

Power Rover

2022 NASA X-Hab Academic Innovation Challenge

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PROJECT PURPOSE

The Power Rover project is a North Dakota State University (NDSU) undergraduate investigation into the design of a rover that would generate, store, and deliver power to other rovers and equipment on the surface of Mars funded through the NASA X-Hab challenge. X-Hab is a portion of NASA that challenges students to act as a new set of eyes and design engineered solutions that address critical needs of the Artemis program. The goal of this specific project was to design, build, and test an Earth-based prototype of a Martian rover called the Power Rover. The Power Rover is a solar, nuclear, and wind powered tele-operated rover that can generate, store, and deliver power to other rovers or equipment on the Martian surface that are in critical power situations. Due to the large complexity of the project, it was assigned to three senior design groups within the NDSU Mechanical Engineering and Electrical Engineering departments. These groups include an electrical team, power generation and storage team, and structure and drivetrain team. This report will detail the information, findings, final design solutions, and testing that have been made by the NDSU teams during the fall and spring semesters of the 2021-2022 academic school year.

ELECTRICAL TEAM

The electrical team was assigned to handle all electronics that were to be put on the rover. The scope of all electronics on the rover changed many times throughout the school year but in the end, we were assigned to make the rover move, charge batteries using the solar panels and wind turbines chosen, move the solar panels and wind turbines with the chosen actuators, and provide a camera system to view the rover's surroundings remotely.

Requirements:

The requirements for the rover's electrical systems changed frequently throughout the Fall semester and even into the Spring semester as the rover was still actively being designed and electrical functions had to be changed as the rover design was made better and better. Ultimately, we had a list of requirements that looked like this (in order of highest to lowest priority):

1. Choose and drive motors capable of moving the rover at greater than 5mph
2. Choose and drive actuators that serve to protract and retract solar panels and wind turbines used for power generation
3. Integrate the charge capabilities of the solar panels and wind turbines so that batteries are charged when environmental conditions are met
4. Choose and implement cameras that form a first-person view(FPV) system so the rover operator can view the surroundings of the rover from a remote location
5. Write code for autonomous movement of the rover and machine learning capabilities in extraterrestrial conditions

Function: Described above, in priority order

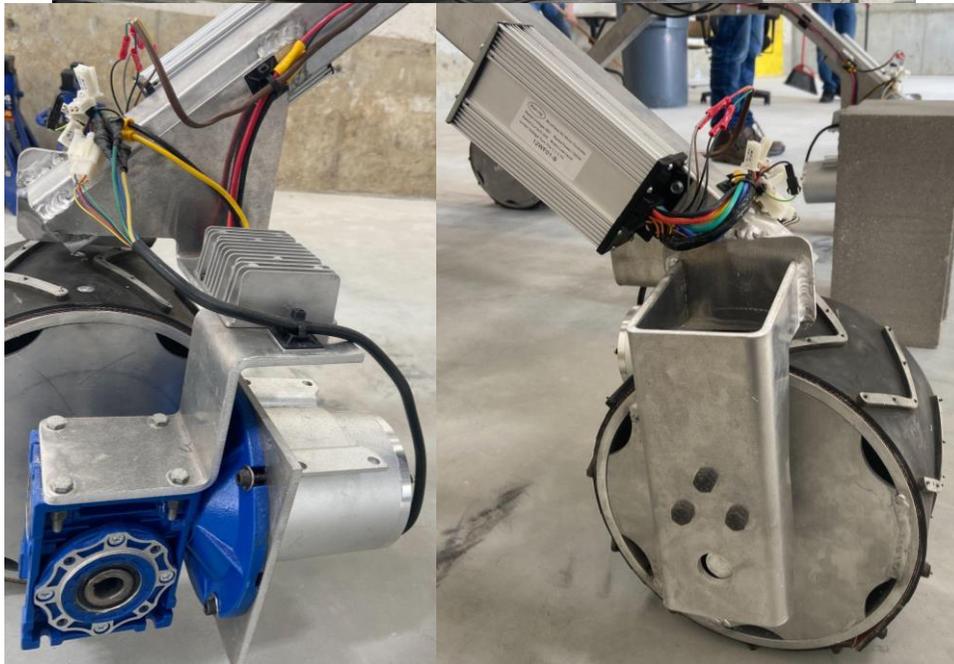
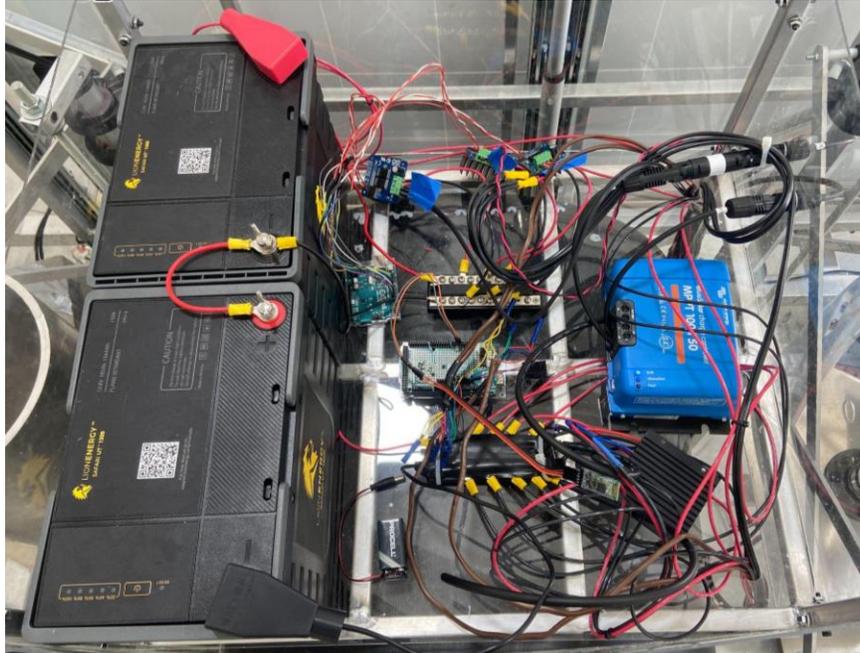
Input Voltage: Implement systems that run on 5V, 12V, 24V, and 48V

Current Draw:

- Inverters/Motors: Minimum Torque: 3A each for total of 12A
- Maximum Torque: 30A each for total of 120A
- All other components total: <1A

- Total Rover Current Draw: 13A at minimum torque, 121A at maximum torque, <1A while powered off
- Total Battery Capacity: 105AH at 150A maximum draw

Pictures of the Electronics on the Rover:



Operations Manual:

In the following pages, you will learn to operate the 2021-22 NDSU NASA Rover Electrical Systems. This will allow you to drive and turn the rover, adjust its speed, and protract and retract

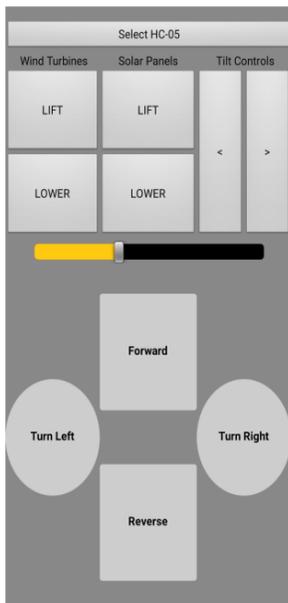
the solar panels and wind turbines. It will also detail the basics of how the rover's systems work for troubleshooting purposes.

How the Rover Electrical Systems Work:

This rover is an Arduino-based system. An Arduino Mega is centrally located in the electronics box and sends commands to drive the motors (in both forward and reverse) and move the solar panels and wind turbines. The Arduino has a Bluetooth Module connected to it so that an Android-based cell phone can drive the rover and actuate the power-generating components.

Connecting to the Rover

To obtain the app interface outlined in this manual, contact Isaac Rud. It is not available online but can be administered to any Android device. To connect to the rover, simply turn the switch on the side of the rover (to turn on the electronics) and wait for the LED to blink on the Bluetooth Module (which can be viewed from the side of the rover). If it is the first time connecting to the Bluetooth module, open the settings on your Android device, and pair with "H05". Next, within the app, select the Bluetooth module up top and wait for the light on the Bluetooth Module to begin blinking slower. This means you have successfully connected to the rover.



Driving the Rover:

The app interface used for driving the rover is pretty intuitive to use but some trouble may be encountered. For this reason, all buttons will be explained in this section. Below, you see the app interface that the next portion will explain.

Slider:

Towards the middle of the screen, you'll see a slider. This controls the speed of the rover. The farther to the right the slider is positioned, the faster the rover will move. Its slowest speed is 0.76mph and its fastest theoretical speed is 7mph, so be careful where you place the slider.

