University Rover Challenge

Final Design Review (FDR)

June 9, 2023

Team Impassability

Logan Pascoe
Lpascoe@calpoly.edu

Dylan Tabalan
dtabalan@calpoly.edu

Daniel Xu
dxu07@calpoly.edu

Jake Stone
jstone21@calpoly.edu

Sponsor:
Mechanical Engineering Department, California Polytechnic State University,
San Luis Obispo

Statement of Disclaimer

Abstract

Our team has designed, created, and tested a base rover for the University Rover Challenge (URC), conducted by the Mars Society. The rover's design focuses on modularity and robustness, incorporating a chassis constructed from aluminum extrusions, a robust rocker-bogie suspension system, a six-wheel drive train, and basic controls. The choice of aluminum extrusions ensures modularity for future enhancements, while the rocker-bogie suspension system, commonly used in other competitive and actual Mars rovers, provides improved stability and maneuverability. Rover operations are governed by a server-client architecture, with an Xbox controller input providing an intuitive user interface for movement control. Comprehensive testing confirmed the rover's capability for remote operations and maneuverability, and it meets URC design specifications with a weight of 35 kg and dimensions of 1.168 x 0.991 x 0.457 m. Future teams will need to incorporate a robotic arm, in-situ testing capability, and autonomous navigation, enabling full competition readiness for the URC.

Table of Contents

1 Introduction

This final design review (FDR) focuses on the design and verification of the chassis, controls system, and rocker bogie system for a competition Mars rover for the Mars Society University Rover Challenge (URC). The objective of the URC is to design and build a rover capable of performing a range of scientific tasks throughout a competition. Our team's mission is to create the base setup for a future Cal Poly team competing in this competition.

In this report, we will be discussing the manufacturing, assembly, and testing of our verification prototype. This will be done through the following sections: Design Overview, Implementation, Design Verification, and Discussion and Recommendations. In the Design Overview, we will be giving a general description of our prototype rover as well as going more in depth at the changes we have made to the design of the rover since the Critical Design Review. The Implementation section will cover the creation of our prototype from material procurement to manufacturing to assembly. Our testing and verification of the prototype is discussed in the Design Verification Section. Furthermore, we discussed the most prominent design flaws in our design and made suggestions on how to improve the design for future teams in the Discussion and Recommendations section.

2 Design Overview

In this section, we will cover the mechanical and firmware design of the rover. This will include the design of the chassis, wheels, and suspension system. Additionally, we will detail the electrical, software, and control elements of the rover.

2.1 Design Description

The design we selected includes a chassis that is a rectangular frame composed of T-slot aluminum extrusions that will be joined with self-aligning nuts. Various other structural components such as the electronics box, wheels and suspension will be manufactured using prepreg carbon fiber composite and aluminum extrusions.

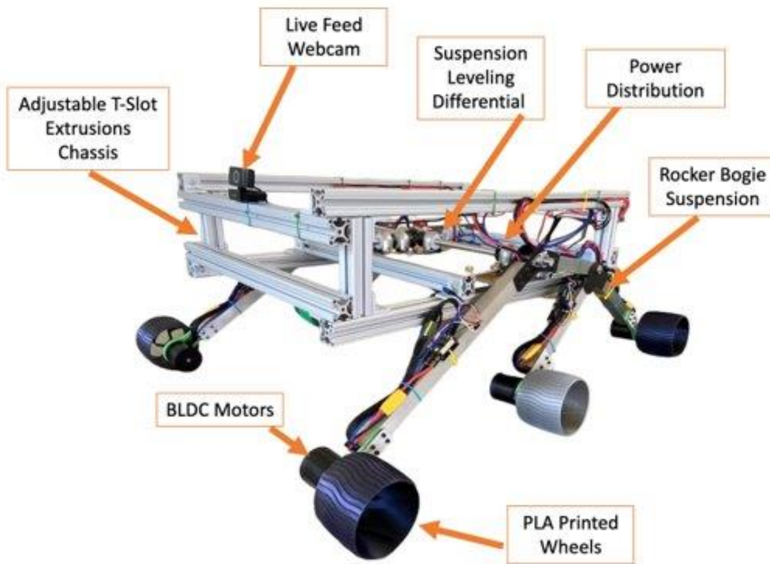


Figure 1. Labeled Isometric View of Constructed Rover

The drivetrain of the design includes six 6” wheels, each controlled by a separate brushless DC motor for 6 brushless DC motors in total. Each motor will be paired with an electronic speed controller. The wheels were intended to be 6” PLA printed wheels with a wide profile for support in sandy environments. However, this was replaced with store bought plastic wheels with rubber tires since the PLA wheels did not have enough traction with the ground. The suspension of the design will be a rocker-bogie design which has been proven to work for traversing difficult terrain.

The wireless functionality will be split into two parts: a base station part and a rover part. The rover part will consist of six VESC6 MCU’s (microcontroller units), a camera, and a Nvidia Jetson Nano. The electric power to the rover will be provided by a dedicated battery. The ground station consists of a laptop communicating with the Nvidia Jetson Nano and an Xbox controller for motion inputs for the rover.

The electronics board will only contain the battery, fuse box, Nvidia Jetson Nano, and USB hub. The electronics box will have ample space for new additions of future teams and the Nvidia Jetson

Nano will still have 3 free USB ports for teams to easily add more electronic components such as a robotic arm or more sensors if necessary for future competitions.

2.2 Design Changes Since CDR

One notable change from the last iteration of the rover was the switch from TPU to PLA wheels. After the first 3D print using the TPU filament was completed, we inspected the prototype wheel. Upon inspection, we determined that the TPU filament was far too flexible and compressed under the weight of the rover. We then switched to a PLA filament and 3D printed a prototype wheel that we determined would be capable of providing the necessary durability required for the harsh environment the rover will encounter. After ensuring this, 6 wheels were 3D printed and fitted to the rover. We then began mobility testing where it was discovered that the PLA wheels, although durable, did not provide the grip needed for the torque output by the brushless motors. This caused the wheels to spin in place on almost all surfaces (concrete, grass, indoor floors).

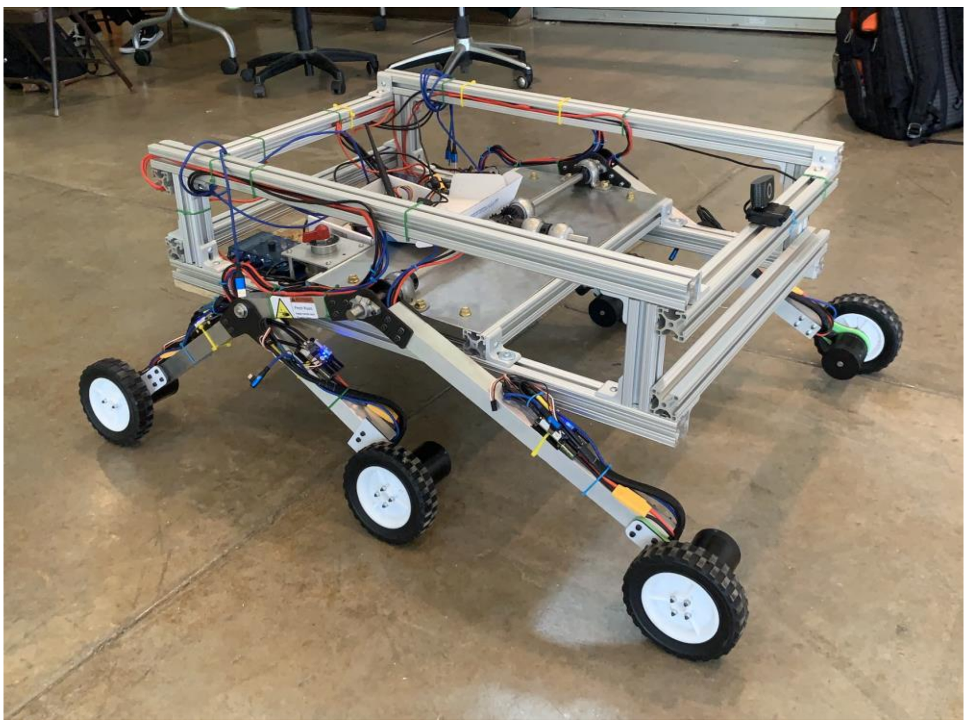


Figure 2. Rover with New Wheels

To prepare for the Senior Design Expo, miniature wagon wheels were purchased and fitted to the rover to provide the traction needed to display the rover's functionality. Notable results from this testing and future improvements include increasing the outer radius of the rover's wheel to give each motor hub more ground clearance and to coat the PLA wheels or find a substitute material that can provide more initial traction. We thought about coating the PLA wheels in some sort of rubber or lining the outer fins with a rubber to provide more traction since the PLA base provided adequate stability and spare wheels are easily printable.

Another design change revolves around the electronics box. In the previous iteration, we had planned to include a separate removable enclosure to house the rover's electrical hardware to provide water and dust protection. However, since the rover was not undergoing these conditions, we did not enclose the electronics box to simplify the disassembly and re-assembly processes. Since the electronics are not in their final placement or on proper hardware, we did not design housing for this temporary placement. Additionally, due to our scope and for consideration for future teams, it was best to not design an enclosed electronics box without knowing exactly what other teams would add. We also strategically diverted the time and resources saved by forgoing these enclosures to further prepare the rover for the expo and finalize its assembly and components.

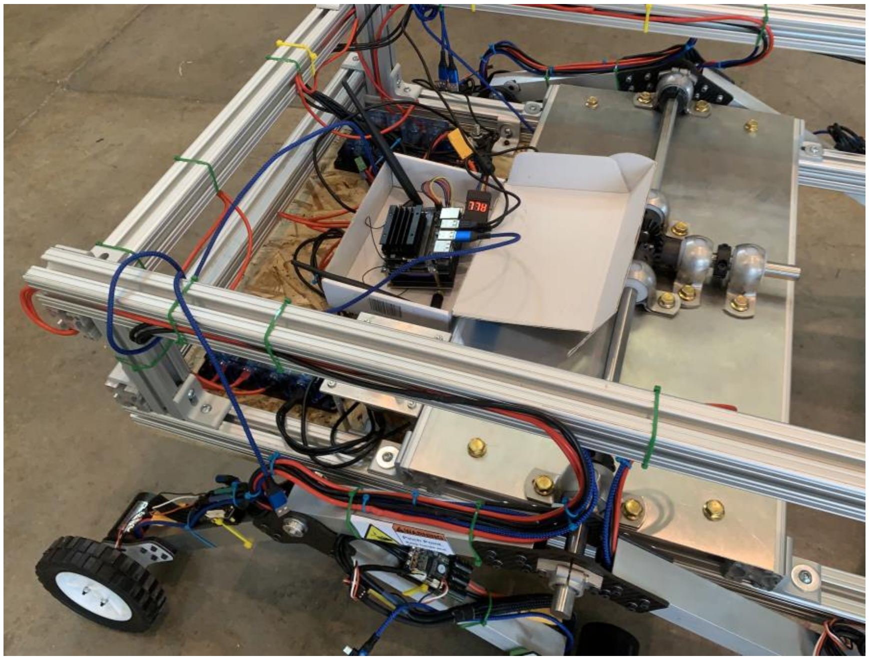


Figure 3. New Electronics Board

Furthermore, we made a significant upgrade to the rover's processing capabilities by replacing the Raspberry Pi with a Jetson platform. This decision was driven by our desire to enhance the rover's computational capabilities at a minimal cost difference. We also wanted to leave future teams with a solid foundation to build off of, capable of incorporating future components of the rover. The Jetson platform is specifically designed for AI and deep learning applications, offering advanced image processing, sensor fusion, and autonomous navigation algorithms. This will make future teams capable of incorporating these functionalities into the rover if necessary.

Additionally, we forewent the use of prepreg carbon fiber composite for structural components due to the limited availability and shipping costs/times. Shipping the materials was unfortunately not within the timeframe needed to complete this project. Aluminum provided an excellent alternative in strength-to-weight ratio, corrosion resistance, and was more readily available. By using aluminum, we ensure the robustness and reliability of the suspension needed for the rover testing and left a good platform to iterate and further explore material research.

