Human Powered Vehicle Operation Manual

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EML 4552C

Senior Design

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Contents

Human Powered Vehicle Operation Manual

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.

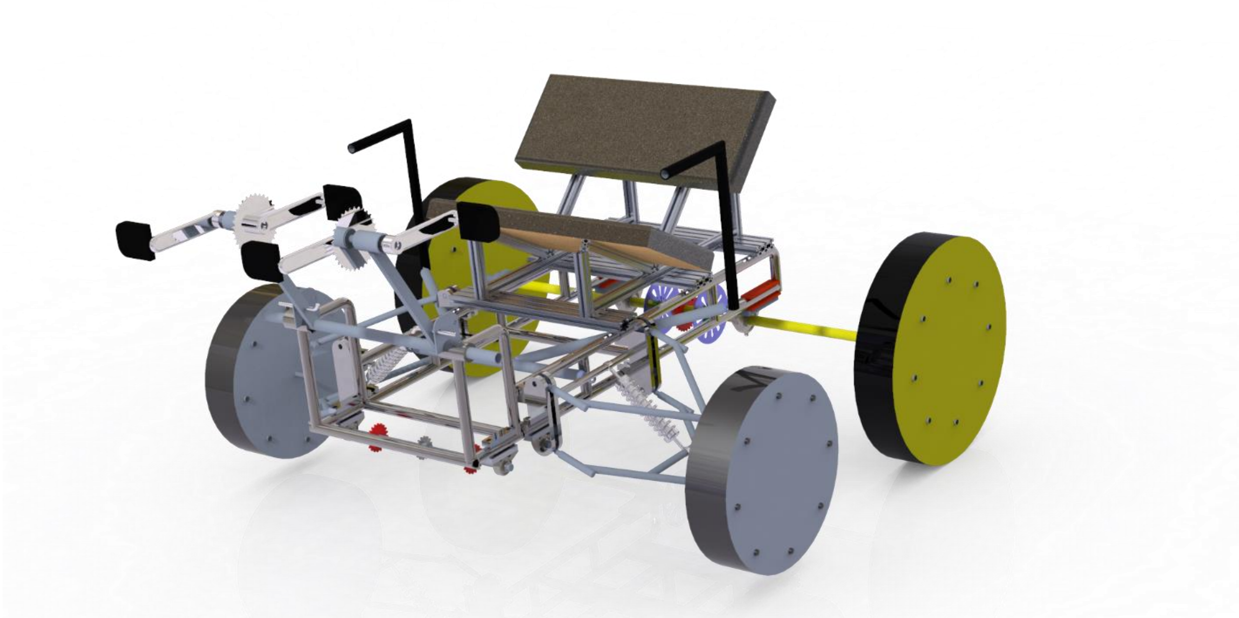

Figure 1: Overall view of Team 509 Human Powered Vehicle

Component Overview

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

Steering

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 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''.

Kingpin Axis Component

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.

Figure 3: Kingpin axis diagram.

Bolted Clamp Component

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

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.

Wheels

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.

Foam Core

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.

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.

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.

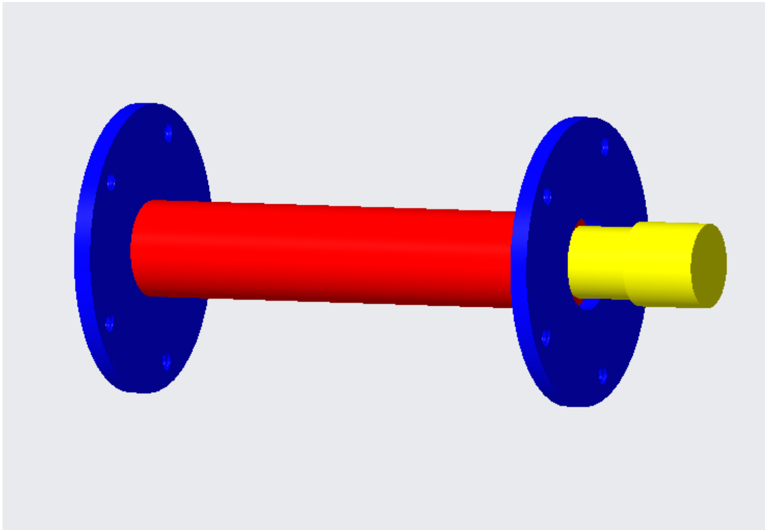

Figure 8: Front inner wheel axle (freewheel).