Forward:

The Forward button will drive the rover forward at the speed at which the slider is set to. (**Warning:** there is not much for acceleration built in. the rover will launch right to the desired speed)

Reverse:

The Reverse button will drive the rover backward at the speed at which the slider is set to. Note that the maximum speed in reverse is greatly reduced as compared to the maximum speed traveling forward.

Turn Left:

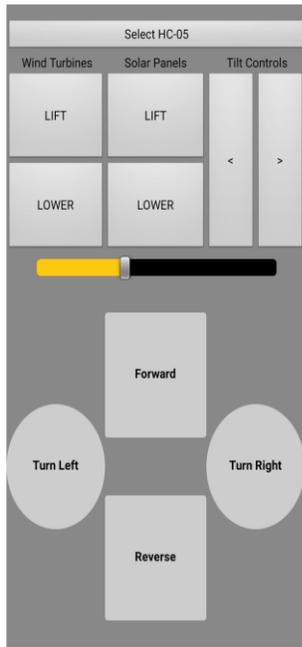
The Turn Left button will turn the rover left at min speed.

Turn Right:

The Turn Right button will turn the rover right at min speed.

Moving the Power Generating Equipment:

The same app interface used to drive the rover is used to protract/retract the solar panels and wind turbines from/into their respective cases.



Wind Turbines:

Lift:

The Lift button will lift the wind turbines out of their case so that they can spin and generate power. The button must be held until the turbines are fully extended.

Lower:

The Lower button will lower the wind turbines into their case so that they can be protected from the outside environment. The button must be held until the turbines are fully lowered.

Solar Panels:

Lift:

The Lift button will lift the solar panels out of their case so that they can soak up the sun and generate power. The button must be held until the panels are fully extended.

Lower:

The Lower button will lower the solar panels into their case so that they can be protected from the outside environment. The button must be held until the panels are fully covered.

Tilt Controls:

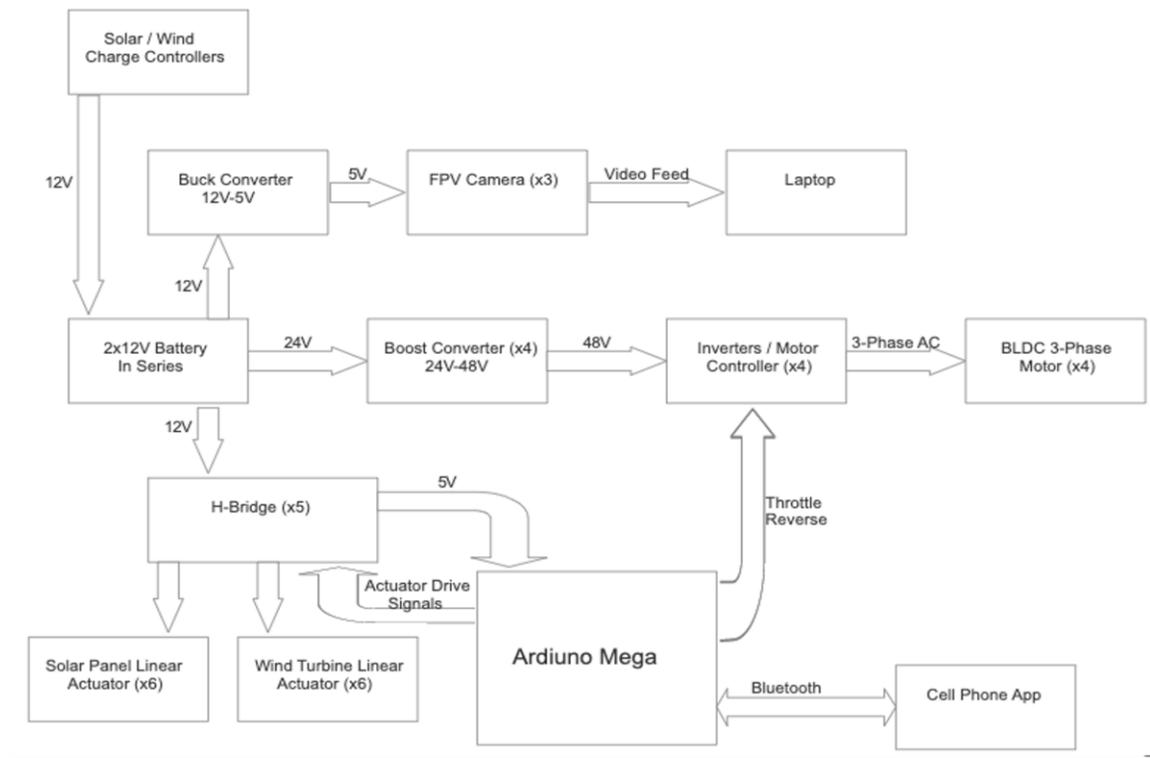
Tilt (>):

The > button will tilt the solar panels so that an ideal angle for sunlight can be reached. **WARNING:** This must only be done when solar panels are **fully extended upward**.

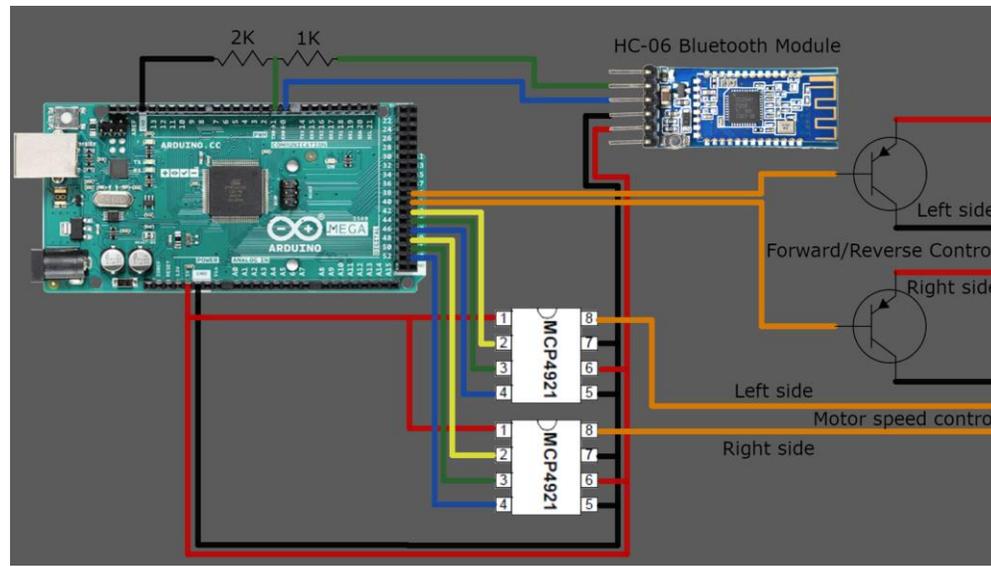
Reverse Tilt (<):

The < button will put the solar panels back into the vertical position so that they can be lowered back into their casing. **WARNING:** This must only be done when solar panels are **fully extended upward**.

Block Diagram of Hardware



Wiring diagram of the hardware



Not pictured: control lines for H-bridges to control linear actuators

Setbacks and Other Difficulties

Many setbacks were incurred as this project went along. When we began this project at the beginning of the school year, the initial goal was to achieve autonomous movement with image

processing by the rover. Thankfully, around 2-3 weeks into the project, we realized that this wasn't going to be possible by a team of 3 electrical engineers with no prior experience in image AI.

The next big hurdle for our team was picking out the motors for the rover. Our original plan was to use smaller 12-volt DC motors paired with 500+:1 gearboxes to be able to move the rover at a slow speed (around 0.1 mph (for reference, a normal mars rover moves at about 0.07 mph)). About one-third of the way through the project, The requirement was determined and added that the rover needed to be able to move at a speed of at least 5mph to be able to move between other rovers quickly. This meant that we needed motors with much higher torque and speed capabilities, and as we found out, 12V DC motors with those specs didn't exist.

We ended up choosing motors designed for go-karts. Our battery voltage of 24V was sent to a 24 -> 48V boost converter, and then powered an electric 3-phase inverter. That inverter then sent 3-phase AC power to our new motors. The choice to go with 3-phase AC motors to get the required speed and torque meant controlling the motors was no longer as easy as PWMing a 12V supply to a DC motor. This meant we added a large amount of extra work for ourselves to be able to learn how to control a new inverter. Thankfully, the inverter only required an analog throttle and reverse signal to function for our needs.

One of our final and biggest setbacks was waiting for the frame of the rover to be built so that we could mount our electrical components and wire everything up. This meant relying on the ME teams to get their work done fast enough and ultimately lead to a scramble at the end of the semester to add components and wiring to the rover once the frame was finally built.