These design changes exemplify the iterative nature of the design process, where we learned from the previous prototypes, CAD iterations, and design reviews. We used combinations of these learning experiences to make improvements and optimize the rover's durability and cost-effectiveness of the prototype.

3 Implementation

In this section we will cover the implementation of the design we have been producing and analyzing. This includes exploring the process of procuring, manufacturing, and assembling the rover.

3.1 Procurement

The funding for procurement was provided by the Mechanical Engineering Department Senior Project budget and the Mechanical Engineering Discretionary-funds Allocation Committee (MEDAC). Procurement was done through online methods from Amazon, McMaster-Carr, mboards, and Flipsky. The latter two are electric skateboard companies who we got parts from for the driving system. All mechanical and structural components were acquired through McMaster-Carr for their quick turnaround time and historical quality. Electronic components, if not ordered through an electronic skateboard company were purchased through Amazon. Products from Amazon are cheaper but have varying quality that became a problem down the road.

Table 1. Summary Budget Table

MECHANICAL ENGINEERING SENIOR PROJECT - UNIVERSITY ROVER CHALLENGE BUDGET TRACKER		
System	Subsystem	Net Cost
Structural		$1,652.90
	Chassis	$443.40
	Rocker-Bogie (Suspension)	$263.06
	Differential	$764.02
	Multi-Purpose Fasteners + Brackets	$182.42
Electronics		$2,573.45
	Computer + Communications System	$352.11
	Motors + Controllers	$1,271.00
	Wiring + Power Distribution System	$501.87
	Batteries	$448.47
	Total Cost	$4,226.35
	Senior Project Budget	$3,000.00
	MEDAC Funding	$1,509.08
	Remaining Funds	$282.73

3.2 Manufacturing

Based on our design intent, the manufacturing processes were intended to be minimal and simple to ensure easy replication by all shop skill and experience levels. It consists of simple mill and hand drilling operations on the differential plate, motor brackets, and suspension arms and suspension brackets. The waterjet was utilized to cut out the complex curved profiles of the suspension rocker bogie brackets and also the motor brackets.

3.2.1 Chassis

Chassis extrusion length were measured out and marked. Ideally, we would use a chop saw to cut the extrusion to size, however the chop saw in Mustang 60 was out of order, so we used a bandsaw to cut to size. A picture of this cutting process is shown in figure 4. The quantity and dimensions of each extrusion cut length is presented in vertical, horizontal and longitudinal T-slot drawing in the drawing package.

Figure 4. Cutting Chassis Extrusion to Size.

3.2.2 Suspension Arms

The suspension arms were first cut to desired length by a chop saw. After cutting, the three different sized arms were all marked to avoid confusion and ensure the correct corresponding holes were drilled. Next, a drawing template of the hole positions were printed to ensure all proper location of the holes. The lengthwise centerline of all the suspension arms were measured out and scribed. We then lined up the center line of the template to the centerline of the arms and secured this together with tape. Once the template was secured to the arm, a center punch was used to locate the centerlines of all required holes based on the drawing. The template drawing could then be removed, and the arm can now be secured into the mill vise. The holes could now be drilled using a 5mm drill bit and moderate speed and pressure. Small amounts of cutting fluid should be used on the drill bit to ensure lubrication and extend the life of the bit. The first hole should be aligned based off one of the center punch divots in the arm. Once the first hole has been drilled through the entire width of the arm, the mill's digital readout (DRO) should be zeros. This gives a coordinate system to locate the next holes based on the drawing specifications for each suspension arm. Locating the proceeding holes with the DRO provides better accuracy and ensures that all the holes are located dimensionally accurate from each other. After all the required holes are drilled, the arm can be removed for the vise in preparation for deburring. Using a deburring tool on all holes and inner edges to smooth and rough edges and burs. Additionally, a flat file should be used on the inside face to remove any interior burs from the hole drilling process. Lastly, the exterior cut edges should be chamfered using a file. A finished arm that is being deburred and chamfered is presented in figure 5 below. This step is critical as any burs or sharp edges have the possibility to sever and of the internally routed power wires.

Figure 5. Deburring and Chamfering of the Suspension Arm.

3.2.3 Suspension and Motor Brackets

The rocker bogie suspension brackets and motor brackets were both manufactured using the Mustang 60' water jet. This process was chosen as both brackets have a complex curved profile which is most suitable for an automated process that can produce numerous identical parts. Since both the rocker and bogie suspension brackets are manufactured from the same carbon fiber plate material, they can be manufactured from the same stock. This also allows for them to be manufactured in the same waterjet operation. This cuts down in manufacturing time as both are cut out in the same setup operation. The motor brackets require a separate setup and waterjet operation as it is produced from a different stock of 1/8” aluminum composite, however this material selection can be altered to the same carbon fiber plate to perform all three parts in the same operation. This will therefore speed up manufacturing time. An image of the waterjet operation is presented in figure 6 below.

Figure 6. Water Jet Operation

After the waterjet operation, the parts must be post processed. The waterjet has difficulty producing dimensionally accurate small holes. It also produces some lead in artifacts on the cut for the hole to minimize delamination when piercing through carbon fiber. Because of this there remain some small tabs within the hole as shown in Figure 7.

Figure 7. Inside tabs on carbon holes for suspension brackets.

Therefore, the holes must be drilled to final size. This was done using a proper 5mm sized drill bit and hand drill. Three brackets were stacked together and clamped to a surface to speed up operation time. A picture of the post operation drilling is shown in Figure 8.

Figure 8. Post Operation Drilling of Motor Brackets

3.2.4 Wheels

Wheels were 3D printed with PLA material with the assistance of Innovation Sandbox. First the CAD files were exported to STL files. The STL files were then used in PrusaSlicer to prepare them for the 3D Printer. The final product wheels are pictured in figure 9.

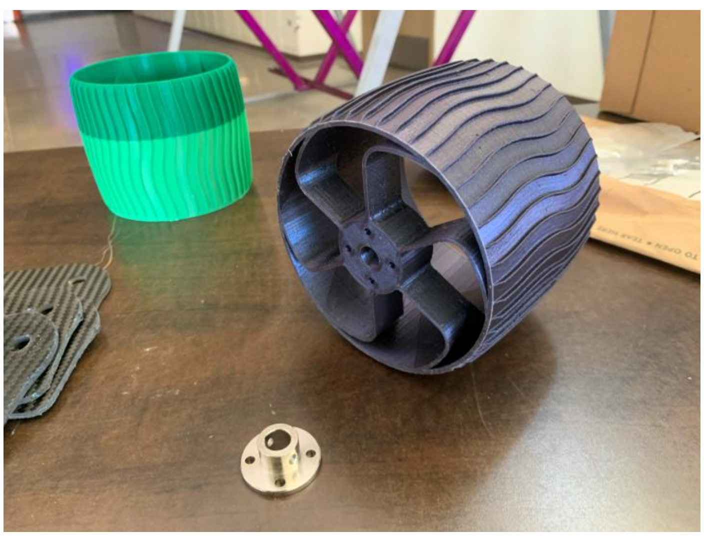


Figure 9. 3D Printed PLA Wheels

3.2.5 Differential Plate

The aluminum plate that is the structure for the differential supports was manufactured by hand. Ideally it would be cut on the waterjet to ensure accurate hole positioning. However due to delay in receiving the material and waterjet workorder backups, it was drilled by hand. This was not difficult as the stock was the exact 12”x24” dimensions we desired so it did not require additional complex profile cutting. To ensure accuracy in hole positioning, a one to one scaled drawing was printed and lined up to the plate. This properly scaled drawing ensured all required holes were in the correct position. In order to align the drawing with the plate, a centerline lengthwise and widthwise was measured out and scribed using a speedsqaure. These scribed centerlines were aligned with the drawing centerlines. This overlay of the drawing on the material is shown in figure 10.

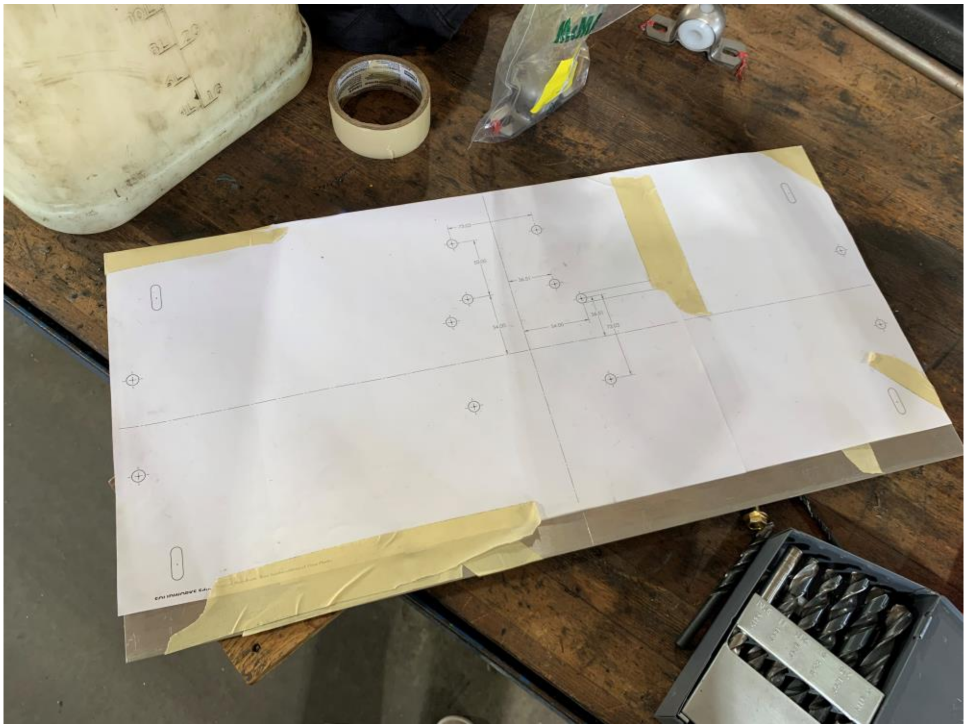


Figure 10. Overlay of the drawing on the material to align center holes.

From this step the centers for the holes were marked with a centerpunch and the drawing could be removed for drilling. The holes were drilled by first using a small drill bit at the point of the centerpunch and then the drill bit size was stepped up until reaching the desired 8.5mm diameter.

3.3 Assembly

Assembly consisted of assembling the various sub-assemblies and their components separately securing them all together to the chassis with nuts and bolts made for aluminum T-slot extrusions. These sub-assemblies are the chassis, suspension, and differential sub assembly. The labeled sub-assemblies are shown below in figure 11.

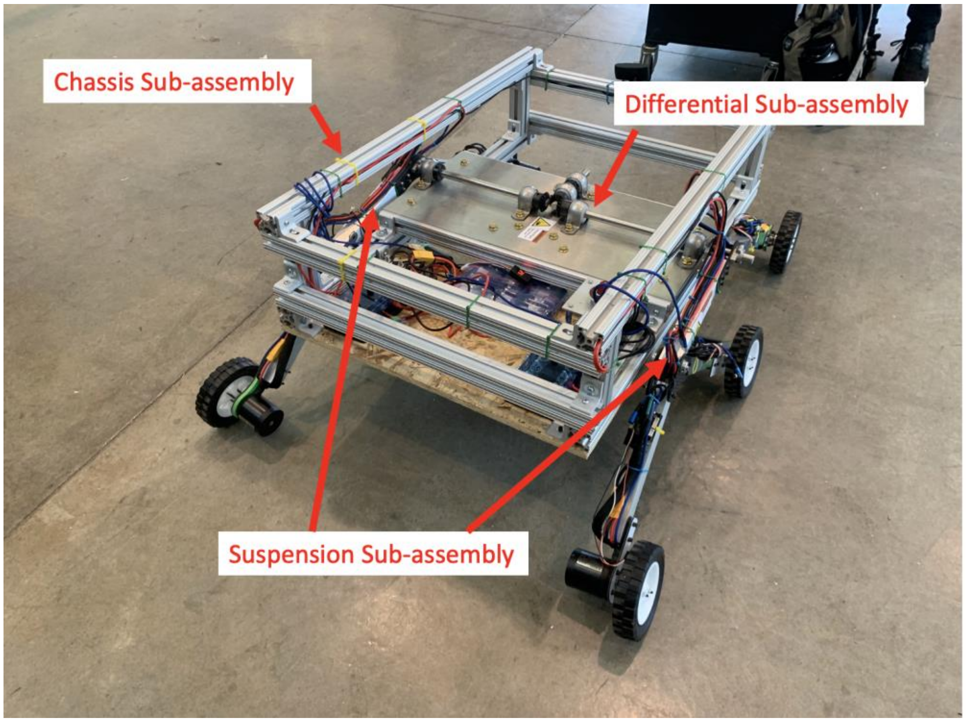


Figure 11. Sub-assembly diagram

Firstly, the chassis should be assembled with cut-to-length aluminum extrusions. Using the purchased T-slot nuts and button head M4 kit, the extrusions should be secured together with the purchased extrusions brackets positions according to the drawing package. The fully assembled chassis is shown below in figure 12.

