NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Northern Arizona University

NASA Human Exploration Vehicle Competition

Report Two: Proposal Report

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1 Introduction

This vehicle is being designed to participate in the NASA Human Exploration Rover competition. The objective of this project is to design and build a vehicle that can navigate a multitude of terrains through a half-mile course. The sponsors' that are interested in this project are NASA, along with the Society of Automotive Engineers advisor (SAE), Dr. John Tester. Their interest comes from the want to be able to cross the predicted terrains of planet Mars, and to aid with their design for the actual prototype. The completion of this project will provide a working prototype of a design that will suit their needs, as well as become a possible design for future NASA missions.

1.1 Project Description

Following is the original project description provided by the sponsor:
"NASA Human Exploration Rover Challenge revolves around NASA's plans to explore planets, moons and asteroids across the solar system. The project is to design, construct, test and race mobility devices–lightweight, human-powered rovers–capable of performing in the varied, demanding environments to be explored. The challenge will focus on designing, constructing and testing technologies for mobility devices to perform in these different environments."

1.2 Original System

This project involves a completely new design for a Human Exploration Rover. This project is not a revision build that focuses on the improvement of one aspect of the vehicle, because of this, we used other designs, products, and projects to help us better understand the design challenges. With no previous or original system to reference, we used projects such as the Human Powered Vehicle (HPV), along with consumer products such as a recumbent bicycle, a quad-cycle, and a tandem bike. The comparison and usefulness of each system will be discussed alter in the report.
Quadra-cycle, HPV, recumbent, and tandem.

2 Requirements

This section begins with a description of the requirements outlined by the customer. The customer requirements are then weighted numerically, with higher numbers signifying a more important requirement. Also included are target objectives, which are not substantial requirements that necessitate a weighting, which indicates goals that the team aims to meet. Customer requirements and target objectives are compiled into a House of Quality along with corresponding weight ratings. This section may refer to the design objective as a vehicle or a rover, which are synonymous ways of describing the design objective.

2.1 Customer Requirements

The customer requires that the team build a vehicle that is solely human powered and propelled around the test course by two students – one female and one male. Tires on the vehicle cannot be inflatable or pneumatic. The vehicle must be sturdy enough with wheel technology able to traverse large obstacles, provide traction and support on soft, hard, rough and smooth surfaces, and cross cracks, crevasses and ruts. The vehicle must be able to do this on flat or inclined surfaces from a moving or static start. All wheels must be covered with dust abatement devices, or fenders, sufficient to mitigate the hazard of flying debris.

To verify ship-ability, the vehicle must be easily deconstructed to fit within a cubical container of sides measuring five feet. The vehicle must be lightweight and portable, such that collapsed shipping configuration can be lifted by the two drivers and carried 20 feet without contacting the ground.

Assembled, the vehicle is constrained to a width no greater than five feet, with no restrictions on length or height. The ground clearance of the vehicle at its lowest surface must be no less than 15 inches. The turning radius of the vehicle can be no greater than 15 feet. The vehicle is required to have a specific set of accessories, which may be real or simulated during testing. They include a high-gain antenna, a national or institution flag, two batteries, a video camera and an electronic control panel. To address safety concerns, the vehicle seats must have adequate restraints to secure the driver. Furthermore, all sharp edges and geometries must be guarded or eliminated.

2.2 House of Quality

This section briefly discusses the HoQ that is attached with this report. The HoQ consists of 17 customer requirements (CRs) each weighted by the importance of its inclusion in the final design. The two most important characteristics of the design are that the vehicle is human powered, and can be easily transported. Cargo space is limited during space travel, so having a light compact design will be more desirable for NASA. To view the rest of the CRs, see the HoQ attached.

3 Existing Designs

The following section lays out the preliminary research for the Mars Human Powered Vehicle project. Research was conducted to ensure preventable mistakes are avoided. Below, the research is divided into sub-categories in order to establish the alternative areas to learn about human powered vehicles. The system level and subsystem level sections divide the key areas of focus in order to better understand what the research was focused at studying.

3.1 Design Research

The research for the Mars human powered vehicles comes from the following areas: personal experience, internet research, the Northern Arizona University SAE club (Students of Automotive Engineer), NASA Curiosity engineers and prior internship bike research. The areas of research are broken up into categories to show the various forms of research. The key focus when collecting the data was to evaluate systems and subsystems that the team will encounter in the designing and construction of the vehicle.

3.1.1 Personal Experience

Personal experience includes the experience of all the team members. This experience comes from our own personal interactions with vehicles, whether human powered or motorized, throughout our engineering experience. This experience ranges from repairing and restoring bicycles to fixing cars. The team experience is important in the design and construction of the Mars Rover vehicles. This experience is important for understanding proper materials and the manufacturing of parts and subsystems.

3.1.2 Internet Research

The internet research includes processes and information from various industries including bike shops, motorcycles manufactures, automotive industries, and engineering companies. A large influence in changing the paradigm of the problem came from the competing teams that have pictures on the NASA website [1]. It is important when viewing the competitor's designs to not begin creating vehicles that operate similarly, but to approach it with the goal of learning of possible routes for subsystems. Additional internet research was done with the SAE, but is explained in the following section.

3.1.3 Northern Arizona University SAE

The Northern Arizona University chapter of SAE is one of the project's most valuable resources. All members of the Mars Exploration Rover team are new associates of the organization and are learning about the vast resources of the SAE organization. Such resources include fellow peers within the program, senior engineering professors, machine shop capabilities, and a library with automotive resources of such as the SAE magazines. The importance of SAE is that the chapter heads have decades of experience in automotive vehicles, design, and testing.

3.1.4 Prior Internship Bike Research

Two of the team members, Greg and Josh, spent a summer interning at a Flagstaff small business shop. This internship allowed months of hands on experience creating a bicycle-like vehicle. Lessons included control, safety, and steering.

3.1.5 NASA Curiosity Engineer

The lead engineer of the Mars Curiosity rover will be in contact with the team leader to help explain challenges and issues that NASA Curiosity group had when designing their multi-million dollar rover. This resource will be most for educational purposes with a small possibility of design help.

3.2 System Level

This section describes the results of the multiple methods of research previously mentioned.
There were many different types of designs the team had looked at ranging from tandem bicycles to quad-cycles. The designs looked at were diverse and not directly related to the actual project to give different perspectives of subsystems and how they function together. Each design was looked at by their subsystems and analyzed how each of them worked together. The pros and cons were then weighted against each other to figure out which system is best.

3.2.1 Existing Design #1: Quad-Cycle

The quad-cycle can be a one or two person bike with four wheels. Pros of this design are that it is stable, can easily carry two passengers, has plenty of storage space, and is all terrain capable. Cons are that the frame has a small profile, it appears that the weight is off center and wheel axels appear to be fragile. The quad-cycle cannot navigate large obstacles and currently has no dust abatement fenders. It is unknown if this design has a 15 foot turn radius or if the undercarriage height is at least 15 inches. This design satisfies the requirements of transporting two people, store accessories, less than five feet in width, and can be easily collapsed down into a 5-by-5-by-5 container.

3.2.2 Existing Design #2: NAU Human Powered Vehicle

Northern Arizona University's Human Powered Vehicle performed well at last year's competition. Pros of the HPV are that it is lightweight, aerodynamic, and fast. However, it cannot go over large obstacles, cannot accommodate two riders, has no storage space, extremely poor turn radius, cannot be collapsed down, it is too low to the ground, and it can't hold required accessories. This design can be carried by two riders.