Potential for Future Work

The rover was designed with the capability of autonomous movement in mind so that future teams could work to implement this feature. To do this, several more cameras would need to be added, and an image processing computer would need to be installed on the rover to be able to receive destination coordinates, run image processing, and send throttle and turning signals to the current microcontroller.

Another feature that could be added is a better steering system. In collaboration with the Mechanical engineering teams, we decided that tank-style steering (having no rotating wheels and using differential throttles) would be adequate for the rover, but after the first attempt at steering, it was clear that there was too much slop on the joints of the suspension system leading to poor turning capability. Future teams could work to modify the wheels to turn and provide better steering to the rover. Another option would be to design Omni-wheels to use instead.

POWER GENERATION AND STORAGE TEAM

The final Power Generation and Storage Team's design consists of a simulated radioisotope thermoelectric generator situated in the center of the rover with an electronics storage box above it. There are two 650-Watt vertical axis wind turbines which sit on either side of the nuclear and electronics box system. The wind turbines can extend and retract from the rover base to allow for storage when not in use. Two 200-Watt solar panels are located on opposing sides of the rover frame. A sun tracking system was designed for the panels. When not in use, the panels will sit inside protective plexiglass cases that also clean the panels with a soft bristle brush upon insertion. Lastly, an actuating plug system is located on the front of the rover to allow for power transfer with other devices. The power generation systems can produce 1510 Watts, which at a 90% system

efficiency, can charge a single battery in 63 minutes. All custom cutting, machining, welding, 3D printing, and assembly was performed by students. Each subsystem had an individual manufacturing process designed. These processes take into consideration the tooling and machinery accessible. Using manufacturing engineering techniques allowed students to build all custom components in house. This report further defines the detailed design documentation, testing plans, bill of materials, and project plan. It also reviews the budget, ethical and safety considerations, and engineering standards. At the conclusion of this report, recommendations are made, and future work is defined.

Design Problem and Objectives

The objective of this project is to design and manufacture a Mars rover prototype for NASA capable of generating, storing, and transferring electricity. It has the capability to travel to locations with ideal power collection/generation and can travel to working rovers in critically low power situations which saves those rovers time spent in power saving mode. The Power Generation and Storage team is responsible for the design and fabrication of all power generation, storage, and transfer components. The Power Generation and Storage Team took broad qualitative customer requirements given by NASA and decided on quantitative engineering specifications. At system efficiency, the prototype will take a minimum of 12 hours to charge. Additionally, the internal electricity transfer must be at least 80% efficient. The rover will run on a 24-volt DC system with a 105 Amp Hour capacity. The total power output of the rover will exceed 110 W, which is the power output of NASA's current Perseverance rover. All rover components will convert the energy harnessed into DC electricity. The storage area for critical electrical components must stay below 100 °F.

Detailed Design Documentation

Assembly Designs

The final Power Generation and Storage Team's design consists of a simulated radioisotope thermoelectric generator situated in the center of the rover with an electronics storage box above it. There are two 650-Watt vertical axis wind turbines which sit on either side of the nuclear and electronics box system. Due to supply chain issues, only one wind turbine arrived on time for manufacturing. The wind turbines can extend and retract from the rover base to allow for storage when not in use. Two 200-Watt solar panels are located on opposing sides of the rover frame. A tracking system was designed for the panels. When not in use, the panels will sit inside protective cases that also clean the panels upon deployment. Lastly, an actuating plug system is located on the front of the rover to allow for power transfer to other rovers. The power generation components are designed to bolt onto the Structure and Drive Train design. Figure 1 shows the final Creo model of the rover prototype. All custom cutting, machining, welding, 3D printing, and assembly was performed by students. Each subsystem had an individual manufacturing process designed. These processes took into consideration the tooling and machinery accessible. Using manufacturing engineering techniques allowed us to build all custom components in house. Figure 2 shows the final manufactured prototype rover.



Figure 1. Final CAD Model Prototype Rover



Figure 2. Final Manufactured Prototype Rover

Solar Power Generation Design

Solar Panel Storage and Cleaning Design

The final design is composed of an outer case and bristle brush to clean the panel shown in Figures 3 and 4. Square aluminum tubing was welded together to make a case around the solar panels allowing clearance for the panel to be deployed and retracted without scraping on the frame. The case was initially going to have a sheet metal cover. This was changed to plexiglass to allow for better showcase and demonstration. With this change the solar panels generate power at all times that the sun is out, specifically during windier weather while they are being stored to prevent breakage. The cleaning system consists of a bristle brush mounted to the top of the storage case. These brushes are secured using self-tapping sheet metal screws. The brushes are designed to wipe away any dust on the panel as it is deployed and retracted. There is also a dust funnel welded to the bottom of the storage case for any dust to be funneled out of the case and off the side of the rover. There was originally going to be an air compressor system to spray the panel clean on deployment, but this did not make it onto the final design as it was a bulky system and had a large power draw that could not be compensated for with the current design.

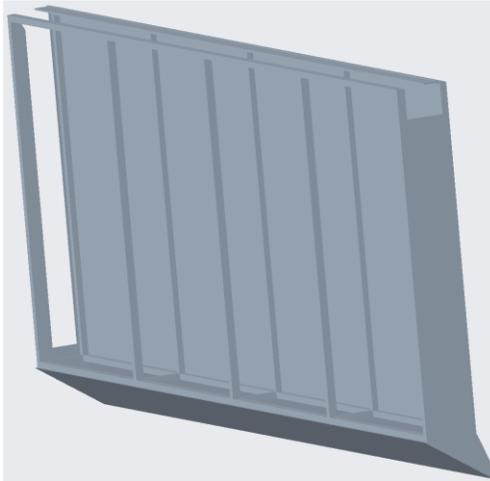


Figure 3: Creo Model of Storage Case

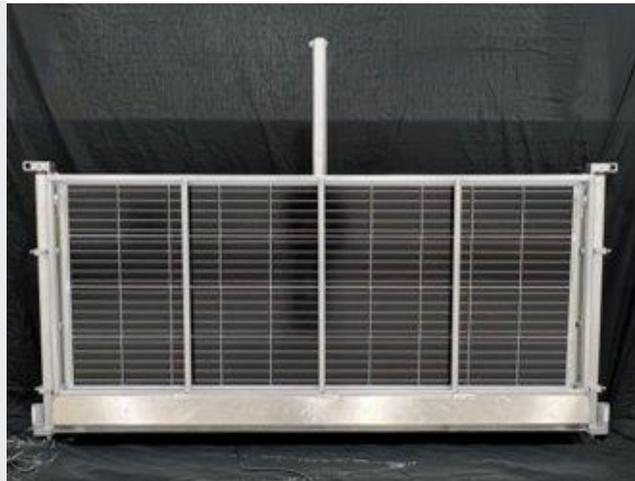


Figure 4 :Manufactured Storage Case

Solar Panel Deployment and Tracking Design

The solar panel deployment and sun tracking system has undergone several changes throughout the design process. It started out as non-retractable arms that would pull the panel up a track system with a wire pulley. This was changed to using a linear actuator system to lift the panel to make the overall design more compact. Along with the actuators a secondary frame was welded together and attached to the solar panel mounting brackets. This frame supports a third actuator with a linkage system to rotate the solar panel once it is fully extended. Three drawer glides were attached between the case and the rotation frame to add stability as the panel and frame are being extended and rotated. Extra 2-inch aluminum tubing was used to attach the sides of the case to the rover body and add stability to the system as a whole. Figure 5 shows the initial design modeled in Creo and Figure 6 is the final manufactured design. The solar subsystem can produce a max of 200 Watts at 24 volts during optimal sun conditions. A sun tracking system was designed to keep the solar panels at an optimal angle to the sun. This tracking system was not implemented on the fabricated prototype, but the design implemented a sun tracking sensor on each of the solar panels. This sensor would signal the computer to turn the actuator until the panels are at an optimal angle to the sun. When the sensors experience this optimal angle, they signal the tilt system to turn off. Due to time constraints this was not completed.