Figure 12. Rover chassis sub-assembly

Next the suspensions arms can be assembled. This requires the rocker and bogie suspension arms, rocker and bogie suspension brackets, and motor brackets and hardware according to the assembly drawing from the drawing package. The wires for the motors and VESC should be routed through the arms during the assembly process. The fully assembled suspension is shown in figure 13.

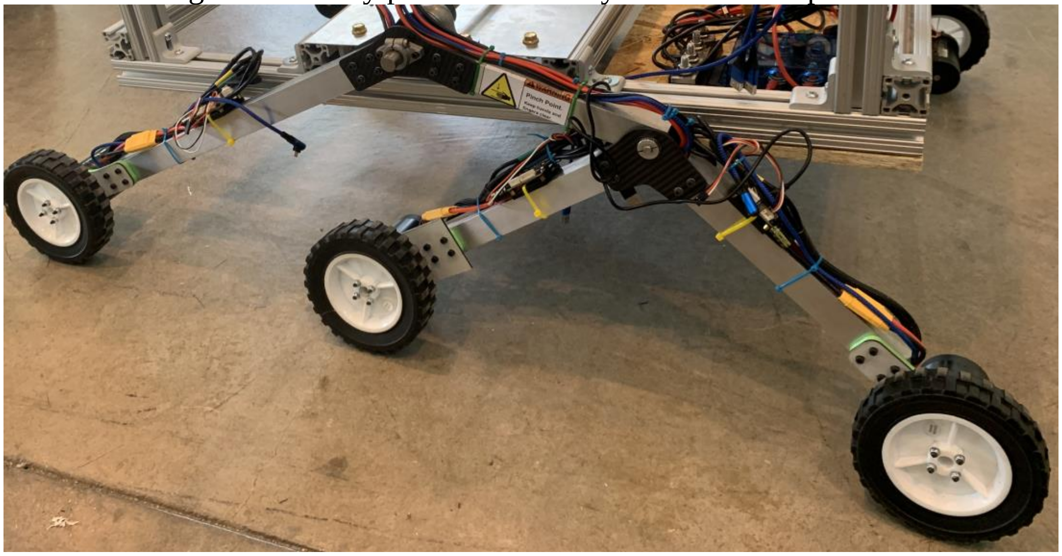


Figure 13. Rover left side suspension with completed wiring.

Lastly, the differential sub-assembly can be assembled. This just requires securing the shaft supports, bevel gears, and D-slot shaft together with the required hardware based on the assembly drawing. The assembled differential plate is presented in figure 14.

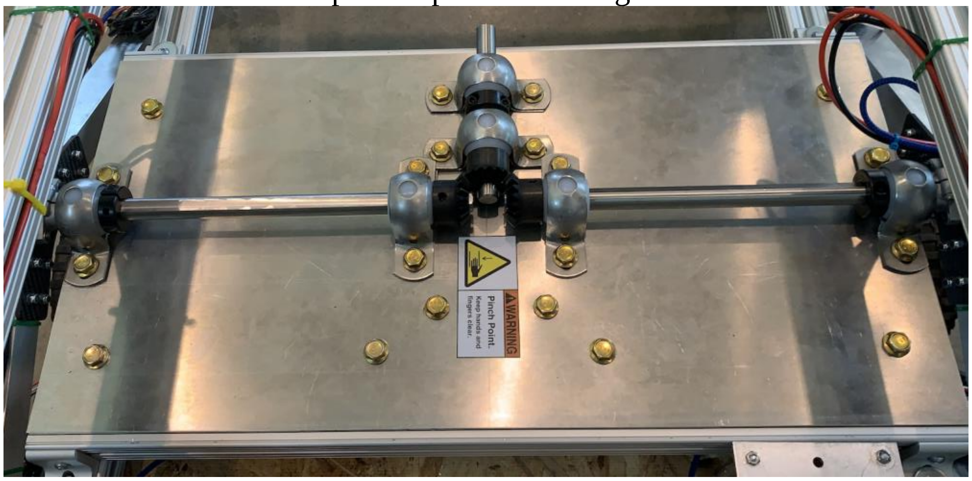


Figure 14. Differential gearbox sub-assembly.

Once all sub-assemblies are constructed, the differential sub assembly should be secured to the chassis using the same hardware for joining the chassis extrusions together. From there the suspension can be attached by securing the shaft clamps to the D-slot shaft from the differential assembly. Finally, all wiring should be routed and secured neatly to the chassis extrusions to complete the rover assembly.

3.4 Software & Electronics

The electronic speed controllers, XT90 connectors, and wires were soldered, and heat shrunk in the Mechatronics Laboratory (192-118) and the wire lugs were attached to the wires using the wire crimps, wire strippers, and wire cutters in the Electrical Engineering department’s Student Project Lab (20-111).

The software was specifically engineered to streamline the communication between the rover and the base station. A dedicated C++ code, designed for the Nvidia Jetson Nano within the rover, enabled the capture and transmission of real-time webcam footage to the base station.

As part of the software configuration, a segment was tailored specifically to receive navigational directives from the base station, facilitating remote control. This setup included a key component: the code responsible for managing six individual motors, employing differential torque steering for proficient maneuverability. One significant challenge encountered during this phase was the development of an interface for the VESC (Vedder Electronic Speed Controllers), a fundamental aspect of motor control. The primary challenge with interfacing with the VESCs involved developing custom software to facilitate detailed communication in the absence of comprehensive documentation. This necessitated an in-depth exploration of the available source code and the creation of necessary components from scratch.

Additionally, C++ code was developed for the base station to receive and display the rover's video feed. This was paired with a separate module designed to read controller inputs and transmit corresponding data. A graphical user interface (GUI) was implemented to provide a user-friendly platform. This consolidated the video feed, controller inputs, and other essential data into an accessible visual display, streamlining the control and monitoring of rover operations. This GUI is pictured below in figure 15.

Figure 15. Screenshot of Working GUI

4 Design Verification

In this section we will cover the verification of the design we have manufacturted. This includes exploring the specifications to meet and the tests to verify them.

4.1 Specifications

The specifications for our design verifications are mostly derived from the competition and project constraints with a few specifications being functional design parameters. These specifications are summarized below in table 2.

Table 2. Specification Table

Spec #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Size	$1.2m^2$ ***	Max	L	A,I
2	Weight	50 kg.***	Max	M	A,I
3	Production Cost	$4,500	Max	H	A
4	Motor Power	7 N-m.	Min	L	A,T
5	Remote Operation	10m	Min	M	A,T
6	Data Transmission	10m	Min	M	A,T

*Risk of meeting specification: H (High), (M) Medium, (L) Low
** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test
*** Competition Parameters

4.2 Testing and Results

The table below summarizes the tests, methodology, and results for the specifications. It's important to note that Remote Operation and Data Transmission from the Specifications table were combined in the test summary table because they are linked in verification.

Table 3. Summary Test Table

Test	Methodology	Results	Notes
Size	Measure dimensions of rover to verify they are within competition regulation (1.2m cube)	1.168 x 0.991 x 0.457 m Pass	
Weight	Verify weight of rover to verify it is within competition regulation (50kg)	77 lbs (~35 kg) Pass	
Production Cost	Verify that cost of the rover stays under the project budget cap of $4509.08	$4,226.35 Pass	

Motor Power	Test the torque output capability of the motors to ensure that it can climb terrain (7 N-m)	Inconclusive Fail	Motors have a safety feature that reverses motion if it senses that the motor approaches torque limit, however impact data was collected and statistically analyzed - see section
Remote Operation	Test that the rover can operate remotely (10 m)	Pass	

4.2.1 Size Test

We measured the size of the rover in length, width, and height dimension from furthest point to point. We needed to meet the requirement of it fitting in a 1.2 x 1.2 x 1.2-meter space. Based on our measurements, the rover had dimensions of 1.168 x .990 x .457 meters.

4.2.2 Weight Test

We measured the full weight of the rover with all its current equipment. This weight was measured to be 35 kilograms. This was under the permitted weight of 50kg. We are satisfied with the results as it meets our design criteria. Since future teams will need to add future equipment, we still have plenty of weight allowance left. Additionally, our initial design prototype left us with experience and understanding of areas that can be modified to reduce overall weight.

4.2.3 Motor Power

The motor torque test was meant to test the torque output of the motor so that we can verify that it output enough torque to climb a 40-degree incline. This experiment required a scale, which was borrowed from the Mechatronics II lab (192-118), to measure weight; a wooden block to disperse the force of the motor; a powered motor mounted with a straight object of known length (12”). All of this is shown in figure 16 below.

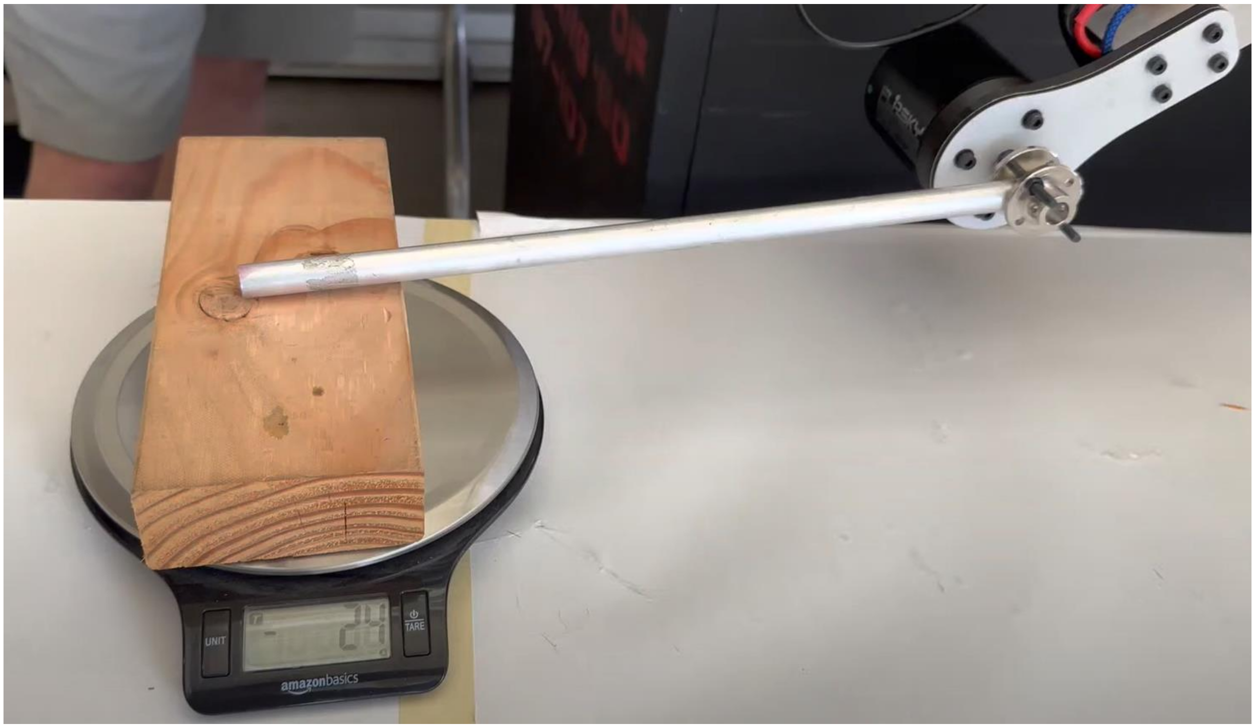


Figure 16. Motor Torque Test Set Up

Originally the procedure to test involved moving the motor forward and forcing the motor to output max torque which we would read as a force on the scale, which was already zeroed with the wooden block. Then we would convert the scale reading to a force and with the known length we could calculate for torque. Unfortunately, there was an impassible safety feature on the motors that reversed motion if the torque limit was being approached. This combined with the user input of forward caused the motor to “play the drum” on the wooden block and hit the block multiple times in quick succession. This test result was deemed inconclusive, however since it is our only test with numerical analysis, we decided to pull impact torques and conduct analysis on them despite not being as reliable sources. Video was taken of the test and data points were taken manually from the video every second and plotted in the graph below in figure 17**.**

