Midterm I Report: Conceptual Design and Specifications

Team 17

Design and Development of a Human Powered Vehicle
Challenge Hosted by NASA

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09/29/16

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ACKNOWLEDGMENTS

Thank you to our faculty advisor Dr. Nihkil Gupta for the pictures, videos and project planning advice. Thank you to Gordon Hansen for granting permission to use his reciprocating lever transmission technology. Thank you to Drake State's Design team for giving us access to their PowerPoints and resources from their entry last year. Thank you to Dr. Patrick Hollis for his help in advising us in drivetrain ideas, materials selection, and other insights on vehicle design.

ABSTRACT

The goal of the project is to create a man powered vehicle that will compete in the NASA Human Exploration Rover Challenge. The vehicle must be capable of traversing varied and difficult terrain that isn't unlike the terrain found on extraterrestrial surfaces. The vehicle must be powered completely by two drivers; one male and one female. No energy storage devices of any kind can be used. The wheels need to be designed and custom-fabricated by the development team; no commercially available wheels, tires or components are allowed. The design focus of this paper is on chassis selection and future goals. The vehicle must be in accordance with all competition rules and regulations in order to compete. Any violation of the rules and regulations results in a time penalty or disqualification. With these constraints in mind, a sliding style single bar frame was found to be the best option for the chassis design.

1. Introduction

It was in February of 1964 when Wernher von Braun, the director of NASA’s Marshall Space Flight Center, initiated the discussion for the need of a lunar surface vehicle that would allow astronauts to travel further distances away from their lander, explore different terrain, and conduct more experiments[3]. After approximately five years of research, final development and building of a rover finally began. It was to be named, The Lunar Roving Vehicle (LRV) [3]. The design constraints called for a pressurized, battery-powered four-wheeled vehicle that weighed between 6,490-8,470 lb, and could accommodate two astronauts with their expendables and instruments for up to two weeks of traverse on lunar surface. Furthermore, the LRV could be folded into a 5 ft by 20 in. space inside a cabin, and specific procedures were followed to remove it from the cabin and deploy it.

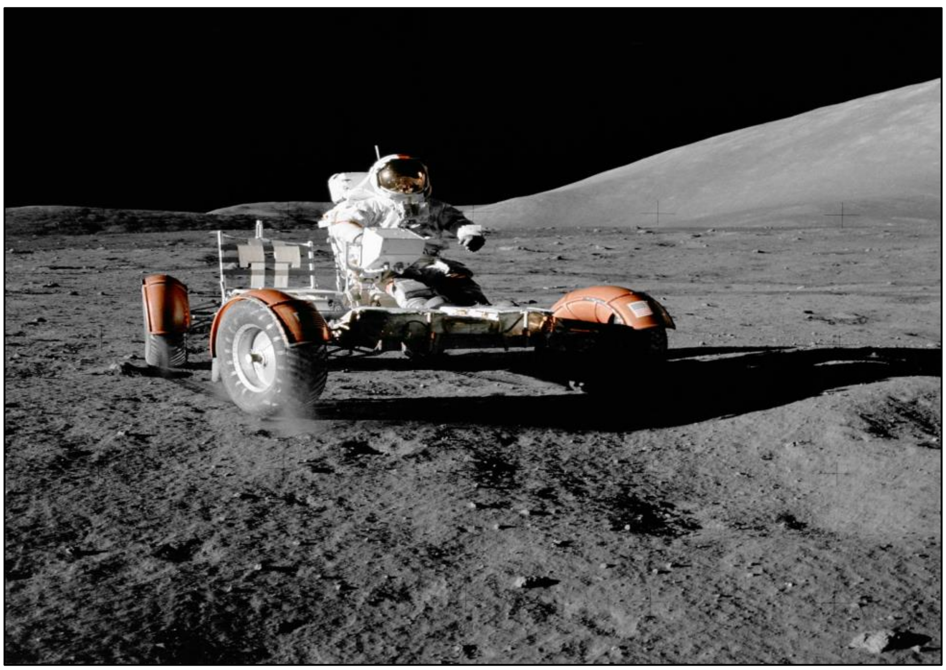

Figure 1: Astronaut test drives the Apollo 17 lunar rover shortly after unloading Rover[2]

The LRV, coined “The Dune Buggy”, was used on the Moon in missions 15, 16, and 17 of the American Apollo program (Figure 1). According to scientist-astronaut Harrison Schmitt of Apollo 17, "The Lunar Rover proved to be the reliable, safe and flexible lunar exploration vehicle we expected it to be. Without it, the major scientific discoveries of Apollo 15, 16, and 17 would not have been possible; and our current understanding of lunar evolution would not have been possible[3]."

Today, NASA continues to keep the rover a relevant part of research by encouraging young scientists and engineers to participate in the research and development of new [rover] technology[1]. Thus, the NASA Human Exploration Rover Challenge was created. It encouraged the development of vehicles and technologies that are up to the task of exploring such harsh environments, as well as fostering interest and creativity in young minds interested in further exploration of the universe. Just like the LRV, the competition rovers must abide by specific constraints such as: collapsed vehicle dimensions for storage, and making a vehicle that accommodates two drivers (one male and one female). The main portion of the challenge consists of a time trial around an obstacle course (A.3) designed to simulate the terrain of barren planets, but it also includes optional secondary awards given out for innovations in design (such as the Featherweight Award for the lightest vehicle, the Drive Train Technology Challenge for the best chainless drive, etc) and robustness in documentation. Below, Figure 2 shows a winning rover from a previous competition.