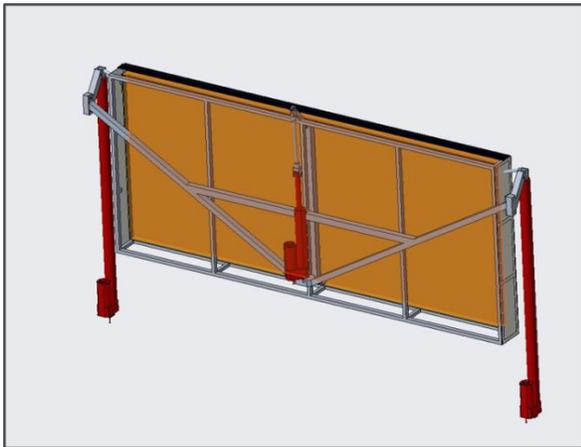


Figure 5: Creo Model of Rotation System

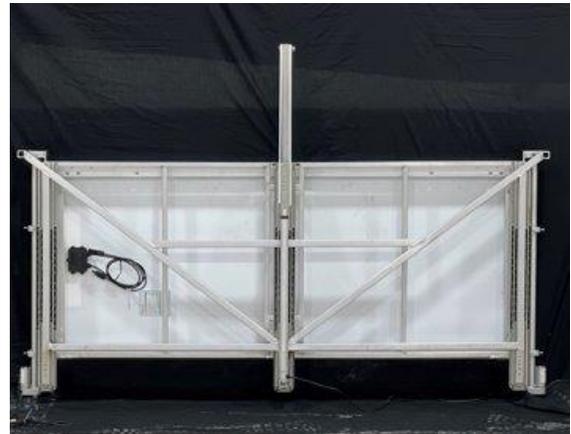


Figure 6: Manufactured Rotation System

Wind Power Generation Design

The final design chosen for the wind power generation subassembly is shown in Figure 7. The wind turbines are mounted to a triangular plate that is attached to three linear actuators. When activated, these actuators will synchronously raise the wind turbine into power generation mode. The main goal for the wind power generation design is to have the ability for the turbines to be sheltered in extreme weather and or stored away when not in use. During the manufacturing stage, it was concluded that the final design was extremely unsteady and wobbled with ease. To combat this, a supportive bracing system was designed. A structural frame was also designed to aid in the mounting of the system onto the body of the rover. Figure 8 shows the final manufactured wind power generation design with the NINILADY wind turbine mounted into the assembly.

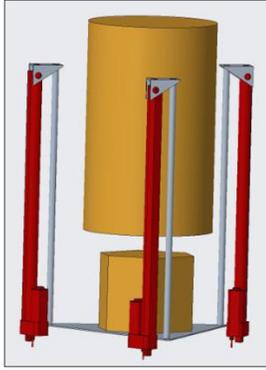


Figure 7. Creo Model of Wind Power Generation

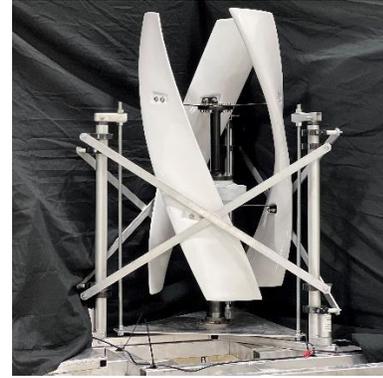


Figure 8. Manufactured Wind Power Generation

The manufacturing process for this assembly included machining and welding of aluminum, as well as 3-D printing with PETG. The first step in the manufacturing process was the baseplate in which the wind turbine will rest upon. An aluminum sheet was cut using a vertical bandsaw. Holes were later hand drilled into the plate for the mounting of the wind turbine and the support rods. These rods were cut to size using a horizontal band saw and were previously fully threaded. A connector piece was manufactured to connect the actuators to the support rods holding up the base plate. This connector piece was made from 1"x1" hollow square aluminum rods. They were cut to length using a horizontal band saw. Holes were drilled using a milling machine to ensure accurate placement.

Once the structure and drive train team finished manufacturing the base frame of the rover and the wind power generation assembly was tested, two modifications were needed. Figure 9 shows the completed wind power generation assembly based upon the CAD model. It was concluded that a mounting frame was needed for the wind power generation system to be mounted to the rover frame. This frame consisted of three 1"x1" hollow square aluminum rods welded together at perfect 120° angles. Holes for the actuators to mount to the frame were drilled using a milling machine, as well as a hand drill for the holes to attach the frame to the rover. Figure 10 shows the wind power generation assembly with the base frame, as well as a mounted wind turbine. After assembly, the unsteadiness of the system was noticed. Therefore, 6 cross body aluminum braces were cut and milled to be attached to the actuators via 3D printed brackets shown in Figure 11. These brackets were designed to be strong enough to hold up to strong winds while also being flexible enough to clamp the insert. To achieve this, two materials were considered, Pro PLA and INNOVA 18000 PETG, both in thickness of 2.85mm. The PETG was chosen as it offered the most strength and resilience. The printed part was made with 40% infill with a cubic subdivision pattern. This pattern was chosen as it has the highest strength to infill density ratio. The extrusion thickness was set to 0.32mm and the shell thickness was set originally to 2 layers. It was observed that these parts had poor rigidity and improper lamination. To combat this the shell thickness was increased to 4 layers and the print temperature was raised. The final manufactured wind power generation can be seen above, in Figure 8.

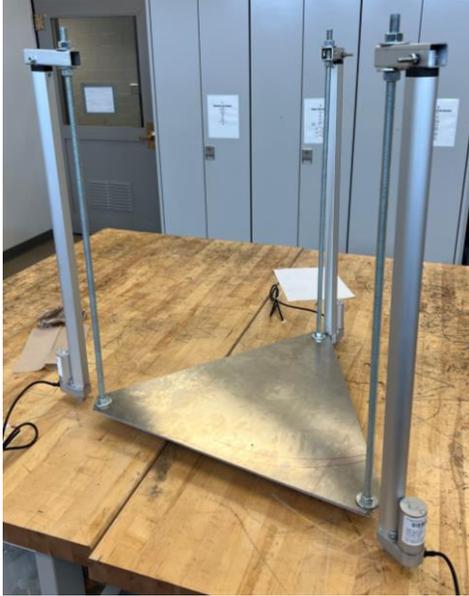


Figure 9 Manufactured Wind Power Generation Based on CAD Model with Base Frame



Figure 10 Manufactured Wind Power Generation

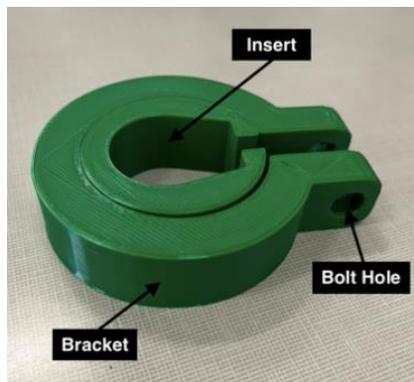


Figure 11: 3D Printed Bracket

At the end of Senior Design Semester 1, two ATLASX Wind Turbines from Tesup were chosen and purchased as the final design for the wind power generation concept. This vertical axis wind generator can produce an average of 750 Watts of energy, with a max of 1,000 Watts. Due to several supply chain issues; these wind turbines are unable to be obtained on time for completion of the project. Taking into consideration the limited time and the fact the lift system of the wind turbines had already been designed and manufactured for the ATLASX, a limited selection of wind turbines was available. To show proof of concept, two NINILADY vertical wind turbines were purchased from Amazon. However, due to supply chain issues again, only one wind turbine was able to arrive on time. This wind turbine has a rated max power output of 650 watts, which is significantly lower than the originally selected wind turbine. The given specs provided by the company prior to the arrival of the wind turbine showed the turbine would fit within the constraints of the manufactured lift system. However, once the turbine had arrived and was properly assembled, the outer most diameter of the turbine was larger than the spec sheet listed and was too large for the lift system. The turbine was then modified to fit within the lift system by altering the support rods of the blades by removing 6 inches off the diameter. A mounting rod was also needed

for this wind turbine to be assembled on the lift system. This was created by purchasing a 12” long rod and welding a flange to the end of it. The alteration to the turbine significantly changes the wind turbines rated specifications. Due to time constraints, the difference in power output caused by this design change was not able to be calculated. For proof of concept and final power generation calculations, this subassembly can produce a max 1,300 Watts power output (with two NINILADY wind turbines).

Electronics Storage Box and Simulated Nuclear Generator Design

There are many electrical components required for rover functionality that need storage space on the prototype. These components include two 12-volt DC batteries, an Arduino Mega, fuse boxes, a 100/50 MPPT solar charge controller, a wind charge controller, five H-bridges, and wiring. To store these components, an electronics storage box was designed. The final manufactured design includes a frame made from 0.75-inch aluminum tubing with a space for the simulated nuclear system below and a plexiglass outer casing above. The dimensions of the upper electronics storage compartment is 26x21x12 inches. The aluminum frame is TIG welded, and the plexiglass casing is bolted to the frame.

