EML4551-2

Team 509: FSGC-NASA Human Powered Vehicle

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Abstract

During the Apollo 14 Lunar mission, astronauts ran into trouble while trying to explore on foot. Low on oxygen and energy, they had to abort their tasks and return to the lander. This incident led to the creation of the NASA Human Powered Rover Competition. This annual competition allows students to design and build their own human powered rovers. The rovers must be able to hold two people and traverse difficult terrain, similar to that of the moon. Points are awarded for rover weight, finish time, and completed tasks.

Our team is designing a small rover to help solve the astronauts' problem. The rover is being built according to earth conditions since the competition is not actually on the moon. We have taken a systems engineering approach to design and implement five subsystems for the rover. The primary rover systems include a rear drivetrain, dual tiller steering, a steel frame with front suspension, foam wheels, and tools with a rear-end storage compartment. Two riders sitting side-by-side will pedal the rover like a bicycle. The seats are reclined to provide comfort as well as a low center of gravity. Our design includes a 2.0 factor of safety to ensure the rover's robustness and reliability.

The rover has a top speed 4 miles per hour with the riders and tools loaded in. The rover is able to traverse inclines up to 28° due to the high torque powertrain. The rover also has a tipping angle of 40° and a stopping distance of 8-feet. The suspension design uses two wishbones of equal length to ensure constant stability. Wheels made of a solid lightweight foam avoids the need for pneumatic wheels. Overall, the rover is capable of easily conquering rough terrain and will be a crucial tool for the astronauts' next trip to the moon.

Disclaimer

Acknowledgement

~~These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4~~

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We thank the NASA Florida Space Grant Consortium for providing the funds to the project, for which without would not have been possible. Their gracious funding allowed the team to order all necessary parts and provide all necessary materials for the rover.

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Special thanks to Dr. Shayne McConomy for having provided mentorship and advice to the team throughout the past two semesters. His great input provided ideas and help to the team in coming up with concepts and ways to assemble the rover. In addition to his idea input, he provided some manufacturing for the rover assembly which allowed the team to progress in the creation of the rover wheels. His expertise and mentoring was critical in the success of the project and the team greatly appreciates his time and effort spent assisting the team.

Additionally, we thank Neil Coker, Jonathan Cloos for their prompt responses when submitting purchase orders and their feedback when parts had arrived.

Special thanks to the FAMU-FSU NSBE Jr. chapter for their participation and help in the community outreach event coordination. They were very friendly and welcoming to our

approach in reaching out to the community to foster interest in the STEM field for younger audiences.

Special thanks to Justin Pogge and Jeremy Philips for their help in machining parts and providing input when coming to machine the parts for the rover. Justin's input on the parts to be machined allowed for revisions which strengthened the design of parts, made the assembly easier and overall allowed for the implementation of our designed systems onto the rover. The machine shop was also gracious enough to provide steel and aluminum stock for the project which aided in the manufacturing of our components.

Finally, we would like to thank Jessica Meeker of the previous year's human powered vehicle team as she provided input for the competition, rover design and even forwarded the CAD model files for the frame that we utilized. Her input was a great heads up into what to tackle and prioritize during the competition and project.

- ~~Paragraph 3 thank those that provided you materials and resources.~~
- ~~Paragraph 4 thank anyone else who helped you.~~

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Notation

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

	Difference between the calculated and measured
Difference	BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

NASA hosts an annual competition for students to design a vehicle that is operated solely on the power generated by its user(s). The objective of the project is to design and manufacture a human powered vehicle to traverse exoplanetary terrain in a NASA hosted competition. The vehicle will be designed to safely traverse and tolerate the concentrated forces of asteroid debris, boulders, erosion ruts, and crevices. In competition, the vehicle will be operated by one male and one female participant. The competition awards points for weight classes, time of finish, and completed mini missions. This encourages rover designs to be made lightweight, efficient, and easy to operate.

Key Goals

The key goal of the project is to deliver a fully functioning human powered vehicle for two riders that can participate in all the available events at the NASA competition. The rover should be capable of traversing challenging exoplanetary terrain. The goal of the competition is to be entered into as many of the challenges as possible and gain the maximum amount of points.

Markets

Primary Markets

The primary market for this product would be the NASA Human Exploration Rover Challenge competition as they proceed to find optimal designs for human-powered vehicles for possible future moon landing exploration.

Secondary Markets

One of the secondary markets would be endurance competitions and races in which similar human-powered vehicles are used by teams to compete with one another. Space-faring organizations and companies would also be part of the possible secondary markets as they may be in search for human-powered vehicles for their own exploration missions. The human powered vehicle could also be used as an alternative mode of transportation for areas that do not allow motorized personal off-road vehicles as it will be built to handle rough terrains and obstacles. The dual-rider design could be used for outdoor recreational activities and leisure use. The human-powered vehicle could also appeal to cyclists and other exercise enthusiasts.

Assumptions

The project budget is limited and is only for to be used for the entirety of the parts, manufacturing and travel costs associated. All the CAD, modeling, and simulation software needed to complete the project will be provided by the FAMU-FSU College of Engineering. Access to the on-site engineering machine shop will be available to the team for the manufacturing process of the selected design. Though the vehicle will be designed to traverse in exoplanetary conditions, all testing and calculations will be done using Earth conditions as that is where the vehicle will primarily be used.

Stakeholders

Advisor/Sponsor: Dr. Shayne McConomy

Dr. McConomy is our Senior Design professor assigned the project to the team and is our sponsor and advisor for the project. He has stake in the competition as he is providing resources, funding and personal time towards the progress of the project.

FAMU-FSU College of Engineering Dean of Engineering

Project funding for the competition will be approved and provided by the Dean of Engineering, Murray J. Gibson. He will have a vested stake in allowing the team to use funding for the project and represent the college and its reputation in the competition.

FAMU-FSU College of Engineering

Team 509 is representing the FAMU-FSU College of Engineering for the competition. The performance and presence of Team 509 reflects the college and there is a possibility that additional funding will be requested from the college.

National Aeronautics Space Administration (NASA)

The purpose of the competition is to foster an authentic engineering experience to the participants and prepare them for future engineering endeavors while innovating along the way.

NASA has a stake in the performance the team as they want to see working designs that can accomplish the assigned tasks. They are investing resources into the creation of the courses, the event and the overall competition in order advance the knowledge of young engineers.

1.2 Customer Needs

Explanation of Results

The customer statements were gathered through two methods. The first method was reviewing the competition guidelines, which provided quantitative restrictions and goals. The second method was a question-and-answer survey. The questions were designed to be concise and specific to move forward with the project. Questions were answered by the project advisor/sponsor, Dr. Shayne McConomy. The main takeaway from the competition guidelines is to create a human powered rover that can handle harsh terrain. As the design is meant for a competition, additional standard specifications and criteria that has to be met was specified by the guidebook provided by NASA. Additional requirements made by Dr. Shayne McConomy can be translated into completing the rover well before competition as well as maximizing points in the competition.

Customer Need Analysis and Interpreted Needs

After reviewing the competition guidelines and interviewing Dr. McConomy, a synthesis was performed on the gathered information. This information was then translated into tangible customer needs for the project.

Shayne McConomy

After reviewing the competition guidelines and a potential competition strategy, Dr. McConomy outlined additional project requirements for the team. Those requirements were synthesized into the following condensed interpreted needs. Dr. McConomy indicated that the final product will be operational in the competition. A systems integration approach will be taken for the CAD development of the components to ensure seamless integration. Previously neglected components such as steering, and powertrain will be further developed from past iterations. The team will also follow all regulatory guidelines of the competition and the baseline specifications. Tolerances for the design will be kept in mind to allow for additional wiggle room to allow for error in manufacturing process.

Competition Guidelines

Most of the customer needs for this project are derived from the competition guidelines provided by NASA. These specifications are required to be met by every team in order to participate in the competition. Rather than creating a customer needs and questions table, a table of interpreted needs derived from the guidelines was created to further the development of the project.

Table 1: Interpreted Customer Needs from Competition Guidebook

Vehicle will collapse into a volume less than or equal to the specified guidelines.
Track width of the vehicle will fit onto the competition course.
Vehicle will be able to traverse varying and uneven terrain
Per safety guidelines, sharp edges in the design will be eliminated or guarded
Vehicle will be capable of traversing hills and inclined pathways
Vehicle will have a small turning radius within competition guidelines
Vehicle wheels will be designed and fabricated by the team

Vehicle wheels will be non-pneumatic
Vehicle will be completely human powered

**Tabulated form of customer needs and interpretations can be found in Appendix B*

1.3 Functional Decomposition

Introduction

Through the project scope it was identified that we will be designing a human powered rover that will traverse rough and uneven terrain. The key goal of producing an operational human-powered vehicle further broken down by customer needs. The customer needs highlighted that sub-systems like the powertrain and steering needed to be fully developed. Moving on, the functions and sub-functions of all of the vehicle's sub-systems were then identified through a functional decomposition. This process performed to breakdown the design's main functions, or systems into smaller, more specific functions. We decided to first breakdown the main functions using a hierarchy chart. This was chosen over a flow chart as it is synonymous with a systems engineering approach. A cross reference table was then created to evaluate the first and second level functions and see where they overlap.

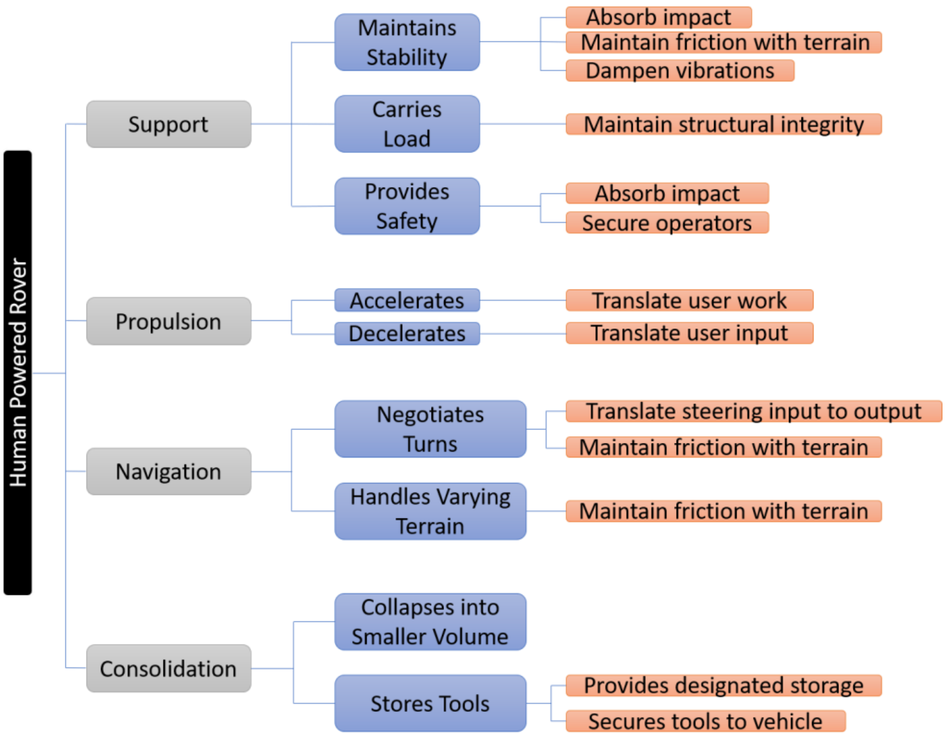

Figure 1: Hierarchical Chart

Explanation of Results

After evaluating the key goals and customer needs, the primary functions, or systems, for the project were determined to be support, propulsion, navigation, and consolidation. We have identified further subsystems, sub-subsystems, and functions within each primary system. This provides us with more specific functions to focus on, which will ultimately contribute to fulfilling the primary functions. A hierarchical chart was used to show the highest-level systems and the connected subsystems that would accomplish the functions. Once the primary functions were broken down into the smallest components, they were then reviewed in a cross-reference table to evaluate the importance and shared utility. Using the cross-reference table, it became evident that some of the systems and subsystems shared functions.

Table 2: Cross Reference Table

Cross Reference Table	Support	Propulsion	Navigation	Consolidation
Maintains Stability	X			
Carries Load	X			X
Provides Safety	X			
Accelerates		X		
Decelerates		X		
Negotiates Turns	X		X	
Handles Varying Terrain	X		X	
Collapses into Smaller Volume				X
Stores Tools	X			X

Connection to Systems

The four main functions of the system are support, propulsion, navigation, and consolidation. Analysis of the cross-reference table highlights that support is the most important major function. The table shows that support has six sub-functions that fall within it, meaning it is the most important system to focus on. The vehicle's support is the centerpiece of the design which explains why it has the most functions fall within it. After support is consolidation, followed by propulsion and navigation. Implementing consolidation into the rover includes carrying the load without failure, collapsing into a smaller volume, and tool storage. While these sub-functions are not considered essential for the completion of the rover, they are scored for points in the competition. Propulsion and navigation each have two straightforward, important sub-functions. Development of the propulsion subfunctions (acceleration and deceleration) are an absolute necessity for the system. Negotiating turns and handling harsh terrain are the two sub-functions under navigation and will be carried out by a steering system and non-pneumatic wheels.

Smart Integration

A cross reference table provides a way to link functions of a system that are relatable among several subsystems. The table is used to dictate the shared functions the systems use. Implementing the cross-reference table can identify the functions and systems that are most significant. The functions containing the most checked boxes are the most important. The cross-reference table for our focus areas of designing a human powered vehicle shows carries load, negotiates turns, handles varying terrain, and stores tools as the most repeated functions. These functions are related to support, consolidation, and navigation to design a vehicle that can enable turns and can handle various terrains while still providing support. The cross-reference table also displays most functions falling under support.

Action and Outcome

The support system will be made from a material with high elastic strength and low density to carry out the sub-functions such as absorbing impact and maintaining structural integrity. This will result in the operators and terrain being tolerated, despite the imposed high stress due to weight and concentrated forces, respectively. A high-functioning and reliable powertrain and steering system are vital for the time in which the rover finishes each “mission”. The powertrain will take advantage of gear ratios and make efficient use of the kinetic energy produced by the operator. Wheels with lower friction coefficients are more desirable to make turning easier for the operator. Storage compartments will be incorporated within the frame to minimize overall volume of the rover.

1.4 Target Summary

Introduction

The functions identified in the functional decomposition have now been tabulated with a corresponding target and metric. Competitive benchmarking, engineering intuition, and the competition guidelines were utilized for creating these targets and metrics. For competitive benchmarking, companies that produce tandem bicycles or go-carts were researched, as the function and performance of these “vehicles” are like the human-powered rover. The engineering intuition we applied is the implementation of our technical knowledge and opinion(s). The competition guidelines provided straightforward quantitative targets. The full list of targets and metrics were tabulated and stored in Appendix C of this document.

Establishment of Targets/Metrics (Derivation of Targets and Metrics)

The metrics for providing designated storage as well as securing tools to vehicle are *currently* number of tools and number of samples. The number of tools and samples are reasonable metrics because the size of the tools are not established as they are still being developed. The competition requires each team to perform certain tasks with tools created by the team. Since our team is in the process of fabricating the tools, it would be premature to establish a metric such as volume or surface area for this function. Collapsing into a smaller volume with length, width, and height dimensions all less than 5 feet is a requirement of the NASA human-powered rover competition. The competition has this requirement in place to mimic their goal of maximizing space in the landing bay by minimizing the space the rover takes up.

The steering ratio and maximum steering angle were then determined as a rack and pinion steering system was going to be re-used from the previous competition team. The steering ratio of the system was determined to be a 1:1 according to the manufacturing website and reviews (Maxpeedingrods). The fixed steering ratio was then paired with a maximum turning angle of 20 degrees for the wheels in order to meet the maximum turning radius parameter given by the competition. Using the turning radius limit of 15 feet is a requirement of the competition due to the challenging courses and the size of the track. The turning radius was then determined to be approximately 13.75 feet with the following equation:

$$Tan(Turning\ Angle) = \frac{Wheelbase}{Turning\ Radius}$$

This formula shows the relationship between turning angle, wheelbase, and turning radius (Menon, 2017).

Translating the user work was determined to have two targets and metrics, that of the powertrain gear ratio, and the combined average torque supplied by the riders. Since the powertrain was still in the development phase, the exact gear ratio had not been chosen but was given in the ranges of 16-24 pinion gear teeth, and 32-42 cassette gear teeth. This range of gear ratios was determined by researching bicycle hill climbing for endurance competitions (Ellington, 1995). This would allow for the team to decide the kind of torque vs speed tradeoff needed for the competition. The torque provided by the average rider was then researched and found to be approximately 50 Nm of torque per rider on a casual ride (Gardner, Martin, Martin, Barras, & Jenkins, 2007) . Since the human powered vehicle will have two riders, the target of 100 Nm base input torque was determined for the vehicle (Bike Forums, 2006). This will then be translated to further lower end torque with the gearing ratio for the powertrain anywhere between 1.333, to 2.625 times the base torque. This is needed as most of the competition events will have some sort of hill or climb for the rover to overcome.

For maintaining friction with the terrain, the tire friction coefficient and rolling resistance coefficient were determined by researching mountain bike tires (Xbits, 2020). This is because the terrain that the rover will have to traverse is most comparable to that of a mountain bike trail. The higher the friction coefficient, the more grip that the wheels can have with the terrain, this can also however make it harder to move, which is why the rolling resistance coefficient is lower. This could then be used to determine the amount of torque that can be applied under a no slip condition with the riders and vehicle weight.

For absorbing impact, compression of the suspension will be made to compress no more than 7 inches. This is considering another target dimension: 12 inches of ground clearance. A minimum of 12 inches of ground clearance for a static rover is a requirement of the competition. While the riders are traversing the terrain and the suspension is being compressed, there needs to be room between the rover and the ground. A maximum suspension compression of 7 inches leaves 5 inches of ground clearance, which should be plenty of room to pass over small debris.

Dampening vibrations and securing operators are targets that are established through rider approval. Quantifying the exact number of vibrations dampened and the operator's security is not an efficient use of time. Adjustments will be made for that function until 100% rider approval is met. Meaning, both riders must be completely satisfied with the number of vibrations they feel as well as how secure they feel.

A factor of safety of 2.0 is being implemented to maintain structural integrity. Typically, a factor of safety of 3.0 is used for automobiles; however, a higher factor of safety comes with higher costs and/or higher weight (Mint, 2019). A factor of safety of 2.0 was decided on given the limited budget and weight requirements for the competition.

Track width and wheelbase targets of being less than 5 feet are tied back to the volumetric requirements that were previously stated. These targets are made with the assumption that the wheels are detached.

Critical Targets and Metrics

After reviewing the targets and metrics derived from the functional decomposition, some were noted to be critical for operation and competing in the NASA Human Exploration Rover Challenge. These targets and metrics play a major role in designing the vehicle and completing obstacle courses of the challenge. These targets and metrics will be used in the concept generation and selection portion of our project. Below is the table displaying the critical targets and metrics.

Table 3 Critical Targets and Metrics Table

Function	Target	Metric
Collapses into Smaller Volume	5 ft, 5 ft, 5 ft 125 ft^3	Length, Width, Height Volume
Ground Clearance (with riders onboard)	12 in 30-degree departure/approach/ breakover angles	Height Degrees
Secure Operators	100% Rider Approval	Rider Approval
Translate Steering Input to Output	1:1 20 degrees	Steering Gear Ratio Max Turning Angle
Maintain Friction with Terrain	FC $\geq$ 0.75 (RRC) $\leq$ 0.005	Friction Coefficient (FC) Rolling Resistance Coefficient (RRC)
Track Width	$\leq$ 5 ft	Length
Wheelbase	$\leq$ 5 ft	Length
Translate User Work	100 N-m (Gear Ratio Range) Pinion 14-24 teeth Cassette 32-44 teeth	Torque Gear Ratio
Turning Radius	$\leq$ 15 ft	Radius Length
Translate User Input	Stopping Distance $\leq$ 2.5 m (10 mph to stop)	Distance

Method of Validation

Different methods involving various tools will be used in order to measure and validate the established metrics. A tape measure will be used to measure multiple metrics including length, width, and height, ground clearance, track width, and wheelbase. For ground clearance, the approach, departure, and breakover angles will be determined by measuring the angles between the front tire and the frontmost point of the frame, between the rear tire and the rearmost point on the frame, and between the tires and the longitudinal center of the frame respectively. Securing operators will be validated through an open discussion between the operators where they will decide if they feel properly secured to the vehicle. Comparing the gear teeth between the pinion and the cassette will yield a gear ratio to validate the translation of user work.

For translating steering input to output, the steering ratio has been determined from the manufacturer as we already have the rack and pinion steering leftover from the previous team. The second metric for this function, maximum turning angle, will be found by turning the steering wheel to its furthest position (clockwise or counterclockwise) where the angle between the heading of the straight wheel and the heading of the turned wheel will be measured using a protractor. The turning radius can then be determined from the maximum steering angle and the wheelbase using the equation mentioned above.