Figure 2: Rover from students at Huntsville Center for Technology[1].

2. Needs Statement

The objective of this project is to design, assemble, and drive a vehicle through the 2017 NASA Rover challenge obstacle course against time. The vehicles intent is to compete against other vehicles in a time trial. 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 collapsible configuration of the vehicle[1].

“There needs to be a ground vehicle capable of competing in the NASA Human Exploration Rover challenge.”

1.1 Goal Statement and Objectives

The goal of this challenge is to design a human powered ground vehicle capable of placing first in time in the 2017 NASA Human Exploration Rover challenge. In order to reach this goal, we must define a few objectives, these objectives are[1]:

- Determine feasibility of previous challenge team's design vs. current concept design
- Determine wheel design based off dynamic analysis
- Finalize ground vehicle design based off structural and dynamic analysis
- Purchase, gather, or manufacture all components
- Assemble vehicle prototype and conduct time-trial testing
- Quantify vehicle performance and determine improvements
- Assure that at least three team members are physically prepared for competition
- Ensure safety at all time
- Compete at competition

3. Design and Analysis

1.1 Constraints

Based on the NASA Human Exploration Rover Challenge competition and rules, the manned rover is expected to navigate an off-road course (A.3) in a sufficient amount of time. The following constraints and requirements were taken from the NASA Human Exploration Rover Challenge website[1].

1.2 Team Requirements

- The rover must be the work of the university's student design team
- All of the team members must be enrolled in college/university and at least 19 years of age; the team must be able to prove their age and enrollment.
- The team must have an adult at least 21 years or older.
- The rover drivers must consist of one male and one female team member.
- Each team is required to compete for the Technology Challenge Award which will concentrate on Wheel Design and Fabrication (details of this challenge in Design Requirements)

1.3 Design Requirements

- The rover must be human-powered. It may not use energy storage devices, such as springs, flywheels, batteries, or others.
- Technology Challenge: Wheel Design and Fabrication:
- The wheel mounting plate, hub, rims, spokes, dish, and tire will now be referred to as wheel.
- No commercial (purchased) rims, tires, or strips of tires are allowed.
- The only commercial items that can be used in the fabrication of the rover wheels are the hubs containing bearings or bushings.
- Commercially available wheel rims and spokes may not be used.
- The collapsed dimensions must fit into a 5 x 5 x 5 feet cubical space
- The assembled rover may not be wider than 5 feet as measured from the outside wheel to the outside of the wheel on the opposite side.
- There are no height and length constraints for the assembled rover
- If the rover is deemed unsafe it may not be allowed to race the course.
- All parts of the vehicle, including the seat, steering controls and pedals, with which riders have normal contact must be designed such that their lowest surface must be at least 15

inches above the ground when the vehicle is assembled on a level surface and with riders on board.

- The vehicle should have turning radius of 15 feet or less
- The vehicle should safely handle slopes of 30 degrees' front to back and side to side
- Each rover must have seat restraints for both drivers
- All sharp edges and protrusions must be eliminated or guarded
- Dust abatement devices, fenders, must cover a minimum area of 120 square inches each and must be installed on all wheels

1.4 Competition Description

The competition starts off by the vehicle being lifted and carried 20 feet by the two team members, one male and one female, without any outside help. Once the vehicle is assembled, the team waits for a signal to begin navigating the course. During the race, teams may be subject to penalties that will result in additional time being added to their final time. For example, 1 minute will be added a driver has contact with the ground. Maximum allowed time to complete the course is 8 minutes, and each team will be allowed two trials. The team with the fastest course completion time wins the competition.

1.5 Concepts

Initial research involving chassis design began by looking at previous teams from the NASA rover competition. From these teams we found that there were two main styles of seat orientation, which has major impact on how the chassis will be designed. There were three types: side by side, front to front, and front to back. Along with the chassis is the drivetrain, suspension, steering, and most importantly wheels. We began with the chassis as this is needed before the other concepts can be generated since they would need to work based on what chassis style we chose. We designed basic concepts for each type of seating orientation to help decide on which one worked best with our ideas. Figure 1 shows the side by side design, where 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 1. This designs strength is that it does not require a folding hinge in order to fit the length constraints like other designs likely do. This allows for a unified drivetrain system that can connect the front and rear wheel sets.