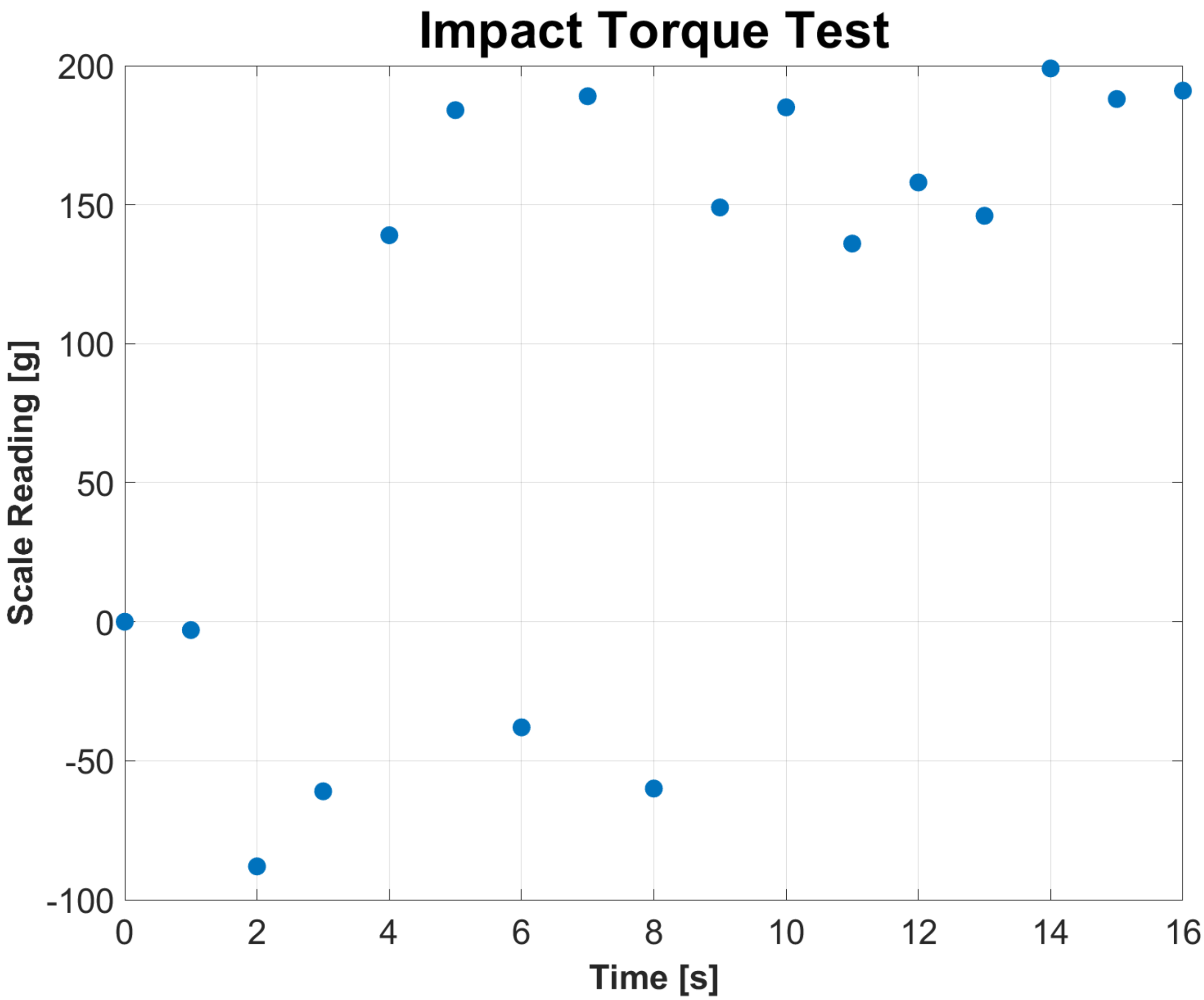


Figure 17. Impact Torque Test Results Plotted

Statistical analysis was conducted for the all the points greater than 0 which yielded: N = 11, $\bar{x}$ = 169.45 g, s = 23.8 g. Since the scale only reads to 1 gram, it means there is a ±0.5 g resolution uncertainty. The full calculation for error propagation is shown below.

$$\tau = (m * g) * r$$

$$\tau = \left(0.16945\ kg * 9.81\frac{m}{s^2}\right) * 12\ in * \left(\frac{1\ in}{39.37\ m}\right)$$

$$\tau = 0.5067\ Nm$$

$$u_\tau = \pm\sqrt{\left(\frac{\partial\tau}{\partial m_1}u_{m_1}\right)^2 + \left(\frac{\partial\tau}{\partial m_2}u_m\right)^2}$$

$$u_\tau = \pm\sqrt{(g * r * 0.0238\ kg)^2 + (g * r * 0.0005\ kg)^2}$$

$$u_\tau = \pm\sqrt{(9.81\frac{m}{s^2} * \left(\frac{12\ in}{39.37\ m}\right) * .0238\ kg)^2 + \left(9.81\frac{m}{s^2} * \left(\frac{12\ in}{39.37\ m}\right) * 0.0005\ kg\right)^2}$$

$$u_\tau = \pm 0.0711\ Nm$$

$$\therefore\ \tau = 0.5067\ Nm\ \pm\ 0.0711\ Nm$$

The result is far from what it should be, but this is due to the inconclusive and volatile method of testing that the data set resulted from. Regardless of the analysis, the test is inconclusive and is thus marked as failed.

4.2.4 Remote Operation

A general pass/fail remote operation test was performed to determine if data from a laptop could be sent to Jetson located on the rover to move the motors. Since the motors successfully moved in accordance with the instructions we sent, the test was a success.

4.2.5 Maneuverability

Due to hardware failure of the speed controllers, we were not able to perform a full 6-wheel drive test of the rover. This means that we could not test whether the rover would be able to traverse rough terrain or scale slopes. However, we were able to successfully get the rover to move and turn during the final week of the project but did not have enough time to perform the tests to verify its maneuverability.

5 Discussion & Recommendations

In this section we will cover the discussion and reommendations on the rover that we have created and tested. This includes discussion of the rover as well as recommendations and next step for the project.

5.1 Discussion

This project, like many others, was not without its obstacles and problems. For starters our scope and direction on the project was very dynamic and freeform. Since we were a competition team that was not aiming to compete this year, we had a hard time determining the scope of what we should focus on and what we can and cannot design without input from future teams. Additionally, when we did run into problems in manufacturing and testing it would become difficult to determine what we should go back and try to fix versus what we should cut our losses with and give recommendations for the next team. Juggling these factors as well as adjusting our scope away from future competition and towards a successful senior expo demonstration made the project difficult to make progress on.

Additionally, for future teams to compete in the URC, we recommend at least 4 senior project teams to collaborate on this project. Each team should be responsible for one of the competition missions, which includes developing a robotic arm, an in-situ life-detection analysis device, and a method for autonomous navigation. There should also be a team responsible for improving the design of the rover itself.

5.2 Recommendations and Next Steps

After our design verification of our initial prototype, we determined several design modifications will be needed to ensure stability and durability of the rover. The following sections will address key issues that we encountered during our verification testing, our understanding of the issue and possible solutions are addressed. The following recommendations are ordered based on importance ranking from high to low.

5.2.1 Rocker Bogie Suspension Pivot

Firstly, issues were discovered in the pivot joint of bogie portion of the rocker bogie suspension. The issue is there is too much clearance between the hole in the carbon bogie plate bracket and the 8mm dowel pin. This clearance allowed too much slack in the joint and allows for the bogie to bow outward and away from the rover. This is an unstable condition and if the rover is driven in reverse, the suspension will pull outward and flex near the point of breaking. A demonstration of this joint and the bogie bow is presented in figure 18, figure 19, and figure 20.

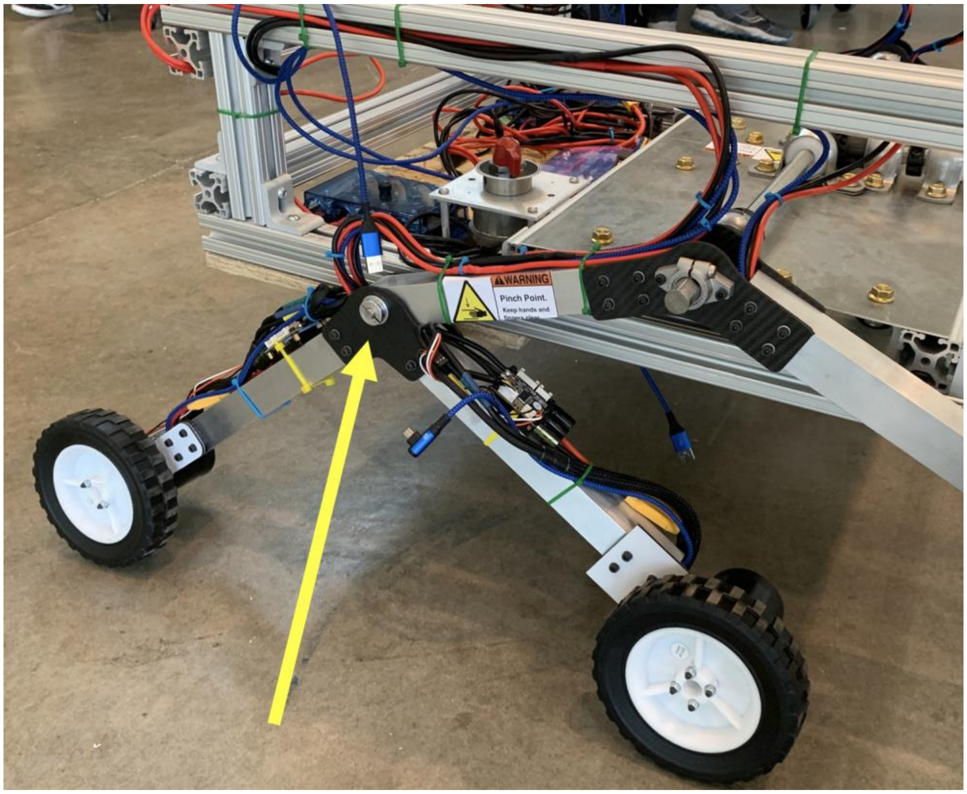


Figure 18. Annotation of bogie pivot joint.