3.2.3 Existing Design #3: Recumbent Bike

A recumbent bike is similar to NAU's Human Powered Vehicle. Recumbent bikes excel at stability, turning radius, are lightweight, and have the potential for storage space. However, a recumbent bike is too low to the ground, it cannot hold two people, cannot collapse into a 5x5x5 box, and cannot traverse over large obstacles, and it has inflatable tires.

3.2.4 Existing Design #4: Tandem Bike

The tandem bike is a bicycle built so two people can ride single file while peddling on the same gear train. They are typically lightweight, fast, have a minimized turning radius, and can navigate over large obstacles. Tandem bikes do not have storage space, cannot collapse, and cannot carry required accessories.

3.3 Subsystem Level

3.3.1 Subsystem #1: Wheels

The effectiveness of the wheels will be a factor in how much force is needed to overcome various terrain in the competition. Durable wheels with good traction that do not require air are necessary if the team wants to do well at the competition. The design could have the best brakes, steering and frame, but if the wheels do not propel the vehicle forward when a force is applied, everything will fall apart.

3.3.1.1 Existing Design #1: Rubber Wheels

The common wheels are standard rubber, inflated wheels. They are good for traversing rough terrain are easy to transport and light enough to have spares on board the vehicle. These wheels can traverse large obstacles with the proper propulsion, they have decent traction, and provides some support over soft, hard, and rough surfaces. The cons of these wheels are that they need to be inflated, there are no dust abatement devices, and they can where down quickly.

3.3.1.2 Existing Design #2: Solid Rubber Wheels

Solid rubber wheels are the same as the previous design, except that they need no inflation. The life span of these wheels are long with very minimal maintenance if any. The problem with these wheels are that they are heavy and difficult to purchase.

3.3.1.3 Existing Design #3: 3D Printed Wheels

3D printed wheels of a new design by Dr. Tester have the potential to be very effective. The problem with this wheel choice, is that he has not chosen to explain their exact specifications, but plans to debrief us upon request.

3.3.1.4 Existing Design #4: Solid Aluminum Wheels

Solid aluminum wheels are another option. These are currently what the Mars Curiosity Rover uses. These wheels are long lasting and greatly exceed the amount of payload they can support when compared to similar designs. The problem with this choice is the added weight, the high cost of material/machining, and the low amount of grip on solid surfaces (no dirt).

3.3.2 Subsystem #2: Braking

As important as propulsion is, braking is equally important. The vehicle needs to brake well to be able to maneuver the terrain and obstacles present at the competition. A good braking system will increase handling around turns as well as protect the drivers and the vehicle is there is a need to come to an abrupt stop.

3.3.2.1 Existing Design #1: Disk Brakes

Disk brakes are very common on bicycles. Pros of disk brakes are the durability, no rim wear/tear, long lasting, resistant to mud/water, and stronger than rim brakes. Cons of disk brakes are the added stress to the spokes, they heat up quickly, require readjustment, and cause torsional stress on the wheels. Disk brakes are relatively standard and provide good control over the vehicle.

3.3.2.2 Existing Design #2: Pad Brakes

Pad brakes are simple, but effective brakes. These brakes allow for easy assembly and low design times. They can be found on most low quality brakes due to their low cost. The problems with them are that they have long distance and ware quickly. Replacing these brakes requires an entirely new assembly, which is not feasible for NASA applications.

3.3.2.3 Existing Design #3: Reverse Gearing Brakes

Reverse gearing breaks are common on cruiser bicycles. This is the quickest build system as it is simply making it so that any backwards pedaling slows the tires and ultimately the vehicle. Some problems include: possibly tire damage, unstable stopping, can hurt the drivers if pedaling fast enough, and low stopping time.

3.3.2.4 Existing Design #4: Drum Brakes

Drum brakes are very common. These can be found on most vehicles today and all older vehicles. The design of the mechanism allows for long life cycles with dependent results. A major problem is that a small version of these brakes has not been found as would be needed for the project.

3.3.3 Subsystem #3: Steering

Having good wheels and great brakes will not mean anything if the drivers cannot steer the vehicle. Steering is essential in any vehicle, especially any space-faring vehicles. The operators of this bike need to be able to dictate where the bike goes when. Steering in combination with propulsion and brakes are what make the vehicle useful. However, if the steering is lacking, no amount of propulsion will help the drivers reach their destination if the vehicle cannot be controlled.

3.3.3.1 Existing Design #1: Stem-Wheel

The Quad-Cycle uses a stem-wheel steering apparatus. A steering wheel connected to the stem turns the wheels to steer the vehicle. The exact turning radius is unknown. A stem-wheel design is more familiar to most riders. It provides optimal control of the vehicle without sacrificing functionality.

3.3.3.2 Existing Design #2: Pulley Mechanism

Pulley systems succeed in small designs and can allow for high torque in the vehicle control. The problem with this is that drivers require a long time to learn how to steer in order to grasp how to control the vehicle without damaging it.

3.3.3.3 Existing Design #3: Pull Bars

The NAU Human Powered Vehicle team, last year, integrated pull bars steering into their design and showed many advantages including: easy control of the system, able to be done in a very tight building area, and light weight. The problem is that the turning was sensitive and had a very small turning radius that they were not concerned with.

3.3.4 Subsystem #4: Frame

The frame is the key structure within the vehicle. All of the subsystems need to be compatible with the frame design. The material choice for the frame could change the weight from being 20lbs. to 40lbs. or more. The main three materials to choose from are 6061 aluminum, 6031 steel, and chromoly.

3.3.4.1 6061 Aluminum

Aluminum is a practical, light weight material used in most modern bike frames. This material allows for an inexpensive frame and low weight to strength ratio. The problem with aluminum is that it is difficult to weld, which is going to be the most prominent way to make a frame. Another problem is that it can get damaged quickly in testing applications

3.3.4.2 6031 Steel

6031 steel is one of the most available steels to find today. It is one of the strongest steels that can be purchased from any steel vender. This grade of steel can be welded by all forms of welding. The key issue is that this is a heavy material. The finished frame will also need to be heat treated if using this steel to cure and remove strength reductions caused by welding.

3.3.4.3 Chromoly

Chromoly is a four thousand series of steel. This steel is prominent in the automotive industry. This steel works well with welding as well and can be purchased from every steel vender. This is the most common steel an engineer can get a hold of for its machining, bending, and structural fabrication. The weight is less than 6031 steel and greater than the aluminum.

3.3.5 Subsystem #5: Propulsion

A good propulsion system is essential in any vehicle. Any vehicle can have the best tires, frame, brakes and steering, but without propulsion, it will not go anywhere. To complete the competition, the bike needs a good propulsion system the drivers can utilize to get the vehicle from start to finish.

3.3.5.1 Existing Design #1: Bicycle Drive-train System

The first design is a bicycle drivetrain. This design is a working and well tested method of transforming human foot power into movement. The benefit of going with a system such as this is that any bicycle system can be taken apart and manipulated for the rover's mechanism. The problem comes with a chain length and stability. The machine being designed needs to be able to withstand high torques to move heavy loads and typical bicycle chains are not the best in high torque situations.