For maintaining friction with the terrain, the friction coefficient will be found by locking the wheel, so it is unable to rotate then applying a measured normal and horizontal force. The horizontal force will be increased until it slips. The friction coefficient is then found by dividing the normal force by the horizontal force. The rolling resistance coefficient is found in a similar way however the wheel can rotate. The horizontal force is then increased until the wheel begins to roll. The rolling resistance coefficient is equal to that horizontal force divided by the normal force.

1.5 Concept Generation

Concept Generation Methods

After determining the critical targets and metrics that need to be met to compete in the NASA Human Exploration Rover Challenge, concepts to meet the targets and metrics were then generated using a variety of methods. The primary method for the generation of concepts was the morphological chart as this method combines many useful ideas into single concepts. Using the chart, a mix and match of components could be generated by combining horizontal components from the provided vertical columns. The other primary form of concept generation was using the brainstorming method to allow the team members to openly discuss and generate possible options for concepts for the design or components of the rover. A third form of concept generation was the “crapshoot” method which involved using wild, or unconventional ideas to see what works. This often-yielded innovative ideas that then allowed concept generation to flow and led to further discussions of ideas. Ultimately the goal of concept generation is to gather the best concepts for the project and then iterate through them to determine medium and high-fidelity concepts. The medium and high-fidelity concepts will later be quantitatively analyzed and ranked.

Morphological Chart

The morphological chart was crucial in our concept generation as we are taking a systems integration approach. The chart allowed us to generate multiple ideas for the major subsystems of our design and consider different combinations of them. This will help us to consider the merits of different subsystem concepts and how they might work together, rather than evaluating each subsystem separately. The morphological chart was developed with five columns for the main subsystems that encompass the critical targets and metrics. The five selected subsystems for the morphology chart were selected to be the steering, suspension, drivetrain, support, and wheels. Possible types of mechanisms under those selected components were then selected and added to the columns. This allows for combinations to be created with a mix and match approach to concept generation. As depicted with the colored arrows, two possible combination sets are down in the table shown below. The blue and orange line selections depict a possible set of combinations for the overall rover design. Using the total combinations yields a total of 7,776 possible permutations of the presented options.

Table 4 Morphology Chart

Steering	Suspension	Drivetrain	Support	Wheels
Single rack and pinion	Leaf spring	Chain and sprocket (single gear)	Side by side seating	High density rigid polymer foam
Tiller steering	Double wishbone (front only)	Belt driven pulley drivetrain	Opposed seating	Cork
Tank steering	Fully independent double wishbone	Chain and sprocket (multi gear)	3-point seatbelts	Parallel grained wood
Pedal steering	No suspension	Direct drive mechanism	2-point seatbelts	3 wheels
Dual front rack and pinion steering	MacPherson struts	Chain-free driveshaft, multi gear ratio	5-point harness	4 wheels
Four-wheel steering	Rear pivot suspension	Chain drive, single gear ratio, dual clutch	Back to back seating	Bicycle wheel (non-pneumatic)

Brainstorming

Another form of concept generation implemented was the brainstorming method which involved the group openly discussing possible designs and combinations. Each of these ideas would then be written down and discussed again later in conjunction with the S.C.A.M.P.E.R. (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse) method. This eventually yielded some of the medium and high-fidelity concepts for the rover design. This method was the one we utilized most.

Crapshoot

The third concept generation technique used was the crapshoot method which involved throwing out wild ideas that could possibly be useful in some applications. This allowed us to cast out wild ideas and then reel them back in and find more reasonable suggestions that could be applied to the critical systems.

Medium Fidelity Concepts

Medium fidelity concepts were identified as concepts that had potential to meet some of the specified critical targets and metrics selected for the project but not all the criteria. Some of these ideas could be combinations of several generated concepts from all the tools used. A total of six medium fidelity concepts were generated. These concepts for each of the critical systems of the project were then determined to be as shown below.

1. Disk Brakes

Disk brakes could be implemented and attached to the axle of the powertrain. This type of brake system is used on 4-wheeled go-carts that are built similarly to the rover and can handle high speed braking. They are a fairly simple design and can be easily implemented with almost any wheels. In addition to being easy to implement, they are also user serviceable in the field which can be useful if there are any issues with it during the competition. The image below depicts the current set of disk brakes that are remnants of the previous team's rover construction.

Figure 1.5.1 Disk brake and caliper trigger system.

2. 3-Point Seatbelt

A 3-point seatbelt could be used to secure each operator to the vehicle. The NASA competition guidebook states that the users This provides a high level of safety and security to the operator. They restrict movement both vertically and laterally and restrict both the upper and lower body. Most 4-wheeled automobiles use this type of seatbelt to maximize user comfort and safety.

Figure 1.5.2 Three-point seatbelt diagram (Late Model Restoration, 2020).

3. Fronk (front trunk) Design

A front tool storage trunk would help offset the rear-heavy rover. Storing the tools in the front of the vehicle allows the users to easily reach for tools they may need for their tasks.

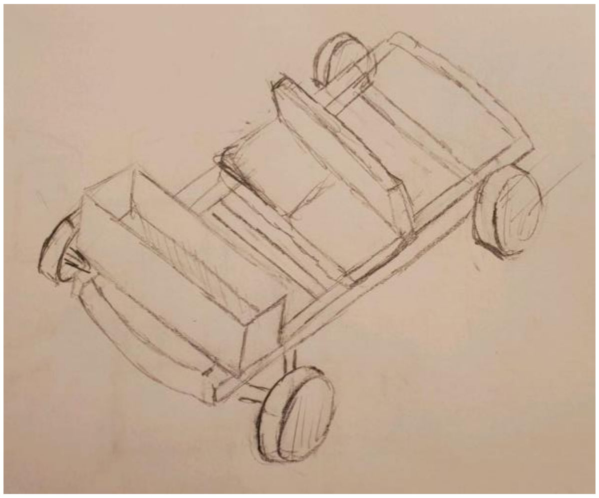

Figure 1.5.3 Fronk design on four wheeled base rover.

4. <u>Sample Gathering Tool</u>

The handheld device with a grip and squeeze mechanism helps with picking up multiple samples. The grip helps with grabbing slippery and smaller samples. The handheld device reduces hand fatigue and helps with reaching to further distances. The grabbers can hold a cup to pick up liquid samples. This tool also keeps riders from bending over and stepping out of the vehicle.

Figure 1.5.4 Depiction of a gripper arm with squeezing mechanism (Grainger, 2020).

5. Tiller Steering Mechanism

A steering system in the middle of two riders will give access for either or rider to steer. The steering system provides leverage in the form of torque like sailboat steering. Tiller system in the front will give a rider the control of front wheel turns. Like a sailboat, when a rider turns the tiller left, both front wheels will turn right together. When a rider turns right, the wheels will turn left. In addition to being a robust steering mechanism, it is also simple and can be designed to be lightweight.

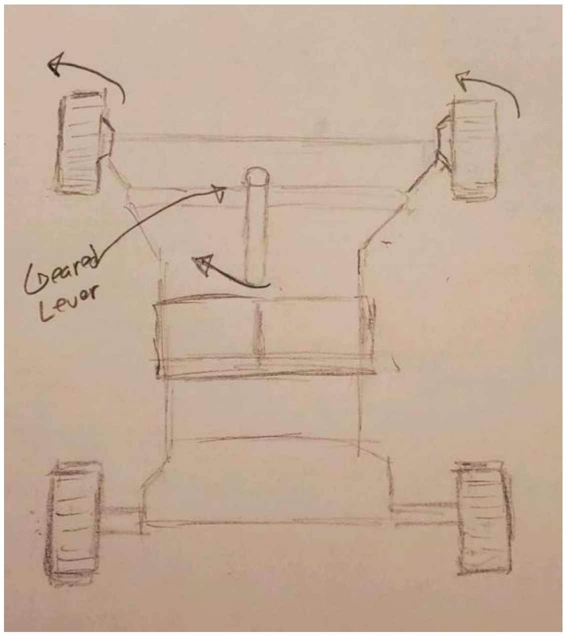

Figure 1.5.5 Tiller steering mechanism location and reaction motion on a mock rover.

6. Double Wishbone Suspension in Front and Rear

Double wishbone suspension in the front and rear would allow for independent movement of every wheel. This would be very helpful absorbing all the impact from bumps, allowing the vehicle to maintain stability and traction. It could be difficult to implement a drivetrain with this suspension.

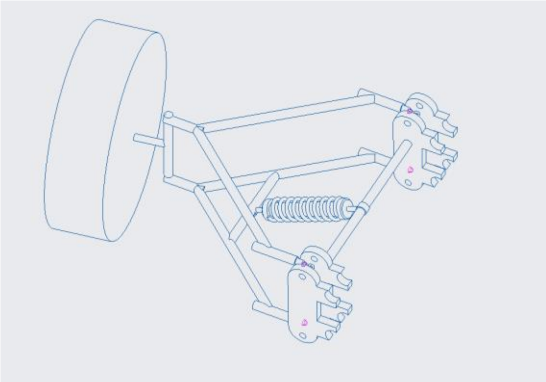

Figure 1.5.6 Schematic of double wishbone suspension that will be used for front and rear axles.

High Fidelity Concepts

High fidelity concepts were identified as concepts that best fit the critical targets and metrics and had little to no downsides. The high-fidelity concepts consisted of many smaller combined concepts which created a more robust and promising concept revision. A total of seven high fidelity concepts were generated. We feel that these concepts detailed below will be the best options going forward with the design.

1. High Density Rigid Polymer Foam Wheels

The material for the interior of the wheels could be made from high density rigid polymer foam. The wheels will be solid all the way through. All four wheels will be made from this material and they will have the same dimensions. It is vital that these wheels do not fail while under load of the cart, riders, and traversing terrain. This material is optimal for minimizing mass and cost. It is important to minimize mass, as the competition awards more points to lighter rovers.

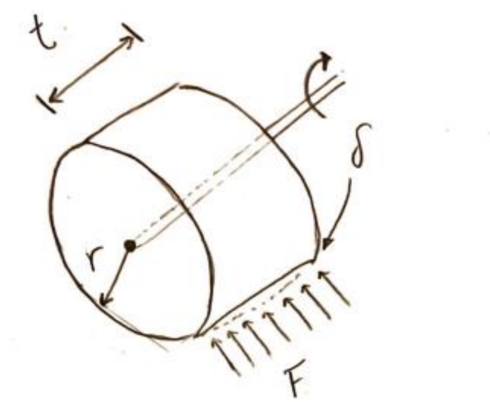

Figure 1.5.7 High Density Rigid Polymer Foam Wheels with relevant dimensions that are to be determined.

2. <u>Frame from Previous Year</u>

This frame is relatively small and made of steel tubing. While it could pose some issues, reusing the frame from last year's team would enable our team to save time and money on developing this subsystem.

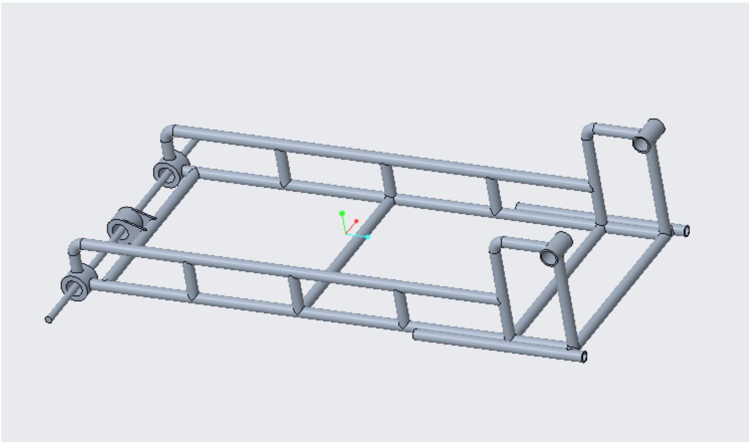

Figure 1.5.8 Steel frame from 2019 team 514.

3. Side-by-Side Forward Faced Seating

This type of seating arrangement would allow for both operators to see where the rover is moving and would simplifies the powertrain configuration. The rover will only be able to traverse forward and brake, so having both operators face in the direction of movement is important. Also, the side-by-side seating enables the powertrain to have only one axis of rotation. This further simplifies the design, which is time effective.

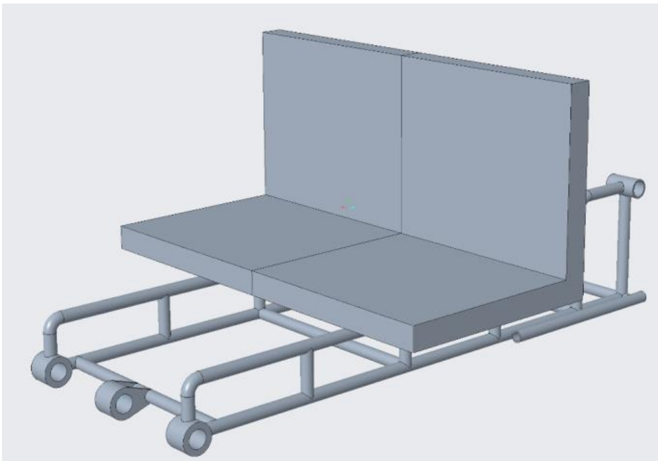

Figure 1.5.9 Side by side rover seating for the operators.

4. Front Wheel Double Wishbone Suspension with Solid Rear Axle

Reusing the double wishbone suspension from last year's team would enable our team to save time and money on developing this subsystem. This kind of suspension setup allows for a more rigid rear end of the vehicle while allowing some suspension motion in the front end for stability and rough terrain. This will reduce the complexity of the suspension and drivetrain so that it can remain robust, yet versatile.

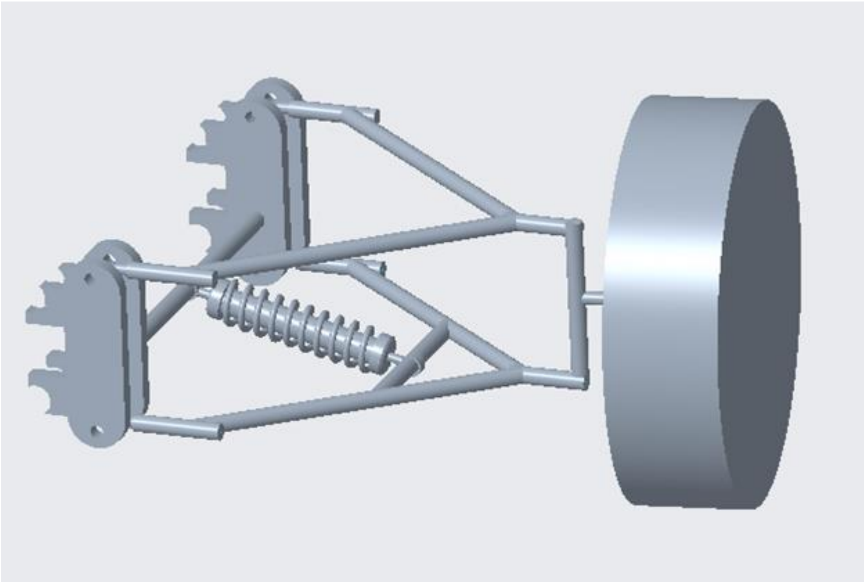

Figure 1.5.10 Front Wheel Double Wishbone Suspension. Modified version from the previous team's design.

5. Solid Rear Axle Powertrain with Dual Disk Brakes

A solid rear mounted axle with dual disk brakes would allow for a versatile drivetrain and braking system. Utilizing the rear mounted axle, the driving gear could be directly attached, or welded to the driveshaft and allow for direct power transmission from the bike chain and pedals. The bolt on design would allow for ease of attachment and repair should damage occur to the shaft. The dual disk brakes also allow for faster braking, and a single brake handle can be given to each of the riders so that they can have individual control over deceleration. The torque input from the user will be transmitted via two intermediate chain linkages and from the dual clutch pedal system at the front of the vehicle as depicted in the following images.

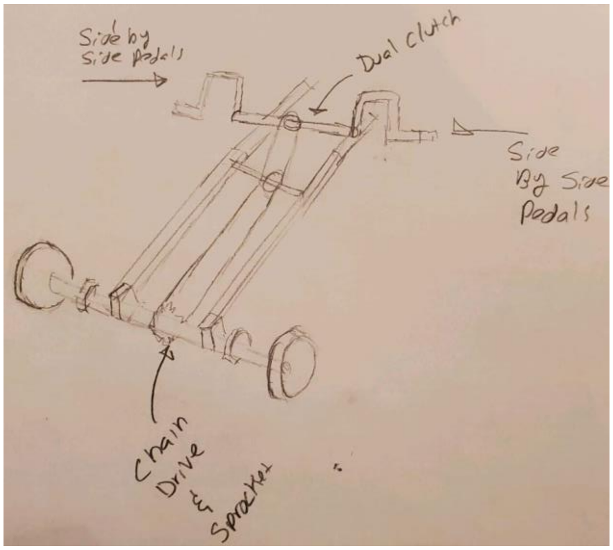

Figure 1.5.11 Chain drive and solid rear axle with dual caliper brake system.

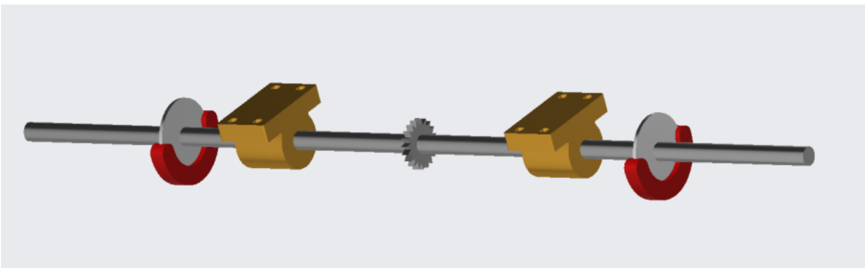

Figure 1.5.12 Dual disk brake, solid rear axle driveshaft.

6. Rack and Pinion Steering from Previous Year

Rack and pinion steering are one of the most commonly us steering systems in vehicles. It is easy to use and simple to implement as it allows the driver to proportionally move the steering system in real time. In addition to this, the steering mechanism has been handed down from the previous design team and is readily modifiable for the updated rover.

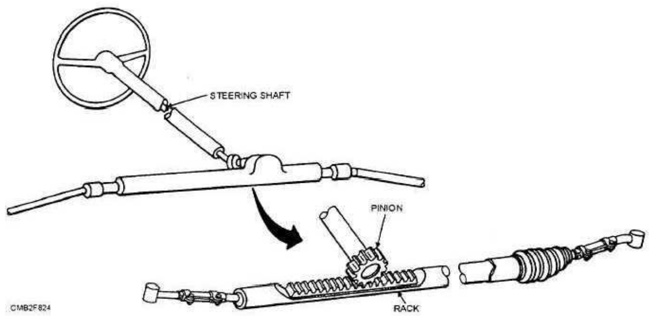

Figure 1.5.13 Rack and pinion steering diagram (Integrated Publishing).

7. <u>2-Point Seatbelt</u>

2-point seatbelts consist of a lap belt which connects on both sides of a person's waist. They help prevent any vertical body movement and limit lower body lateral movement. They are commonly used in low speed or low risk situations where a person's upper body would not be subjected to large forces.

Figure 1.5.14 Two-point seatbelt restraint (Quadratec, 2020)

1.6 Concept Selection

Using the generated concepts that were derived by the mission critical customer requirements from the NASA Human Exploration Rover Challenge 2021, the team analyzed each of the medium and high-fidelity concepts using a binary comparison table as shown in Table 1.6.1. The purpose of this is to compare the criteria determined for the rover project and their relative importance. Using the binary comparison table, a weight factor is then determined which is used for the numerical analysis of the generated concepts.

Table 1.6.1
Binary Comparison Table

	1	2	3	4	5	6	7	8	Total
1. Handle rough terrain	-	0	0	0	0	0	1	1	2
2. Maintain operator safety	1	-	0	1	1	0	1	1	5
3. Maintain functionality	1	1	-	1	1	1	1	1	7
4. Ease of production	1	0	0	-	1	0	1	1	4
5. Rider size accommodation	1	0	0	0	-	0	0	1	2
6. Cost effective	1	1	0	1	1	-	1	1	6
7. Ease of assembly	0	0	0	0	1	0	-	1	2
Total	5	2	0	3	5	1	5	7	-

House of Quality

The House of Quality (HoQ) chart helps to translate the customer needs into engineering characteristics. Relative ranking and weighting are then determined from of the HoQ which then can be used to compare concepts against one another. The goal of this analysis is to mathematically determine the concepts that satisfy the customer's needs.

Table 1.6.2
House of Quality Table

		Engineering Characteristics						
Improvement Direction	↑	↑	↓	↑	↑	↑	↑	↑
Units		N/A	inches	Number of seats	inches	inches*lbf	in	in^3 N/A
Customer Requirements	Importance Weight Factor	Stability	Turning Radius	Seating Accommodation	Ground Clearance	Rover Torque	Stopping Distance	Storage
Handle rough terrain	2	8	4	0	8	4	2	0
Maintain operator safety	5	4	2	8	2	0	2	0
Maintain functionality	7	2	2	0	2	8	8	4
Ease of production	4	0	0	4	4	4	2	2
Rider size accommodation	2	4	0	8	2	2	2	4
Cost effective	6	4	2	2	2	4	0	2
Ease of assembly	2	2	2	4	2	2	0	0
Raw Score (552)		86	48	92	76	112	82	56
Relative Weight (%)		15.58	8.70	16.67	13.76	20.29	14.86	10.14
Rank Order		3	7	2	6	1	4	5

Pugh Charts

Pugh charts were developed to analyze concepts of similar systems. A total of five systems were analyzed: steering, suspension, frame, wheels, and powertrain. These systems each started with four concepts and were compared to a datum. A second iteration was conducted on each system to narrow down its concept designs that most matched the engineering characteristics. The final concepts will be used in the development portion of the human powered vehicle project.