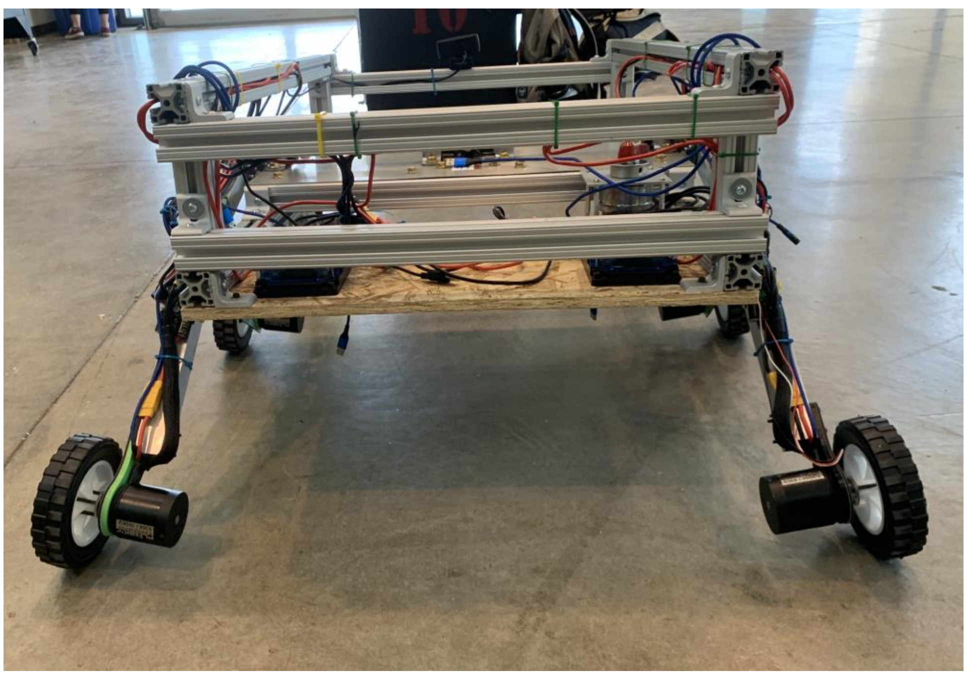


Figure 19. Demonstration of suspension bogie bow when observing rear of the rover.

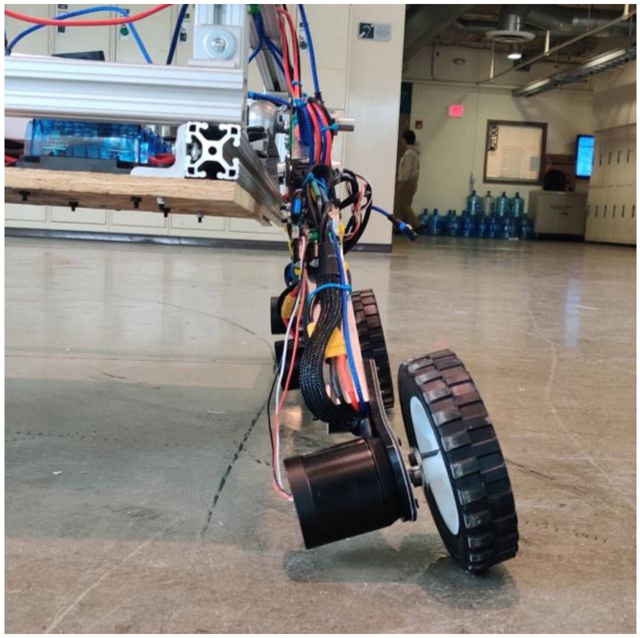


Figure 20. Close-up of suspension bogie bow when observing rear of the rover

We determined there are several methods for solving this issue. A combination of one or both of the solutions should be performed to ensure that the rocker bogie suspension performs as desired. First, a bushing could be incorporated to remove the clearance and allow smooth motion between the carbon bogie brackets and the pivoting pin. Second, the rear most motor bracket and motor could be flipped and secured to the inboard side of the aluminum bogie arm. This is demonstrated in figure 21.

Figure 22. Demonstration of flipped motor bracket and motor.

By performing this modification on each side of the rover, the normal force on the wheel from the ground would be on either side and equidistance from the pivot. This thus provides equilibrium from the pinned support joint and removes the bending moment that created the bogie bow.

5.2.2 Differential Alignment

Additionally, there are issues with the meshing of the bevel gears on the suspension differential. When the rover is suspension in the air and no weight is on the suspension, all the differential shafts line up in plane and the gears sit flush between each other and the teeth mesh properly. However, one standing on its own weight, the idler bevel gear that is in the middle moves out of plane and causes both sides of the suspension bevel gears to contact at an angle where the teeth do not meshy correctly. A demonstration of this issue is provided in figure 23.

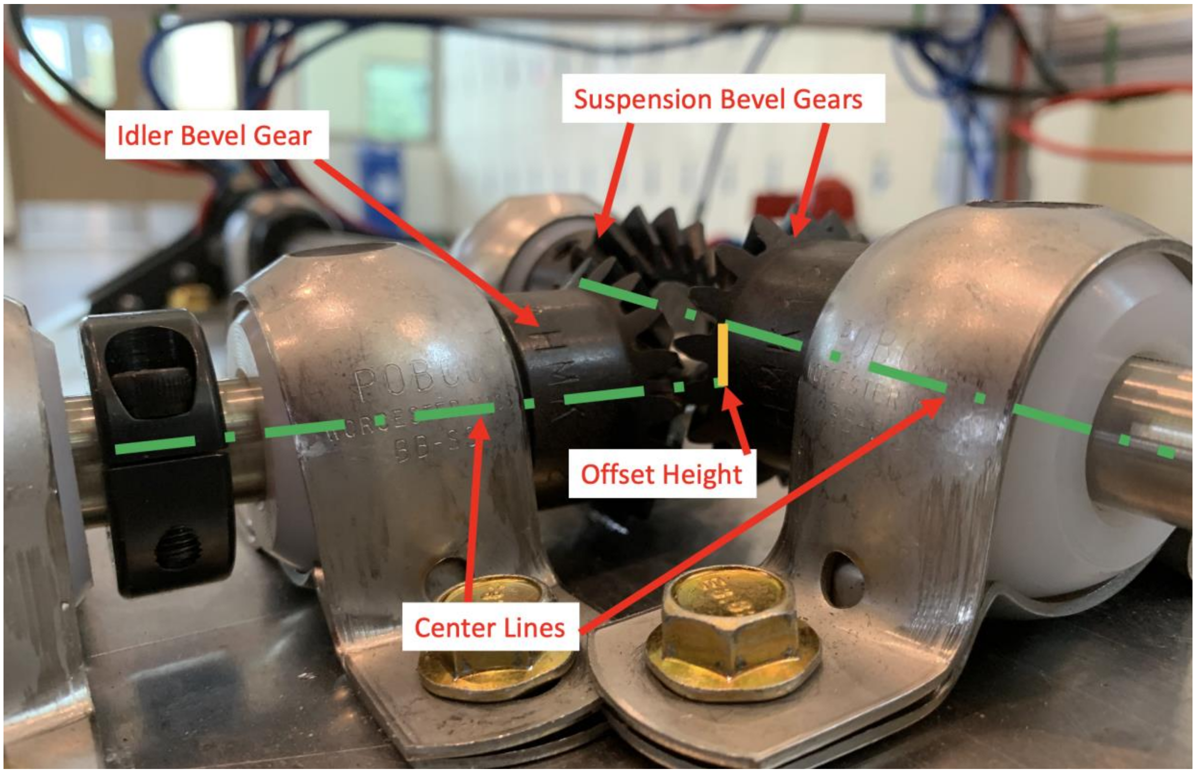


Figure 23. Demonstration of offset differential gear.

In an attempt to resolve this issue, the team manufactured a supporting brace out of scrap material. This brace was intended to tie the two idler shaft supports together with a thicker and more rigid 1/8” aluminum plate underneath the existing 0.05" 6061 Aluminum Sheet. By tying these two supports together, we hoped that it would solve this issue as our thinner aluminum plate was bending, causing the idler support next to the bevel gear to move downwards. We had initially thought this bending was causing the misalignment. This brace is shown in figure 24.

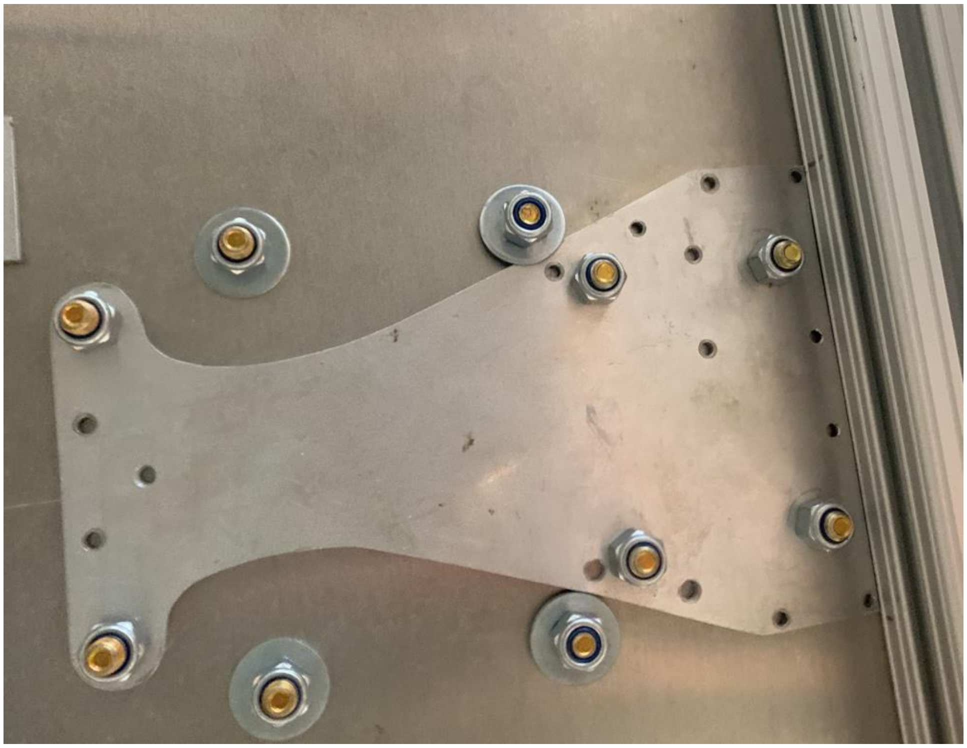


Figure 24. Demonstration of idler support brace shown from underneath the rover.

This brace did increase rigidity of the 0.05” aluminum plate and idler shaft however it did not solve the bevel gear misalignment. A larger plate could be manufactured to tie all four shaft supports together. However, after consideration, this method may also not solve the issue. The shaft supports use a ball joint of a hard plastic that rotates within its outer sheet metal shell. This design is to provide rotational pivot to allow for slight misalignments between shafts. This allowance for rotation appears to be what is causing the misalignment in bevel gears when the weight of the rover is being supported on the shafts. Therefore, we recommend that the future team build a solid one-piece differential support or housing that located and secured all three bevel gears and shafts. This piece could either be machined or milled by hand to reduce complexity. Having all three bevel gears and shafts in a singular rigid piece will prevent the chance for misalignment.

5.2.3 Video and GUI Rework

The GUI was designed so that different elements of the GUI were updated separately through different threads, which is improper practice. This leads to a Segmentation Fault Error to occur after some time. To improve the reliability of the GUI, it is recommended that the GUI be reworked so that all GUI elements are instead updated through a single main thread.

Furthermore, the livestream video feed from the rover to the computer can be reworked to add additional clarity. The video is compressed from 1920x1080 to 192x108, which is a significant loss in image quality. This was done so to decrease the packet size of each frame and minimize the latency. However, as seen in figure 25, it is very difficult to discern any details. The livestream video feed could be improved by utilizing a better library meant for livestreaming such as GStreamer, which could allow for both higher quality video and the addition of streaming audio.

Figure 25. Livestream Video Quality

5.2.4 VESC Enclosure

Furthermore, the VESC boards will need a proper mounting solution. Our current solution for the VESC boards is securing them to the suspension arms using zip ties as shown in figure 26.