3.3.5.2 Existing Design #2: Belt System

The second design is the belt system. This system is great with high torque scenarios and allows for error in the pedaling that is associated with quick jerks and turns on a tram. The problem with a belt system is the lengths and thickness of the belts as they are most commonly a set length and width and can be over-engineered for the design itself.

4 Designs Considered

4.1 Brakes

This section will discuss three different brake subsystem designs considered, with pros and cons, for the team's final design. Also considered for each design is how well it addresses the customer requirement of safety.

4.1.1 Stagecoach Brakes

The first braking system considered is the stagecoach brake design. In this design, a large lever is used to actuate the brakes that apply pressure and create friction between the surface of the tire and the brake shoe. This design is simple, in mechanics and operation, and would be easily implemented in the final design. However, this style of brakes has the least stopping power of the three designs discussed in this section. If too much pressure is applied to the brake shoe through lever actuation, there is potential of chipping the tire material and creating an uneven braking surface leading to even less stopping power. Minimal stopping power warrants these brakes to be less safe than the other brake designs considered. An example of a stagecoach can be seen in Figure 1.

Figure 1: Stagecoach Brake

4.1.2 Rim Pad Brakes

The second braking system considered is the rim pad brake design. This design consists of two brake shoes that rest on the inside and outside of the rim of the wheel each connected to a rigid metal cantilever. Brake compression is achieved by pulling a wire connecting the free ends of the two rigid metal cantilevers, shortening the distance between them and subsequently the distance between the brake shoes. The driver achieves the wire pull by pulling the brake handle attached to the steering handles. There is more braking power in this design than in the stagecoach brake design, along with a longer expected lifetime. However, this design has an exceptionally high potential to warp the rims of the wheel when too much pressure is applied to the system leading to some loss of stopping power. Some rim pad brakes can be seen in Figure2.

Figure 2: Rim Pad Brakes

4.1.3 Disc Brakes

The third braking system considered is the disc brake design. This system consists of two brake shoes resting on either side of a disc that is rigidly attached to the wheel. The brake shoes are contained in a caliper that has pistons that expand when filled with oil, creating pressure between the brake shoes and the disc. Oil is fed to the pistons in the caliper through brake lines connected to a brake booster with inputs controlled by the driver. This design is complex and, consequently, expensive to implement. Disc brakes provide the most stopping power of the three designs discussed in this section, and have the longest expected design life. Maximum stopping power warrants these brakes as the safest design of the three brake designs considered. A disc brake system can be seen in Figure 3.

Figure 3: Disc Brakes

4.2 Wheels

Three main designs were considered for the Human Powered Mars Rover vehicle once the CR's and ER's were finalized. The three designs are tread over wheels, tread in wheels and clamped tread wheels. All designs considered were for wheels that met the customer requirements. The customer requirements for wheels are that they are not inflated, they need to be able to traverse obstacles, maintain traction, and have dust abatement devices and a minimum diameter of 20".

4.2.1 Tread Over Wheels

Tread over wheels are two separate components, the tread and wheel. The tread is mounted on the wheel by forming it to the wheel for a tight fit. These type of wheels are very common on bicycles and cars. These wheels satisfy the no air requirement. However, while a tread over design is easy to impendent it is not always reliable. The tread is simple to secure but could come off the wheel under the wrong conditions. A tread over wheel design is shown in Figure 4.

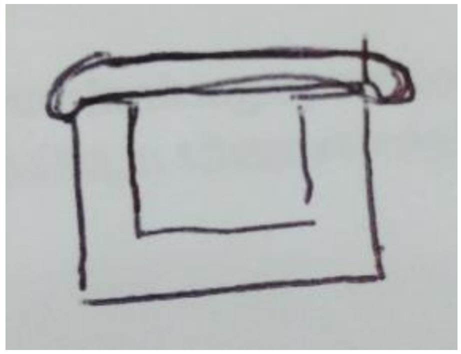

Figure 4: Tread Over Wheel

4.2.2 Tread In Wheels

A tread in design connects the tread to the wheel using pins to secure it in place. This design allows the team to use any material desired for the tread because the final product can be pinned in whereas with a tread over design, a more elastic tread is needed. While the pins hold the tread and wheel together, they also act as stress concentrators that could potentially tear the tread. A tread in wheel is shown below in Figure 5.

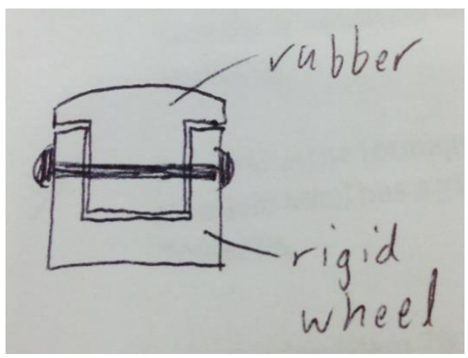

Figure 5: Tread In Wheel

4.2.3 Clamped Tread Wheels

The final design is a clamped tread wheel. Similar to a wheel chair wheel, a solid tread is clamped into a wheel housing without any pins. This is the best design as it guarantees that tread will be secured in the wheel housing whereas a tread over can come off and a tread in can be torn. However, a clamped tread in only works with certain materials such as solid rubber. These wheels are easily obtainable and serve the rover well as there is no air in the tires and they are very durable. An example of a clamped tread wheel is shown in Figure 6.

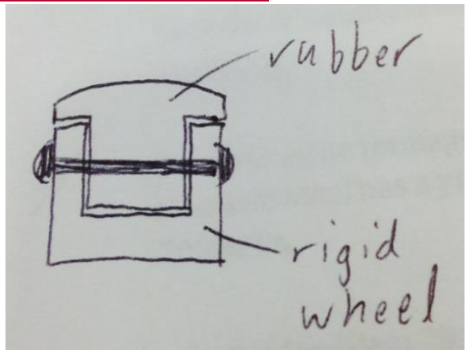

Figure 6: Clamped Tread Wheel

4.3 Suspension

This subsection contained seven different types of suspensions: hydraulic, spring, leaf spring, long arm, and coil over, hoop wheels and rigid body. A basic description, the pros/cons, and a picture of each type of suspension will be provided below.

4.3.1 Hydraulic

Also known as Shock Absorbers, use an incompressible fluid to oscillate the shock arms. The pros of shock absorbers are that they come in many sizes, are cost effective, and durable. The cons are that they are not well controlled and mostly have a rigid feel for the driver. An example is shown in Figure 8.

Figure 7: Hydraulic Suspension

4.3.2 Spring

Spring suspension is a helical shaped metal that is used to absorb an impact, or uses tension to hold an item at a certain length. The pros of the springs are that they are extremely durable, great for constant absorption, and have wide variety of properties and sizes. The cons for springs are that they do not hold shape from shear forces, and mounting is not straightforward. A spring suspension can be seen in Figure 9.

Figure 8: Spring Suspension

4.3.3 Leaf Spring

A leaf spring is a set of pieces of metal curved upwards to create a tension that holds the vehicle up. The pros are that they can be made and attached to the frame quickly and with little fabrication. The cons are they are commonly rigid, and the damping cannot be controlled. An example of a leaf spring suspension system can be seen in Figure 10.