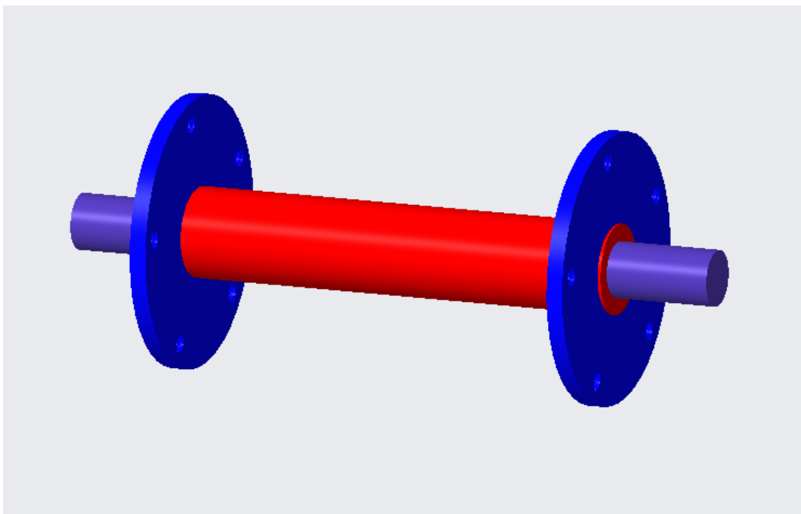

Figure 9: Rear inner wheel axle (rigid).

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.

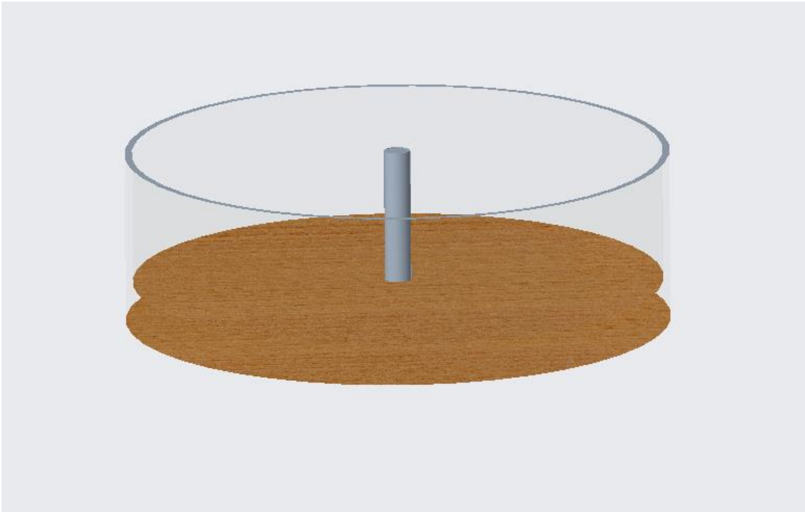

Figure 10: CAD rendering of mold.

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 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.

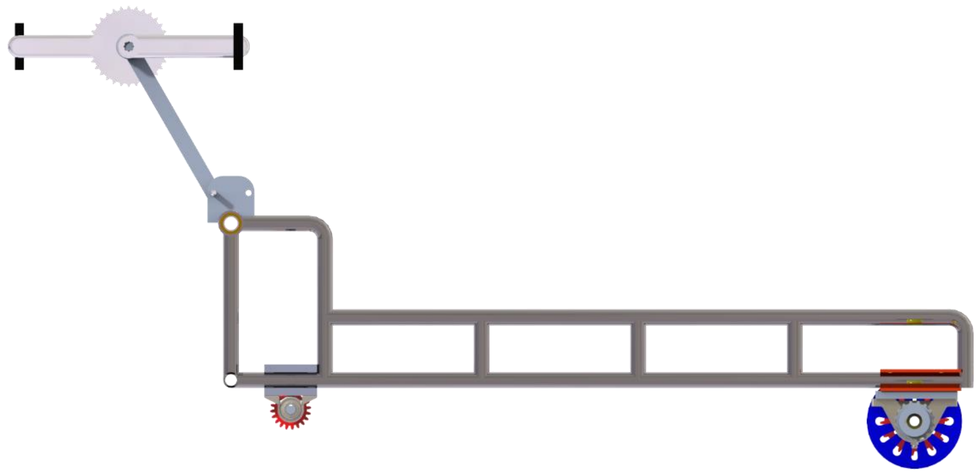

Figure 13: Side view profile of frame and powertrain.