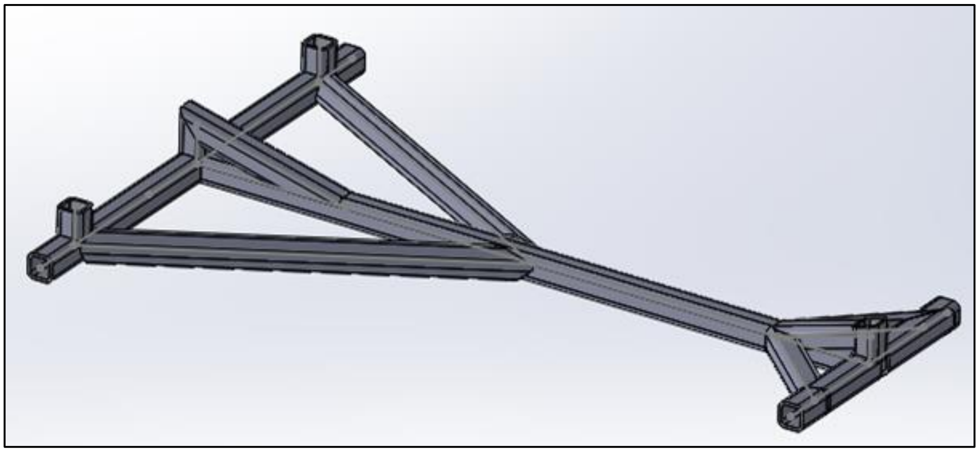

Figure 3: Chassis Design for Side by Side Configuration

The next design, show in Figure 3, shows a single beam as the primary section of the chassis and was actually done as study of the winning team from the rover challenge the previous year. This design supports two types of seat arrangements, front to front and front to back. Some advantages of this style is that the width constraint of five feet will be easy to accomplish, but it also means there will need to be a joint in the middle in order to accommodate both riders and the five feet length constraint. While this design allows for a simple and probably light weight chassis, it does require the other components to the rover to be places around it in a bolted-on fashion which may not be as strong as other designs would allow.

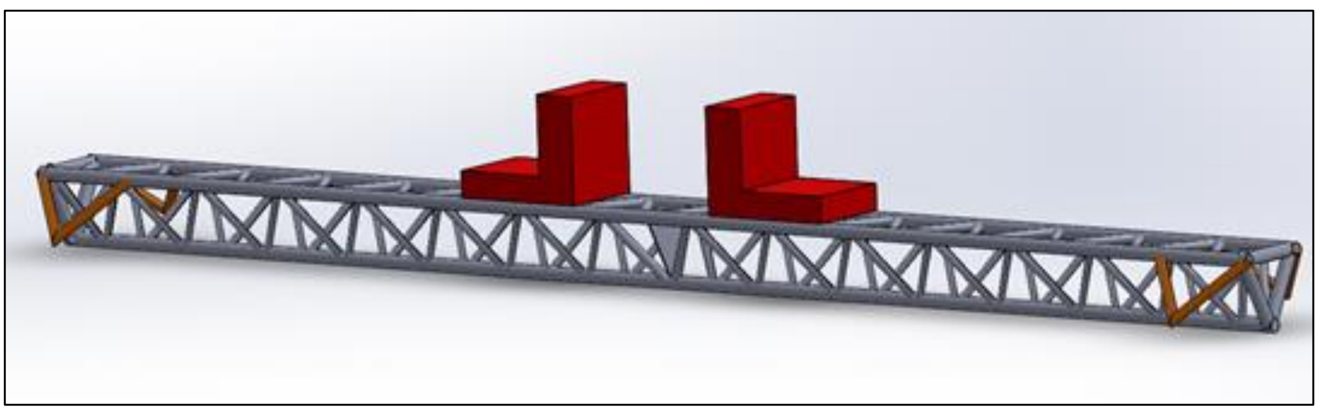

Figure 4: Chassis Design for Front to Back Configuration.

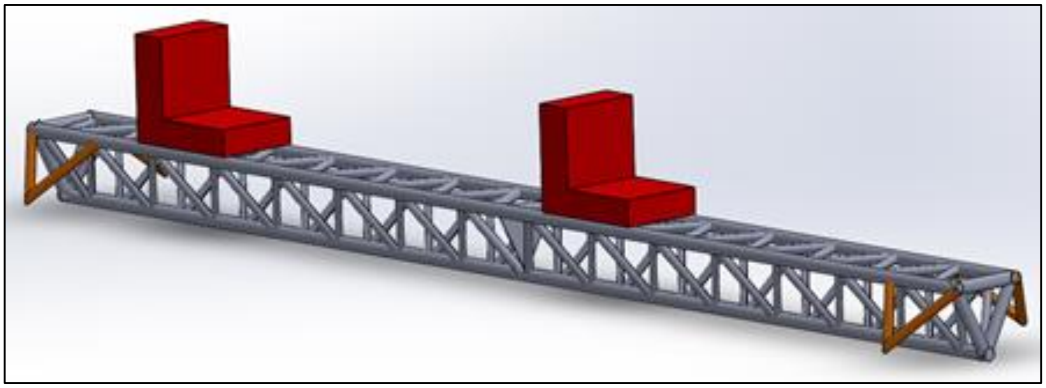

Figure 5: Chassis Design for Back to Back Configuration.

The final design, shows in Figure 6, is a simple box style frame with sections for seats. the figure shown is in the style of front to front though it could also be done front to rear if the seat support sections were both done in the middle. This design allows for components to go inside the frame side pieces rather than above, like in the previous design.