Figure 9: Leaf Spring Suspension

4.3.4 Long Arm

Long Arm uses a combination of springs and control arms to attach a solid axil to the frame. Long arm suspension has great flexion, can be controlled well with different size springs and arms, and is a well-known type of suspension. The cons are the number of components, the weight of all the components, and are not an easily maintained system. A long arm suspension can be seen in Figure 11.

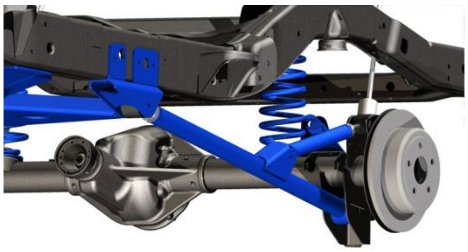

Figure 10: Long Arm Suspension

4.3.5 **Coil over**

A coil over is a manufactured combination of a spring and shock absorber to create a relationship between absorption and tension. It uses are spring to create a desired length, and is used for oscillation. The shock is used to take extreme impacts and allow for controlled travel. The pros of coil overs are that they create the best ride quality for all speeds and terrains, made in various sizes, and the damping can be controlled. The main con are that the coil overs are expensive. An example of a coil over suspension can be seen in Figure 12.

Figure 11: Coil over Suspension

4.3.6 **Hoop Wheels**

Hoop Wheels are an innovative type of suspension system where the use of tensioned plastics are used to create the rim of the wheel. The pros of the hoops wheels are that they technically have no components, make the overall design simplistic, and can be maintained. The cons is they have not been proven to be durable or work well, they are expensive, and cannot be obtained. A hoop wheel example can be seen in Figure 13.

Figure 12: Hoop Wheel Suspension

4.3.7 **Rigid Body**

This suspension system utilizes the design of have rigid supports for the wheels. Rigid body uses no type of compression or tension component to absorb shock or help with flexion, but relies solely on the strength of multiple components attached together. The pros of this system are it is inexpensive, has no components, and can be maintained. The cons are there is no flexion, and the ride quality is poor. A rigid body system is shown Figure 14.

Figure 13: Rigid Body Suspension

Each of these systems was graded with the criteria that would help our team identify the most suitable suspension system for our competition. The criteria was chosen with our engineering and customer requirements in mind, as well as thinking toward the build stage, and how to build and incorporate the suspension into the final design. None of the criteria is listed in any specific order.

- Travel: The distance that the system can stretch and compress under a load.
- Flexion: A strong relationship to travel, is the ability for the whole design to have the tires and suspension follow an inclined terrain while keeping the drivers/frame from rolling over.
- Size: Length, width, and height of the system, and all of the incorporating components.
- Cost: Expenses of the components along with the amount it would take to fabricate it to the final design.
- Maintenance: Involves the difficulty of fixing a problem, the cost if a part breaks, and how quickly the problem can be resolved.
- Weight: How heavy all of the suspensions components weigh in pounds.
- Obtainability: How readily available the suspension components are, as a whole system and individual parts for maintenance.
- Damping: The ability to control the amplitude of the oscillations and vibrations.
- Number of Components: The amount of mechanical parts used.
- Ride Quality: The comfort for the drivers while traversing different environments.
- Transferred Force: The amount of shock/impact the whole design absorbs.

4.4 Drivetrain/Seating

In this section, three main designs for the drivetrain and seating arrangements will be considered. The three designs are: having the drivers face opposite directions, having the drivers oriented in a way that resembles a tandem bicycle, and where the two drivers are laying side by side. Each design is considered with its pros and cons to decide how well each design fits the customer's needs.

4.4.1 Back to back

The first drivetrain/seating arrangement considered is where the drivers sit facing back to back. In this design each driver will be pedaling, but they will be applying their power to different axels. This divides up more power overall to the rover allowing it to be more efficient for testing. The center of gravity is also more central in this design making it much more capable of traversing tougher environments while keeping it more stable. With both drivers facing the opposite directions, this means that one of the drivers will not know what is coming up next in the course and will have to rely on the judgment of the one driver who can see the course. An example of a back to back seating arrangement is shown in Figure 15.

Figure 14: Back to Back Seating

4.4.2 **Tandem**

The next drivetrain/seating arrangement considered is the Tandem style method. This method has both riders facing forward and in line with each other as would those riding a tandem bicycle. This design is a much easier construct than the other considered designs. Both drivers also can face the same direction allowing for both of them to make calls as to how they should traverse the upcoming obstacles. This design also puts both drivers on the same drivetrain system meaning that all the power given by the drivers is on one axel. While this gives more power to that one axel, it leaves the other set of wheels to just roll and have no power at all. A tandem bike example can be seen in Figure 16.

Figure 15: Tandem Bike

4.4.3 **Side by Side**

The final drivetrain/seating arrangement considered is the side by side method. This method has both drivers facing the same direction, but instead of them sitting in a line, they would sit next to each other. This orientation would be similar to the tandem bike style where both drivers would be on the same drivetrain system. This design also has a much higher storage capacity which is required by NASA. The center of gravity on this vehicle design is set much further back than the other considered designs which makes this more unstable when traversing difficult obstacles. A side by side seating system can be seen in Figure 17.

Figure 16: Side-by-Side Seating

4.5 Frame

In this section the selected frame design, material, and tubing will be explained. The designs were created to meet the following engineering and customer requirements:

1. The center of gravity is greater than 30 inches above the ground.
2. The design must be suitable for one cubic foot of storage
3. The width of the vehicle can be no greater than five feet wide.
4. The vehicle must collapsible to fit into a 5ft. by 5ft. by 5ft. box before the competition.
5. It must be able to seat two drivers, one of each gender.
6. The finished design, without drivers, weighs less than 100 pounds and able to be carried by the drivers.
7. The vehicle must be able to be taken apart in order to lower shipping costs.

4.5.1 Geometry

The frame geometry had many variations of in appearance and application. Weight, cost, and simplicity weighed heavily when designing each of the following frames.

4.5.1.1 Compact Car

The first frame design considered was the car which can be seen below in Figure 18.