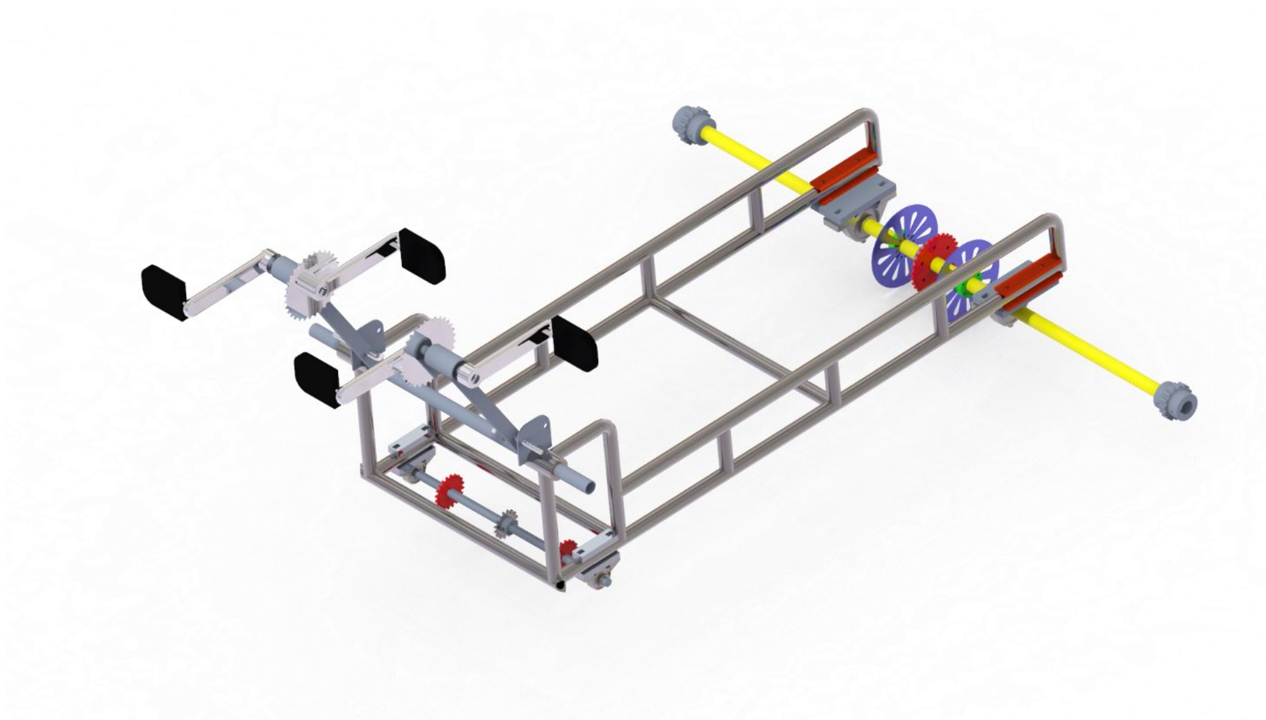

Figure 14: Quarter view profile of the frame and powertrain.

Pedal System Components

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.

Pedal System Maintenance

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.

Intermediate Axle Components

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.