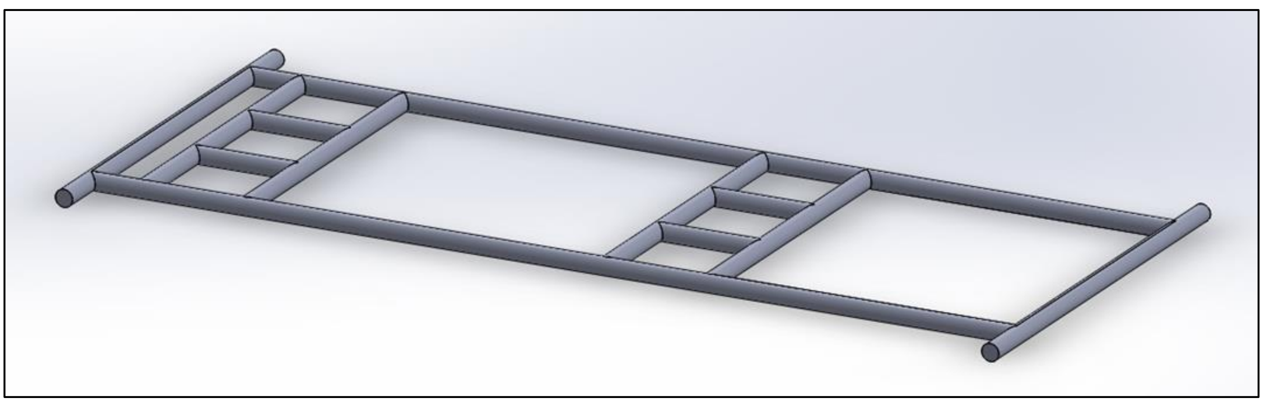

Figure 6: Simple Box Frame Design

1.6 Concept Selection

The largest obstacle in selecting a design for the chassis was settling on the seating orientation for the drivers. There were three major configurations being considered: tandem, back-to-back, and side-by-side. Each setup had its advantages and drawbacks.

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 assembly should be relatively simple to design and execute since the team could mimic the methods from previous competition entries. 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 bending stress from the weight of the drivers, as well as an increasing the overall turning radius. Another issue is power delivery. In a tandem configuration, either seat powers their respective axle, meaning that front and rear wheels are turning at different rates, and that on an incline, the rear driver needs an increased amount of torque to propel both members up the hill.

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 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 of a bending moment on the overall frame the weight of the drivers would concentrated closer to its weakest point, adding to the complexity of the design. 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.

The final idea being considered was to have the rover pilots sit side-by-side. The greatest advantage of this setup is that wheelbase can be made dramatically shorter than with either of the in-line configurations because it only considered the recumbent length of a single driver. 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. 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 decision, a decision matrix was set up to help guide the team in selecting a final design. As seen in Table 1, not only did the advantages of the side-by-side configurations far outweighed its drawbacks but it also had stronger positives than either of the other configurations, and so we settled on a side-by-side driver configuration as our final design.

Table 1: Concept Selection for Seating Orientation.

Seating Orientation				
Pros/Cons	**Importance**	**Tandem**	**Back-to-Back**	**Side-by-Side**
Wheelbase	3	2	4	5
Ergonomics	2	5	4	2
Complexity	5	3	1	2
Weight Distribution	3	4	5	3
Turning Radius	3	2	2	4
Assembly Time	5	4	2	3
Power Delivery	4	2	1	5
Score		**77**	**60**	**85**

1.7 Final Concept

With the initial designs presented in section 2.5 and the selection method in 2.6, Team 17 was able to select the design that satisfied the needs the most. The design incorporates a single bar for the chassis that stems off in the front and back to create axils with suspensions. As is mentioned in section 2.3 one of the design requirements is that it must fit in a 5x5x5ft box unassembled and then be assembled as quickly as possible. The winning team last year was able to assemble in 9 seconds. In order to compete with that time a telescoping chassis design was created. As can be seen in Figure 5 below, the chassis is collapsed.