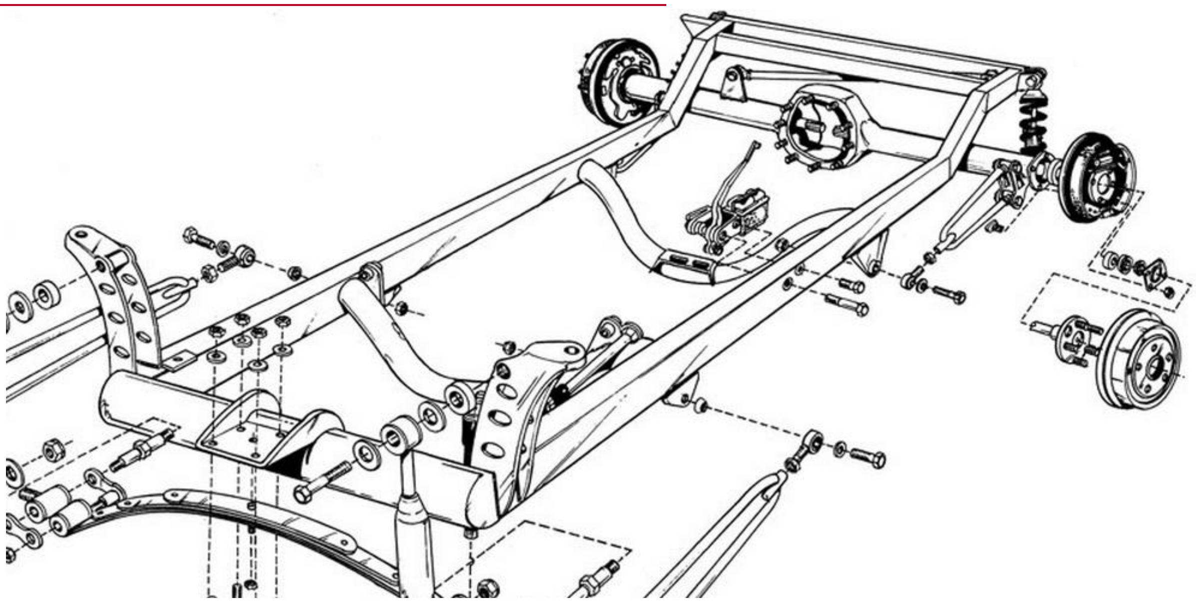

Figure 17: The basic frame of a T-Bucket to show the concept of car frames using c-rail and box steel members

The frame is made into a rectangular shape using both c-rails and box shape members. Typical frames allow for maximum top loads and adjustability. The diversity in the frame would allow for seating, steering, and other key systems to be easily attached. The disadvantage with this design is the fabrication and material costs. This frame would need to be a custom build and is difficult to establish since any errors in fabrication would likely result in a rebuild of the entire frame which is costly and timely. Weight is another concern as the drivers are required to carry the vehicle. This heavy design is typical due to car frames needing to accommodate for long life expectancies.

4.5.1.2 *Go Kart*

The go kart design is made of tube members and is designed to allow for a large storage space inside the vehicle. This design is a hybrid between the following frames and the previous car designs. The go-kart frame can be seen below in Figure 19.

Figure 18: The go-kart frame that utilizes a wide spacing to allow for storage and low ride

This design uses a wide base to allow for the engineering team to build storage around the drivers as well as keep the drivers inside the vehicle (as opposed to on top of the frame). The simply design allows for ease of fabrication. The frame also allows for a low center of gravity which is contrary to one of the engineering requirements. The greatest disadvantage to this design is the inability for the vehicle to collapse.

4.5.1.3 Trapezoidal Tube Design

The next movement of design was to go for a narrow build to accommodate for the five feet width requirement. This lead the team to design a long, two piece system frame with a trapezoidal cross section. This shape and design can be seen below in Figure 20.

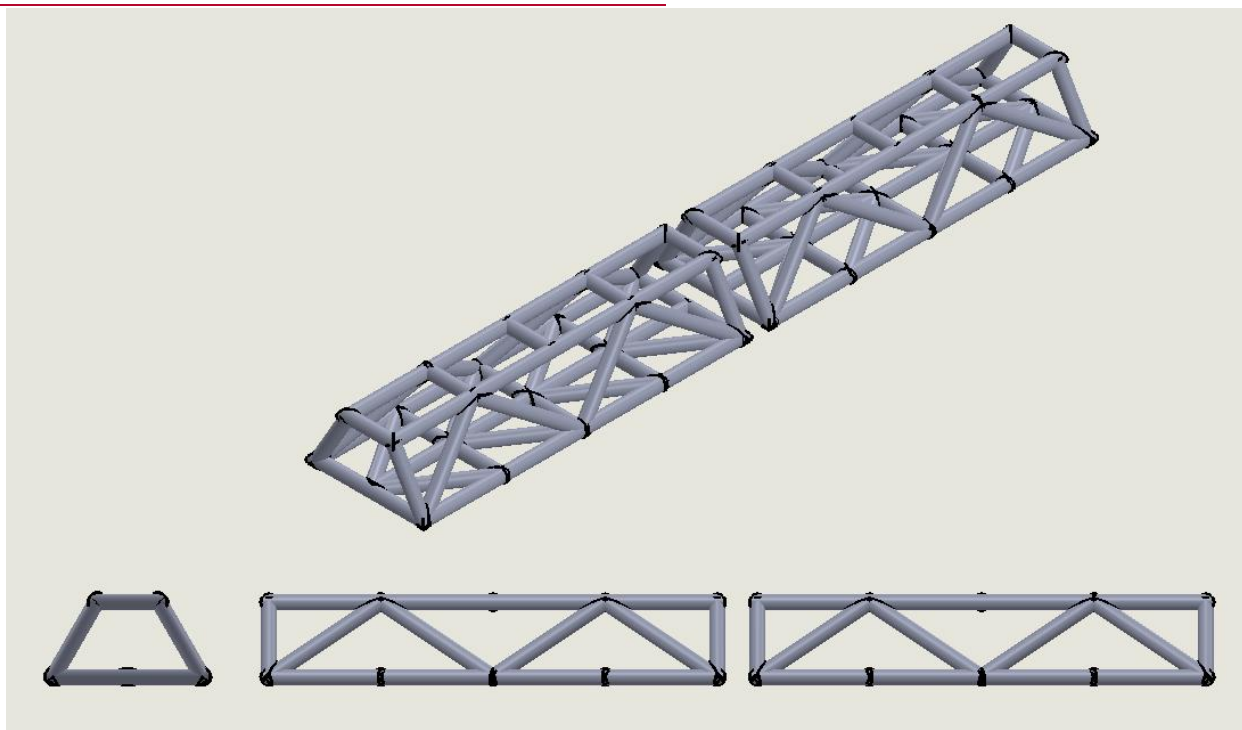

Figure 19: Two piece trapezoidal frame with the front, side, and isometric view

The trapezoid geometry of the frame allows for high loads in all directions. The two piece system allows for the frame to collapse in the middle into half of the original length. The narrow design and tube frame allows for ease to carry. The flat top allows for simple attachment of seating. The hollow inner section would be used for the gearing and chains as well as over two cubic feet of storage. The disadvantage comes from the weight. This design requires a high amount of tubing in comparison with the triangular frame that will be explained next.

4.5.1.4 Triangular Tube Design

The triangular tube design is a close comparison with the trapezoidal design. The difference between the two is the cross sectional shape being triangular. This design can be seen below in Figure 21.