In the Pugh Charts below, each concept consists of plus (+), minuses (-), or satisfactory (S). Concepts were given a (-) if they were determined to be worse than the datum in the specific engineering characteristic. Concepts were given a (+) if they were determined to be better than the datum in the specific engineering characteristic. Concepts were given a (S) if they were determined to be equivalent to the datum in the specific engineering characteristic. In each Pugh Charts comparison, the (+) and (-) are totaled for each concept. In iteration process, the concept with the most (+) became the new datum and the previous datum was eliminated. This process was done until the concepts were narrowed down.

Table 1.6.3

Steering Pugh Chart 1

Steering					
	Concepts				
Engineering Characteristics	Datum	Rack and pinion steering from previous year	Tiller steering mechanism	Double wheel steering	Rear wheel steering
Stability	Front wheel steering	S	S	-	-
Turning Radius		+	-	-	-
Seating Accommodation		S	S	S	S
Ground Clearance		+	+	S	S
Rover Torque		S	S	S	S
Stopping Distance		S	S	S	S
Storage		S	S	S	S
# pluses		2	1	0	0
# minuses		0	1	2	2

Table 1.6.4

Steering Pugh Chart 2

Steering				
	Concepts			
Engineering Characteristics	Datum	Tiller steering mechanism	Double wheel steering	Rear wheel steering
Stability	Rack and pinion steering from previous year	S	-	-
Turning Radius		-	-	-
Seating Accommodation		S	S	S
Ground Clearance		+	S	S
Drivetrain Torque		S	S	S
Stopping Distance		S	S	S
Storage		S	S	S
# pluses		1	0	0
# minuses		1	2	2

Multiple steering concepts were compared against each other in the Pugh Charts above, Table 1.6.3 and Table 1.6.4. The rack and pinion steering was the best concept in the first analysis, so it was then used as the datum in the next Pugh Chart. After the second analysis the rack and pinion steering was identified as the best steering concept. This supports what the team expected as rack and pinion steering is simple and easy to integrate. The parts necessary for a rack and pinion steering system are also already available to us from last year's team.

Table 1.6.5

Suspension Pugh Chart 1

Suspension					
	Concepts				
Engineering Characteristics	Datum	Double wishbone suspension (front)	Double wishbone suspension (front and rear)	MacPherson Strut (front)	No suspension
Stability	Leaf spring suspension (front and rear)	+	-	+	-
Turning Radius		S	S	S	S
Seating Accommodation		S	S	S	S
Ground Clearance		+	-	+	+
Rover Torque		S	+	S	-
Stopping Distance		+	+	+	-
Storage		S	S	S	S
# pluses		3	2	3	1
# minuses		0	2	0	3

Table 1.6.6

Suspension Pugh Chart 2

Suspension				
	Concepts			
Engineering Characteristics	Datum	No suspension	Double wishbone suspension (front and rear)	MacPherson Strut (front)
Stability	Double wishbone suspension (front)	-	+	-
Turning Radius		S	S	S
Seating Accommodation		S	S	S
Ground Clearance		+	-	S
Rover Torque		-	+	S
Stopping Distance		-	-	S
Storage		S	S	S
# pluses		1	2	0
# minuses		3	2	1

Different suspension concepts were compared using Pugh Charts above in Table 1.6.5 and Table 1.6.6. The double wishbone suspension in the front only was found to be the best concept in the first chart and was subsequently made the datum in the second chart. In the second Pugh Chart two concepts were tied for the best, the double wishbone in the front only and the double wishbone in the front and rear. The double wishbone suspension is relatively easy to design and very effective for off-road terrain, so these concepts being the best came as no surprise.

Table 1.6.7

Frame Pugh Chart 1

Frame					
	Concepts				
Engineering Characteristics	Datum	Frame from previous year	Single beam, segmented frame	Wooden frame with center fold joint	Elongated and segmented frame from previous year
Stability	Short wheelbase wooden frame	+	-	-	-
Turning Radius		S	-	-	-
Seating Accommodation		S	S	S	S
Ground Clearance		S	S	S	S
Rover Torque		S	S	S	S
Stopping Distance		S	S	S	S
Storage		S	+	-	+
# pluses		1	1	0	1
# minuses		0	2	3	2

Table 1.6.8

Frame Pugh Chart 2

Frame				
	Concepts			
Engineering Characteristics	Datum	Elongated and segmented frame from previous year	Single beam, segmented frame	Wooden frame with center fold joint
Stability	Frame from previous year	-	-	-
Turning Radius		-	-	-
Seating Accommodation		S	S	S
Ground Clearance		S	S	S
Rover Torque		S	S	S
Stopping Distance		S	S	S
Storage		+	+	-
# pluses		1	1	0
# minuses		2	2	3

Comparing multiple frame concepts, the frame from the previous year was identified as the best concept in the first Pugh Chart, Table 1.6.7. After making this concept the datum in the second Pugh Chart, Table 1.6.8, it was still shown to be the best option. The frame from last year is an excellent overall concept as it is relatively small and will provide stability and a small turning radius.

Table 1.6.9

Wheels Pugh Chart 1

Wheels					
	Concepts				
Engineering Characteristics	Datum	High density rigid polymer foam wheels	Cork wheels, solid throughout	Wooden wheels	Patterned aluminum wheels
Stability	Classic bike wheel with rim and spokes	+	+	-	S
Turning Radius		S	S	S	S
Seating Accommodation		S	S	S	S
Ground Clearance		-	-	S	S
Rover Torque		+	+	-	S
Stopping Distance		S	S	S	S
Storage		S	S	S	S
# pluses		2	2	0	0
# minuses		1	1	2	0

Table 1.6.10

Wheels Pugh Chart 2

Wheels				
	Concepts			
Engineering Characteristics	Datum	High density rigid polymer foam wheels	Wooden wheels	Patterned aluminum wheels
Stability	Cork wheels, solid throughout	+	-	-
Turning Radius		S	S	S
Seating Accommodation		S	S	S
Ground Clearance		+	+	+
Rover Torque		S	-	-
Stopping Distance		S	S	S
Storage		S	S	S
# pluses		2	1	1
# minuses		0	1	2

The wheel concepts were also compared using Pugh Charts above. From the first chart, Table 1.6.9, the high density rigid polymer foam wheels and the solid cork wheels were both found to be the equally top options. The solid cork wheels were then used as the datum in the second chart, Table 1.6.10, from which the high density rigid polymer foam wheels were identified as the preferred concept. This is exactly what the team expected as the high-density rigid polymer foam has an extremely high strength to density ratio.

Table 1.6.11

Powertrain Pugh Chart 1

Powertrain				
	Concepts			
Engineering Characteristics	Datum	Chain drive, single gear, single clutch, RWD	Chain drive, single gear, dual clutch, RWD	Chain drive, multi gear, single clutch, FWD
Stability	Direct drive, FWD	S	S	S
Turning Radius		+	+	S
Seating Accommodation		S	S	S
Ground Clearance		S	S	S
Rover Torque		+	+	+
Stopping Distance		S	S	S
Storage		S	S	S
# pluses		2	2	1
# minuses		0	0	0

Table 1.6.12

Powertrain Pugh Chart 2

Powertrain			
	Concepts		
Engineering Characteristics	Datum	Chain drive, single gear, single clutch, RWD	Chain drive, multi gear, single clutch, FWD
Stability	Chain drive, single gear, dual clutch, RWD	S	S
Turning Radius		S	-
Seating Accommodation		S	S
Ground Clearance		S	S
Rover Torque		-	-
Stopping Distance		S	S
Storage		S	S
# pluses		0	0
# minuses		1	2

Finally, the powertrain concepts were compared using Pugh Charts. The first chart, Table 1.6.11 revealed two tops options: Chain drive, single gear, single clutch, RWD and Chain drive, single gear, dual clutch, RWD. Using the dual clutch top option as the new datum, the second chart analysis was performed. From this chart, Table 1.6.12, we found that the chain drive, single gear, dual clutch, RWD option was the best for the powertrain. This option will provide good power transfer and allow for high torque through the use of the dual clutch.

Analytic Hierarchy Process

The Analytical Hierarchy process (AHP) was conducted to compare similar concepts for each of the systems to determine the concepts that best satisfy the customer needs. The criteria were compared against one another and their numerical analysis relationship is normalized to determine which concepts best suits the customer needs.

Table 1.6.13

Pairwise Matrix

	1. Material Cost	2. MFG Cost	3. Repairability	4. Reliability	5. Durability	6. Time Production
1. Material Cost	1	0.2	0.33	1	1	3
2. MFG Cost	5	1	0.33	5	0.2	1
3. Repairability	3	3	1	3	3	5
4. Reliability	1	0.2	0.33	1	5	0.2
5. Durability	1	0.33	0.33	0.2	1	0.2
6. Time Production	0.33	1	0.2	5	5	1
Sum	11.33	5.73	2.53	15.2	15.2	10.4

Table 1.6.14

Normalized Pairwise Matrix

	1. Material Cost	2. MFG Cost	3. Repairability	4. Reliability	5. Durability	6. Time Production
1. Material Cost	0.088	0.035	0.132	0.066	0.066	0.291
2. MFG Cost	0.441	0.175	0.132	0.329	0.013	0.096
3. Repairability	0.265	0.524	0.396	0.197	0.197	0.479
4. Reliability	0.088	0.035	0.131	0.066	0.329	0.019
5. Durability	0.088	0.058	0.131	0.013	0.066	0.019
6. Time Production	0.029	0.175	0.079	0.329	0.329	0.096
Sum	1	1	1	1	1	1

Table 1.6.15

Weighted and Criteria Weights

Weighted Sum	Criteria Weights {W}
8.54	0.113
8.19	0.198
7.75	0.343
6.50	0.111
6.58	0.062
7.78	0.173

In order to determine if any bias was found to be in the calculations, the consistency check was conducted. It was noted that the consistency ratio was calculated to be 0.249 which was nearly 2.5 times as high as the 0.10 value that is to be expected for an unbiased numerical analysis of the criteria. This is notable as there was an emphasis on durability, reliability and material cost as can be seen in the pairwise matrix table.

Final Selection

After thoroughly analyzing all the major concepts with the binary comparison chart, House of Quality and the Analytical Hierarchy Chart, the best concepts were identified in each major subsystem. Not only did these concepts receive high rankings during analysis, but they were also evaluated by the team using considerations on the timeline, construction, and cost of components. The combination of these systems will give us a base concept for the entire rover. The final overall combined concept consists of rack and pinion steering, the frame from the previous year, a double wishbone suspension construction in the front and no rear suspension. The wheels will be made of a high-density rigid polymer foam. The powertrain will be chain driven with a single fixed gear on the rear driveshaft. It will utilize a dual clutch at the pedals and will be rear wheel drive only. This design concept is depicted in the figures below.

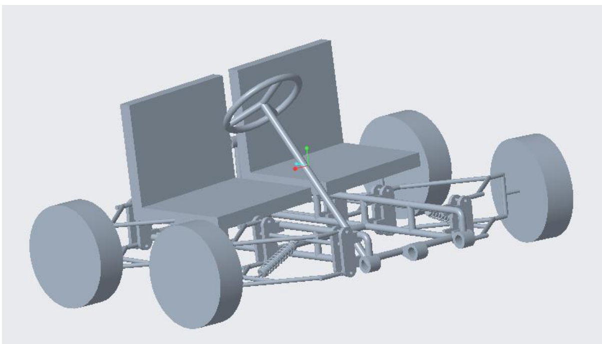

Figure 1.6.1 Concept Selection Rover

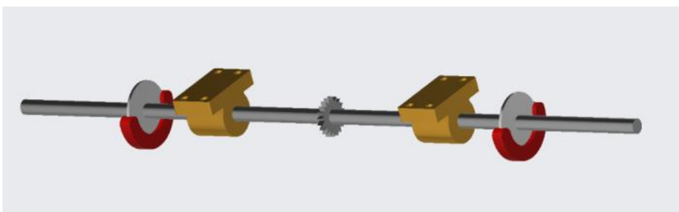

Figure 1.6.2 Dual disk brake, solid rear axle driveshaft.

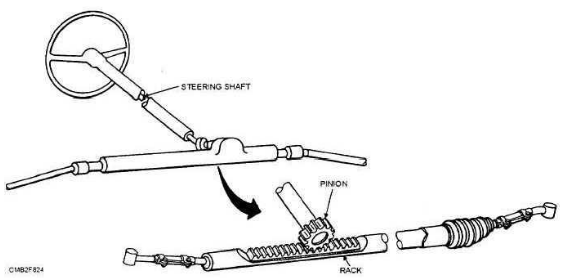

Figure 1.6.3 Rack and Pinion Steering Diagram (Integrated Publishing)

1.8 Spring Project Plan

1/31/21 – Begin sending purchase orders for parts

1/31/21 – Begin sending purchase orders for parts

1/31/21 – Begin sending purchase orders for parts

2/11/21 – Submit media release forms, student data information and team photos

3/01/21 – Finalize CAD prototype

3/10/21 – Submit Operational Readiness Report (ORR)

3/13/21- Youth Outreach Engagement

3/25/21 – Machine and assemble parts as they come in

4/01/21 – Begin testing and validation of assembled subsystems

4/04/21 – Finalize all obstacles for use in final video

4/05/21 – Begin filming of final videos

4/07/21 – Complete and submit final videos

~~**Project Plan.**~~

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~~**Build Plan.**~~

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Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

NASA hosts an annual competition for students to design a vehicle that is operated solely on the power generated by its user(s). The objective of the project is to design and manufacture a human powered vehicle to traverse exoplanetary terrain in a NASA hosted competition. The vehicle will be designed to safely traverse and tolerate the concentrated forces of asteroid debris, boulders, erosion ruts, and crevices. In competition, the vehicle will be operated by one male and one female participant. The competition awards points for weight classes, time of finish, and completed mini missions. This encourages rover designs to be made lightweight, efficient, and easy to operate.

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2.2 Results

The rover ended up being fully assembled with all five subsystems being developed. The frame had a lower ground clearance than expected due to the suspension not being as stiff as calculated. The imposed angle of the suspension struts (~26° to the horizontal) resulted in them not supporting the distributed weight effectively, resulting in a ground clearance of 13.5” rather than 16”.

The wheels ended up being more expensive to fabricated due to the volumetric expansion ratio being smaller than advertised. This could have been due to many factors such as weather conditions, age of liquid foam, etc. The resultant price of fabricating four wheels ended up being $256.58 instead of $51.10.

Design modifications to the steering and drivetrain had to be made last-minute due to small dimensioning errors in the CAD model. These dimensioning errors along with practicality led to cable steering instead of dual-tiller steering.

2.3 Discussion

Many of our teams' problems could have been avoided with more research. Specifically referring to the wheel fabrication and steering implementation. The foam for the wheels failing to expand to the expected volume was heavily influenced by the conditions in which the foam is poured. Research should have been done for maximizing the expansion of the foam, as well as ideal conditions for pouring the foam.

In regards to the steering, the originally selected dual-tiller steering could not function with our current rover frame and axle setup. Justin Pogge in the machine shop gave guidance for this, as he is very experienced in human powered vehicles. A cable steering with two tie-rods attached to each wheel was used instead.

2.4 Conclusion

This senior design project was considered a success by every group member. The valuable lessons we learned about subject research, team dynamics/communication, and precise CAD dimensioning will all be applicable in our future endeavors. We are all proud of the entire finished product, as well as our individual subsystems. We hoped to have finished the assembly and validation at an earlier date, but we are looking forward and have learned from our mistakes.

2.5 Future Work

Further testing and validation would be required for the rover to safely compete in a NASA hosted competition. While the rover is currently assembled and can be driven over flat ground safely, it has not been field tested. Inclines, declines, and low-friction terrain would have to be traversed over safely before deeming the rover fit for competition. Also, the fasteners and welds would be double-checked. Many of the fasteners differ in size and threading. The team would further ensure that all of the fasteners are uniform and the tac-welds are strong.

References

Bike Forums. (2006, July 11). Maximum Human Torque. BikeForums.net. Retrieved from https://www.bikeforums.net/general-cycling-discussion/210283-maximum-human-torque.html#:~:text=Torque%20is%20force%20times%20radius,much%20lower%2C%20something%20about%2050NM

Ellington, S. (1995, February 14). Bicycle Gearing for Wisconsin Hills. Retrieved from http://sdellington.us/gearing/gearing.html

Gardner, A. S., Martin, J. C., Martin, D. T., Barras, M., & Jenkins, D. G. (2007, October 10). Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. PubMed.gov. doi:10.1007/s00421-007-0498-4

Grainger. (2020). Trash Pickers & Grabbers. W.W. Grainger. Retrieved November 4, 2020, from https://www.grainger.com/category/cleaning-and-janitorial/waste-recycling-trash-supplies/trash-pickers-grabbers

Integrated Publishing. (n.d.). Rack-and-pinion steering gear. *Construction Mechanics Basic Volume 2*. Retrieved November 5, 2020, from http://constructionmanuals.tpub.com/14273/css/Rack-and-Pinion-312.htm

Late Model Restoration. (2020). 3-POINT RETRACTABLE SEAT BELT - UNIVERSAL. Late Model Restoration. Retrieved November 5, 2020, from https://lmr.com/item/LRS-B4051000/3-point-retractable-seat-belt

Maxpeedingrods. (n.d.). For 110cc Go Kart Steering Wheel Quad Parts W/ Steel Gear Rack Pinion. Retrieved from https://www.maxpeedingrods.com/product/fit-110cc-go-kart-steering-wheel-quad-parts-w-steel-gear-rack-pinion.html

McConomy, S. (2020, September 16). Senior Design Professor; Project Sponsor; Project Advisor;. (A. Schlar, R. Floyd, N. Sanchez, & N. Picard, Interviewers)

McConomy, S. (2020, September 22). Senior Design Professor; Project Sponsor; Project Advisor;. (R. Floyd, & A. Schlar, Interviewers)

Menon, A. (2017, July 4). What is the method to calculate turning radius if only the steering ratio and vehicle's basic dimensions are known? Retrieved October 29, 2020, from https://www.quora.com/What-is-the-method-to-calculate-turning-radius-if-only-the-steering-ratio-and-vehicles-basic-dimensions-are-known#:~:text=Tan%20(a)%20%3Dwheelbase%2Fturning%20radius.&text=Steering%20Ratio%20is%20just%20a,steering%20ration%20is%2030%

National Aeronautics and Space Administration (NASA). (2020, August). National Aeronautics and Space Administration Human Exploration Rover Challenge 2021 Guidebook. *1*, 48.

National Aeronautics and Space Administration. Retrieved September 19, 2020, from https://www.nasa.gov/stem/roverchallenge/guidebook/index.html

Quadratec. (2020). Seatbelt Solutions 2 Point Non-Retractable Lap Belt with Push-Button Buckle. Quadratec. Retrieved November 5, 2020, from https://www.quadratec.com/products/24247_20X_PG.htm

Tire Friction and Rolling Resistance Coefficients Calculator. (n.d.). HPWizard.com. Retrieved from http://hpwizard.com/tire-friction-coefficient.html

Xbits. (2020). MTB Tire Comparison. BicycleRollingResistance.com. doi:https://www.bicyclerollingresistance.com/mtb-reviews/compare

~~2.1 Spring Plan~~

~~Restated Project Definition and Scope~~

~~parts~~

~~**Project Plan.**~~

~~**Build Plan.**~~

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~~Restated Project Definition and Scope~~

~~Results~~

~~Discussion~~

~~Conclusions~~

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~~**Appendices**~~

Appendix A: Code of Conduct

Mission statement

Team 509 is committed to being thorough with every idea and action implemented to deliver products of the highest practicality and functionality.

Team Roles

Ryan Floyd – Project Engineer/Materials Engineer/Webmaster

- Responsible for overall project progress, submitting all documents, project logistics, material selection, wheel fabrication, website production.

Nicolas Picard – Design Engineer

- Responsible for CAD modeling of competition tools, assisting other teammates in designing their respective subsystem, static & dynamic force calculations.

Ninett Sanchez - Design Engineer/Point of Contact

- Responsible for communication between the team, advisor and sponsor, CAD modeling, static & dynamic force calculations for steering system, presentation logistics

Andrew Schlar – Project/Design Engineer/Team Leader

- Responsible for drivetrain CAD modeling, model video rendering, assisting with website development and static & dynamic force calculations.

- Responsible for assigning additional duties to teammates, keeping attendance, and establishing contact with Dr. McConomy and NASA Human Exploration Rover Challenge (HERC) staff.