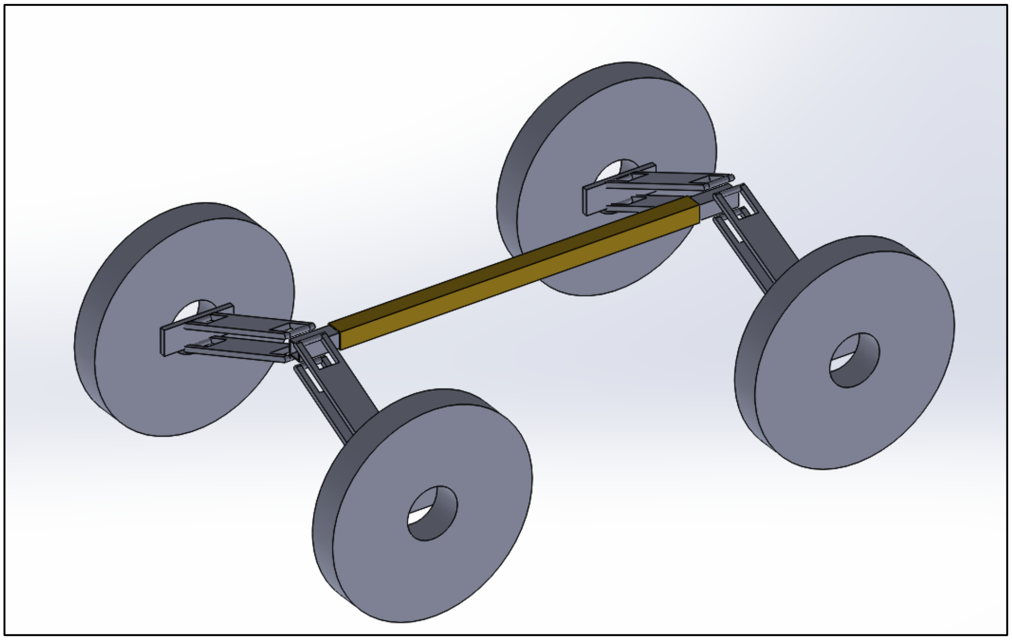

Figure 7: Collapsed Chassis Design Concept

This means that the middle bar (brown) is nesting the ends of the bars that can be seen in Figure 6. The drive train, which has not been modeled yet, will actually fold up when the rover is unassembled. When the rover is assembled the drive train will straighten out into a toggle position at which point it will operate normally. The telescoping design allows for a quick team lift and pull by the two drivers. The chassis will lock into place and the assembly will be complete.

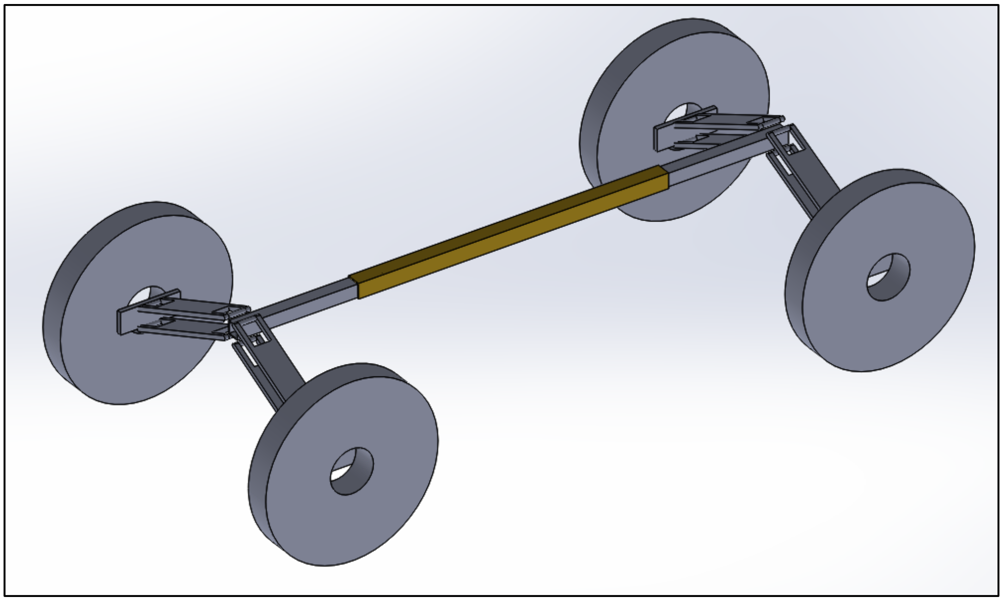

Figure 8: Extended Chassis

The initial idea for configuration of seats is to have a side by side formation. The chassis will have an additional support plate that will support the weight of the drivers. The drivers will sit closer to the back of the rover almost on top of the back axle to create more force on the back tires to allow for more traction. The idea for the drivetrain is to have a combined drivetrain with both drivers.

The other configuration for seats that is to have a tandem formation. It would have two drivers sitting in a line directly over the chassis bar. This could allow for dispersed weight on the chassis and even a different option for the drive train. This could allow for two separate drive trains, one for the front wheels and one for the back wheels.

3. Scheduling and Resource Allocation

1.1 Work Breakdown Structure

Below is a list of tasks along with their description. Table 4 expands to include sub-tasks, as well as which team members are assigned to complete it.

- Fundraising: Raising money required for construction and travel costs of the vehicle and the competition through businesses and school entities.
- Conceptual Design: Full planning of entire rover vehicle (chassis, wheels, drivetrain, etc.). This will be iterated on throughout the project up till the end as the need arises.
- Part Selection: Once conceptual design is completed the materials that we want to use to build the rover vehicle must be chosen.
- Purchasing: Using the funding we have available we will purchase the chosen parts we need to construct the vehicle.
- Registration: The team must apply for the competition that is taking place at the end of March and beginning of April.
- Manufacturing: Once appropriate parts are received construction of actual frame can begin through welding in the machine shop at FSU and other components being built as needed by the team.
- Finalize Design: Here the entire rover has been built and passes minimal tests, in this stage no major modifications will be made to the rover.
- Testing: Once final construction is completed testing will be done up till the competition to ensure viability of the rover design and to find where small adjustments will need to be made for optimal performance.

Table 2: Resource allocation according to the team dynamics.