Nuclear power is currently utilized on the NASA Perseverance Rover. This nuclear system is a Multi-Mission Radio Isotope Thermoelectric Generator, or MMRTG. MMRTG’s rely on the Seebeck Effect which states that if there is a temperature difference at a junction of two dissimilar semiconductors, there will be a voltage difference between the two semiconductors. The heat source in an MMRTG comes from the radioactive decay of Plutonium-238 in a ceramic form. At launch, the MMRTG has a max power output of 110 Watts. After 14 years, the max power output decays to 72 Watts [3]. Nuclear energy provides a consistent power output that does not depend on daily atmospheric conditions which is ideal for the objective of this rover. The MMRTG unit weighs approximately 100 pounds and is 26” long with a 25” diameter. MMRTG’s consist of an outer casing with fins for heat distribution, an inner wall with 768 thermocouples, and the inside core with Plutonium-238 in ceramic form. The layout of the Perseverance MMRTG can be seen in Figure 12.

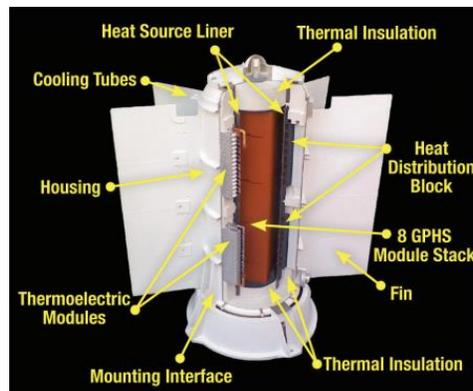


Figure 12: Perseverance MMRTG from nasa.gov

Figure 13 shows the Creo model electronics box, as well as the simulated nuclear MMRTG. Figure 14 shows the manufactured electronics box assembly above the simulated nuclear MMRTG.

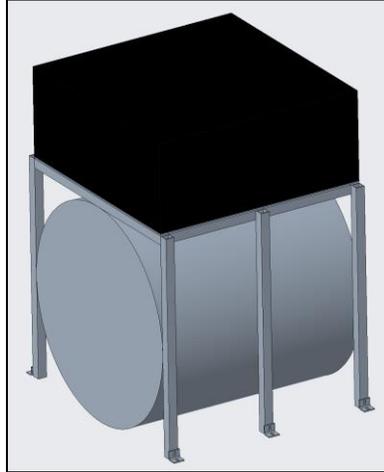


Figure 13: Creo Model Electronics Box and Simulated MMRTG

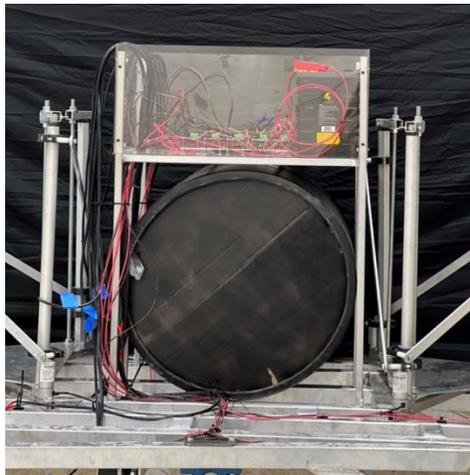


Figure 14: Manufactured Electronics Box and Simulated MMRTG

Due to safety concerns associated with radioactive materials, a nuclear generator is not feasible to create for this prototype. To simulate the placement of the MMRTG, a 2' x 2' concrete forming tube was used in place under the electronics box outlined in the section above. This simulation option is chosen as it is a similar size, and shape to an actual MMRTG. There is sufficient data provided by NASA and the Department of Energy on the power output and performance of the MMRTG to theoretically show how the power generation from the nuclear source will factor into the total power of the prototype rover. These theoretical values also will aid in future plans which is predicted to expand the scope to include real nuclear power generation.

Plug Extension and Interface System Design

One of the main deliverables provided in the project description was the ability for the rover to transfer electricity to another rover. The chosen concept used a traditional style male-female style plug like a 12-volt car charging adapter but customized with various sensors as well as an X-Y-Z gantry that uses linear ball screw modules for X and Y travel and one linear actuator for travel in the Z direction. After review of the initial Gantry design, it was recognized that the system was only able to cover three of the six degrees of freedom. One of the degrees (rotation about Z axis)

can be ignored due to the design geometry. This left the design with two degrees of freedom to account for to get full alignment. A spring-loaded cam driven rotation system to rotate the gantry about the Y axis was designed and reviewed by the team. It was decided that to achieve rotation about the X and Y axis would require the manufacture of a gyroscope style device that could not be completed in the timeframe of the project. Rotation about the X axis was omitted and is recommended as future work.

Fabrication of the plug extension and interface system began with the X-Y Gantry frame. Aluminum tubes and flat stock were slotted at the ends to create a keyway for tight and streamlined fit. This slot system can be seen in Figure 15. The X direction linear ball screw module was then mounted to the top of the Gantry frame. A linear bearing was mounted to the bottom of the Gantry with motion oriented perpendicular to the X direction ball screw module. The linear ball screw module and linear bearing can be seen in Figure 16. two mounts for the Y direction ball screw module were machined, one attaching to the X ball screw module and one attaching to the bearing slide block. The Y direction ball screw module was bolted to these. A bracket for the Z direction linear actuator was cut welded and installed on the Y direction ball screw module. All permanent joints aside from the machined slot system were welded or bolted.



Figure 15: Slotted Tube and Flat for Gantry Frame



Figure 16: Linear Ball Screw Module (top) Linear Bearing (bottom)

The second step in fabrication was making the base. The base for the plug system consists of a slider plate and a rotary plate. The slider plate has mounting locations for an eccentric cam, its respective driving stepper motor, a retaining spring, and rotation axle. It also has radial slots used for alignment of the rotary plate. These radial slots were cut into the plate using a rotary table installed on a manual knee mill allowing for near perfect radiused slots. The rotary plate is the primary base for the X-Y gantry and is affixed to the gantry frame by weld. It has a hole for the rotation axle and a mount for the retaining spring. The rotary plate and slider plate are held together using four 3/8-inch bolts dropped through the radial slots on the slide plate. Nylon locking nuts were selected to allow the bolts to be left slightly loose without untightening themselves. This allows for free rotation of the gantry/rotary plate while keeping the plug system upright. The relatively large diameter bolts were selected for rigidity against the moment created by the top-heavy weight of the X-Y-Z gantry. A centering axle was fabricated out of 1 inch aluminum shaft. This axle sandwiches between the slider plate and the rotary plate and ensures repeatable and accurate rotation about the Y axis. Finally, an eccentric cam was turned on a lathe to the desired diameter and thickness. The rotation point was milled out in the shape of a square so an adapter could be inserted to rotate the cam without slippage. This adapter was made from 0.5" x 0.5" steel bar stock and was turned on a mill to fit a stepper motor axle. When assembled, the stepper motor turns the eccentric cam, which applies force on the slider plate, counteracting the retainer spring and tilting the entire X-Y-Z gantry. This system can be seen in Figure 17. The final assembly is shown in Figure 18.



Figure 17: Y Axis Tilt Mechanism

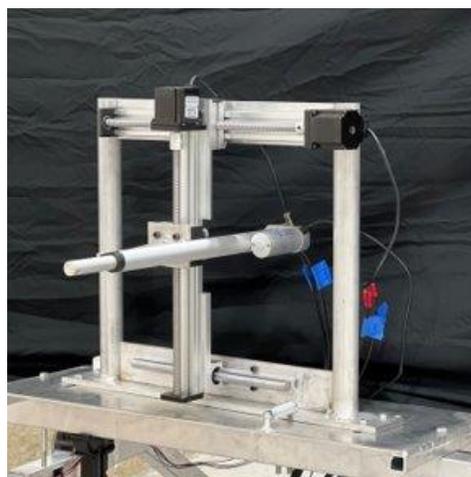


Figure 18: Fabricated Plug Engagement System

All work described on the plug system up to this point has been completed. The design included an automation sequence that was unable to be carried out due to time constraints. The process of how this design works is forwardly described and should be carried out as future work.

Each linear ball screw module runs off a unipolar stepper motor, The linear actuator is driven by a DC motor and the Y axis rotation system is driven by a unipolar stepper motor. An Arduino uno was chosen to control all electronic components and take input signals from sensors. To control the orientation about the Y axis two ultrasonic sensors are to be placed at either side of the X-Y Gantry measuring distance from the target surface. This target surface is a flat white surface with a cross pattern printed on it in reflective silver with the plug hole centered on the cross. The ultrasonic sensors provide distance feedback to the Arduino. This distance feedback is analyzed as “if right sensor is less than left sensor then turns left” and vice versa. The command is sent to the Y axis stepper motor until both sensors are equal within tolerance, the stepper motor then stops. Once rotational alignment is complete, the X and Y axes must align with the plug hole. This process is achieved using reflective infrared (IR) sensors in conjunction with the previously mentioned target plate. The X axis Infrared sensor turns on and X movement begins until the IR sensor senses reflection. After reflection is sensed, the movement stops, and the process is repeated in the Y direction using a separate offset IR sensor implemented to ensure alignment is foolproof. At this point the Z linear actuator is extended and the plug is inserted. The extension of the linear actuator is moderated by a limiter switch calibrated to the correct plug depth. After this limiter switch is engaged power transfer is allowed to begin.