Methods of Communication

GroupMe will be primary form of communication for logistics between team members. School emails will be used for sending and receiving formal documents. Additionally, school emails will be used to communicate between the team, the project advisor and sponsor. Basecamp will be used for task assignment, record keeping and finalized file storage. Response time for emails, texts, and group chat messages must be within 12 hours or less during weekdays, and 24 hours or less on weekends. Weekly mandatory meetings will be conducted via scheduled Zoom sessions on Fridays at 9:00 A.M. – 10:00 A.M.

Dress Code

A dress code will be applied for all events and gatherings. Group members must always be dressed presentable and color coordinated. Group members are expected to be dressed accordingly:

- Team Meetings - Casual attire
- Meetings with Sponsor/Advisor - Business casual incorporating dark colors
- Presentations - Business professional attire (suit and tie) incorporating NASA colors

Attendance Policy

All team members must attend the mandatory virtual meetings every Friday at 9:00 A.M. to 10:00 AM. Weekly meetings with the group advisor, Shayne McConomy, will be held at a time to be determined. Participation on project work and submissions will also be recorded, this is to ensure that assignments are completed timely. Attendance will be kept in an Excel spreadsheet and updated immediately after meetings by the team lead. Absences from meetings will be recorded with explanations as to why the team member was not present. If a team member cannot make a meeting due to a scheduled conference, doctor's appointment, or general event, they must notify the team so that it may be recorded and accounted for. Should a teammate not attend meetings with repeating frequency and no explanation is given, Dr. McConomy will be notified to seek remediation.

Submission Policy

All work will be submitted by the designated project engineer, Ryan Floyd, and a verification email will be sent to the rest of the team. All assignments will be reviewed by the assignment submitter to ensure all the assignment criteria has been met. Should the designated project engineer not be able to submit the work files, this will immediately be relayed to the team to ensure the assignment is turned in on time. The assigned backup for submissions is the team lead, who will email to all team members that the assignment has been turned in. All team assignments will be submitted 36 hours before the deadline to avoid possible technical problems close to the final deadline.

Conflict Resolution

Should conflict arise during the project, a formal write-up will be made to allow the parties to express their concern and to allow for this to be documented. The conflict resolution policy will apply to all conflicts, including, but not limited to attendance, submissions, project disputes and errors in design. An attempt to de-escalate conflict within the team will first be attempted, all group members will then present their grievances and discuss openly what problems they have encountered. If de-escalation does not solve the disagreement between members, mediation will be sought after via project advisor Shayne McConomy. In cases of disagreement on project decisions where there is not a majority vote, mediation will occur via project advisor.

Ethics Policy

All team members agree to comply with local and state laws, rules, and regulations in relation to any aspect of the project. Work must be conducted honestly and by the team, if outside help is used, they must be credited properly for their contribution to the project.

Workload Policy

All members of the team are responsible for their assigned portion of the workload, should there be any issues with completing an assignment or part of a task, other members must be notified immediately to ensure that the assignment is completed. If a team member is not contributing to the project, the team may refer to the conflict resolution guidelines to correct the workload imbalance.

Code of Conduct Amendments

The Code of Conduct rules are to be applied to all members of Senior Design Team 509, however, should some extenuating circumstances occur, the rules may be modified to reflect the new state of the situation. The ratification of any further amendments to the Code of Conduct must be passed by a majority of the vote. All team members must be present to cast their vote and present their arguments for, or against the addition or change. If a deadlock tie is reached during the amendment of the Code of Conduct, resolution may be sought through the appropriate mediation channels. Code of Conduct rules is in effect during the duration of the project, starting in September of 2020 to May of 2021. All amendments made will be in effect as of the ratification date passed by the team members. A section of the amendments will be created and labeled as such on any further revisions of the Code of Conduct document. All changes must be documented, and original versions of documents will be kept for comparison and verification.

Statement of Understanding:

By your signature below, you agree to comply with the team's Code of Conduct guidelines:

Print Name: Andrew Schlar

Signature: Andrew Schlar

Print Name: Ninett Sanchez

Signature: Ninett

Print Name: Ryan Floyd

Signature:

Print Name: Nicolas Picard

Signature: Nico Picard

Appendix B: Functional Decomposition

Appendix C: Target Catalog

Table 5 Total Targets and Metrics Table

Function	Target	Metric
Provides Designated Storage*	6 tools, 1 core sample, 3 images, 1 liquid sample, 1 dry sample	Number of tools Number of samples
Secures Tools to Vehicle	6 tools	Number of tools
Collapses into Smaller Volume	5 ft, 5 ft, 5ft 125 ft^3	Length, Width, Height Volume
Translate Steering Input to Output	1:1 20 degrees	Steering Gear Ratio Max Turning Angle
Maintain Friction with Terrain	(RRC) $\leq$ 0.005 FC $\geq$ 0.75	Friction Coefficient (FC) Rolling Resistance Coefficient (RRC)
Translate User Input	Stopping Distance $\leq$ 2.5 m (10 mph to stop)	Distance
Translate User Work	100 N-m (Gear Ratio Range)	Torque

	Pinion 16-24 teeth Cassette 32-42 teeth	Gear Ratio
Absorb Impact	≤ 7 inches	Suspension compression
Dampen Vibrations	100% approval	Rider approval
Maintain Structural Integrity	2.0	Factor of safety
Secure Operators	100% approval	Rider approval
Ground Clearance **(with riders onboard)**	12 inches 30-degrees departure/approach angles	Height Degrees
Track Width	≤ 5 ft	Length
Wheelbase	≤ 5 ft	Length
Turning Radius	≤ 15 ft	Radius Length
Top Speed	15 mph	Velocity

*The tools have not been made yet; the exact amount of storage space cannot be known right now.

Appendix D: Figures and Tables

Dr. McConomy Customer Statements and Interpretations

Table 6: Dr. McConomy Customer Statements and Interpretations

Question	Customer Statement	Interpreted Customer Need
What are your expectations for the project aside from the competition's expectations?	"Would like to see the project finished, actively participating in the competition. Ideally the team would have the design finish in the events we compete in."	The project will be fully completed to ensure the team's participation in the competition.
Would you like us to focus on specific design areas with an emphasis on funds correlated to them?	"Would like to see placement within CAD for the design and everything must be designed simultaneously."	Systems integration will be utilized in the design process.
What areas of the past design do you think need the most improvement?	"Steering and powertrain are always the part that gets overlooked, build always gets main focus, DO the engineering first."	A high priority will be placed on designing the steering and the powertrain of the vehicle.

Are there any safety, or security concerns that you have for the project/competition?	"None outside the rules, just general rules for manufacturing and build. Do not dimension for exact guidelines."	The competition guidelines will be followed. The vehicle will be designed according to specification requirements.

Appendix E.1: Concept Generation

Table 7 Generated Concepts

Concept Generation Tool	Concept Number & Description
	Drivetrain Components
Brainstorming	1. Direct drive – Drive pedals are directly attached to the solid driveshaft and no mechanical advantage is applied.
Morphological Chart	2. Chain drive, single gear ratio, single clutch – Single gear speed on the drivetrain, the pedals can drive in both directions and both pedal sets move in unison.
Morphological Chart	3. Chain drive, multi gear ratio single clutch – Multi gear speeds on the drivetrain, the pedals can drive in both directions and both pedal sets move in unison.
Morphological Chart	4. Disk brakes (Medium Fidelity) – A combination of disk brakes mounted either on the drive axle or on the wheels directly to allow for faster braking speeds.
Morphological Chart	5. Caliper brakes – A mounted set of caliper brakes on either the drive axle or on the wheels directly, this allows for self-adjustment when braking.
Morphological Chart	6. Cantilever brakes – Mounted set of brakes that allows the wheels to be clamped from either end, uses friction with the rim for braking.
Morphological Chart	7. Chain-free driveshaft, single gear ratio, single clutch – Using solid gears, and combination shafts to transfer power directly to the wheels. The system would use a rear wheel drive, solid axle combination to transfer power to the wheels.

Morphological Chart	8. V-brakes (all wheels) – Braking system applied to all the wheels, used with a combination of standard rimmed, non-pneumatic bike wheels.
Morphological Chart	9. Coaster brakes – Braking system that is used with a single gear drive, allows for forward pedaling of the gearing, does not allow for reversing of the vehicle. When the pedal is reversed, the vehicle locks into position, allows for the rider to leave the vehicle stationary.
Morphological Chart	10. Chain-free driveshaft, multi gear ratio, single clutch - Using solid gears, and combination shafts to transfer power directly to the wheels. The system would use a rear wheel drive, solid axle combination to transfer power to the wheels. This system would allow the operators to change the mechanical advantage on the fly
Morphological Chart	11. Chain drive, single gear ratio, dual clutch – System used in conjunction with a solid rear axle, rear wheel drive system. Allows one user to pedal while the other can rest, has additive input. Does not allow for back pedaling from either user.
Morphological Chart	12. Front wheel brakes only - Brakes positioned only on the front wheels of the vehicle, can be used in conjunction with all four wheeled combinations and three wheeled combinations.
Morphological Chart	13. Rear wheel brakes only – Brakes positioned on the rear wheels or axle, can be used in conjunction with all four wheeled and three wheeled combinations.
Morphological Chart	14. Split single front-rear brake system – Brake set positioned one on the front end and one on the rear end of the vehicle, can work well in conjunction with a split front axle and solid rear axle.

Morphological Chart	15. All wheel braking system – Brake set positioned on all wheels, can be a combination of disk brakes, caliper brakes, and set on solid or split axles, front, rear and all-wheel drive combinations.
Morphological Chart	16. Dual disk brakes on solid rear axle (High Fidelity) – Used in combination with a solid rear axle, disk brakes placed on both sides of the single speed gear. Mechanism is similar to the braking system used on high speed and off-road go-karts.
Morphological Chart	17. Rear axle differential – System incorporates a differential gear to allow power distribution to the rear wheels to be split. Used in conjunction with individual brakes on each of the drive wheels in case one of the wheels is slipping.
Morphological Chart	18. Front wheel drivetrain – Drivetrain composed of the front wheel system driving the rover, to be used in conjunction with independent front-end suspension systems.
Morphological Chart	19. Rear wheel drivetrain – Drivetrain composed of the rear wheel system driving the rover, can use differential, solid rear axle, split axle, and independent suspension.
Morphological Chart	20. All wheel drivetrain – Drivetrain composes of all the wheels driving the vehicle, highly complex system but allows for even distribution of power.
	Frame/Wheels/Suspension/Seating Components
Morphological Chart	21. Side-by-side forward faced seating (High Fidelity) – Riders will sit side by side with the pedaling system positioned in front of them. The seating arrangement can accommodate front wheel drive, rear wheel drive and all-wheel drive arrangements.
Morphological Chart	22. Side-by-side seating with one front facing and one rear facing – Riders would sit back to back in the rover, allowing for more leg motion in the pedaling for the drivetrain.

Morphological Chart	23. Forward facing inline seating – Riders would sit forward facing and have a more compact footprint. Front rider would control the steering of the vehicle while the rear rider has access to additional controls and tools.
Crapshoot	24. Diagonal seating arrangement
Brainstorming	25. Wooden wheels
Brainstorming	26. High density rigid polymer foam wheels (High Fidelity)
Brainstorming	27. Solid cork wheels
Brainstorming	28. Continuous fiber reinforced thermoplastic (CFRP) wheels
Brainstorming **&** **Morphological Chart**	29. Re-use tubing frame from previous semester's team – Recycling the previous team's frame for the sake of time, money, effort, and resources. Modifications will have to be made for it to work as it is based off a double wishbone front steering system.
Brainstorming	30. Frame with folding joint at center – Frame system will have a split joint to allow the length of the frame to be shortened to meet competition criteria.
Brainstorming	31. Segmented frame – Frame system would implement separate components in the frame to allow them to detach and store in a smaller volume.
Crapshoot	32. Triangle frame.
Crapshoot	33. Diamond frame.
Brainstorming	34. Composite materials frame.
Crapshoot	35. Wooden construction frame.
Crapshoot	36. Dovetail construction wooden frame connections.
Brainstorming	37. Tri-wheel design; one front wheel and two in the rear.
Brainstorming	38. Tri-wheel design; two front wheels and one rear wheel.
Brainstorming	39. Four wheeled design; wheel at each corner of the vehicle frame.

Brainstorming	40. Ellipse shaped wheel construction – Unique wheel design using an elliptical offset shape, could be useful for uneven terrain.
Morphological Chart	41. Suspension built into wheel hubs – Combining the suspension into the wheel hub of the vehicle, could allow for multiple suspension systems to be used in conjunction.
Brainstorming	42. Individual bike seats for riders.
Brainstorming	43. Single dual rider detachable bench seat - One bench seat positioned on the frame so that it can detach for storage and transportation.
Brainstorming	44. Laterally adjustable seating
Brainstorming	45. Vertically adjustable seating
Brainstorming	46. Long wheelbase steel tubing frame – Lengthened wheelbase within the competition limits, allows for more room within for the riders to sit in.
Brainstorming	47. Short wheelbase steel tubing frame – Shortened wheelbase, some of the materials may hang out over the frame, would stay well within competition length restriction.
Morphological Chart	48. Front double wishbone suspension with solid rear axle (High Fidelity) – Suspension system would have independent suspension on the front end, no suspension on the rear but a stiff rear axle.
Brainstorming	49. Single beam frame.
Brainstorming	50. Bike pedals in front of and level with operators.
Brainstorming	51. Bike pedals in front of and below operators.
Brainstorming	52. Clip in bike pedals – Pedals lock into position with the rider's shoes so they do not slip.
Brainstorming	53. Standard bike pedals.
Brainstorming	54. Upright seating positioning for riders.

Brainstorming	55. Reclined seating position for riders.
Brainstorming	56. Bottom only seats (no backrest).
Brainstorming	57. Swivel bolted seats.
Brainstorming	58. Five-point harness with racing seat.
Brainstorming	59. Three-point harness seatbelt (Medium Fidelity) – Using a three-point seatbelt in conjunction with a type of seating that includes a backrest.
Brainstorming	60. Lap only seatbelt restraint.
Brainstorming	61. Go-kart plastic bucket seats.
Brainstorming	62. Leading arm front suspension.
Brainstorming	63. Trailing arm rear suspension.
Brainstorming	64. Swing axle front suspension.
Morphological Chart	65. Double wishbone front suspension (High Fidelity) – Suspension system using a double wishbone setup for the front end. This is currently on last year's frame and incorporates a rack and pinion steering component.
Brainstorming	66. Double wishbone all wheel independent suspension.
Brainstorming	67. MacPherson strut front end suspension.
Brainstorming	68. No suspension rigid frame.
Morphological Chart	69. Leaf spring all wheel suspension, solid rear axle – Conjunction of leaf springs akin to Amish wagons, using a solid rear axle for the drivetrain.
Brainstorming	70. Connected leading and trailing arms suspension
	Steering
Brainstorming	71. Dual tiller steering

Morphological Chart	72. Single rack and pinion steering with steering wheel mechanism (Medium Fidelity) – A combination of rack and pinion steering implementing the single tiller steering design for the users.
Brainstorming	73. Handlebar direct steering mechanism.
Brainstorming	74. Pedal steering mechanism.
Brainstorming	75. Dual rack and pinion steering with dual steering wheels.
Brainstorming	76. Front wheel steering
Brainstorming	77. Rear wheel steering.
Morphological Chart	78. All wheel crab walk steering – Front and rear steering mechanism to allow one driver to drive the front end and the other to drive the rear end. Used in conjunction with the all-wheel drive system.
	Storage and Tools
Brainstorming	79. Store tools underneath the rover seats in specialized toolbox
Brainstorming	80. Store tools in designated toolbox between riders
Brainstorming	81. Store tools in a rear mounted toolbox behind the seating arrangement
Brainstorming	82. Attach pegboard toolholder behind each rider seat
Brainstorming	83. Design trunk storage in rear end of rover
Brainstorming	84. Design fronk (front trunk) to store tools directly in front of the riders (Medium Fidelity)
Brainstorming	85. Analog camera with light filter attachments
Brainstorming	86. Polaroid camera with mechanical filters
Brainstorming	87. Solar powered light indicator with on and off switch
Brainstorming	88. Solar powered compass light with power indicator and on/off switch

Brainstorming	89. Digital camera with mechanical light filters, uses mini film printer for images
Brainstorming	90. Handheld core sample retrieval tool, plunges into sample and clamps down around it
Brainstorming	91. Handheld core sample retrieval tool, plungers into sample and consists of an inner hollow tube for collection using sample friction
Brainstorming	92. Solid soil sample scooping arm, shelf grabber design, compresses and closes a scoop arm, paired with sample storage container
Brainstorming	93. Solid soil sample collection arm, individual containers attached with quick release mechanism
Brainstorming	94. Liquid sample collection arm, individual pre-loaded containers attached at the end of an extendable pole
Brainstorming	95. Liquid sample scooping arm to pour samples into individualized containers
Brainstorming	96. 100% 3D printed detachable scooping arms to allow for multiple samples and prevent cross-contamination. Multiple sized scoops available, scoops function as storage devices for samples when detached.
Brainstorming	97. Combination liquid and solid sample retrieval arm, multiple detachable sample containers to allow for varied sample sizes and ease of transportation
Brainstorming	98. Reusable 3D printed liquid sample retrieval arm
Brainstorming	99. Single use 3D printed solid sample retrieval arm; end collector detaches for the storage of sample
Brainstorming	100. 3D printed, solar powered LED light with on and off switch, compact shell design

Brainstorming	101. Handheld vacuum to system to pick up particles
Brainstorming	102. "Sticky" gloves that will collect particles by having everything stick to them
Brainstorming	103. Siphon to suck out liquid core samples
Brainstorming	104. Adjustable nozzle diameter to extract liquid core samples

Appendix E.2: Concept Selection Data Tables

Table 1.6.16

Powertrain Material Cost Pairwise Matrix

	1. Direct drive, FWD	**2. Chain drive, single gear, dual clutch, RWD**	**3. Chain drive, single gear, dual clutch, RWD**	**4. Chain drive, multi gear, single clutch, RWD**
1. Direct drive, FWD	1	0.33	0.33	0.2
2. Chain drive, single gear, single clutch, RWD	3	1	0.33	0.2
3. Chain drive, single gear, dual clutch, RWD	3	3	1	0.33
4. Chain drive, multi gear, single clutch, RWD	5	5	3	1
Sum	12	9.33	4.67	1.73

Table 1.6.17

Powertrain Material Cost Normalized Pairwise Matrix

	1. Direct drive, FWD	**2. Chain drive, single gear, dual clutch, RWD**	**3. Chain drive, single gear, dual clutch, RWD**	**4. Chain drive, multi gear, single clutch, RWD**
1. Direct drive, FWD	0.083	0.036	0.071	0.115
2. Chain drive, single gear, single clutch, RWD	0.250	0.107	0.071	0.115
3. Chain drive, single gear, dual clutch, RWD	0.250	0.321	0.214	0.192
4. Chain drive, multi gear, single clutch, RWD	0.417	0.536	0.643	0.577
Sum	1	1	1	1

Table 1.6.18

Powertrain Material Cost Weighted and Criteria Weights

Consistency Vector	Criteria Weights {W}	Consistency Ratio
4.08	0.076	0.076
4.08	0.136	
4.35	0.245	
4.31	0.543	

Table 1.6.19

Powertrain Manufacturing Cost Pairwise Matrix

	1. Direct drive, FWD	2. Chain drive, single gear, dual clutch, RWD	3. Chain drive, single gear, dual clutch, RWD	4. Chain drive, multi gear, single clutch, RWD
1. Direct drive, FWD	1	0.33	0.33	0.2
2. Chain drive, single gear, single clutch, RWD	3	1	0.33	0.2
3. Chain drive, single gear, dual clutch, RWD	3	3	1	0.33
4. Chain drive, multi gear, single clutch, RWD	5	5	3	1
Sum	12	9.33	4.67	1.73

Table 1.6.20

Powertrain Manufacturing Cost Normalized Pairwise Matrix

	1. Direct drive, FWD	2. Chain drive, single gear, dual clutch, RWD	3. Chain drive, single gear, dual clutch, RWD	4. Chain drive, multi gear, single clutch, RWD
1. Direct drive, FWD	0.083	0.036	0.071	0.115

2. Chain drive, single gear, single clutch, RWD	0.250	0.107	0.071	0.115
3. Chain drive, single gear, dual clutch, RWD	0.250	0.321	0.214	0.192
4. Chain drive, multi gear, single clutch, RWD	0.417	0.536	0.643	0.577
Sum	1	1	1	1

Table 1.6.21

Powertrain Manufacturing Cost Weighted and Criteria Weights

Consistency Vector	**Criteria Weights {W}**	**Consistency Ratio**
4.08	0.076	0.068
4.08	0.136	
4.35	0.245	
4.31	0.543	

~~Appendix A: APA Headings (delete)~~

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~~See publication manual of the American Psychological Association page 62~~

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~~**Table 8**~~

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~~**Level of heading**~~	~~**Format**~~
~~**1**~~	~~**Centered, Boldface, Uppercase and Lowercase Heading**~~
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The objective of this manual is to detail the primary systems developed for the Senior Design Team 509 Nasa Human Powered Vehicle project for the fall 2020 to spring 2021 class. The objective of the project is to design and manufacture a human powered vehicle to traverse exoplanetary terrain in a NASA hosted competition.