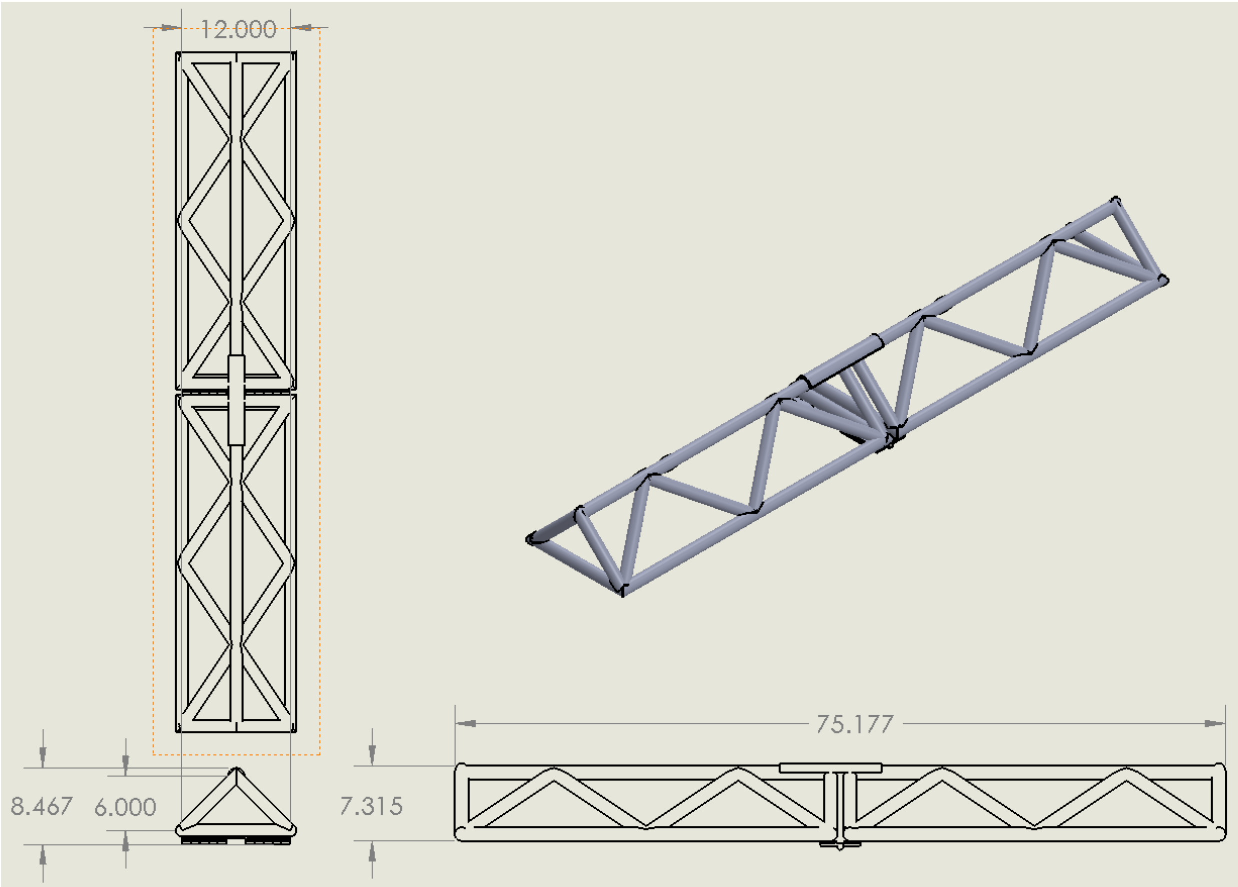

Figure 20: Two piece triangular frame with the front, side, and isometric view

The triangular design allows for a high strength. The structure of this design allows for a decrease in required tubing with a slightly less storage volume. The seat attachment is increasingly difficult initially, but suspension and axel attachment is simplified. The collapsibility is increase in this design by relieving the system of weight when transporting in the collapsed stage. The fabrication of this design is cost effective and easily modified.

4.5.2 Tubing Shape

The tubing of the frame is being evaluated due to the requirement that this project is fabricated by the Northern Arizona University team. The focal points of each tubing design are the ability of fabrication, strength, and weight. The three considered designs are square, hexagonal, and circular tubing. The three designs with dimensions can be seen below in Figure 22.

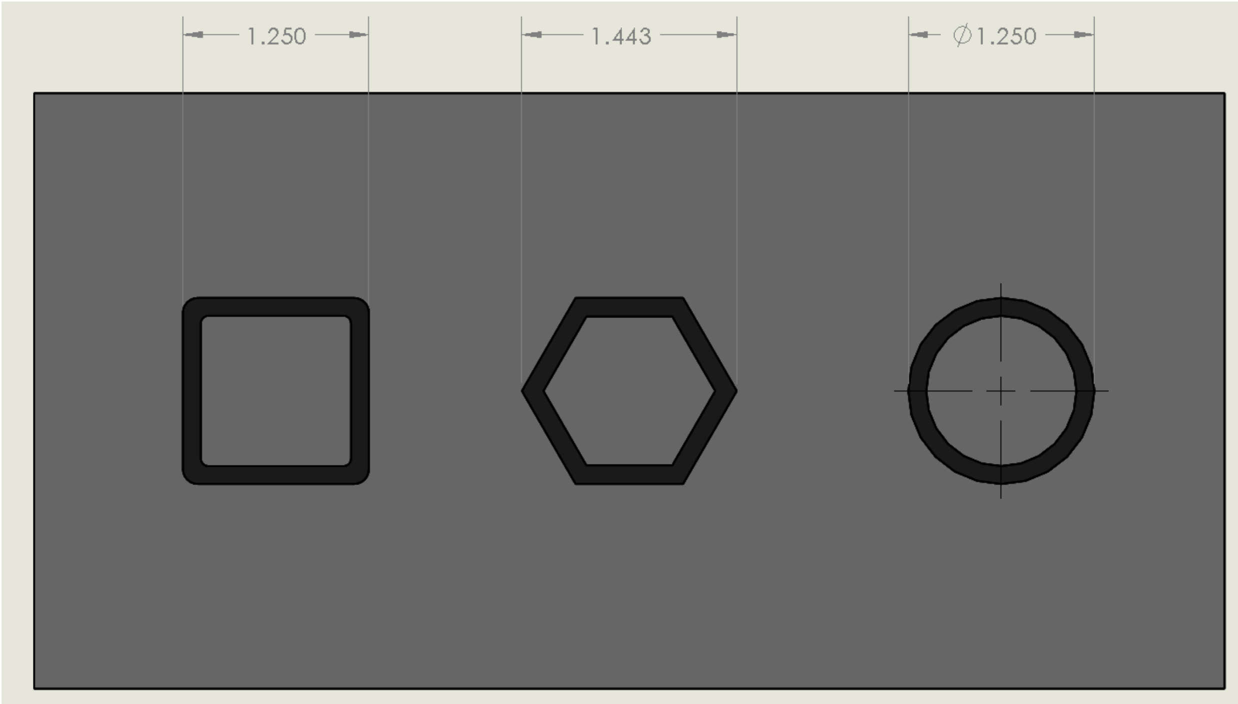

Figure 21: All three tubing designs considered for the frame.

All three tube cross sections have a 0.120" wall thickness. The cross sectional area for all three tubes are: 0.536" for the square, 0.487" for the hexagon, and 0.426" for the circular. The shape with the smallest cross sectional area will have the least amount of material, resulting in a lighter frame. The fabrication of a square or hexagon frame is difficult in comparison with the circular. Circular frames require one saw bit to remove material allows for error while the other two shapes require a band saw with multiple measurements and cuts. In a project with over 100 cuts possible, the time would increase would be in the tens of hours.

4.5.2.1 Material

The materials selected to be evaluated for the frame are 6061 aluminum, 1030 steel and chromoly. 6061 aluminum is the lightest material selected and is standard for many modern bicycle, aero, and vehicle frames. Aluminum is a difficult material to weld onto and requires a specific weld and set up in order to create strong welds.

1030 steel is the heaviest material selected, and comes at the highest cost from online suppliers. 1030 steel is not the most readily available tubing and comes in most circular dimensions, but not others. This steel offers the highest strength. 1030 is also easy to fabricate since almost all welders work with this steel on a regular basis and provide solid welds.