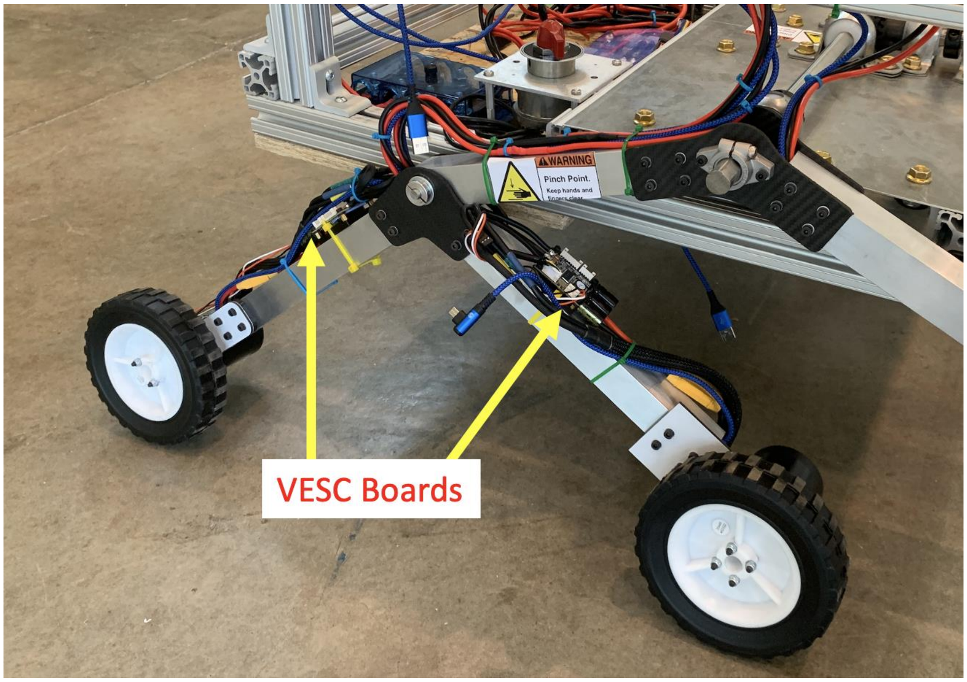


Figure 26. Demonstration of the VESC board mount solution.

This works adequately for testing and problem solving as we have easy access to the wiring and status indicator lights. It also allows for flexibility in mounting solutions of the board as we were unsure if we were going to run into issues while testing that would require us to move the location boards. We were also unsure if future teams would want or need to implement higher quality and reliable VESC boards if their future budget allows. Thus, the zip-ties prevented us from making unnecessary holes in the suspension arms to mount to. However, future teams must decide to either stay with our current VESC boards or utilize their budget to upgrade to more reliable ones. Once this decision is made, they will need to design housing to protect the VESC from dust and water exposure. This enclosure must be fully sealed to the elements while providing adequate passthrough for necessary communication and power cables. It must also integrate or completely replace the heat sink on the VESC to ensure proper cooling for the boards.

5.2.5 Jetson & Battery Mount

Since our scope had changed to not include a full weatherproof electronics enclosure as we wanted to ensure future teams could have the most flexibility and not be space limited for their future electronics implementation, we kept our electronics on an open board. This presented issues as we were storing our rover in a locker that was outside. As a result, we were removing the sensitive components of the Jetson computer and batteries when we were storing the rover. Since we were removing these so frequently and or electronics mounting board was not intended to be left finalized, we had not designed proper mounting solutions for the Jetson or batteries. We had rested the Jetson and its antennas in its box and had set it on top of the battery pack which rested in the center of the electronics board. A picture of our current solution is shown below in figure 27.

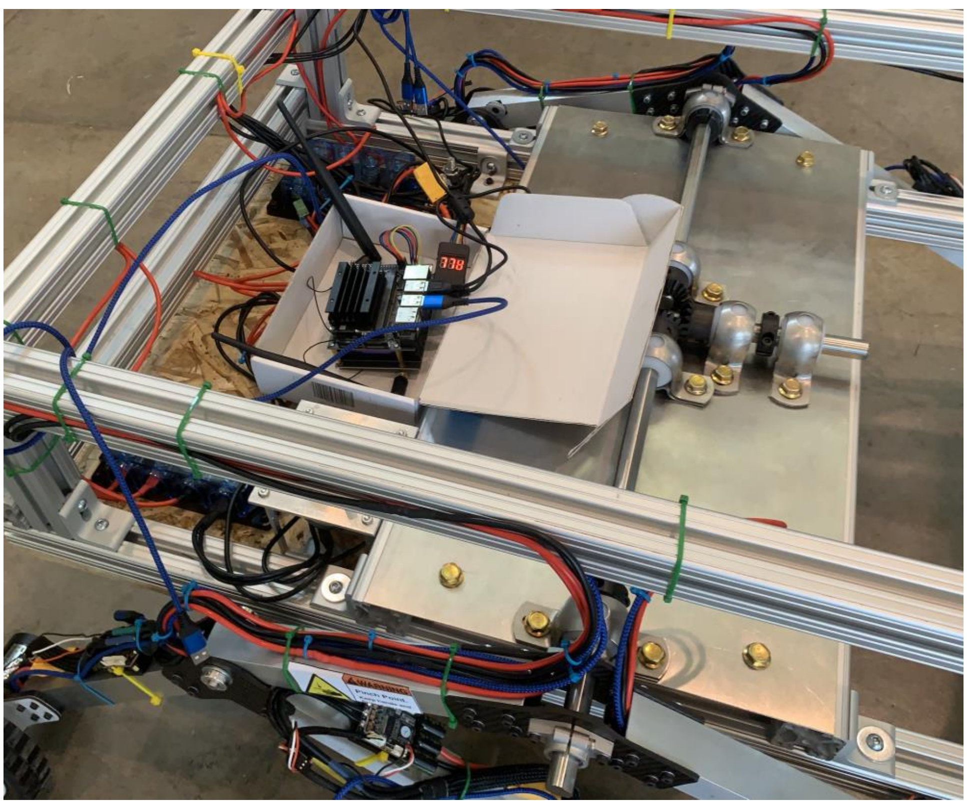


Figure 27. Current Mounting Solution for Jetson computer with battery pack beneath its box.

For future teams to perform more rigorous testing of the rover, we advise that they implement either temporary or permanent mounting solutions for these components. Securing these components could be as simple as Velcro or the teams could design independent waterproof enclosures for the components that could be mounted to the board. The team could also purchase an oversized weatherproof electronics enclosure to replace our current temporary electronics board.

5.2.6 Motor Bracket Reinforcement

The materials that were purchased for the motor brackets was not exactly as intended by design. 1/8” 6061 Aluminum was specified for the brackets to offer proper rigidity. However, a cheaper alternative of 1/8” Aluminum composite was instead selected. It was not discovered until after we had manufactured the brackets that they were actually composed of a sandwich panel construction of Polyethylene surrounded by thin sheets of aluminum. To make up for the loss in rigidity from the Polyethylene, our team utilized two of our designed brackets which were sandwiched together to provide more stability. This solution was not adequate to support the weight of the rover and noticeable bending was still present. To quickly fix this issue to continue testing, our team 3D printed an 8mm thick replica bracket to increase the thickness of the original. This modified bracket was then placed in between the suspension arms and our manufactured motor brackets. A picture of the bracket placement is shown in figure 28.

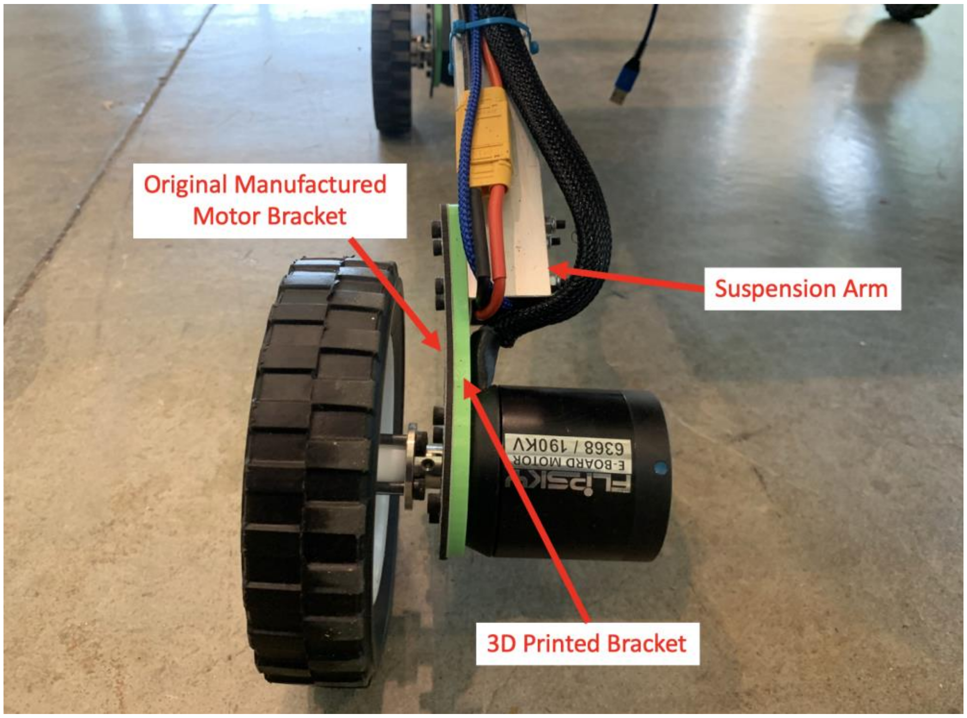


Figure 28. Picture of current motor bracket placement with modified 3D printed bracket.

As seen in the above figure, there is still some slight bending with the current bracket solution. The flex is not drastic enough that it affects our testing, however this issue should be fix to ensure long term durability and performance in more intense tests. A proper solution would be to use the correct 1/8” 6061 aluminum plate material.

5.2.7 Chassis Extrusion Brackets

The purchased brackets that are used to connect all of the aluminum extrusions together to assemble to chassis have large holes and slots that require washers. This is shown in figure 29.

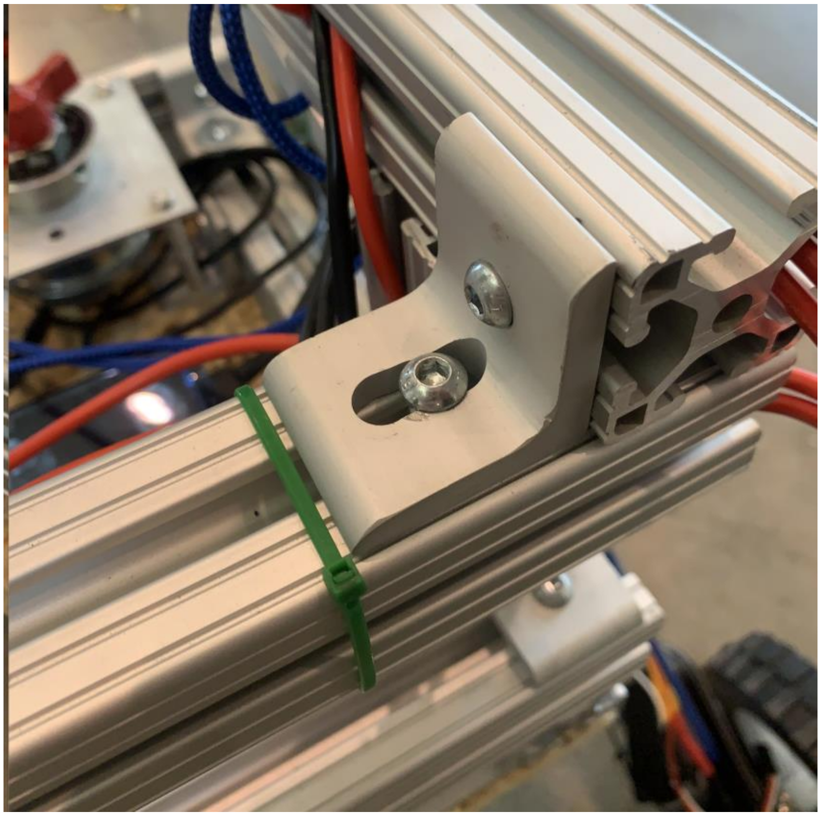


Figure 29. Picture of improper fitting chassis extrusion bracket bolts.

The washers that were ordered have an outer diameter that is the same size as the head of the bolts. So as a result, the washer does not provide an additional clamping surface to the bolthead. Spare washers that were wider were used in an attempt to solve this issue. The use of a larger 11mm washer is shown in figure 30.