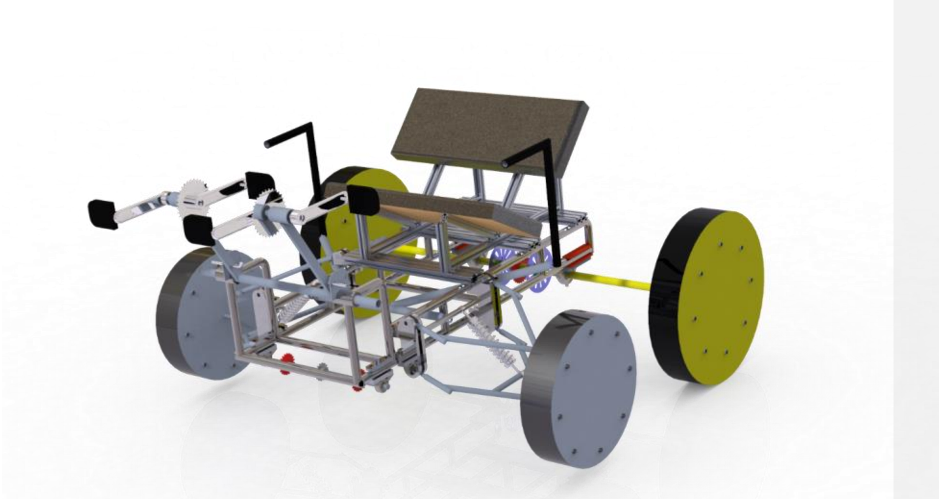

Figure 1: Overall view of Team 509 Human Powered Vehicle

Component Overview

Discuss the primary systems and then the components that make up their systems.

Steering

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The dual tiller steering design incorporates a lever arm on each outer side of the rover, with a linkage arm connecting both to each of the wheels. The dual tiller style provides quick response time and low complexity. The estimated weight for the steering system is 15 lbs. The aluminum handlebars were recycled from a bike purchased a few years ago. Each handle has an L-shape which was machined from a BMX bike handlebar. The handlebars are directly attached to the kingpin axis by a stem via a bolted clamp. To provide elevation to the handles, spacers were placed.

Figure 2: Steering system components.

Handlebar Component

For the right and left handlebars, aluminum recycled pieces from a previous bike purchased were welded together to give it an L-shape. The L-shaped handlebars are identical to one another allowing either or rider to easily provide a force in the left or right

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direction when turning. The handlebars are positioned on the outside of the rider's hips providing reachability for the riders. The arm of handlebar is 8.25'' long with a diameter of 1.042''. The handle has a length of 15'' with a diameter of 0.76''.

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Kingpin Axis Component

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The kingpin axis houses the steering knuckle, headset, spacer, and stem together. The kingpin axis connects the handlebars to wheels providing a rotational axis. The headset assembly is shown in a figure below.

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Figure 3: Kingpin axis diagram.

Bolted Clamp Component

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The bolted clamps are attached at one end of each handlebar to hold the stem and handle end together. The clamp is shown in as the green component in the CAD figure below.

Figure 4: Steering mechanism assembly view.

Tie Rod Placement

The original tie rod coupler given by a previous senior design team had the length of 31’’ Since our rover is for a two-person seater, a new rod was purchased to extend the tie rod. The purchased rod is an alloy steel hollow rod with a length of 3’’, a wall thickness 0.188’’, and a 70,000-psi yield strength. This material is easy to weld due it its low carbon content.

Figure 5: Tie rod extender component.

Steering Maintenance

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The headset and tie rod may wear out over time depending on its use. If these components wear out, they should be replaced. If riders are changed, the stem and handlebar can be adjusted to fit the rider as well.

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Wheels

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The wheel subsystem has four essential components that go into fabricating the wheels. Foam core, exterior tread, inner axle, and a mold to shape the core. The following sections will go into detail about why these components are used, as well as a guide on how to replicate them.

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Foam Core

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A polyurethane 2-part expanding foam is the material used for the four rover wheels. The foam starts out in two separate containers in the liquid form. The two parts should be mixed in a 1:1 ratio and stirred for 15 seconds to yield maximum volumetric expansion. The product is a strong, tough, and light foam.

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The major constraint for the wheels was the thickness being less than or equal to 3.75 inches. This constraint was imposed by the competition's dimensional constraints and the decision to use the frame from the previous year's NASA rover team. The optimized radius was found to be 17 inches for the front wheels and 21.4 inches for the back wheels. The cost to make four wheels out of polyurethane expanding foam is $137.60.

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Minimizing mass and cost were the objectives for the material selection. This is due to the NASA competition awarding points to lighter rovers, and the wheels being built on a limited budget. The function of each wheel is to not fail while under a maximum load of 950 Newtons and experience a deformation of 3.0×10^{-2} inches or less when traversing objects. These values were calculated using a factor of safety of 2.0 and using the weight of the rover and riders.

Figure 6: Polyurethane expanding foam, 8lb density.

Exterior Tread

The foam core does not supply sufficient friction to traverse the competition's obstacles, so an exterior tread is implemented. The exterior tread is wrapped around the entire curved section of the wheel, fastened with adhesive and set screws. The competition does not permit the use of tire tread, so a material similar to tire tread was repurposed to fit this objective. Cleated belting for roller-bed conveyors is utilized, as it is made from rubber and has tread on the top layer.

Figure 7: Repurposed cleated belting.

Inner Axle

The inner axle for the wheels is designed to allow for easy assembly, disassembly, and peak performance. The outer diameter of the axle is *just* smaller than the inner diameter of the foam core hole. The wheel axle is designed this way so that the wheel fits snugly but can still be taken off with ease.

The front and rear inner axles have the same dimensions and are made from the same material. The only difference is that the front inner axles freely rotate around an embedded steel rod with bearings. The rear inner axles are solid throughout, rigidly coupled to the rear driveshaft.

Figure 8: Front inner wheel axle (freewheel).

Figure 9: Rear inner wheel axle (rigid).

Wheel Mold

To yield the desired shape for our polyurethane wheels, female molds were created and used. MDF board was used for the cross-sections of the mold and polycarbonate film was used to wrap around the rim. The polycarbonate film is fastened to the MDF with set screws. Since the expanding foam has an associated pressure while expanding, two layers of polycarbonate are used to ensure structural integrity.

Figure 10: CAD rendering of mold.

Figure 11: Wheel mold with expanding foam.

Figure 12: Bottom of wheel mold.

Wheel Maintenance

Grease should be applied to the front inner axle bearings periodically. The wheel tread should be replaced when user sees fit.

Wheel Assembly

The inner axle should be machined and welded first. This is done so that the inner axle can be placed inside the wheel mold. MDF board is cut into circular cross-sections with a router and polycarbonate film is fastened around the MDF with set screws. The height of the polycarbonate film corresponds to the thickness of the wheels. Once the axle is placed inside the mold, spray the inside of the mold with mold release. After the entirety of the mold is covered in mold release, the liquid polyurethane mixture can be poured inside. Wait 1 hour to let foam expand and dry. Once the foam is completely dry, unscrew the set screws and separate the foam from the mold. Use gorilla glue adhesive on the curved portion of the wheel and wrap the tread around the wheel. Secure the tread by screwing into the foam. Slide the inner axle into the center hole of the foam wheel. Put second flange onto the axle.

Drivetrain

The drivetrain subsystem of the rover consists of three primary components: the pedal system, the intermediate drivetrain axle, and the rear drivetrain axle. The pedals are the initial point of contact with the riders to transfer the input torque, the intermediate shaft is used to then increase

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the output torque by lowering the gear ratio, and the rear axle then drives the wheels and contains the braking system. The following sections will delve deeper into the components that make up each of the primary components.

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Figure 13: Side view profile of frame and powertrain.

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Figure 14: Quarter view profile of the frame and powertrain.

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Pedal System Components

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The pedal system for the vehicle consists of 152 mm pedal cranks paired with 32 tooth standard single speed cassettes to drive the intermediate axle via the two 20 tooth free-wheel pinions. The pedals themselves have integrated shoe clips on them to ensure that when pedaling, the rider does not have their foot slip off the pedal. The system is mounted on a swivel and lock mechanism that allows the pedals to be moved in close to the vehicle to reduce its overall length. This locks the pedals in the frame via a pin and steel plates, additionally, when extended out, the pedals sit at 12 inches away from the frame at 60 degrees from the horizontal. The chain size used for the pedals and free-wheel pinions are 3/32-inch chains.

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Pedal System Maintenance

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To keep the pedals in working condition, the chain must be kept free of obstructions and any misalignment. The chain must be lubricated with bike chain lubricant to ensure that the links do not seize up. The pedals must be cleaned off when they get mud and dirt on them and the bearings on the pedals will need to be lubricated periodically, or when the movement becomes restricted or slowed down. The press fit bearings only require lubrication when they begin to make noises or seize up.

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Intermediate Axle Components

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The intermediate axle for the vehicle consists of a 20-inch long, 5/8-inch diameter solid keyed driveshaft, two Shimano SF-1200 20 tooth one-way free-wheel pinions with 5/8-inch inserts, a single 16-tooth ANSI size 35 pinion with a shaft collar attachment welded on, two 5/8-inch low profile mounted sealed ball bearing mounts and four ½ inch steel plate mounting brackets welded to the frame. The gears and pinions utilize the keyed shaft to mount their positions on the axle to allow for disassembly and maintenance of the system. The free-wheel pinions utilize the 3/32-inch chains to the chainrings on the pedals; however, the solid 16-tooth pinion uses ANSI size 35 steel roller chains to drive the rear axle drive gear.

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Figure 15: Intermediate driveshaft components system view.

Intermediate Axle Maintenance

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The intermediate axle for the vehicle must be kept clean and free of debris after each ride. The free-wheel pinions will need lubrication periodically as they begin to seize up or make louder clicks. The sealed bearings will need inspection periodically to ensure they do not become unseated from their positions or become loose on the shaft setscrews. Alignment of the solid drive pinion at the center of the driveshaft is important to drive the rear axle gear. The gear may be shifted along the axis of the axle to ensure that the chain alignment is correct. Bike chain lubricant will be used periodically on the chains to ensure smooth operations, and chain will be cleaned off after each ride to prevent seizing and rusting.

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Rear Axle Components

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The rear axle for the vehicle contains the main drive gear, dual disk brake system and wheel couplers to transfer the torque to the wheels. The rear axle is made of a 47-inch-long hollow steel driveshaft with an outer diameter size of 1-inch and inner diameter of 0.624-inches. The drive gear consists of an ANSI size 35, 35-tooth solid steel gear that is coupled to the driveshaft via a six-bolt flange-collar shaft mount. The rear drive chain consists of an ANSI size 35 steel roller chain. The attached disk brakes are 160 mm in diameter utilizing caliper brake mounts received from the previous team’s drivetrain. These brakes are operated using a steel cable line that is in combination with standard brake handles. The disk brakes are coupled to the driveshaft using ½ inch steel flange collars with a 6-bolt pattern. Two mounted cast iron housing steel ball bearing axle mounts are used with set screws for the rear axle. A half inch steel plate adapter is used for coupling the bearings to the existing mounts on the frame. The ends of the axle are then coupled together utilizing four high-torque flexible shaft couplings in conjunction with rugged roller chain locks. One hub is attached to the end of each driveshaft end while the other two are added one each to the shaft on the wheels. The locking chain then allows the shafts to be coupled together while allowing for disassembly if needed. These hubs are kept in place with setscrews and driveshaft keys to allow for alignment corrections.

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Figure 16: Rear axle components system view.

Rear Axle Maintenance

The rear axle must be kept clean after use, all debris and obstructions must be removed from the shaft and drivetrain parts. Lubrication will be needed periodically on the rear chain and a check for any loosening or slack on the chain is necessary before each ride. The disk brakes will have to be checked to ensure that the calipers clasp onto the disks. The handlebars for braking on the vehicle are mounted near the edge of the seats on the rover. Alignment of the rear drive gear and bearings needs to be checked by checking the alignment to the intermediate pinion and the setscrew tightness. Lastly, the couplers for the wheel shafts will need to be checked to ensure it is tight and aligned.

Support

The support subsystem consists of the frame, suspension, and seating.

Frame

The frame is made of 1 in. chromoly steel tubing. The tubing is welded together at various points. The frame also has multiple mounts welded onto the steel tubing. This includes mounting for the front and rear axles, brackets for the suspension, and mounts for the seating.

Suspension

The suspension is made of steel tubing and consists of an upper and lower wishbone, a strut, and a wheel mount. The suspension is the same on the left and right sides of the rover. The upper and lower wishbones connect to the upper and lower parts of the suspension bracket via bolts. The lower wishbones can be identified by the extra piece of tubing connecting the two sides. The lower part of the strut is mounted to this cross tubing using a bolt and the upper part is

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connected to the middle piece of the suspension bracket, again using a bolt. There are multiple holes in the top strut mount which can allow for a different mounting angle of the strut.

Seating

The rover bench seat is mounted to the frame using multiple 10 series 8020 aluminum pieces and connectors. There are two 1x3 in. 8020 pieces, one is 20.5 in. in length and the other is 25 in. in length. The 20.5 in. piece is placed horizontally and centered in the front mounts on the frame. Two ¼-20 Double Slide-in Economy T-nuts are used to attach the 8020 piece onto the sides of the mount, both on the left and right. Two ¼-20 Slide-in Economy T-nuts are used to attach to 8020 piece to the bottom of the mount, again being the same on both sides. The other 1x3 in. 8020 piece is placed onto the rearmost frame mount. This is secured to each mount using two ¼-20 Double Slide-in Economy T-nuts. Two 1x1 in. 8020 pieces, both 25 in. in length, are then secured to the middle frame mounts using the same securing method as the 25 in. 1x3 in. 8020 piece. Each Economy T-nut, single and double, is held into place using ¼-20 x 0.75 in. bolts. 24 of these bolts are needed to mount the 8020 pieces to the frame.

From this point on, the same assembly of 8020 pieces needs to be completed twice. These assemblies must each be placed 10 in. from the longitudinal centerline of the frame.

Next, a 1x1 in. piece of 8020, 23 in. long, is placed perpendicular to the already placed pieces. It should be 1 in. from the side of the frontmost and rearmost 1x3 in. 8020 pieces. This is attached using a 10 Series 9 Hole – Wide Slotted Inside Corner Bracket. Two of these brackets are used, one at the frontmost and one at the rearmost connection. The bracket is attached using ¼-20 x 5.00 in. Black BHSCS and Slide-in Economy T-nuts.

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From this point on, every plate is held into place using ¼-20 x 5.00 in. Black FBHSCS and Slide-in Economy T-nuts. There is then a 1x1 in. 8020-piece 5 in. long, placed vertically onto the frontmost 1x3 in. 8020 piece. It should be lined up with the previously placed 23 in. long 1x1 in. piece. The 5 in. piece is attached to the 23 in. pieces using 10 Series 5 Hole – 90 Degree Angled Flat Plates. Two of these plates are used on either side of each 5 in. piece, with four being used in total.

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Next, a 1x1 in. 8020 piece that is 10.25 in. long is mounted to the top of the 5 in. long piece just mounted. This is mounted using two 10 Series 5 Hole – 60 Degree Angled Flat Plates, one on either side of the connection. The other end of the 10.25 in. long piece is mounted to the base 23 in. long piece using two 10 Series 5 Hole – 30 Degree Angled Flat Plates.

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We then have a 1x1 in. 8020-piece 12.73 in. long, placed vertically onto the rearmost 1x3 in. 8020 piece. It should be lined up with the previously placed 23 in. long 1x1 in. piece. The 12.73 in. piece is attached to the 23 in. pieces using 10 Series 5 Hole – 90 Degree Angled Flat Plates. Two of these plates are used on either side of each 5 in. piece, with four being used in total.

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Next, a 1x1 in. 8020 piece that is 18.25 in. long is mounted to the top of the 12.73 in. long piece just mounted. This is mounted using two 10 Series 5 Hole – 45 Degree Angled Flat Plates, one on either side of the connection. The other end of the 18.25 in. long piece is mounted to the base 23 in. long piece using two 10 Series 5 Hole – 45 Degree Angled Flat Plates.

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Now that the entire seat mount is put together, the seat just needs to be attached. The bench seat attaches to the two 10.25 in. pieces using four ¼-20 x 3 in. bolts. The bench back attaches to the two 18.25 in. pieces, also using four ½-20 x 3 in. bolts. The entire seating setup and mount can be seen in the image below.

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Figure 17: Seat with Seat Mounts

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Integration Overview

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The following section will discuss the vehicle's assembly and integration with all four primary rover systems.

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Support

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The support section includes the frame, suspension, and seating. The method of bringing these parts together was already discussed above in detail. The suspension should be attached to the frame first, followed by the drivetrain and the wheels. The seating, along with the seating mount, should be assembled last to allow for easy access while bringing together the other subsystems.

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Steering

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After the frame is completed, the dual tiller steering system is integrated into the vehicle design right before integrating the seating. The steering tie rod is directly connected to the front wheels through the headset components and steering knuckle. A further explanation of the headset can be found in the steering section.

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Drivetrain

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The drivetrain components for the rover are placed on the rover shortly after the frame assembly and suspension assembly is completed. This is done to avoid interference with the seating, steering and wheel components. After initial assembly, none of the parts should be entirely removed or uninstalled to prevent damage or misalignment. The first step in the assembly is to put the pedals in place.

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To mount the pedals the bottom bracket must first be mounted into the bottom bracket shell. After this, one pedal with the gear is attached on one side of the bottom bracket, and one pedal without the gear is attached on the other side. This is done for both sets of pedals. Once they are setup, the necessary chain is placed around the pedal gears to the intermediate axle.

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To begin the intermediate axle assembly, the first step is to mount the solid steel pinion with its shaft key to the shaft at the centerline of the shaft, then tighten the set screw. Next, the free-wheel pinions are mounted 4.24 inches from the ends of the driveshaft and set in place with setscrews and the provided shaft keys. The following step is to mount the bearings for the intermediate axle are onto the intermediate driveshaft with 0.64 inches sticking out from either side of the outer bearing housing. Once the bearings are on the shaft and the primary components are mounted onto the shaft, the assembly can be bolted onto the frame. Once the intermediate axle is integrated onto the frame, the rear axle can be mounted and secured. A detailed schematic is provided in the image below.

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Figure 18: Intermediate axle assembly positioning, units listed in inches.

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To begin the rear axle assembly, the drive gear and flange will need to be mounted first, followed by the dual disk brakes and their couplers, ensure that the setscrews are tightened down. Next, the bearing mounts will be attached to the shaft via the set screws and then tightened down for mounting. Once these are attached, the rear axle can be mounted onto the frame by utilizing the mount adapter provided for each mounting bracket. The shaft couplers will then be added to the ends of the axle and secured by the shaft keys. The corresponding shaft couplers must then be attached onto the individual wheel axles before attaching to the rear axle via the provided chain coupler. A detailed schematic is provided in the image below.

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Figure 19: Rear axle assembly positioning, units in inches.

System

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Discuss the systems integration approach that was used and the general guidelines for putting the vehicle together.

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Operation Overview

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The following section will detail the vehicle preparation and operation steps to guarantee safe and proper vehicle operations. The personal protective equipment must be self-provided and includes gloves, closed toe shoes, a bike helmet, safety goggles and knee/elbow pads.

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Vehicle Preparation

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The human powered vehicle must first be inspected on an individual system maintenance check as explained in the component overview section of this document. The main points of interest are the drivetrain gear alignments, wheel couplers, chain slack and seating position. Once all the components have been verified to be in working condition, the rover is then ready to embark on an expedition.

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Vehicle Operation

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To operate the vehicle safely, the riders must wear their personal protective equipment, secure their feet into the pedals, and strap their seatbelts on. The pedaling mechanism allows for assistive torque input into the rover but also allows the riders to pedal one at a time to take breaks on an excursion. Optimal pedaling consists of synchronizing the pedaling cadence for both riders. The vehicle does not utilize a reverse pedaling mechanism, to back-up, the riders must remove their seatbelts and move the vehicle back. The steering of the vehicle is done with a dual tiller steering mechanism which requires both riders to verbally communicate with one another for optimal turning and maneuverability. Each rider can steer the vehicle by themselves by utilizing their individual steering arm, however it is encouraged to have both riders simultaneously steering for effortless operation. Braking of the vehicle is done via two individual bike handle brakes coupled to the dual disk brakes on the rear axle. To decrease the braking distance, both riders must press down their brake handles simultaneously to assist one another in braking.

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Troubleshooting Overview

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Should the users encounter trouble with the rover, or components within the rover, the following bullet points have insights into some of the possible troubleshooting methods.

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- If steering becomes more difficult spray lubricant inside the tie rod joints.
- If pedaling becomes more difficult grease all sprockets and bearings.
- Should the rear drivetrain chain become loose, slack can be tightened by moving the intermediate and rear axle bearing housings back/forward some.
- If any of the intermediate axle pinions become misaligned, the pinions can be moved along the shaft key to correct for misalignment.
- Seating mounts can be tightened to maintain rigidity and can slide back some if needed for larger riders.

