found RISD. This lead to the use of 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, rear drivetrain, hubs, and braking. During this process we realized we were low on time and funding so the team began to incorporate any used parts from bicycles that we could get for free. This is how the team got to parts of both our drivetrains and our braking system. The suspension system was modeled after a car's suspension system with A-arms and a spring. Overall, the rover was completed in time for the competition but sufficient time for testing was not available to the team and this lead to the majority of the problems experienced at the competition.

8. 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.

9. References

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