Task	Sub-Tasks	Team Member(s) Assigned
Fundraising	Schools	Katherine
	Local Businesses	Luke, Katherine
	Bicycle Shops	Luke
Conceptual Design	Chassis	All
	Drivetrain	Garrett, Luke
	Steering	Quentin, Jacob
	Wheels	All
Part Selection	Materials	Katherine, Luke

	Pre-made Part Selection	Garrett, Jacob, Quentin
Purchasing	Materials	Katherine, Luke
	Pre-made Parts	Garrett, Jacob, Quentin
Registration	Register for event	Katherine
Manufacturing	Welding chassis	Machine Shop
	Install Drivetrain	Jacob, Garrett
	Install Steering	Luke, Quentin
	Construct Wheels	All
Finalize Design	Analyze Wheels	Luke, Garrett

	Tweak Design	Quentin, Jacob, Katherine
Testing	Test Components	All
	Run on Obstacles	All

1.2 Critical Path to Completion

The critical path is the most direct way to complete a project. It describes what tasks are dependent and independent of one another. Figure 7 below shows the Critical Path Network Diagram for the project. An arrow between tasks indicates if a task has to be done before the next task. The numbers in the arrows indicates how many days are anticipated to actually accomplish the task from where the arrow originates.

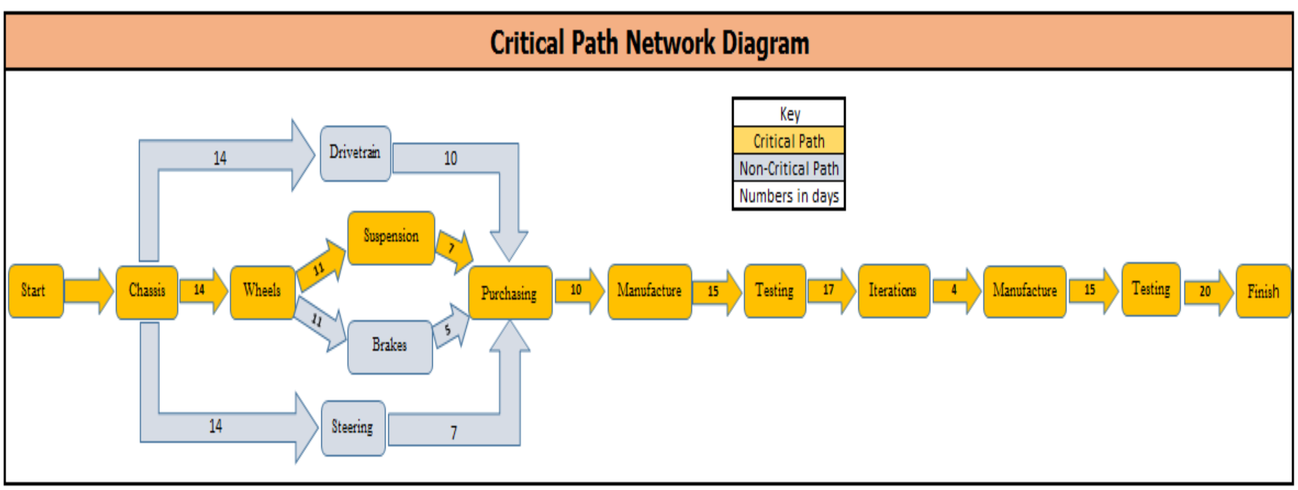

Figure 9: Critical Path Network Diagram

Designing the chassis was found to be the most crucial starting point. In essence, nothing can be tested without a chassis. This is why this is the first thing that is created. There are three things that are dependent on the chassis being done and that is: the drivetrain, steering, and the wheels. Under investigation of the design process, the suspension and brakes were found that they were dependent on the wheels. The suspension and brakes cannot be made without a clear wheel design. Depending on how the wheels are designed will impact how the suspension is made along with what kind of brakes can be used. While that is being researched, at the same time steering and the drivetrain can be created. These two things can be designed without the wheels. Once all of the designs are finished, then parts selection/purchasing is done. From their manufacturing is done and then testing. After testing, iterations to the design are done followed by more manufacturing and testing. It will cycle through iterations, manufacturing and testing until all competition constraints are met and team expectations are satisfied.

1.3 Gantt Chart Reiteration

The original Gantt chart was broad. After delving into the project, more steps were identified. To help with the planning of the project, iterations were needed to the Gantt chart. Originally, there was only one tab for design, during the iteration, individual design components were added to keep the group on a stricter timeline. Looking at Figure 10, the new designs consist of chassis, drivetrain, steering, wheels, suspension and brakes. The Gantt chart was a pivotal part of creating the Critical Path Network Diagram in section 1.2.