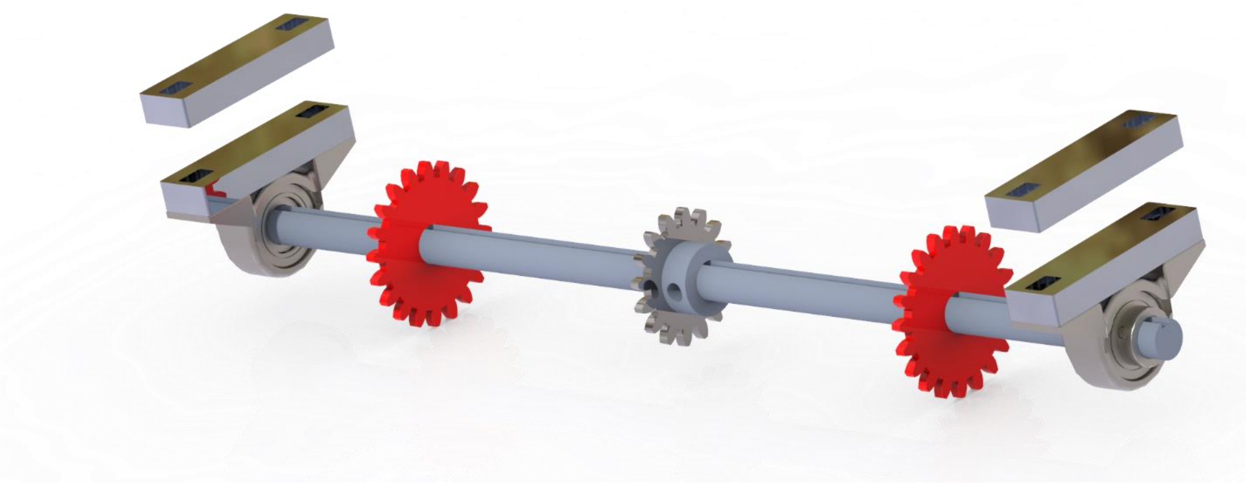

Figure 15: Intermediate driveshaft components system view.

Intermediate Axle Maintenance

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.

Rear Axle Components

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.

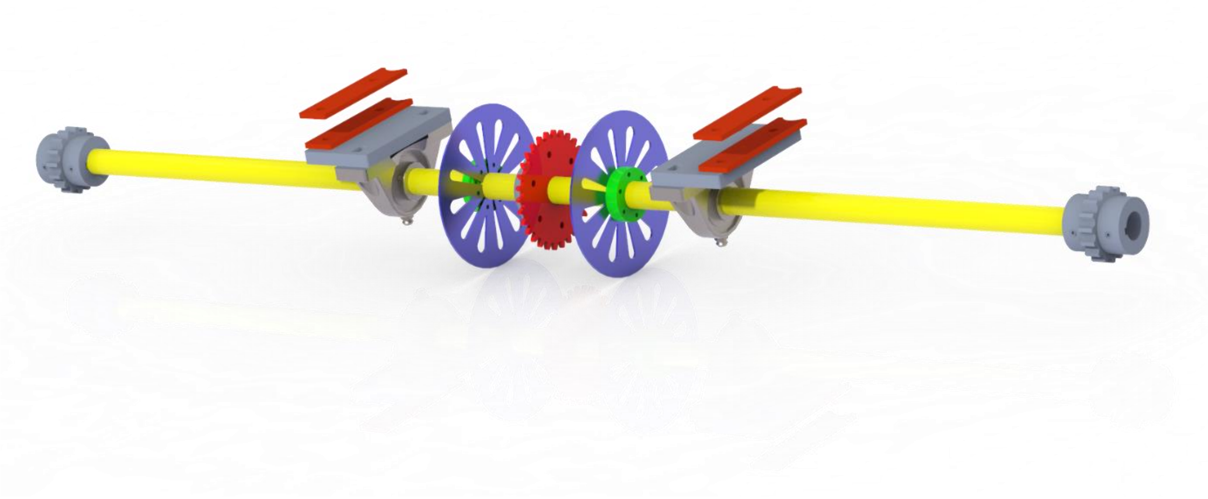

Figure 16: Rear axle components system view.

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 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.

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.

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.

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.

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.

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.