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Important Resources

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Over the course of the project, important resources and knowledge has been gathered and shared with the team, the following section contains this information.

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The Human Exploration Rover Challenge competition requires constant upkeep with deadlines, it is highly recommended that a shared calendar be created to keep track of deliverables. Dual purpose manuals, reports and presentations are also highly recommended as they may coincide with Senior Design reviews. If further information is needed from NASA, their contact email is as follows: MSFC-roverchallenge@mail.nasa.gov.

This project is heavily dependent on machinability so speaking to the machine shop is important. Justin Pogge in the machine shop has been a valuable resource for information and feasibility of designs. Justin has made numerous recommendations for the rover that have been implemented. Justin is also experienced with bike design and manufacturing and will have input regarding using off the shelf components.

Ordering parts for the design is also critical to get right and done in a timely manner, vendors such as McMaster-Carr, Summit Racing, and 8020 have been very useful. In this project, McMaster Carr has been the main source for part orders and generally delivers within 1-2 days. McMaster-Carr also allows the STEP file download which allows for easy CAD implementation into PTC Creo, SolidWorks, or Autodesk applications.

An additional resource that was utilized was our advisor Shayne McConomy. Dr. McConomy has been a resource for information and wheel mold construction, he has input regarding previous teams' parts and additional materials that can be utilized in design. Dr.

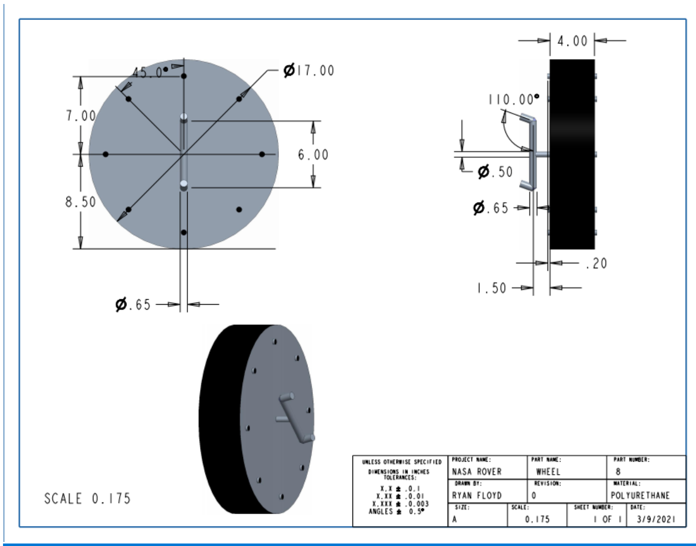
McConomy has access to the files found on Basecamp and all the previous websites for Senior Design.

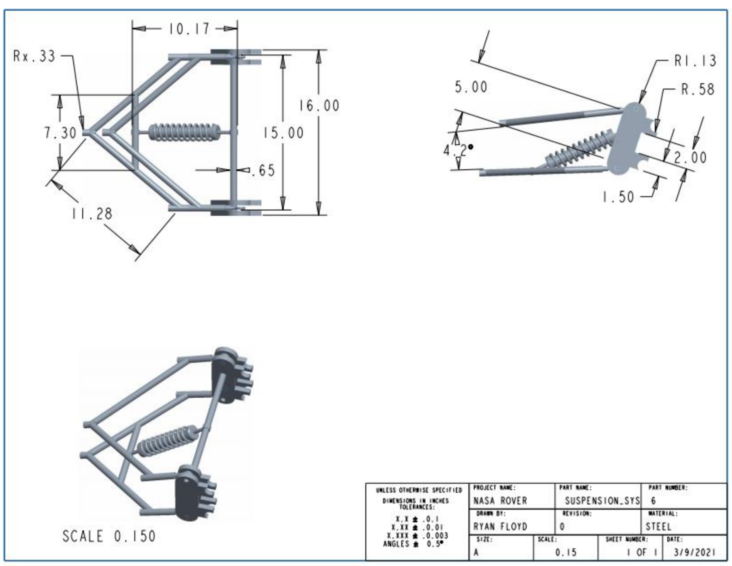
Access to all of Team 509's files, CAD, presentations and deliverables can be found on the following site:

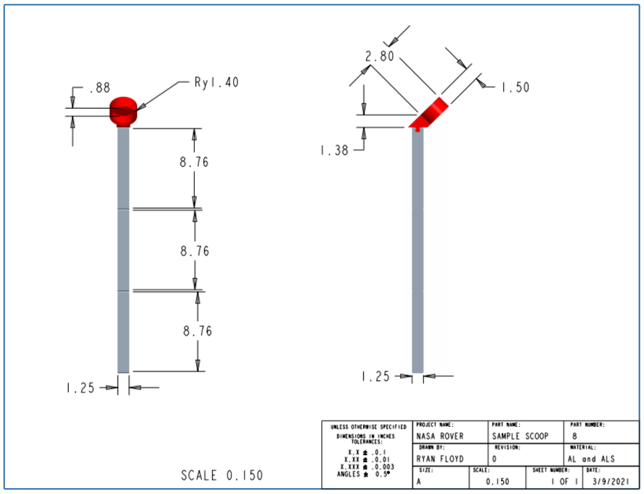
https://adminmyfsu.sharepoint.com/sites/seniordesignnasahumanpoweredvehicleteam

Admin access to this website can be requested by contacting
Andrew Schlar at as18fy@my.fsu.edu or andrew.s28@hotmail.com. If additional information is needed, he can reach out to all former members of Team 509. An Instagram for the project was created and is called "famufsuhumanpoweredroverteam" and ownership and email information can be transferred over to the new Senior Design team by contacting Andrew Schlar.

Appendix G: Engineering Drawings



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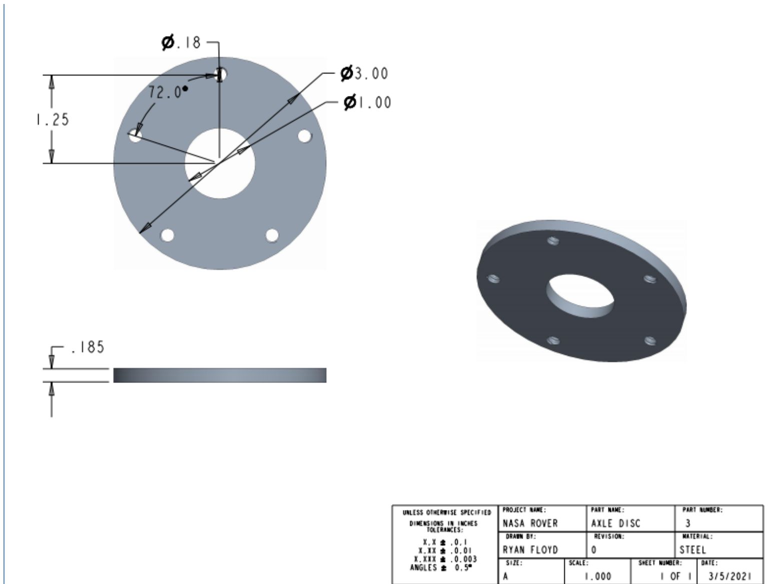
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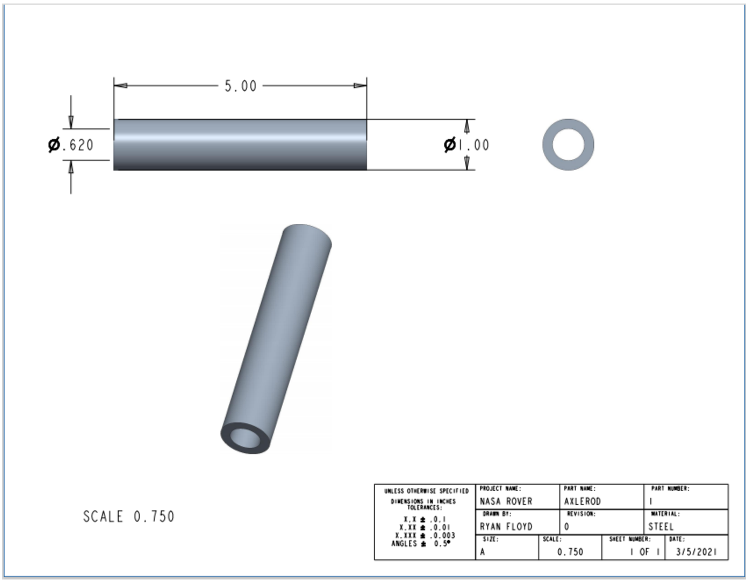
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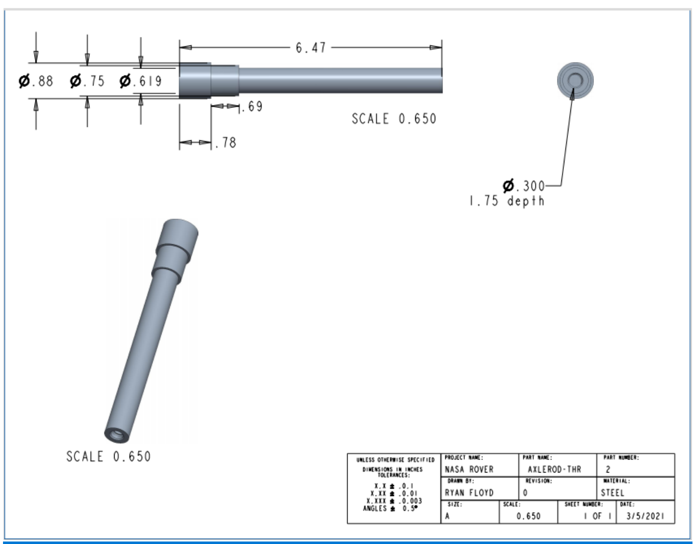
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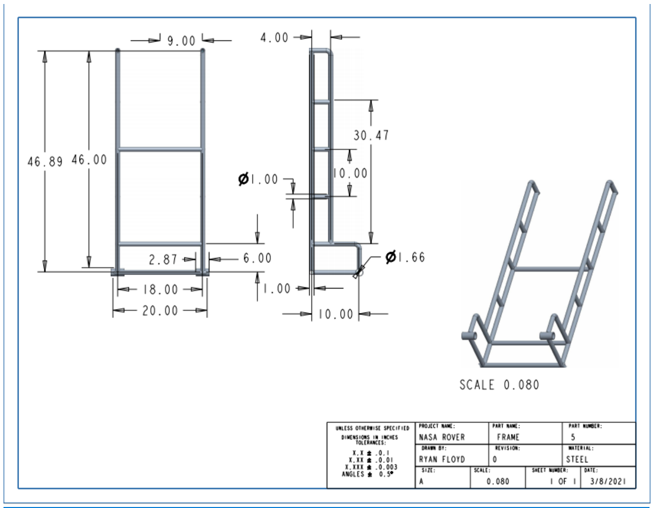
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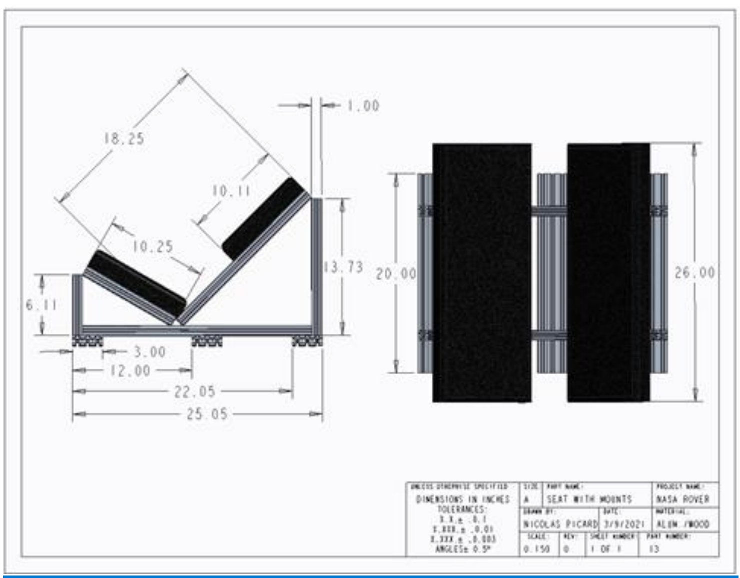
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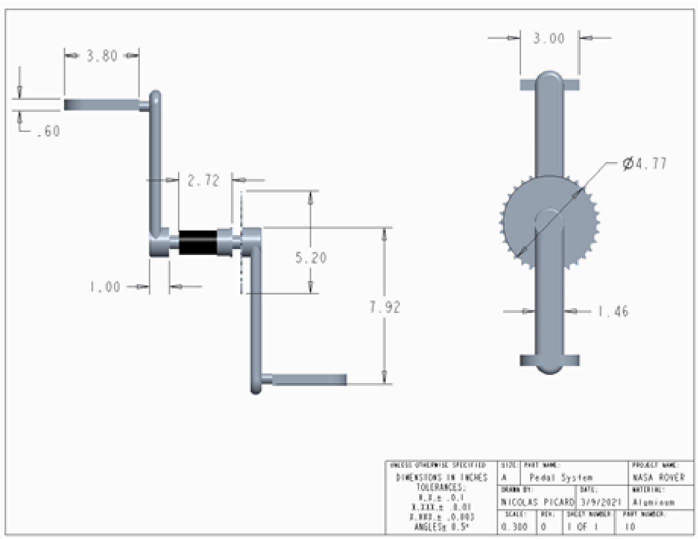
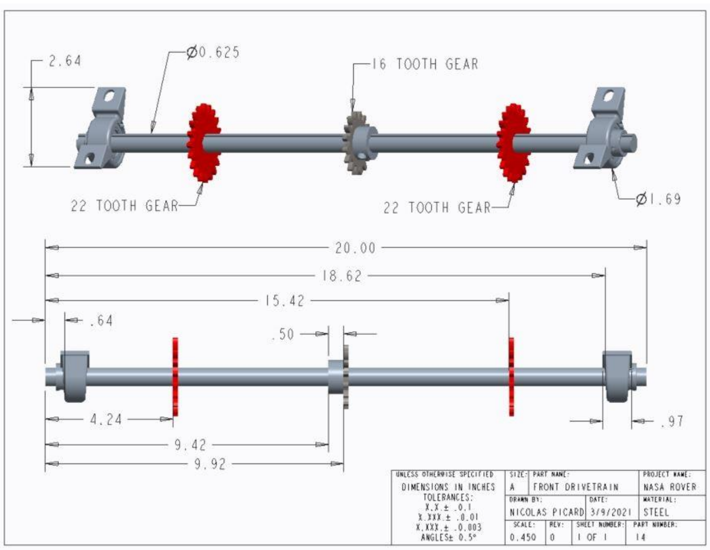
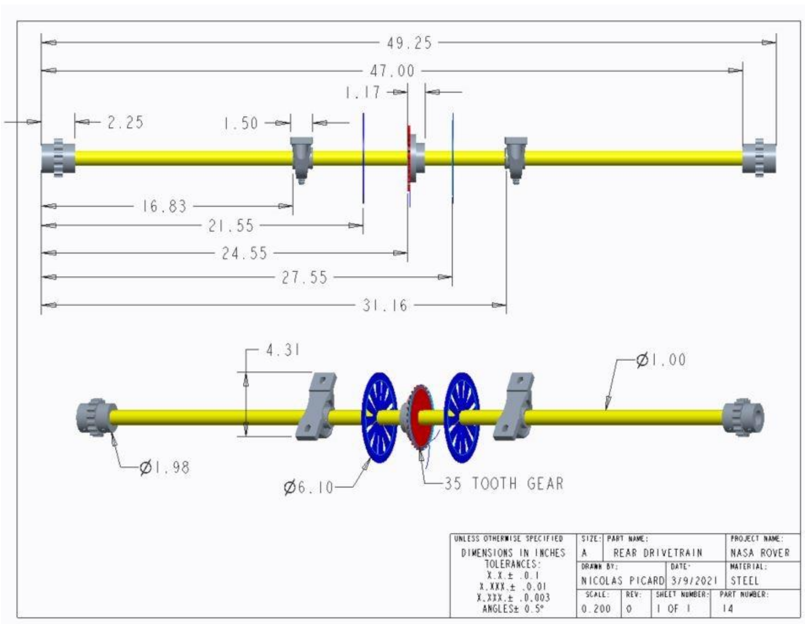
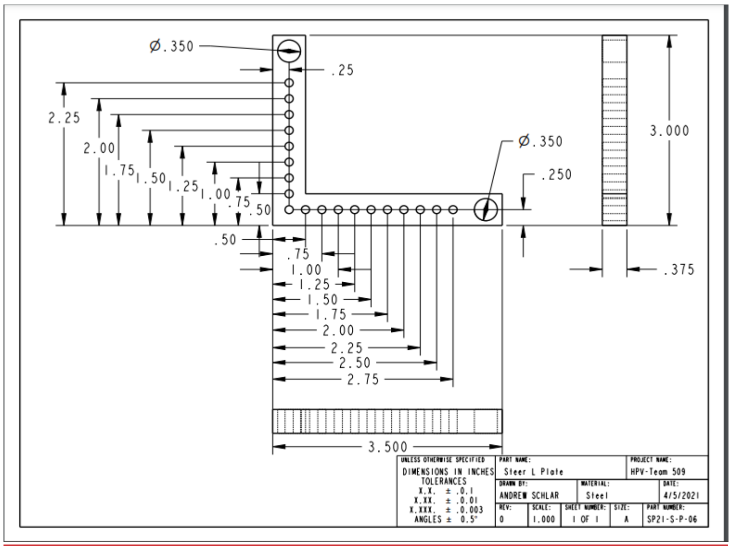
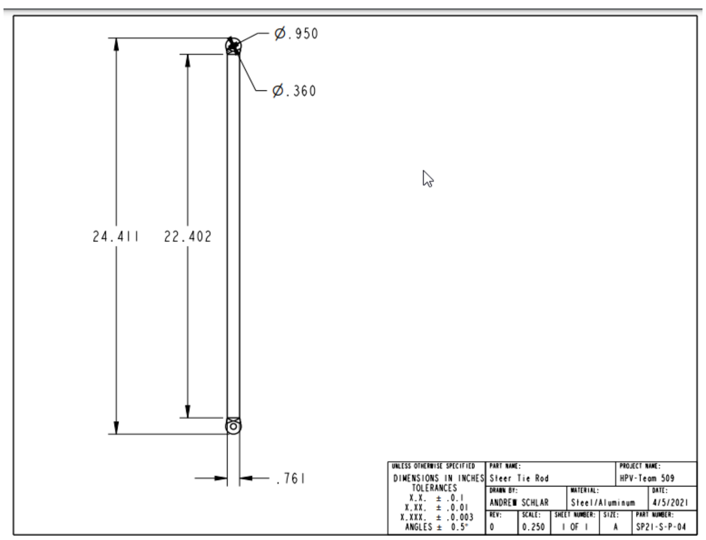
PROJECT NAME: NASA ROVER
DRAWN BY: NICOLAS PICARD
DATE: 3/9/2021
MATERIAL: ALUM. /WOOD
SCALE: 0.150
REV: 0
SHEET NUMBER: 1 OF 1
PART NUMBER: 13

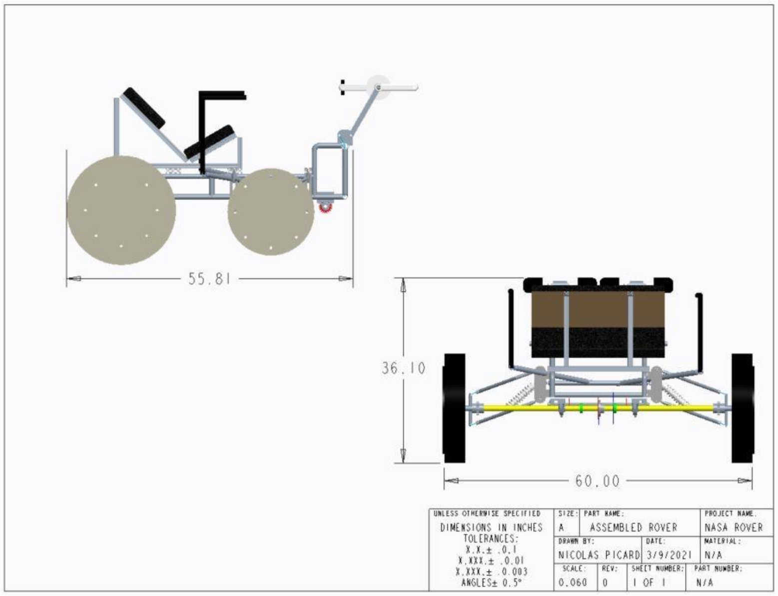

3.80
.60
2.72
5.20
1.00
7.92
3.00
Ø4.77
1.46
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X ± .0.1
X.XX ± .0.01
X.XXX ± .0.003
ANGLES± 0.5°
SIZE: A
PART NAME: Pedal System
DRAWN BY: NICOLAS PICARD
DATE: 3/9/2021
SCALE: 0.300
REV: 0
SHEET NUMBER: 1 OF 1
PROJECT NAME: NASA ROVER
MATERIAL: Aluminum
PART NUMBER: 10