Overall Power Generation

To adhere to the initial engineering specifications decided upon, calculations were carried out to prove that our system can perform to set standards. Table 1 organizes the power outputs of each system at optimal generation situations. This provides a total potential wattage output, which was found to be 1,510 Watts. Table 2 takes values from Table 1 to calculate time to charge different size battery banks at different system efficiencies. When reading these charts, it should be considered that the output values shown are calculated using the rated power of the solar panels and wind turbines. These outputs are most likely higher than a real-life average continuous output, which must consider environmental data. The actual output of the solar panels and wind turbines could differ from the values depicted in this report. For continuity, the decided numbers used throughout the project were the rated values. Table 2 shows calculations for system capacity with various size battery banks. Since the prototype rover will have two 12-volt batteries connected in series to output 24 volts, the rover has a capacity of 2520 Watthours.

Table 1. Generation Typology Statistics Breakdown

Generation Type	Quantity	Individual Output (Watts)	Combined Output (Watts)
Wind	2	600	1200
Solar	2 (series)	200	200
Nuclear	1	110	110
Total Output:			1510

Table 2. Generation Time Statistics

Battery Quantity	Time to Charge (hrs) $\epsilon=90\%$	Time to Charge (hrs) $\epsilon=50\%$	Time to Charge (hrs) Solar + Nuclear	Time to Charge (hrs) Wind + Nuclear
1	1.05	1.254	2.745	1.05
2	1.393	2.507	5.490	1.739
3	2.089	3.761	8.235	2.609
4	2.786	5.015	10.980	4.478

Table 3. Generation Capacity Statistics

Battery Quantity	Individual Capacity (Amp Hour)	Combined Capacity (Amp Hour)	Voltage (V)	Watthours
1	105	105	24	2520
2	105	210	24	5040
3	105	315	24	7560
4	105	420	24	10,080

Laboratory Test Plans and Results

Once all portions of each sub assembly were built, a testing plan was created to test the final system and all features included in the design to facilitate the testing. The following section forms a written record of the performance of the design against specifications.

The solar deployment and rotation system was tested by deploying the system and observing the functionality of the linear actuators for consistent movement speed and extension length. The actuators proved to keep the solar panels level as they are deployed, and no binding was observed as the system was extending or retracting. As seen in Figure 2, the actuators can support the weight of the panels and rotation frame and keep the system level with tolerable deflection.

The solar panel cleaning system was tested by applying a coating of dry dirt to best simulate the dust on mars. The solar panel was then extended and retracted to clean the system. The panel was then inspected to see if any dirt remained.

Testing of the power generation and storage components includes functionality testing of each subsystem and testing the overall power output. TIG welding on aluminum is predominantly used throughout the designs as the method of connection. Proper weld technique is essential to ensuring strong connection points. To check for adequate weld penetration, which is an indicator for weld strength, initial welds were broken and observed. The weld was found to be sufficiently penetrated. Following standards set by the American Weld Society, the welding technique utilized to secure components on the rover adequately penetrates the aluminum.

For the deployment system of power generation components, the linear actuators were tested for consistent extension length under the weight of the wind turbine. Figure 19 shows the fully deployed wind system. During testing it was seen that the three actuators raised and lowered at slightly differing rates, but as the system resets itself after every raise and lower, the difference is negligible and does not affect the performance of the subsystem.

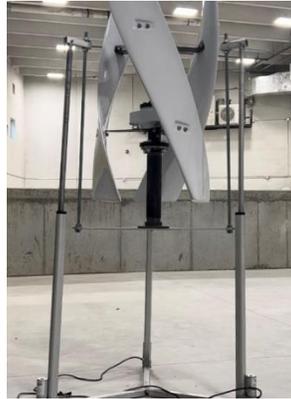


Figure 19: Wind Turbine Actuator Extension

The wind turbine lifts are secured with bracing rods connected to actuator bases with 3D printed clamps. The clamps need to be strong enough to not break under normal usage of the wind turbine assembly. In order to determine which type of 3D printer filament is suitable for use, two materials – PLA and Innova 18000 PETG. To ensure the 3D printed clamps would not break, test prints were made, and the bolts were tightened as far as they could go. Neither material displayed failure which indicated that at the max load the clamps would be under, they would not fail. The infill pattern was also tested to maximize strength while minimizing infill density. The line pattern infill was found to have lamination problems and would separate upon torsional manipulation. Cubic Subdivision infill, shown in Figure 20 was found to provide better strength and rigidity.



Figure 20: Cubic Subdivision Infill Pattern

The range of motion of the plug system was tested for functionality. Using a ruler, the real range of engagement was found. The plug can extend 12 inches out from the rover, maximum movement is 9.5 inches in the X direction, and 12.75 inches in the Y direction. The stepper motor tilt system was tested at its maximum limits to ensure it would not interfere with itself or any other system on the rover. The range of angle when measuring off the front of the rover as 0 degrees is -4 degrees to 8 degrees providing 12 degrees range of motion.

Future Work

The team manufactured a working prototype of a power generation and storage rover. Due to time constraints and supply chain issues, there are improvements that could be made to further the operation of the rover. For the wind turbine sub assembly, future work that would improve the system includes use of stronger, more rigid actuators. The actuators used were commercially available aluminum cylinder actuators. The updated actuators would ideally be made of titanium to improve rigidity while keeping weight similar to the original design weight. The current design works under the foreseen loading but would have higher longevity and less deflection using titanium. Custom drag induced wind turbines with a low cut in speed are also recommended. The original design incorporated this style of turbine, but due to supply chain issues the implementation of drag induced turbines was not achieved. Also, due to supply chain issues, only one wind turbine was able to be installed on the prototype, so to complete the prototype a second wind turbine should be altered to match the currently installed turbine, then installed on the prototype. To test the overall power output of the rover, a digital voltmeter will be used to measure the power output of all the individual subsystems in their optimal power generating conditions. The individual power outputs will then be summed together to obtain the overall power output with any configuration of subsystems being deployed. The measured values will then be compared to the specifications of each subsystem.

The plug engagement system requires further work to become fully operational and autonomous. A precision locating system needs to be installed using ultrasonic proximity sensors for the plug system to autonomously sense and actuate into another rovers charging port.

Along with these improvements, many alterations would need to be made for the rover to be functional on Mars. Space grade solar panels would need to be implemented. Custom engineered wind turbines specifically designed to work efficiently in a Martian environment would need to be integrated. In place of the simulated nuclear system, a functional multi mission radioisotope thermoelectric generator would need to be installed. The electronics box would require a heating system capable of ensuring the internal atmosphere remains within the operational temperatures of the electronic equipment and batteries. Aerogel insulation would be installed in the electronics box to insulate the electronics. Weatherproof plugs would be installed on the box to ensure ingress protection.

STRUCTURE AND DRIVETRAIN TEAM

As space exploration and colonization continues to become more feasible, a power generation, storage and transfer infrastructure needs to be created within colonization sites. This starts with creating easily deployable power generation and storage methods, such as a power generation rover. The rover being designed needs to be large enough to produce and store adequate power, while maintaining maneuverability to travel miles to rovers or other colonization sites in need of power. To house the power generation modes designed for this rover, the frame and suspension need to be light enough to ensure efficient travel, while being strong enough to support the essential power generation components while also withstanding the elements on Mars. Mars is an unforgiving environment that has temperature swings from -100°F to 100°F and sustained winds of 70+ mph. As this prototype is being designed for a foreign planet, stability and durability is necessary. This rover must be able to climb slopes and be able to withstand significant roll angles to ensure this rover stays upright throughout the mission. Lastly, the rover needs to be constructed of materials that fit our budget as well as ensuring the design has manufacturability in mind as the

team members are students and need to ensure that the design is able to be fabricated with the tools supplied to us by the various NDSU manufacturing labs.