Chromoly offers a middle ground between the aluminum and 1030 steel with the cost. The strength is less than that of the 1030 steel and higher than the aluminum. The cost of this material is also the middle ground. The ability to weld with chromoly is almost the same as the 1030 steel.

The comparison of strength, density and cost can be seen below in Table 1.

Table 1- material properties of 6061 aluminum, 1030 steel, and chromoly [7].

Material	Density ($10^3 \frac{kg}{m^3}$)	Yield Strength (MPa)	Cost per foot

6061 Aluminum	2.70	270	11.09
1030 Steel	7.86	800	15.20
Chromoly	7.85	435	12.46

4.6 Steering

This section discusses the three steering subsystem designs considered. Each steering mechanisms will be presented with its pros and cons, in relation to the other considered designs. The three designs are bicycle steering, rack and pinion, and under seat steering. All designs considered were for steering and seating configurations that met the customer requirements. The customer requirements for steering, is that the rover must have a 15' or less turning radius. The customer requirements for seating are that the passengers are secured in their seat, and they do not touch any surfaces that are 15" or less from the ground. At the end of the section, the team's final design will be discussed.

4.6.1 Bicycle Steering

Bicycle type steering uses a handlebar design, historically used in consumer bicycles. This design is simple, easily implemented, and a comfortable choice for nearly all possible drivers of the rover. However, this design does not allow for a high turning ratio, or for the driver to plant themselves in their seat in order to have maximum leverage while delivering power to the drivetrain. This design also has the highest turning resistance due to the direct input of driver to turning the wheels, without any mechanical aids. An example of bicycle steering can be seen in Figure 26.

4.6.2 Rack and Pinion

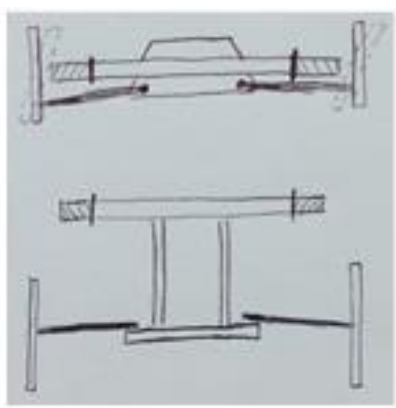

Figure 22: Bicycle Steering

Rack and pinion steering uses a pinion gear mounted to a straight input shaft, to drive a rack gear. Input from the driver rotates the pinion gear and causes linear motion to the rack which is connected to tie-rods to turn the wheels. This design has the highest turning ratio of all the designs considered. This design also has the lowest turning resistance because the use of gears reduces the power input needed to get the same result. However, this design constrains the geometry of our vehicle due to the need of a straight steering shaft, or a series of input shafts. With the geometry constrained, the driver would need a steering wheel type input mechanism, which like the bicycle steering system, does not allow the driver to put all of their energy into the drivetrain. A rack and pinion example can be seen in Figure 27.

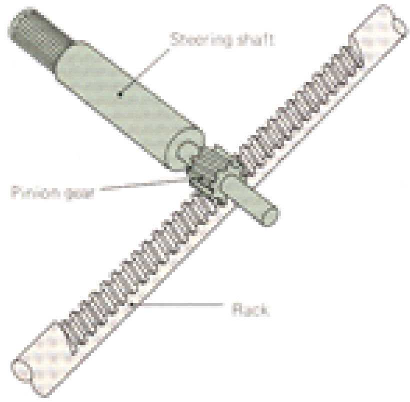

Figure 23: Rack and Pinion

4.6.3 Under Seat

Under seat steering utilizes a set of levers at the sides of the driver that are positioned such that the driver can use them to hold them in their seat while pedaling over difficult terrain. This design articulates the wheels through input links that run parallel to the frame, and depending on if the levers are pulled or pushed, the links pull on, or push out on the spindle just behind where the wheel is mounted. This design has more turning resistance than the rack and pinion design, but less than the bicycle steering. This design also has a lesser turning ratio than rack and pinion, but larger than the bicycle steering design. Because this design was a compromise between the comfortable bicycle steering, and the efficient rack and pinion steering, it was chosen as the final design for the rover. An example of under seat steering can be seen in Figure 28.

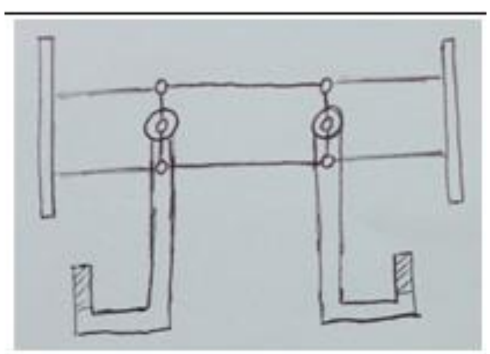

Figure 24: Under seat Steering

5 Design Selected

5.1 Design Chosen: Disc Brakes

The brake design chosen for the final system is the disc brakes as it scored highest in the weighted Pugh Chart. This design addresses most the customer requirement of having a human propelled rover. Power to move the rover must be counteracted by a safe braking system to allow the driver to have full control of the mechanical system. Furthermore, the disc brake design scores high in the braking distance, maintenance, and longevity factors of the weighted Pugh chart. A short braking distance is synonymous with the stopping power discussed in the previous brakes subsystem section, and is why the disc brakes score high in this category. High longevity and maintenance scores correspond to the long expected design life and low maintenance expectancy over that life, that are desirable for a rover being sent into space where performing maintenance is difficult.

5.2 Design Chosen: Clamped Tread Wheels

After considering multiple designs and narrowing the choices down to these three, the final design selected was Clamped Tread wheels. Clamped tread wheels are readily available, have great traction with their solid rubber, are not inflated, and can have a minimum diameter of 20" easily. With a clamped in tread, it is highly unlikely that the tread would come off or tear during competition unlike a tread over or tread in design. With enough power from the drive train, they could also navigate obstacles easily. An example of a clamped tread wheel can be seen in Figure 25.

Figure 25: Clamped Tread Wheel

5.3 Design Chosen: Coil over

Coil overs were chosen as the final design. When graded with each criterion, the coil over suspension design scored the highest overall. The most successful criterion of the coil over is the flexion it allows in the vehicle, the amount of travel that is capable with different designed coil overs, and increased ride quality they create. These were not the only criterion they excelled in, they are great for absorbing the force on the vehicle and reducing the amount of transferred force, they damping is completely controllable for different types of terrain, and have only a few components. Even though the costs of the coil overs are the most expensive of all the possible designs, they are easily obtainable, low weight, and have a wide variety of sizes. For our design, as long as our budget allows, coil overs are the best available choice.

5.4 Design Chosen: Back-to-Back

Overall, the design with the drivers seated back to back was the best option. This design was best suited to traverse the many different types of obstacles that will be tested on the course. With the central center of gravity, the stability is increased making it much easier to traverse slopes as well as rocky terrains fairly easily. Having each driver in control of a different axel will allow for a lot more power to be given to the rover overall making it easier to cross other obstacles such as the sand pit. This design is also relatively simple to build as it is symmetric. Once one side of the rover is built, the other should be relatively the same. This also allows for the rover to be broken down or folded in half much easier. This design is also malleable to be able to meet other requirements such as storage capacity. Although one driver will not be able to see the course, the team decided that this design had more positive aspects that outweighed the negative.