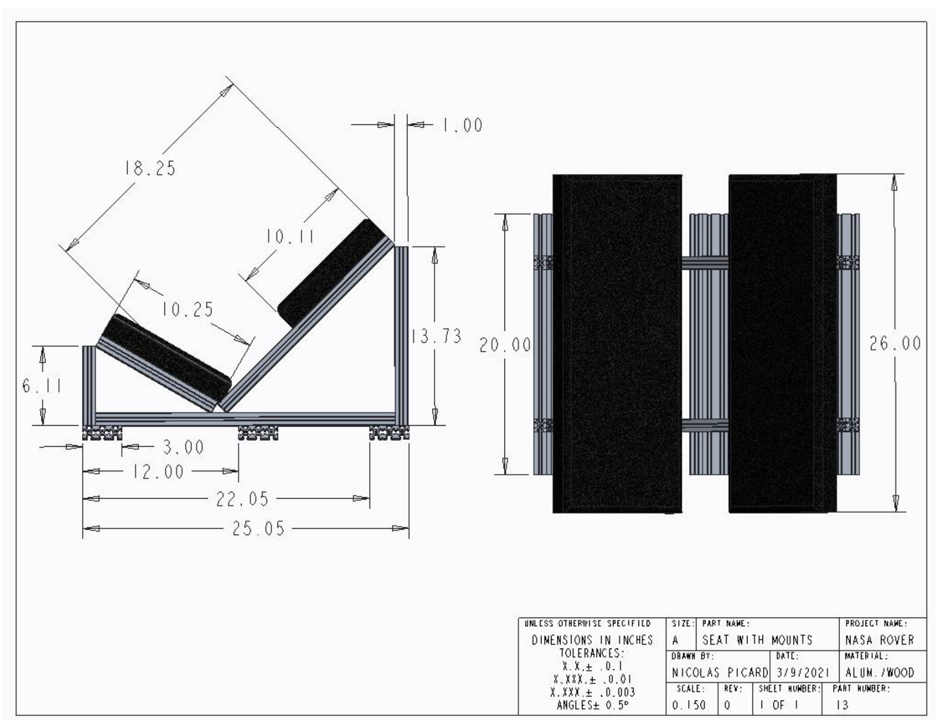

Figure 17: Seat with Seat Mounts

Integration Overview

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

Support

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.

Steering

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.

Drivetrain

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.

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.

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.

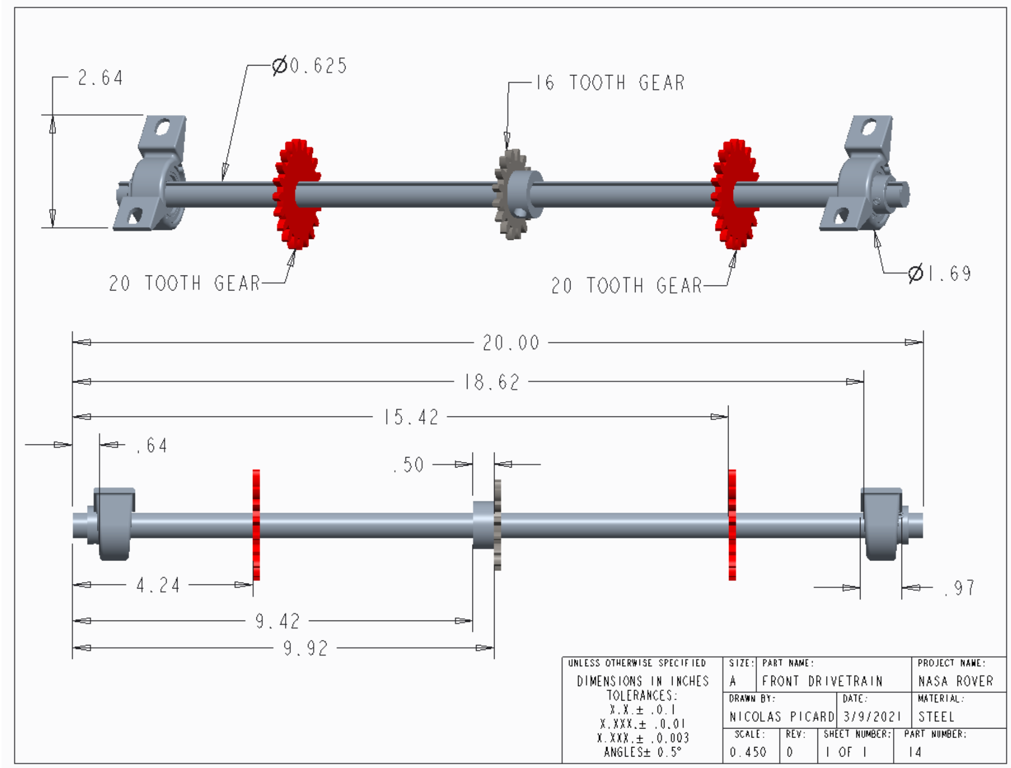

Figure 18: Intermediate axle assembly positioning, units listed in inches.