Detailed Design Documentation

Wheels

There was a total of 4 drive wheels and 2 pivot wheels manufactured for the rover. They are shown in figure 1 and figure 2 respectively. The drive wheels consisted of a 10.375" diameter tube 6" wide. There is a black rubber tread approximately ¼" thick riveted around the tube. With a 1" shaft connecting the wheel to the gearbox and motor. The gearbox shown has a 15:1 ratio. This gearbox connects to a brushless DC go-kart motor. There is a transmission plate that is mounted in-between the gearbox and motor with a shaft/set screw combination connecting the two shafts. This gearbox/motor combination provides enough torque and speed to make the rover have a max theoretical speed of 7 mph. Shown in figure 1 is also the DC/DC converter that is mounted on top of the aluminum plate.



Figure 1: Drive Wheels



Figure 2: Pivot Wheels

Differential Bar

There are 3 2 x 2 x 0.25" aluminum square tubes welded together that are then bolted to the frame. This is a shoulder bolt so that the differential bar is allowed to rotate as desired. There are 0.25" plates welded on the end of the tubes to support the Heim joint and aluminum shaft system. A 1" shaft was tapped and the Heim joints were threaded onto the shaft.

Steel plates were mounted onto the suspension to support the 1" shaft and the bearings that are mounted. There are a total of 4 bearings used on each side of the rover. This makes the system strong and rigid. Set collars are used on each bearing to ensure that the shaft does not slide in and out of the bearings.



Figure 3: Differential Bar

Suspension

A rocker-bogie system was manufactured. The suspension was made from the same 2 x 2 x 0.25" aluminum square tubing. It was cut and welded together as shown in figure 4. The rocker and bogie were connected to each other with the use of a heavy-duty shoulder bolt.

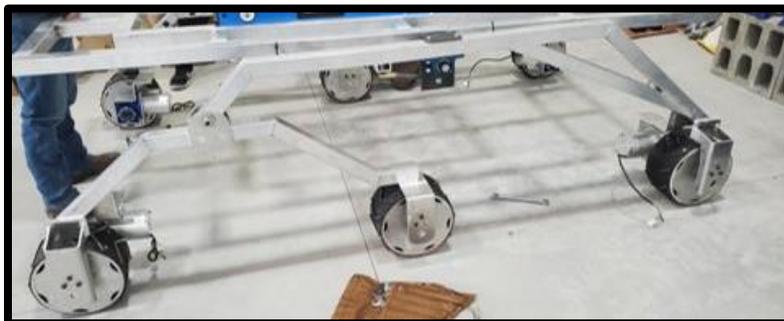


Figure 4: Rocker Bogie Suspension

Frame

The frame was made from 2 x 2 x 0.25" aluminum square tubing. It was designed in such a way that the frame could support everything above it. Thus, it needed to be rigid and strong. The frame was also designed so that the power generation's stuff could be mounted directly into the tubing. Finally, the frame needed to be manufactured and done so well. Therefore, we made sure that every cut was straight, and the weld points were easy to weld.

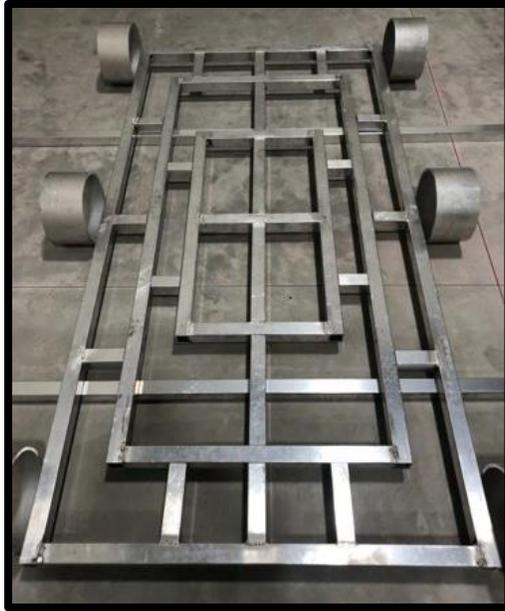


Figure 5: Frame

Finite Element Analysis (FEA)

Finite Element Analysis was completed on all parts that were manufactured and thought to be a part that could potentially fail. A factor of safety on all parts was made sure that they were high enough to make sure the parts were not going to break. This process also helped the design of the frame. Knowing where the part is going to fail in a simulation can be beneficial since then we can add or move parts around to help support the area that is under the most amount of stress.