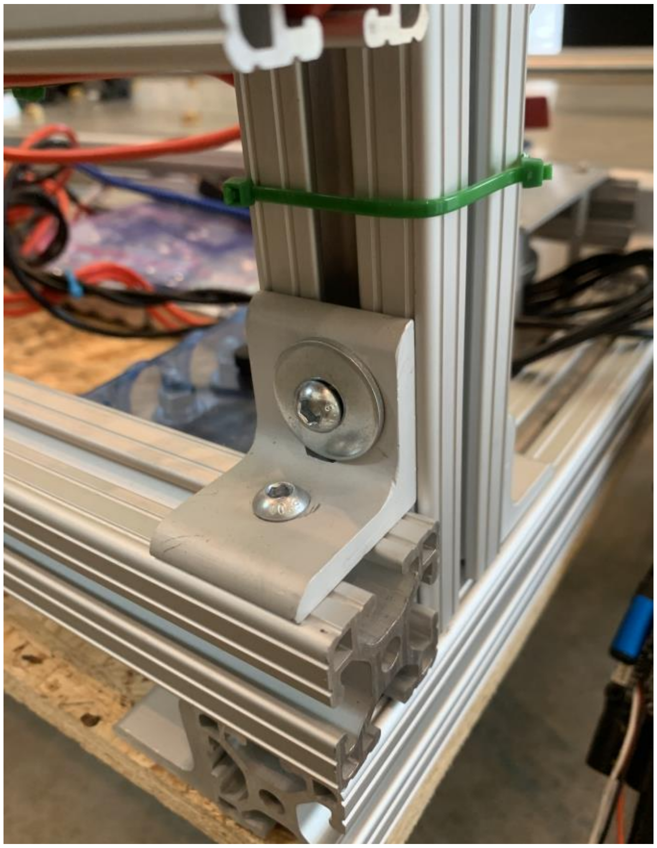


Figure 30. Picture of current incorrectly fitting washer.

The outer diameter of this washer is adequate to provide a proper clamping surface between the bolt and bracket. The issue is the washer is indented for a M6 bolt, so the inner diameter is too large for the m4 bolts that are used to connect the extrusions to the brackets. A correctly sized washer for a m4 bolt that has an outer diameter of 11mm must be purchased and installed on all the chassis brackets. Fixing the bolt and washer stack-up for the chassis brackets will help ensure that the entire chassis stays secure and does not loosen apart.

5.2.8 New Wheel Hubs

New wheels were selected for the rover during our initial testing. We had intended on using our wider 3D printed wheels; however, they did not provide adequate traction on hard surfaces. To continue our verification testing and operation for the expo, we replaced our wheels with hard rubber cartwheels. To secure them to our BLDC motors, we utilized our original wheel hubs to prevent major redesign. This hub was not ideal for the newer wheels as it didn't sit flush with the face of the wheel and the bolt holes aligned very poorly without any suitable regions to secure nuts to. To account for this, holes were very carefully drilled near the edge of the wheel face and the hub was faced to inner protrusion. This method of securing the wheels to the hub is shown in figure 31 and figure 32.

Figure 31. Picture of rear side of wheel and hub assembly.

Figure 32. Picture of current incorrectly fitting washer.

As a result of this solution, longer bolts than necessary are required and the nuts and washers don't entirely sit on the face of the wheel. With our initial testing, the wheels and hub appear to still be concentric, and the wheels still spin evenly and balanced. However, this solution does not present itself as proper and professional and the overall long-term durability is questionable so a proper method of securing the wheel to the motor is desired. This could be done by either coupling a shaft to the motor and wheel through the wheels' axle hole or purchasing a hub that could better fit the wheels.

5.2.9 Electronics Component Upgrade and Considerations

Many electronics either had quality issues and/or were mishandled throughout manufacturing and testing. First, 3 of the electronic speed controllers seemed to somehow stop working throughout testing. We tested all 6 controllers when we first got them, so we knew that they all worked. All electronics were originally stored in an indoor locker separate from the outside locker that stored the main chassis of the rover. However, as electronics were added onto the rover, they moved outside. This was considered, but we thought that factoring the weather coast of the central coast and the robustness of the controllers seeing that they are made for electronic skateboards and should be able to withstand outdoor weather. Unfortunately, 3 of the controllers stopped working and we are not entirely sure why. One of the controllers showed some kind of corrosion due to moisture, which even considering the abnormal amount of rain we got in 2023 should take many more cycles to make that kind of effect. A recommendation for this is to get an indoor locker or space to store the rover. The rover is still currently stored outside, but the high-fidelity electronics have been removed and stored in an electronic bin. Another recommendation is that if the next team intends to compete, they should invest in better motor/controllers. Many competitors for the challenge custom order them from companies instead of getting them from electronic skateboard companies.

Additionally, some of the 6 ft micro-USB to USB A wires from Amazon stopped working as well. We believe this is a quality issue as wires overall should be able to be more robust than what we put the wires through, so we recommend investing in better quality wires.

Finally, more as a word of caution, make sure that when you are making electrical changes to the system that you not only switch off the system but also disconnect all power sources from the system. The batteries used have a very high discharge rate and can be very dangerous if not handled correctly. We made a mistake of not disconnecting the battery while making changes and the wires from the battery shorted and blew up the wires. The wire insulation was burned off and even the wire itself in some locations was burned off itself. The wires are shown below in Figure 33.

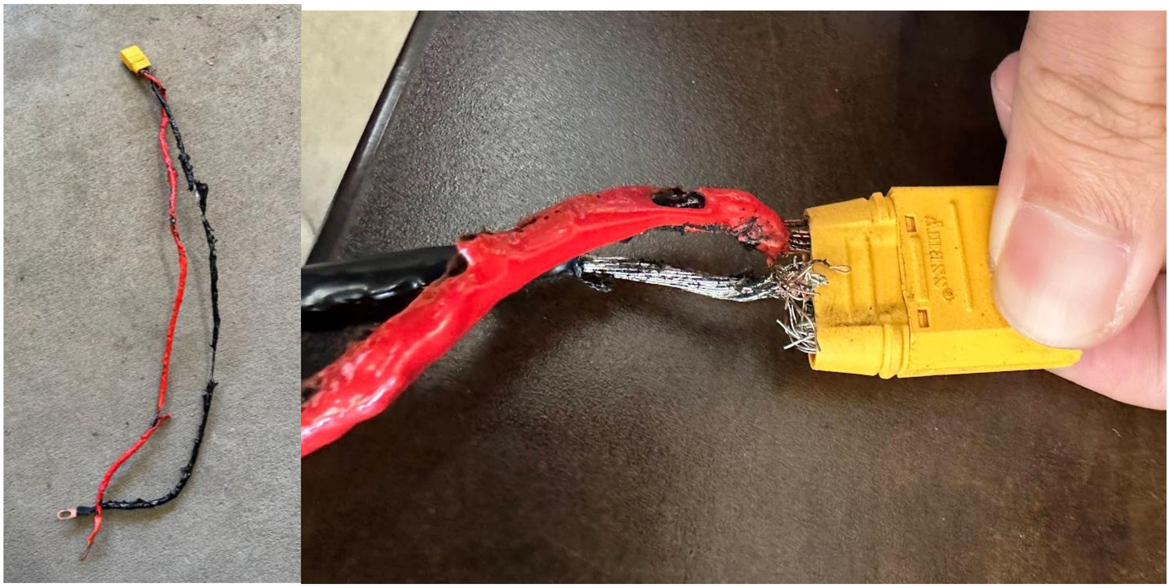


Figure 28. Improperly Used Battery Wire

6 Conclusion

In conclusion, we have created a solid foundation for future teams to work off of, despite all the hardships we encountered along the way. We have a strong base of knowledge and a functioning chassis, suspension, drive system, and communications protocol that we have demonstrated. Unfortunately, we did not accomplish all that we would have hoped including 6-wheel drive and obstacle maneuvering. These shortcomings were a result of electronic problems that we could not foresee even with the input of some professors. Our conclusions and recommendations along with the verification prototype that functions within the competition constraints will be helpful for future teams to continue to develop what we have started and hopefully be able to participate in the University Rover Challenge and score competitively against the other schools.

7 References

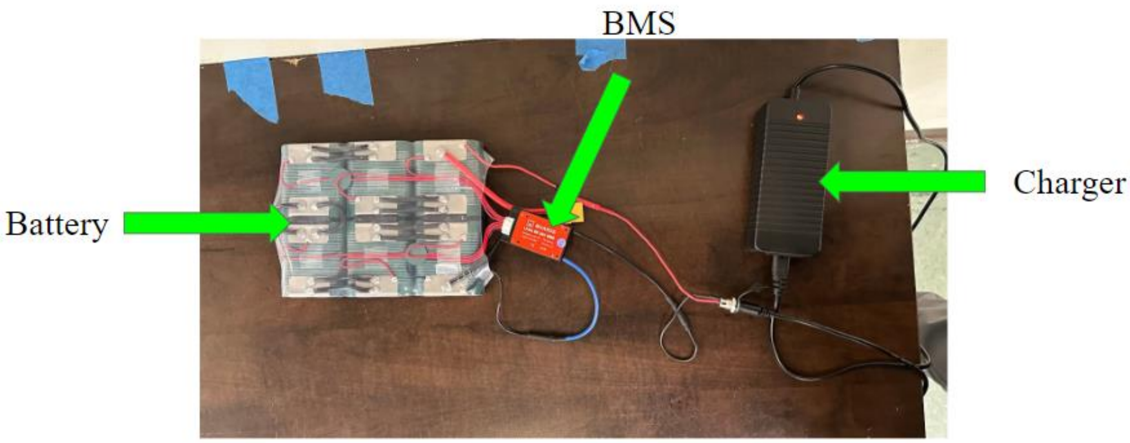
[1] “Requirements & Guidelines.” University Rover Challenge, Mars Society, https://urc.marssociety.org/home/requirements-guidelines

Appendices

Appendix A – User Manual

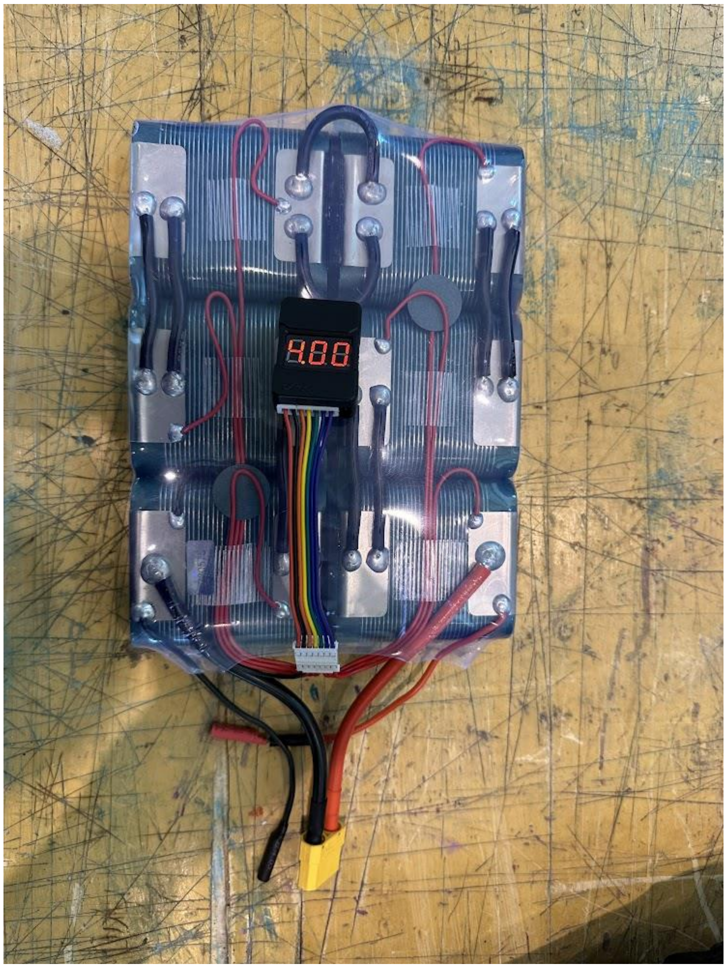
Charging Batteries

1. Plug the Battery Management System (BMS) into the battery, this should consist of 3 connections (the BMS should already be connected to the charger):
    a. 7 small wires a header connector
    b. Black (Battery) to Blue (BMS) connection
    c. Red (Battery) to Red (BMS) connection
2. Plug the charger into the wall socket and it should light up red if not charged fully charged.
3. When charged the charger LED should light green (this process can take hours)