		Task Mode	Task Name	Duration	Start	Finish
1		Manual	Fundraising	47 days	Sat 10/1/16	Mon 12/5/16
2		Manual	Conceptual Design	17 days	Sat 10/1/16	Sun 10/23/16
3		Manual	Chassis	11 days	Tue 10/11/16	Tue 10/25/16
9		Manual	Part Selection	7 days	Fri 10/21/16	Mon 10/31/16
4		Manual	Drivetrain	10 days	Tue 10/25/16	Sat 11/5/16
8		Manual	Suspension	7 days	Tue 10/25/16	Wed 11/2/16
5		Manual	Steering	7 days	Fri 10/28/16	Sat 11/5/16
10		Manual	Purchasing	10 days	Tue 11/1/16	Mon 11/14/16
6		Manual	Wheels	11 days	Thu 11/3/16	Thu 11/17/16
11		Manual	Manufacturing	15 days	Mon 11/7/16	Fri 11/25/16
7		Manual	Brakes	5 days	Thu 11/17/16	Wed 11/23/16
12		Manual	Revisiting Design	4 days	Fri 11/25/16	Wed 11/30/16
13		Manual	Finalize Design	17 days	Thu 12/1/16	Fri 12/23/16
15		Manual	Refine Reports	14 days	Wed 12/14/16	Sat 12/31/16
14		Manual	Continue Manufacturing	15 days	Wed 12/21/16	Tue 1/10/17
16		Manual	Tweek Design	14 days	Sun 1/1/17	Wed 1/18/17
17		Manual	Testing	17 days	Mon 1/9/17	Tue 1/31/17
18		Manual	Continue Testing	20 days	Wed 2/1/17	Tue 2/28/17

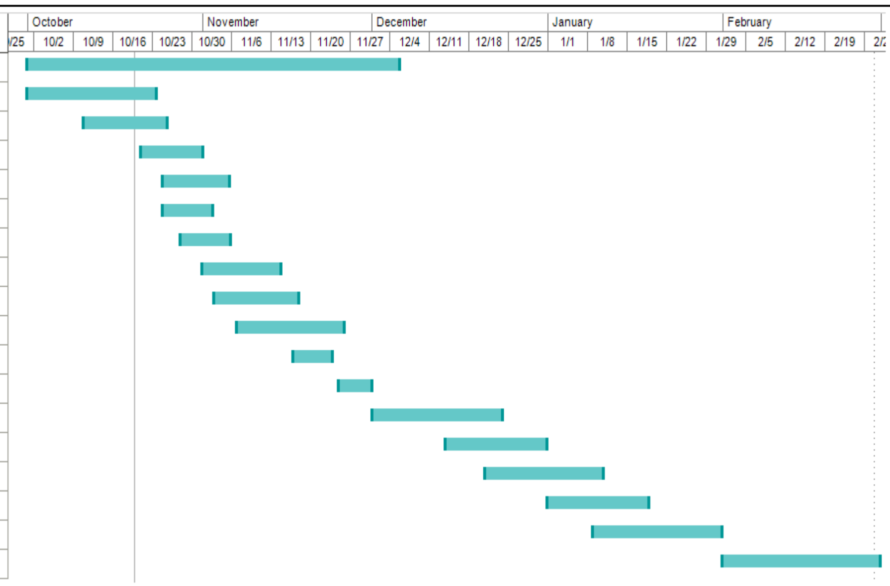

Figure 10: Gantt Chart

4. Results

1.1 Uncertainty and Risks

With the design selected in section 2.7, there are some risks. With a telescoping design of the chassis, the telescoping components must not bend. If there is any significant bending then the chassis will not expand correctly or at all. It could get stuck and that would prevent the assembly from occurring. Another such risk, is one bar may not be strong enough to support two drivers, a drive train and all of the stresses that the vehicle will feel while traversing the course.

As far as uncertainty, there is going to be a good deal of it. Largely because it is going to be difficult to simulate the dynamic forces that the vehicle will endure during the race. As a result, a safety factor of 3-4 has been set. This is not a set number as of now, because according to Dr. Hollis, there are ways to accurately do dynamic analysis on our vehicle. This is important because if the safety factor can be reduced, then material can be removed and the vehicle will be lighter. More research into dynamic analysis will be done as the project continues to help eliminate the uncertainty and risks.

5. Conclusion

To date, the focus of this design phase was on the chassis. The chassis design selected satisfies all of the competition restraints. Unassembled, the rover will fit in the required space and it can easily be assembled which is a huge advantage for the competition. Now that a design for the chassis has been selected, a finalization of the chassis can be manufactured and tested. Calculations on the design can be done based on the material and estimated weights and forces the chassis will experience. From the critical path method diagram, it can be seen that the chassis is the foundation of the project. The other designs cannot be designed and tested without the chassis design selected. From this point, the next phase of the design will move forward. If the timeline is going to stay on pace, then the Gantt chart must be followed.