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.

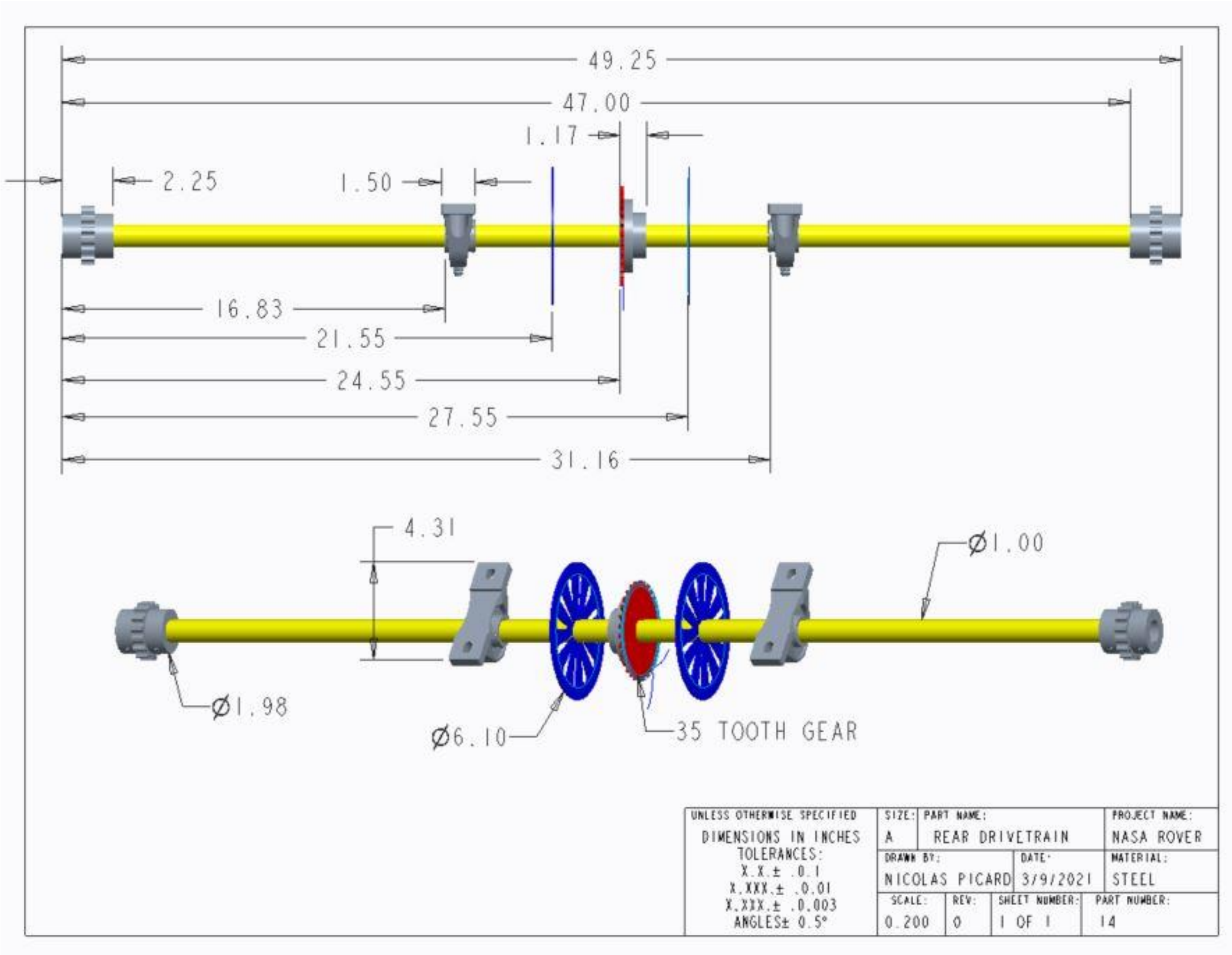

Figure 19: Rear axle assembly positioning, units in inches.

System

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

Operation Overview

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.

Vehicle Preparation

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.

Vehicle Operation

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.

Troubleshooting Overview

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.

- 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.

Important Resources

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

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.