5.5 Design Chosen: Triangular Frame with circular tubing made of 1030 Steel

5.5.1 Geometry

The geometric shape chosen for the final design is the triangular shape. The frames were all compared using the engineering and customer requirement in Section 3 of the report. In addition to the requirements, the team chose additional design considerations and compared each frame in a weighted Pugh chart. The additional design considerations are:

a. Versatility / Adaptability – the ability of the frame to be altered or added upon
b. Amount of Tubing Required – the physical footage of tubing required for the final design
c. Approximate Width – how wide the final frame is from left to right
d. Approximate Length – how long the final frame is in driving position (non-collapsed)
e. Maintenance – the amount of foretold work needed to keep the vehicle working
f. Fabrication Difficulty – the level of skill and time required to build the frame
g. Maximum Load Capacity – the maximum amount of weight that can be applied to the frame without damage or failure occurring
h. The Flexion – the ability of the frame to deform without damage or failure to the system

The triangular frame is easily adaptable due to the tube framing and geometry of the vehicle. It was not better than the trapezoidal shape, but the next best option. Axles, chains, and suspension can be built either outside or inside the hollow center space of the frame without interference of the drivers and cargo.

The amount of tubing for the triangular frame was the least. The triangular frame required 51.2% of the amount of tubing needed for the trapezoidal frame. The reduction in tubing is a direct relationship to the weight. In other words, the triangular frame would weigh approximately half the weight of the trapezoidal frame.

The approximate width of the frame would allow for a width much less than the 5ft. requirement. The length would be anywhere between 6ft. and 8 ft. long. This length would allow for a small turning radius and agility needed for obstacles.

Maintenance of the vehicle would be minimal and simple. The reduction in tubing needed allows for quick repairs throughout the system without high amounts of restriction. Fabrication difficulty is low due to the geometry of the frame. No angle would restrict a welder or circular cutter from getting inside the frame.

Due to the triangular shape, the load capacity is maximized in all axial directions. Twisting would be restricted, consequently, removing stress on axles and directing the load toward the suspension. The flexion in the system is small. This lack of give in the system forces the suspension to take most of the impact in abrupt points of acceleration.

The final design factor when creating the frame is the collapsibility. If the vehicle cannot fit inside the 125 cubic foot box then the team will be immediately disqualified. Both the extended and collapsed pictures can be seen below in Figure 27 and Figure 28.

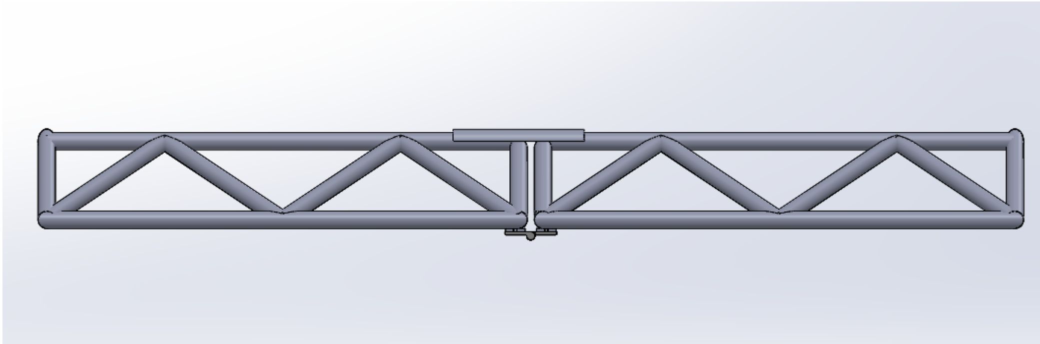

Figure 26: The triangular frame is extended in the driving position.

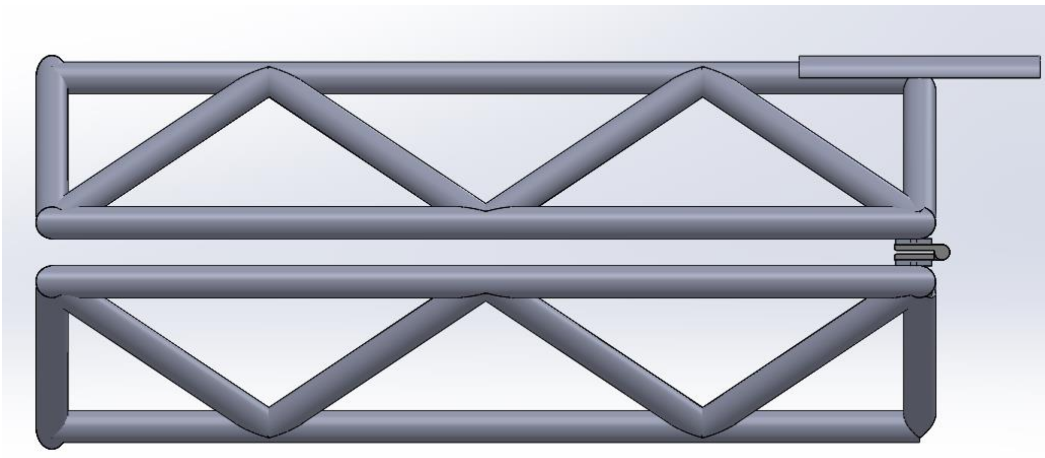

Figure 27: The triangular frame is collapsed in the closed position.

The brace location and pivot hinges alloy for the length to be cut in half and detached if desired. This fits the shipping and storage requirements established above.

5.5.2 Tubing Shape

The tubing shape selected is the circular cross section. The circular cross section is the least difficult to fabricate due to need for one drill bit and a high amount of error allowable. Both the hexagonal and square shapes would require a many measurements and cuts for one weld. The tolerance of the tube being cut at an improper angle is small due to the colliding geometries. The circular tubing is the cheapest and most attainable tubing.

5.5.3 Material

The material selected was the 1030 steel. The main reason for this is the cost. The SAE machine shop has this available for free. The decrease in strength between this and the chromoly will most likely be unnoticeable in competition. The 6061 aluminum was chosen to not be used due to the difficulty in welding and the decrease in strength.

5.6 Design Chosen: Under Seat Steering

The Pugh chart resulted with the under seat steering design being the highest scored. This was favorable with the team because the design allows for the drivers to deliver more power to the drivetrain by using the steering levers to plant themselves firmly into their seats.

Upon finalizing the CR's and ER's for the Human Powered Exploration Rover (Chapter 2 above), the three main steering designs from Chapter 4, were put into a weighted Pugh chart. The criteria below denoted with their weightings, were used to evaluate the designs.

a) Turning Resistance (15)
b) Turning Ratio (20)
c) Fabrication Difficulty (25)
d) Adjustability (10)
e) Number of Parts (10)
f) Durability (20)

The under seat steering design uses levers that the driver uses to control the vehicle. The levers are connected to a primary link that runs underneath and parallel to the frame. The primary link connects to a junction that is central to the vehicles width, from the junction, secondary links/tie-rods that connect to the spindle at the end of each drive shaft. The connection from secondary link to spindle will be located behind the axis of the drive shaft to ensure enough torque will be produced to overcome the frictional turning resistance in the system, and between the wheels and the ground. Pulling one lever and pushing the other lever will cause the wheels to articulate in one direction, while doing the opposite will action with the levers will articulate the wheels in the opposite direction.

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