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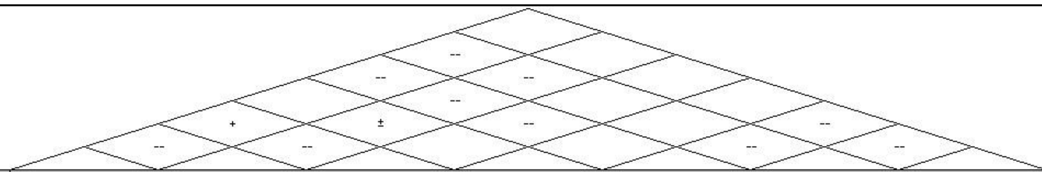
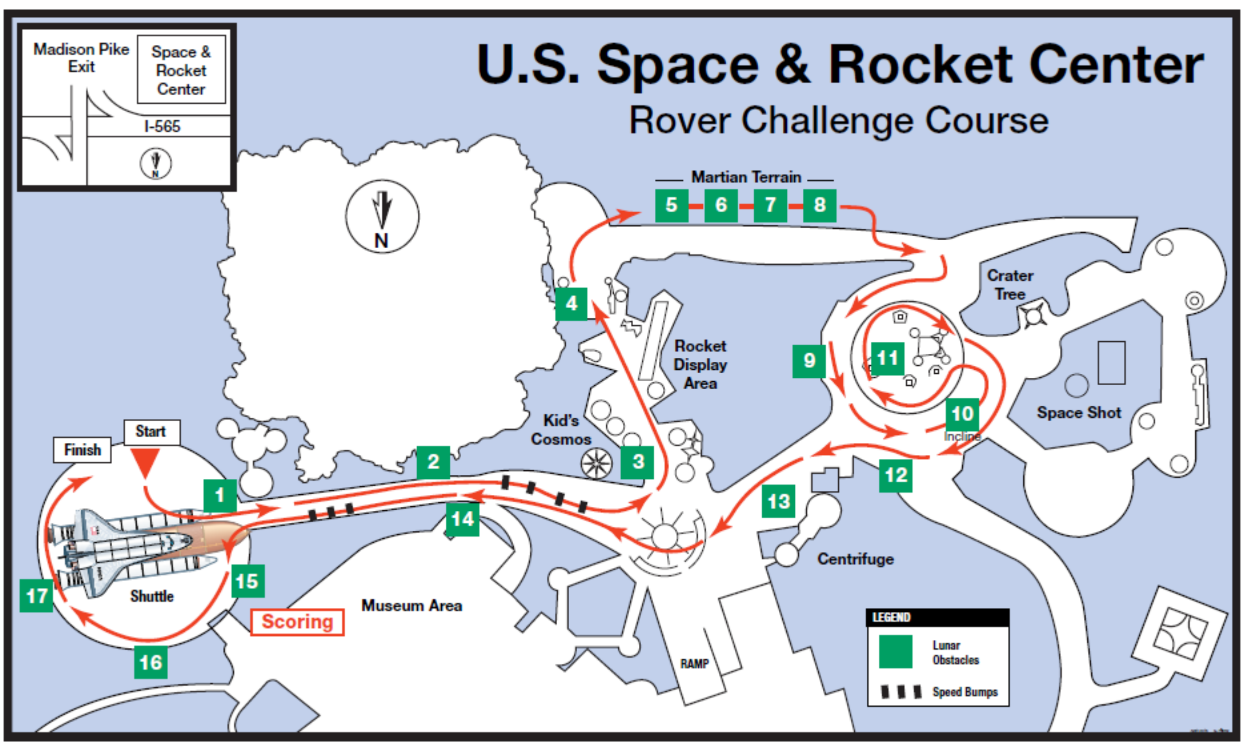
Appendix A

A.1 House of Quality (HOQ)



Customer Requirements	CI	EC						
		Frame Strength	Vehicle Weight	Number of Wheels	Wheel Design	Frame Length	Frame Width	Frame Height
Lightweight	6	7	10	7	7	5	5	5
Strong	7	10	7		7	7	5	3
Stable	10			8			7	8
Fast	5		7	7	7		5	
Safe	10	7		5				6
Can traverse obstacles	7	5		7	9	5		
Seats Two Adults	10	7				8	8	
Fits in a 5x5x5 ft box	10					10	10	10
Less than 15 ft Turning Radius	10			5		7	7	
		287	144	256	189	364	410	291

A.2 Course Map



*Biographies of Team Members

Jacob Van Dusen

I grew up in Cocoa Florida down by the space coast. I am an Eagle Scout, an engineering major at FSU, and going into the United States Air Force after college, currently with the job of Combat Systems Officer.

Luke Maeder

I am from Rockville, MD. I am an Eagle Scout. My focus in Mechanical Engineering is Sustainability and Power Generation, but I have experience with manufacturing and mechatronics as well. I am applying for Officer Candidate School and graduate programs after my bachelors degree.

Katherine Estrella

I was born in Santo Domingo, Dominican Republic, and came to the United States at the age of 12. I study Mechanical Engineering at Florida State University, and have research experience involving the synthesis and characterization of carbon nanotubes. Lastly, I am currently on track to become a Navy Nuclear Submarine Officer after graduation.

Garrett Rady

I am 23 years old and was born and raised in Tallahassee, Florida. I study Mechanical Engineering at Florida State University. I plan to work in sports in engineering in near future.

Quentin Hardwick

Born in Louisville, KY but spent most of my life in Tampa, FL. Originally majored in Pure Mathematics before being exposed to Physics, at which point I switched my major to Mechanical Engineering because solving physics problems is even more enjoyable. My focus is on dynamics largely due to a love of ODE’s and general motion equations. After graduation I hope to work for a civilian contractor for the D.O.D. because I would like to feel like I’m doing something that matters.