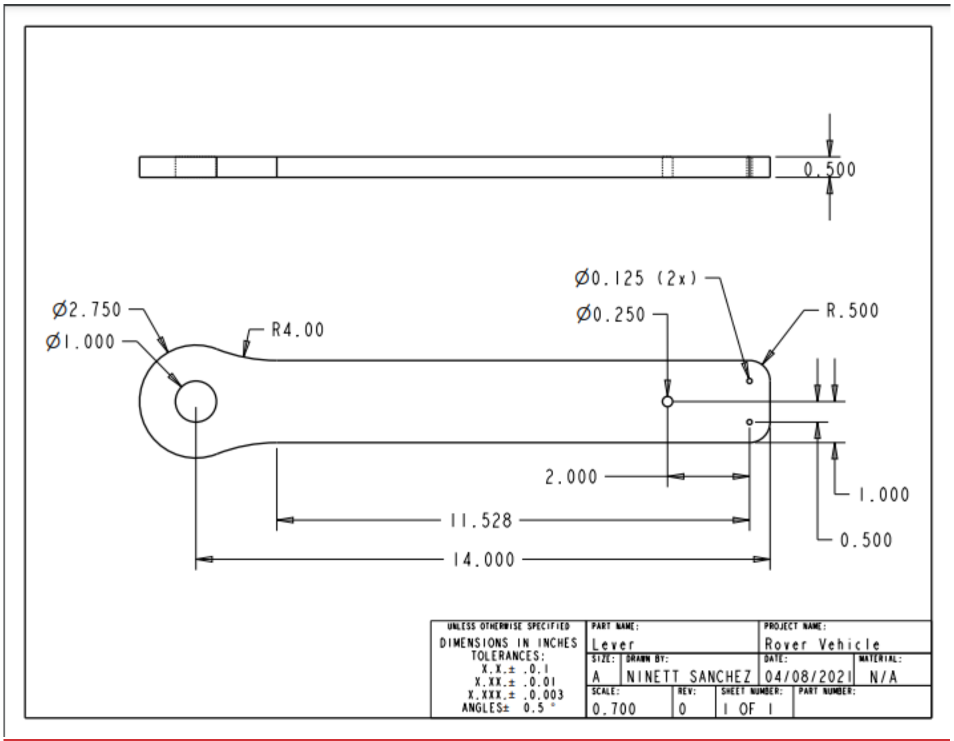

2.64
Ø0.625
16 TOOTH GEAR
22 TOOTH GEAR
22 TOOTH GEAR
Ø1.69
20.00
18.62
15.42
.64
.50
4.24
9.42
9.92
.97
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X ± .0.1
X.XX ± .0.01
X.XXX ± .0.003
ANGLES± 0.5°
SIZE: A
PART NAME: FRONT DRIVETRAIN
DRAWN BY: NICOLAS PICARD
DATE: 3/9/2021
SCALE: 0.450
REV: 0
SHEET NUMBER: 1 OF 1
PROJECT NAME: NASA ROVER
MATERIAL: STEEL
PART NUMBER: 14


49.25
47.00
1.17
2.25
1.50
16.83
21.55
24.55
27.55
31.16
4.31
Ø1.00
Ø1.98
Ø6.10
35 TOOTH GEAR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X ± .0.1
X.XX ± .0.01
X.XXX ± .0.003
ANGLES± 0.5°
SIZE:
A
PART NAME:
REAR DRIVETRAIN
PROJECT NAME:
NASA ROVER
DRAWN BY:
NICOLAS PICARD
DATE:
3/9/2021
MATERIAL:
STEEL
SCALE:
0.200
REV:
0
SHEET NUMBER:
1 OF 1
PART NUMBER:
14

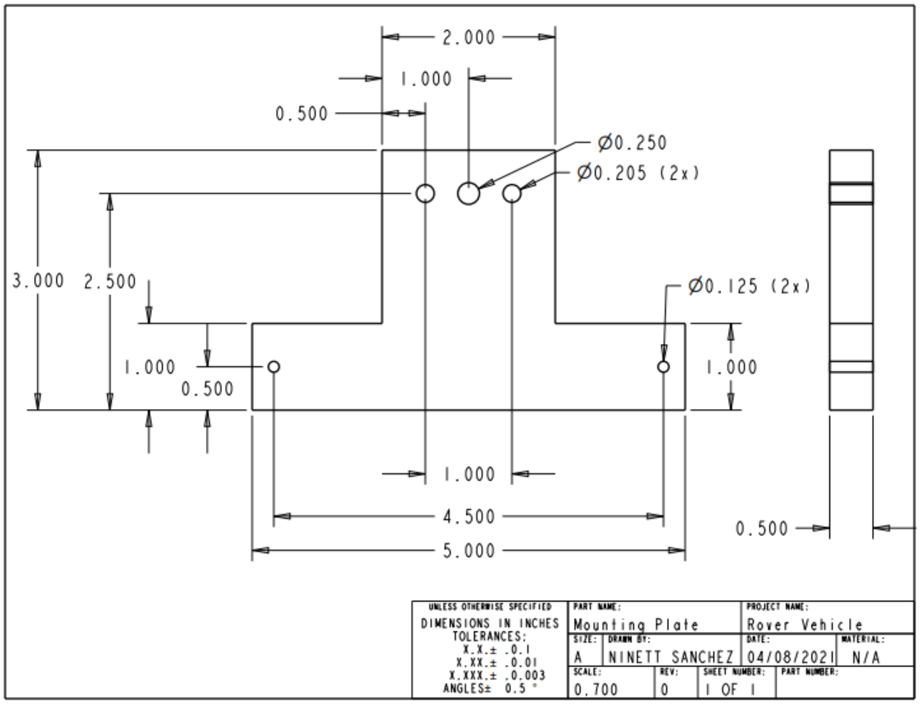

Ø.350
.25
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
Ø.350
.250
3.000
.50
.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
.375
3.500
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Steer L Plate
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
4/5/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-S-P-06

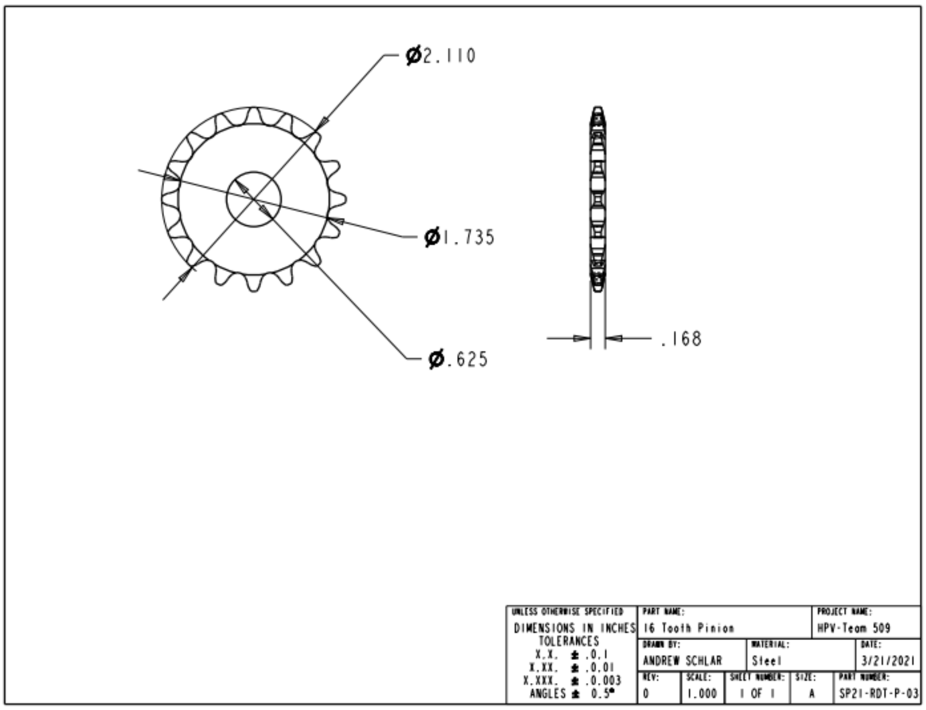

Ø.950
Ø.360
24.411
22.402
.761
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Steer Tie Rod
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel/Aluminum
DATE:
4/5/2021
REV:
0
SCALE:
0.250
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-S-P-04

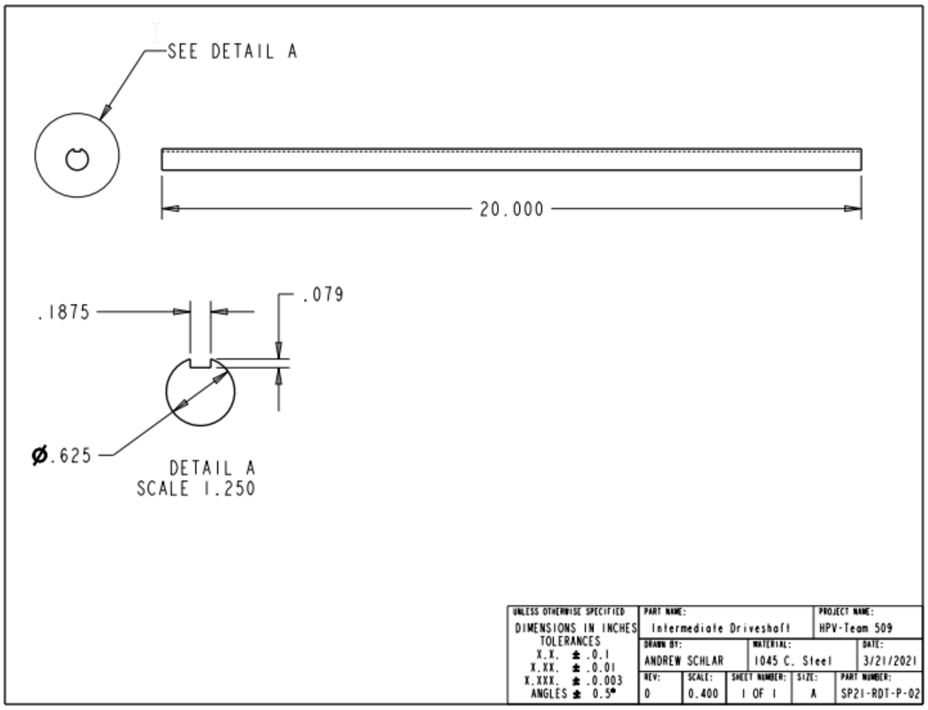

55.81
36.10
60.00
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X.± .0.1
X.XXX.± .0.01
X.XXX.± .0.003
ANGLES± 0.5°
SIZE:
A
PART NAME:
ASSEMBLED ROVER
PROJECT NAME.
NASA ROVER
DRAWN BY:
NICOLAS PICARD
DATE:
3/9/2021
MATERIAL:
N/A
SCALE:
0.060
REV:
0
SHEET NUMBER:
1 OF 1
PART NUMBER:
N/A

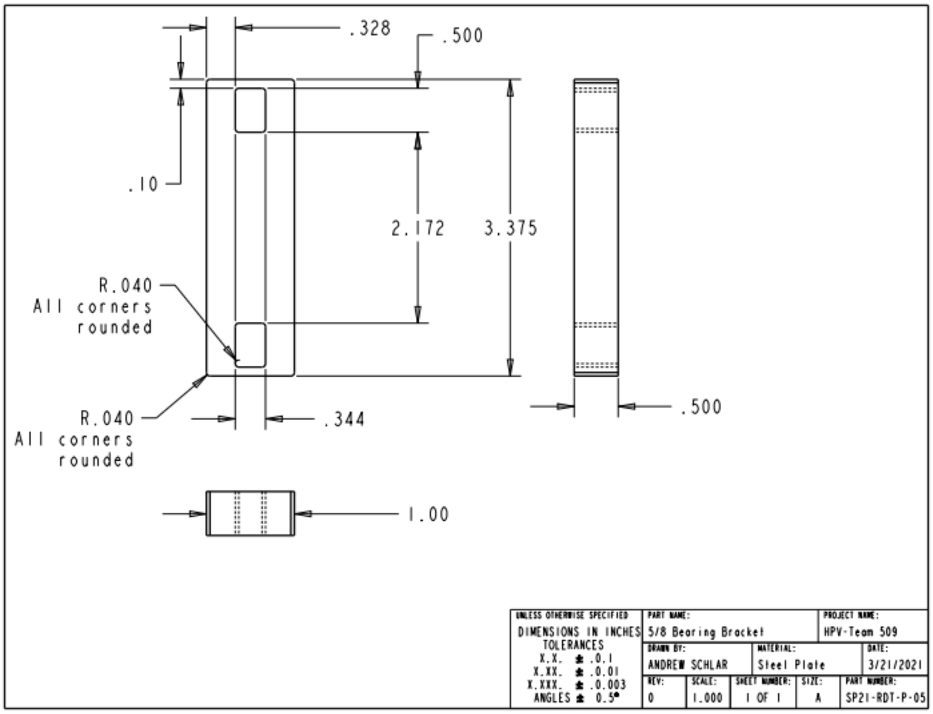


0.500
Ø0.125 (2x)
Ø2.750
Ø0.250
R.500
Ø1.000
R4.00
2.000
1.000
11.528
0.500
14.000
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X.± .0.1
X.XX.± .0.01
X.XXX.± .0.003
ANGLES± 0.5 °
PART NAME:
Lever
SIZE:
A
DRAWN BY:
NINETT SANCHEZ
PROJECT NAME:
Rover Vehicle
DATE:
04/08/2021
MATERIAL:
N/A
SCALE:
0.700
REV:
0
SHEET NUMBER:
1 OF 1
PART NUMBER:

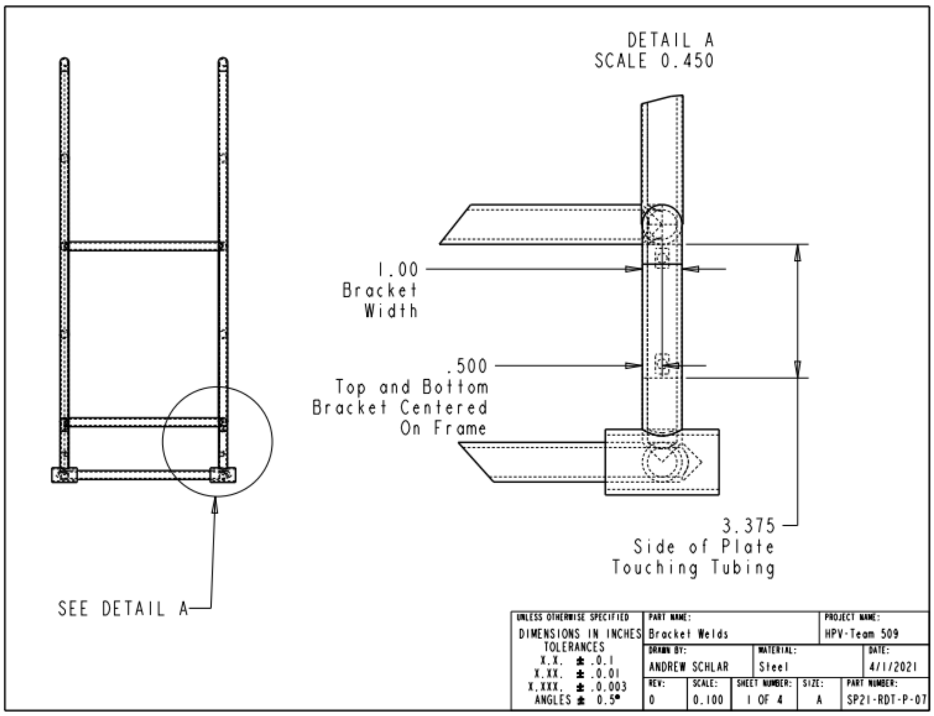

2.000
1.000
0.500
Ø0.250
Ø0.205 (2x)
3.000
2.500
Ø0.125 (2x)
1.000
0.500
1.000
1.000
4.500
5.000
0.500
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X.± .0.1
X.XX.± .0.01
X.XXX.± .0.003
ANGLES± 0.5 °
PART NAME:
Mounting Plate
PROJECT NAME:
Rover Vehicle
SIZE:
A
DRAWN BY:
NINETT SANCHEZ
DATE:
04/08/2021
MATERIAL:
N/A
SCALE:
0.700
REV:
0
SHEET NUMBER:
1 OF 1
PART NUMBER:

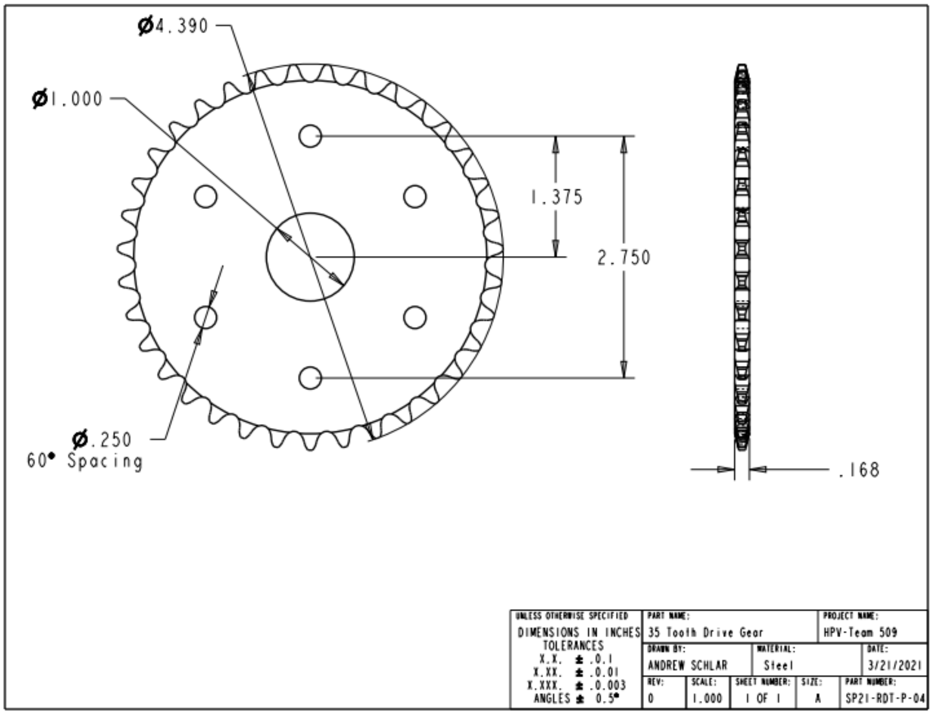

Ø2.110
Ø1.735
Ø.625
.168
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
16 Tooth Pinion
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
3/21/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-03


SEE DETAIL A
20.000
.1875
.079
Ø.625
DETAIL A
SCALE 1.250
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Intermediate Driveshaft
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
1045 C. Steel
DATE:
3/21/2021
REV:
0
SCALE:
0.400
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-02

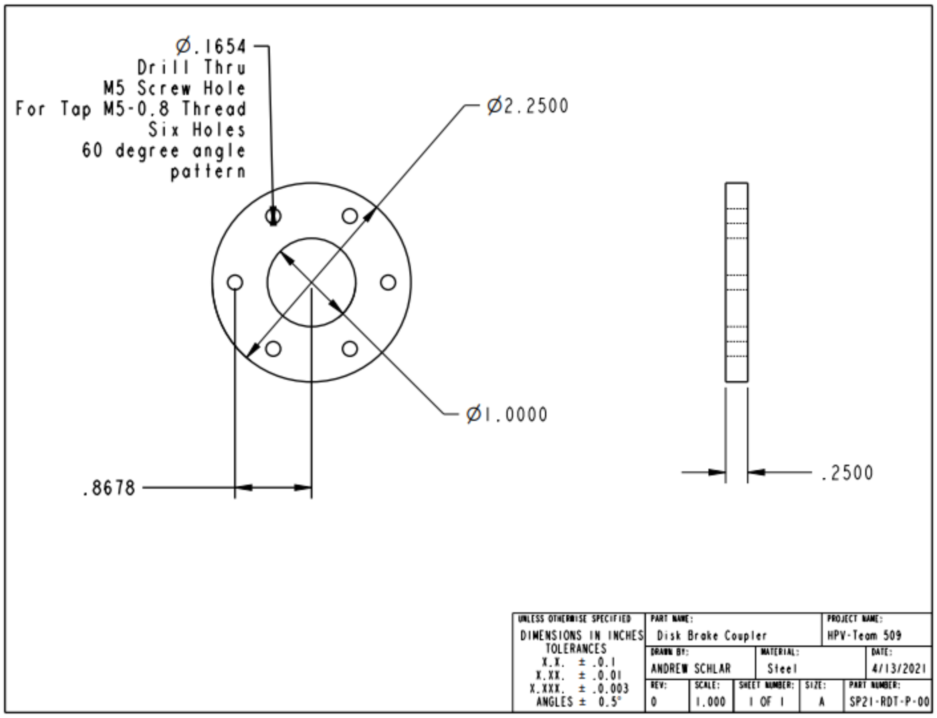


.328
.500
.10
2.172
3.375
R.040
All corners rounded
R.040
All corners rounded
.344
.500
1.00
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
5/8 Bearing Bracket
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel Plate
DATE:
3/21/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-05