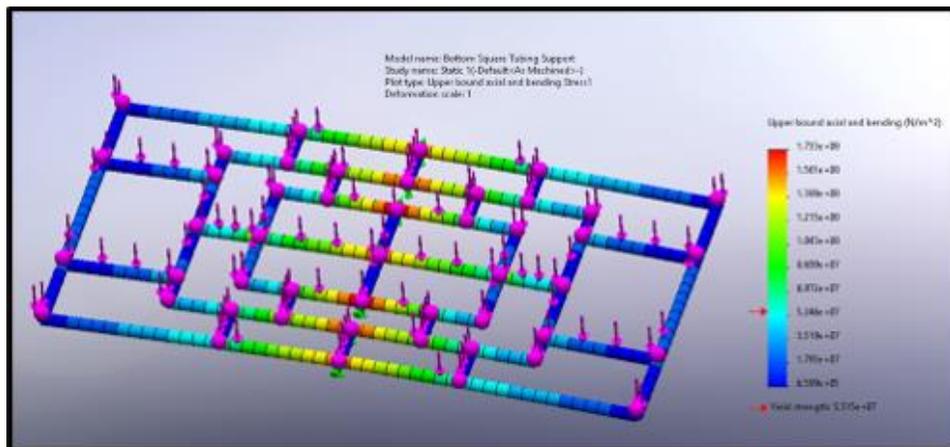


Figure 6: FEA 1

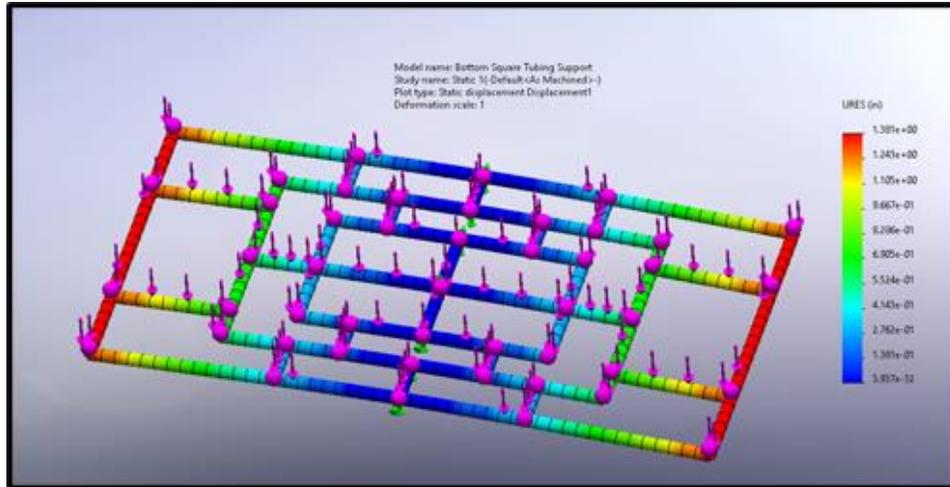


Figure 7: FEA 2

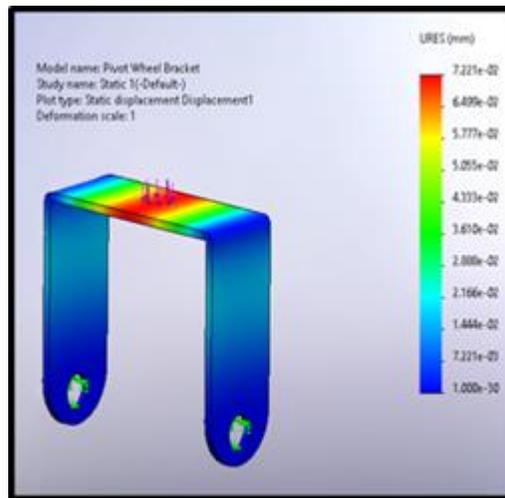


Figure 8: FEA 3

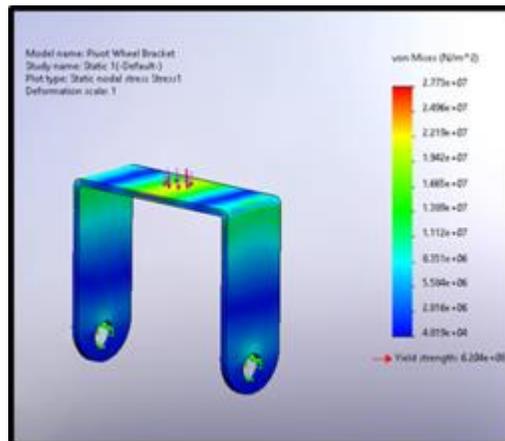


Figure 9: FEA 4

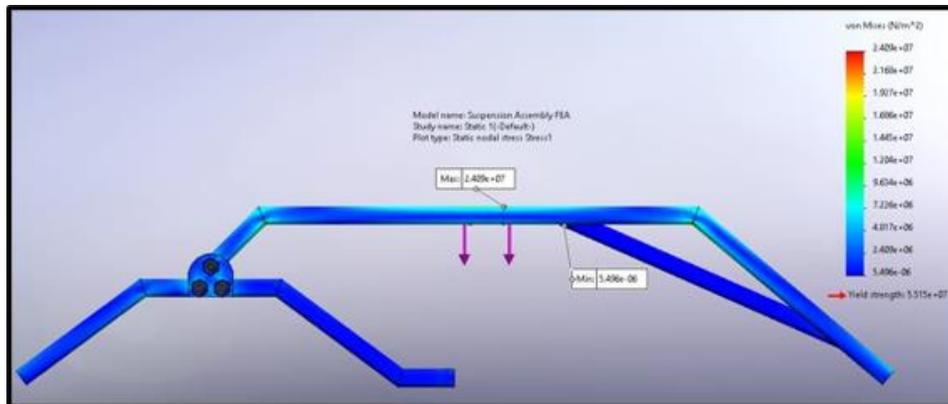


Figure 10: FEA 5

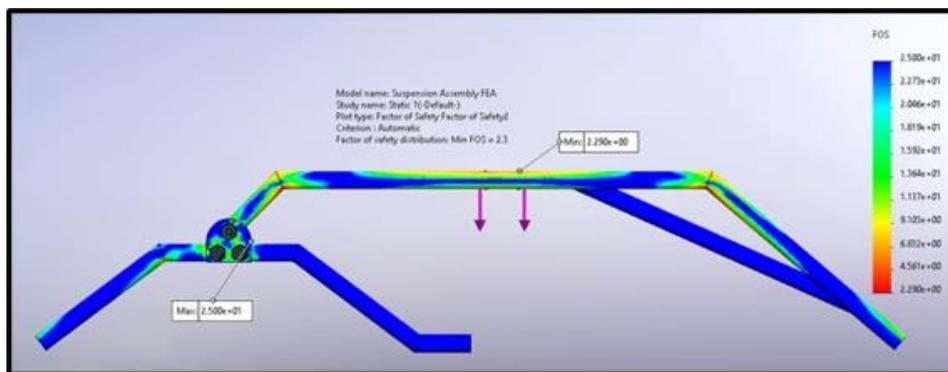


Figure 11: FEA 6

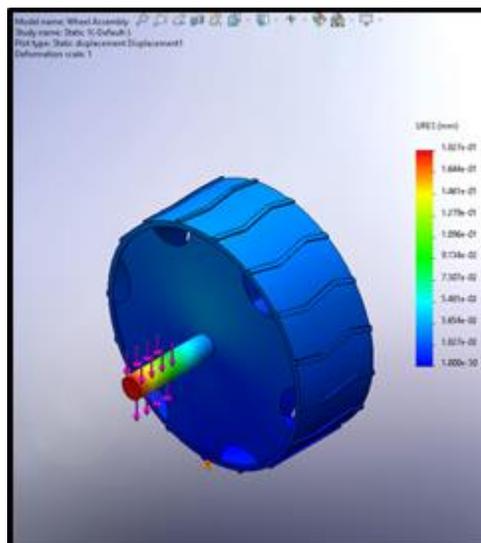


Figure 12: FEA 7

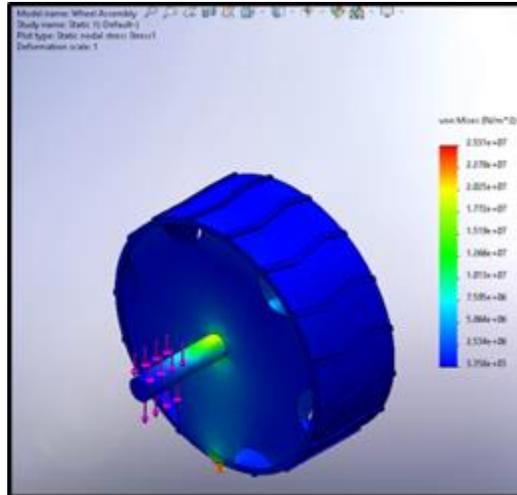


Figure 13: FEA 8

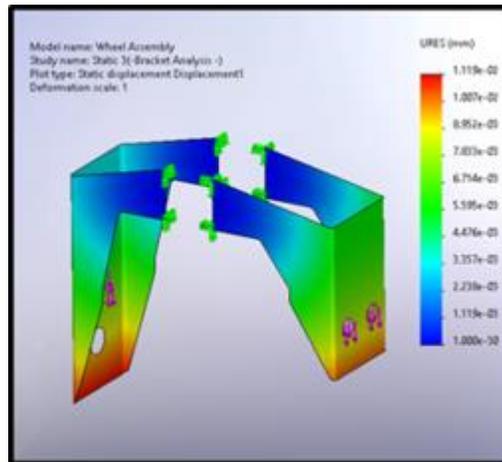


Figure 14: FEA 9

Laboratory Test Plans and Results

After FEA was completed, the parts were ordered. All material was measured to cut with each measurement being checked several times to ensure accurate dimensions. With the parts cut to proper dimensions, most were taken to be welded. Welds were completed in batches. (The batches were: the outer frame square, the middle frame square, the inner frame, the connection between the outer and middle square frame, the connectors between the middle and inner square frame, two batches for each side of the suspension, and each individual wheel.) After each batch was completed, a load was placed on the welds. This was often done by resting the cooled welds on square tubing and walking over them. This simulated a concentrated load that greatly exceeded the expected load on each batch of welds. This lasted until the frame was complete, which was when the rover was placed on blocks and jacks to allow for rover assembly. After the frame and suspension were attached by the differential bar, through testing it was discovered the differential bar needed to be reinforced. After this was complete, satisfactory performance of the differential bar was acquired, and testing the rocker-bogie system was completed by elevating the wheels to various heights with blocks placed underneath each. The differential bar was also tested after the

power team added their parts to the rover and performed to acceptable levels. The rocker-bogie system reaction to elevation was not tested with load due to concerns over physically lifting the wheels with the increased weight. However, the rover has been left to be free standing. Due to time constraints, no complete dynamic testing of the rover has occurred, as the rover has not been made to move. Such testing will still be performed if possible.

Future Work

When building the rover there were some things that came about that could be improved upon. To start with the wheels are too small for the size of the rover that was built. The wheels are currently approximately 10.375" in diameter and 6" wide. The wheels need to be about twice as wide and two times bigger in diameter. Larger wheels would allow for lower motor RPM requirements while also providing more carry over rough terrain. Also, we would suggest designing something like the way Perseverance was designed regards to the differential bar. There is an immense amount of torque that is put onto the bar. Our design was not as rigid as we hoped. The aluminum is not as strong and rigid as we planned thus the bar was bending and allowing the whole frame to be floppy. If the bar was made from steel this would help. But the best way is to design it to ensure that it is super rigid and uses engineering beam principles to minimize the size and maximize the strength of the system. Another thing that could help is adding stops to the suspension system so that it can only rotate a certain distance. Also, the suspension could possibly need some more gusseting at certain points. But we are not sure since we did not conduct enough testing to determine where the weak points are located. The pivot wheel also needs to be redesigned slightly. Our original design did not allow the wheel to pivot as it should. The wheel needs to be offset so that it pivots about its rotating shaft. This means that when the rover is turned without the wheel being able to pivot the wheel will drag on the ground.

OUTREACH

The 2022 NDSU NASA X-Hab team participated in a few different outreach activities aimed at introducing the younger generation to the STEM fields. On Monday February 28th, Tuesday March 1st, and Tuesday March 8th members of the NDSU X-Hab team visited different middle schools in the Fargo Public Schools system and led activities in 8th grade science classrooms demonstrating the engineering design process and problem solving.



On Thursday May 5th, the College of Engineering at NDSU hosted our annual Senior Design Expo from noon to 4pm in our Memorial Union. The event included student teams from all departments within the college displaying the final prototype designed and built by their team as a celebration of their hard work over the years. Each team displayed a poster describing the design process they



completed and were allowed to bring their prototype with them for demonstrations. 3-minute videos produced by some of the teams were also broadcast on big screens throughout the venue during the expo. The NASA X-Hab teams displayed posters inside the ballroom and their rover was parked just outside the window next to their posters on the plaza for all to see walking by. Following the Expo the team demonstrated the functionality of their rover by driving it around campus, stopping to visit the daycare children on campus.

APPENDIX:
Arduino Code

Android

App

Code