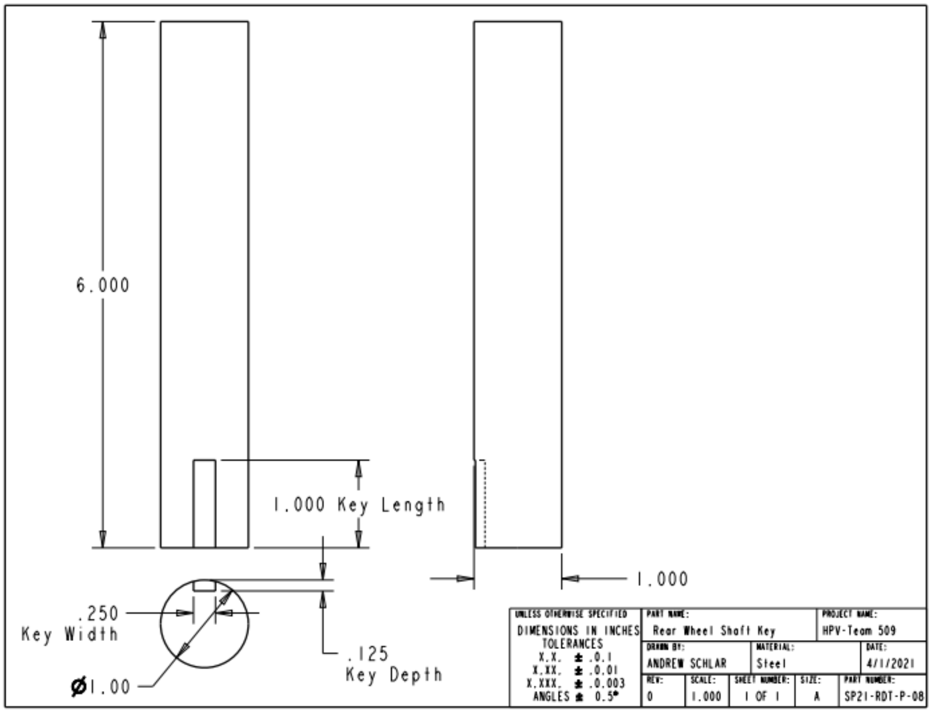

DETAIL A
SCALE 0.450
1.00
Bracket
Width
.500
Top and Bottom
Bracket Centered
On Frame
3.375
Side of Plate
Touching Tubing
SEE DETAIL A
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Bracket Welds
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
4/1/2021
REV:
0
SCALE:
0.100
SHEET NUMBER:
1 OF 4
SIZE:
A
PART NUMBER:
SP21-RDT-P-07



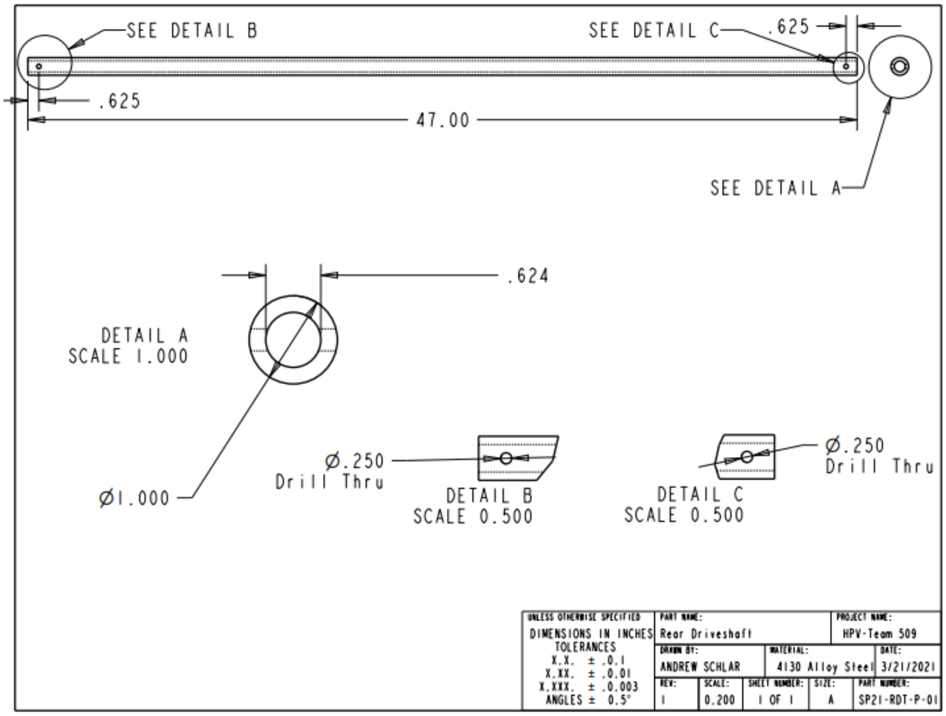
Ø4.390
Ø1.000
1.375
2.750
Ø.250
60° Spacing
.168
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
35 Tooth Drive Gear
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
3/21/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-04

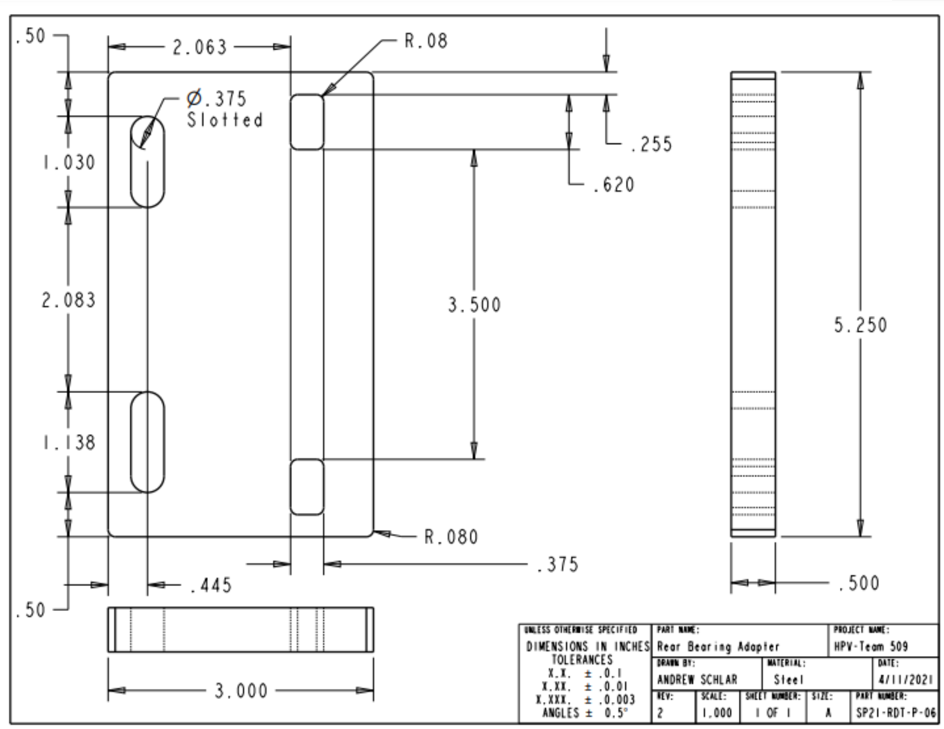


Ø.1654
Drill Thru
M5 Screw Hole
For Tap M5-0.8 Thread
Six Holes
60 degree angle
pattern
Ø2.2500
Ø1.0000
.8678
.2500
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Disk Brake Coupler
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
4/13/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-00



6.000
1.000 Key Length
1.000
.250
Key Width
.125
Key Depth
Ø1.00
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Rear Wheel Shaft Key
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
4/1/2021
REV:
0
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-08


SEE DETAIL B
SEE DETAIL C
.625
.625
47.00
SEE DETAIL A
.624
DETAIL A
SCALE 1.000
Ø1.000
Ø.250
Drill Thru
DETAIL B
SCALE 0.500
DETAIL C
SCALE 0.500
Ø.250
Drill Thru
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Rear Driveshaft
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
4130 Alloy Steel
DATE:
3/21/2021
REV:
1
SCALE:
0.200
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-01


.50
2.063
R.08
Ø.375
Slotted
.255
.620
1.030
2.083
3.500
5.250
1.138
R.080
.375
.445
.500
.50
3.000
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
X.X. ± .0.1
X.XX. ± .0.01
X.XXX. ± .0.003
ANGLES ± 0.5°
PART NAME:
Rear Bearing Adapter
PROJECT NAME:
HPV-Team 509
DRAWN BY:
ANDREW SCHLAR
MATERIAL:
Steel
DATE:
4/11/2021
REV:
2
SCALE:
1.000
SHEET NUMBER:
1 OF 1
SIZE:
A
PART NUMBER:
SP21-RDT-P-06

Appendix H: Calculations

Powertrain

35 tooth drive gear, 16 tooth intermediate

Assume 55 Nm input, 65 rpm

1st Stage

max rpm input = 75 rpm

$$T_{out} = \frac{20}{32}\left(2\left(40.5659\right)\right) = 50.707 \text{ ft-lb}$$

2nd Stage

$$T_{out} = \frac{35}{16}\left(50.707\right) \text{ ft-lb} = 110.9223828 \text{ ft-lb}$$

rear wheel radius 10.675

$$\tau_1 \omega_1 = \tau_2 \omega_2$$

$$81.1318(65) = 50.707\,\omega_2$$

@ 65 rpm input 55 Nm

intermediate axle $\rightarrow$ $\omega_2 = 104.000$ rpm

$$50.707(104) = 110\,\omega_3$$ rear axle

$$\omega_3 = 47.941 \text{ rpm}$$

Linear vel = $r \times RPM \times \underbrace{0.10472}_{\text{unit conversion}}$

$V = 3.04$ mph @ 65 rpm

Avg speed

Powertrain continued

35 tooth rear drive, 16 tooth intermediate

@ 75 rpm

55 Nm

input max torque $\rightarrow 81.1318(75) = \tau_2 \omega_2 = 50.707\,\omega_2$

$\omega_2 = 120\,rpm$

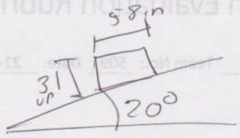
$50.707(120) = 110.922(\omega_3)$

$\omega_3 = 54.8569\,rpm$

$V = 3.48$ mph max speed

Assuming 94% efficiency chain drive

COM - Calculations [Tipping Risk]



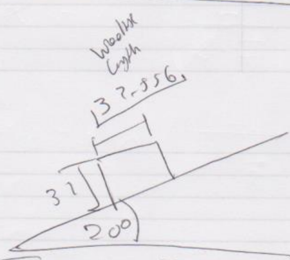
$$\theta_c = \tan^{-1}\left(\frac{\frac{T}{2}}{H}\right)$$

$$\theta_c = \tan^{-1}\left(\frac{\frac{4.740833}{2}}{\left(\frac{31}{12}\right)}\right)$$

$$\boxed{\theta_c = 42.53888^\circ}$$

Sideways Tipping Angle

Sideways

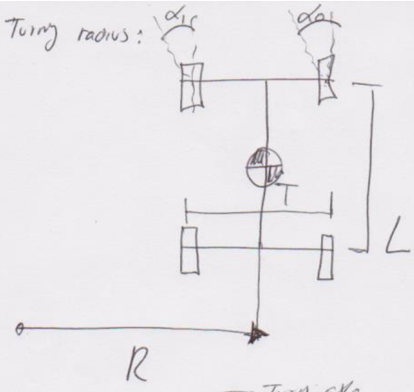


Com
28" + 31"

@ 28" 30°
@ 31" 28°

Forward Tipping Angle

Turning radius: ④



overall length 58 in

COM 31 inch up

$ft = 2.713$

$L = ?\ 32.556\,in$

$R = ? = 15\,ft$

$T = ?\ 56.89\,in$

$ft = 4.740833$

Turning angle

$$\alpha_1 = \tan^{-1}\left(\frac{L}{R - \frac{T}{2}}\right)$$

Turning angle

$$\alpha_o = \tan^{-1}\left(\frac{L}{R + \frac{T}{2}}\right)$$

$\alpha_1 = 12^\circ$ $\quad$ $15 \to 20^\circ$

$\alpha_2 = 8.8777$

$$R = \left(\frac{L}{\tan(20)}\right) + \frac{T}{2} \qquad \tan(20) = \frac{L}{R \cancel{+} \frac{T}{2}} = 10\,ft$$

Appendix I: Risk Assessment

Project Hazard Assessment Worksheet				
PI/instructor: Shayne McConomy	Phone #: 850-410-6624	Dept.: Mech Eng.	Start Date: 9/3/2021	Revision number: 1
Project: NASA Human Powered Vehicle			Location(s): FAMU-FSU College of Engineering Marshall Space Flight Center in Huntsville, AL	
Team member(s): Ryan Floyd Nicolas Picard Ninett Sanchez Andrew Schlar			Phone #: 305-542-7542 407-714-8610 508-405-6281 850-812-9173	Email: Rmf17@my.fsu.edu Np16b@my.fsu.edu Nos16@my.fsu.edu As18fy@my.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Prototype rover	Home	All group members	None	N/A	None	N/A	HAZARD: 1 CONSEQ: Negligible Residual: Low	N/A
Inventory/collect leftover parts from	FAMU-FSU College of	Andrew Schlar, Ryan Floyd	Ergonomic hazard, mishandling parts, misusing tools.	Carefully handle parts and pick appropriate	Protective gloves, safety glasses, masks,	N/A	HAZARD: 1 CONSEQ: Minor Residual: Low	Use multiple people to lift heavy

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Field Code Changed
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previous teams	Engineering			tools for disassembly.	hand sanitizer			parts, lift with legs. Wear gloves when dealing with sharp objects.
In-person team meetings	FAMU-FSU College of Engineering	All group members	COVID-19 Exposure	Social distancing	Masks, hand sanitizer	N/A	HAZARD: 2 CONSEQ: Moderate Residual: Low Medium	Wear masks at all times, maintain social distancing
Assemble rover	Home and FAMU-FSU College of Engineering	All group members	Mishandling parts, misusing power tools, spilling of oil and non-organic lubricants, COVID-19 exposure	Pick appropriate tools for assembly, keep oil cleanup tools accessible, wear masks.	Protective gloves, safety glasses, masks, hand sanitizer	Bandages must be treated as a biohazard in case of cuts or scrapes. They will be sealed in a red bag labeled biohazard.	HAZARD: 2 CONSEQ: Moderate Residual: Low Medium	Tend to open wounds, maintain social distancing

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Testing rover	FAMU-FSU College of Engineering	All group members	Mishandling equipment, improper riding procedure, crashing vehicle, COVID-19 exposure	Wear all protective equipment, conduct pre-ride vehicle inspection for loose/broken parts. Ensure riders are fastened to the vehicle.	Helmet, knee pads, elbow pads, protective gloves, seatbelts	Bandages must be treated as a biohazard in case of cuts or scrapes. They will be sealed in a red bag labeled biohazard.	HAZARD: 3 CONSEQ: Moderate Residual: Low Medium	Maintain social distancing
Visiting bike shops	Tallahassee	All group members	COVID-19 Exposure	Wear masks, social distancing	Masks, hand sanitizer	N/A	HAZARD: 1 CONSEQ: Minor Residual: Low	Maintain social distancing

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Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

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Name	Signature	Date	Name	Signature	Date

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Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures followed.

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Name	Signature	Date	Name	Signature	Date

Ryan Floyd	Andrew Schlar [illegible]	12/1/2020	Ninett Sanchez	[illegible] Nico Picard	12/1/2020
Andrew Schlar		12/1/2020	Nicolas Picard		12/1/2020

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

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Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

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- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

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The instructions to use hazard assessment matrix (table 1) are listed below:

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1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3
	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

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The instructions to use residual risk assessment matrix (table 2) are listed below:

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1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.

3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.

4. Enter value next to: RESIDUAL on the PHA worksheet.

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Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

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Specific rules for each category of the residual risk:

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Low:

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- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

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- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

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- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

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- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.

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- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.

- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Hazard types and examples

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.

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Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.
Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.

Project Hazard Control - For Projects with Medium and Higher Risks

Name of Project: NASA Human Powered Vehicle		Date of submission:
Team member	Phone number	e-mail
Ryan Floyd	305-542-7542	rmf17@my.fsu.edu
Nicolas Picard	407-714-8610	np16b@my.fsu.edu
Ninett Sanchez	508-405-6281	nos16@my.fsu.edu
Andrew Schlar	850-812-9173	as18fy@my.fsu.edu
Faculty mentor	Phone number	e-mail
Shayne McConomy	850-410-6624	smcconomy@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Lifting Heavy Parts/Rover:

- Use multiple people to lift
- Lift with legs
- Wear closed-toed shoes

Handling Power Tools/Sharp Objects:

- Wear gloves
- Use most appropriate piece of equipment for task
- Tie hair up
- Wear closed-toed shoes
- Wear safety glasses

Testing Rover:

- Wear helmets
- Wear protective knee pads, elbow pads, shoulder pads, gloves and safety glasses
- Do not operate under the influence of drugs, alcohol or prescription medication

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

Should a cut, or scrape occur, the wound must be tended to immediately using a first aid kit and any applicable safety measures. In the case of a serious accident, the riders must remain in position to check for possible bodily damage and then apply first aid if necessary. In the event of a serious accident, remain in position and wait for medical staff will be called and the proper authorities notified.

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List emergency response contact information:			
• Call 911 for life threatening injuries, fires or other emergency situations • Call your department representative to report a facility concern			
Name	Phone number	Faculty or other COE emergency contact	Phone number
Zackary VonZimmerman	251-597-4942	Shayne McConomy	850-410-6624
Benji Charles	850-692-4222		
Edwin Ulysse	904-708-7928		
Safety review signatures			
Team member	Date	Faculty mentor	Date
Ryan Floyd	12/4/2020		
Nicolas Picard	12/4/2020		
Ninett Sanchez	12/4/2020		
Andrew Schlar	12/4/2020		

~~**References**~~

~~Bike Forums. (2006, July 11). Maximum Human Torque. BikeForums.net. Retrieved from https://www.bikeforums.net/general-cycling-discussion/210283-maximum-human-torque.html#:~:text=Torque%20is%20force%20times%20radius,much%20lower%2C%20something%20about%2050NM~~

~~Ellington, S. (1995, February 14). Bicycle Gearing for Wisconsin Hills. Retrieved from http://sdellington.us/gearing/gearing.html~~

~~Gardner, A. S., Martin, J. C., Martin, D. T., Barras, M., & Jenkins, D. G. (2007, October 10). Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. PubMed.gov. doi:10.1007/s00421-007-0498-4~~

~~Grainger. (2020). Trash Pickers & Grabbers. W.W. Grainger. Retrieved November 4, 2020, from https://www.grainger.com/category/cleaning-and-janitorial/waste-recycling-trash-supplies/trash-pickers-grabbers~~

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~~Late Model Restoration. (2020). 3-POINT RETRACTABLE SEAT BELT - UNIVERSAL. Late Model Restoration. Retrieved November 5, 2020, from https://lmr.com/item/LRS-B4051000/3-point-retractable-seat-belt~~

~~Maxpeedingrods. (n.d.). For 110cc Go Kart Steering Wheel Quad Parts W/ Steel Gear Rack Pinion. Retrieved from https://www.maxpeedingrods.com/product/fit-110cc-go-kart-steering-wheel-quad-parts-w-steel-gear-rack-pinion.html~~

~~McConomy, S. (2020, September 16). Senior Design Professor; Project Sponsor; Project Advisor;. (A. Schlar, R. Floyd, N. Sanchez, & N. Picard, Interviewers)~~

~~McConomy, S. (2020, September 22). Senior Design Professor; Project Sponsor; Project Advisor;. (R. Floyd, & A. Schlar, Interviewers)~~

~~Menon, A. (2017, July 4). What is the method to calculate turning radius if only the steering ratio and vehicle's basic dimensions are known? Retrieved October 29, 2020, from https://www.quora.com/What-is-the-method-to-calculate-turning-radius-if-only-the-steering-ratio-and-vehicles-basic-dimensions-are-known#:~:text=Tan%20(a)%20%3Dwheelbase%2Fturning%20radius.&text=Steering%20Ratio%20is%20just%20a,steering%20ration%20is%2030%~~

~~National Aeronautics and Space Administration (NASA). (2020, August). National Aeronautics and Space Administration Human Exploration Rover Challenge 2021 Guidebook. *1*, 48. National Aeronautics and Space Administration. Retrieved September 19, 2020, from https://www.nasa.gov/stem/roverchallenge/guidebook/index.html~~

~~Tire Friction and Rolling Resistance Coefficients Calculator. (n.d.). HPWizard.com. Retrieved from http://hpwizard.com/tire-friction-coefficient.html~~

~~Xbits. (2020). MTB Tire Comparison. BicycleRollingResistance.com. doi:https://www.bicyclerollingresistance.com/mtb-reviews/compare~~

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