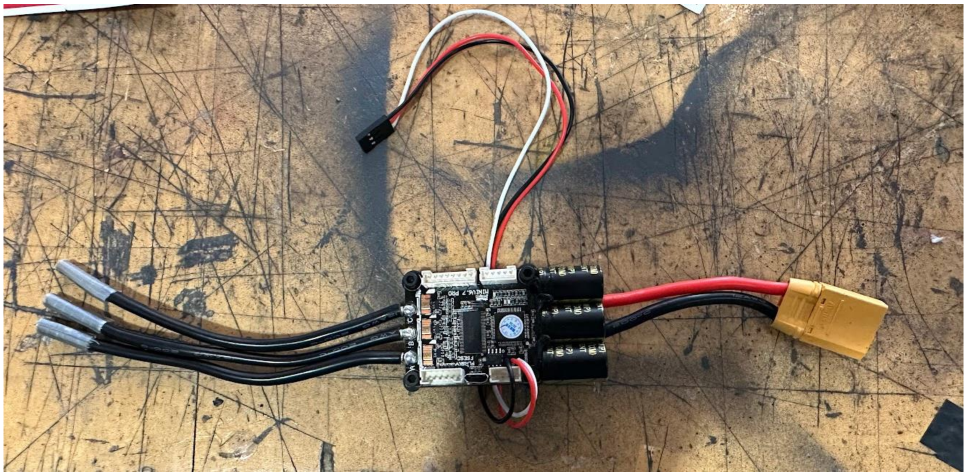
Discharging

1. Attach LiPo Alarm to wire (if not done already). The wires should be aligned to the left with the LED side up as there is more slots than there are wires.
2. Attach the LiPo Alarm to the Battery in the same location you attached the BMS to charge. **<u>Make sure the left most wire leads to the black wire on the battery</u>**
3. The LiPo Alarm will beep to verify that it is working and then it will cycle through the voltages of the 6 cells and then the voltage of All the cells combined.
    a. The LiPo Alarm will beep when the voltage of the individual cells falls below 3.2V but can be changed by pressing the button on the LiPo alarm
4. Once the battery is attached you can attach the battery to the system via the yellow XT90 adapter. **<u>Make sure the switch on the system is off before connection.</u>**



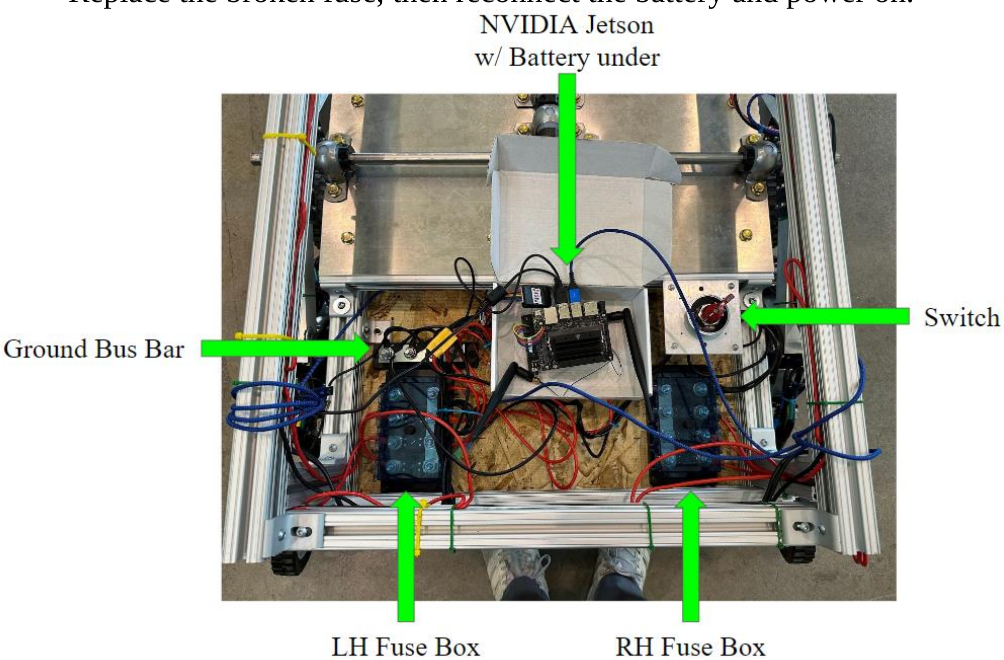
Electronic Speed Controllers (ESC)

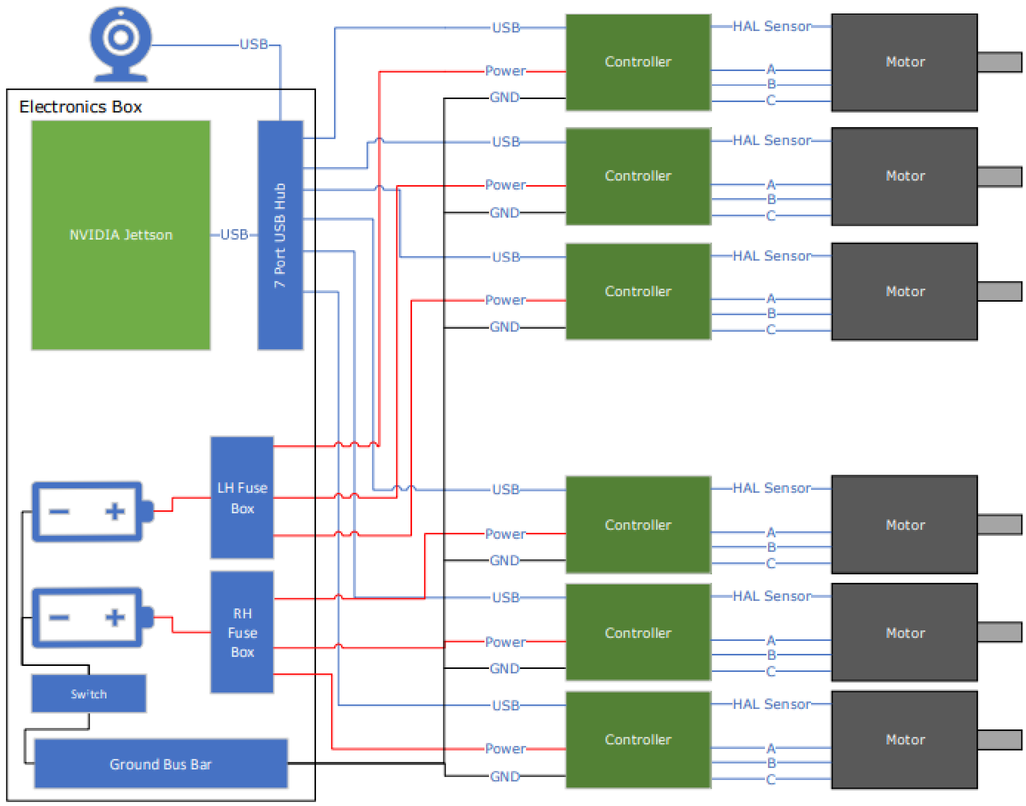
1. Connect to the motor via the 3 wires on the left (from view pictured below) Next to each of those wire there should be a letter A, B, and C connect to the motor's color-coded wires:
    - A (ESC) to Green (Motor)
    - B (ESC) to Blue (Motor)
    - C (ESC) to Yellow (Motor)
2. The 3 colored wires (White, Red, Black) are not needed and can be snipped off if necessary.
3. Connect the power wires (right side on view pictured below) to system via XT90 connectors.



Electronics Box

1. The wiring diagram is below. Check that all wires are connected correctly and tighten down
2. Connect the battery
3. Turn the switch on and the ESC’s should turn on.
4. In the event that a fuse is blown, switch off the system and disconnect batteries
    - The fuse that is broken should be visibly broken through the center window
    - Replace the broken fuse, then reconnect the battery and power on.





Software

To operate the rover, the base station must be running on a Linux operating system such as Ubuntu.

First Time Linux Base Station Library Installations

1. The Qt5, OpenCV, and SDL2 libraries are required to run the program and need to be installed onto the base station computer.
2. Installing SDL2: https://wiki.libsdl.org/SDL2/Installation
3. Installing OpenCV: https://www.geeksforgeeks.org/how-to-install-opencv-in-c-on-linux/#
4. Installing Qt5:

```
sudo apt-get install build-essential
sudo apt-get install qtcreator
sudo apt-get install qt5-default
sudo apt-get install qt5-doc
sudo apt-get install qt5-doc-html qtbase5-doc-html
sudo apt-get install qtbase5-examples
```

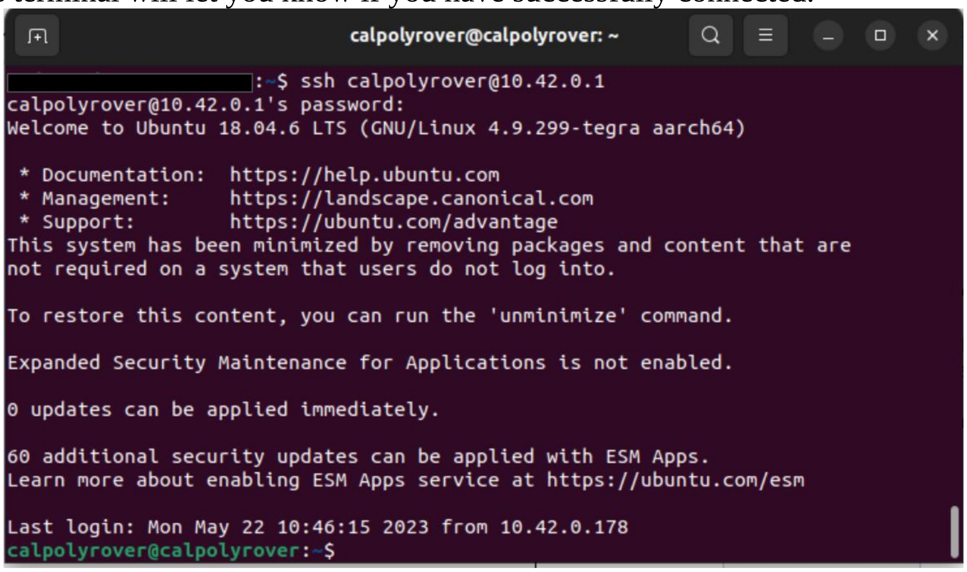
Connecting to the Rover for Headless Operation

1. Turn on the Nvidia Jetson Nano and wait for the small lcd screen on the power module to turn on.
2. On the base computer, connect to the rover's hotspot
   SSID: calpolyrover
   PSWD: rover
3. Open up the terminal (CTRL + ALT + T) and type the following:

```
ssh calpolyrover@10.42.0.1
```

If you choose to connect the Jetson to another network, then replace the 10.42.0.1 the Jetson's Ip address. This address is displayed on the small lcd screen.

4. The terminal will then request a password for the jetson, which is: PSWD: calpolyrover
5. The terminal will let you know if you have successfully connected.



Running the Program

1. To run the program on the nvidia jetson through ssh, utilize the SSH terminal.
2. Type the following into the terminal to enter the directory in which the program is located in:

```
cd testserver/build/
```

3. Once you are in the directory, type the following into the terminal to run the program:

```
./testserver
```

4. As of now, there is no error checking for client-side connections, which means the rover side code must be run first. To start the client-side code, on another terminal, cd in testclient program:

```
cd Senior-Project-Code-Repository/GND_Station/testclient/build
```

   Note: The destination of the program may vary depending on file organization structure.
5. Run the client side code with:

```
./testclient
```

6. The ssh terminal should output "Connected" indicating a successful connection.

Starting the Rover for Operation

1. First ensure that the power switch is turned off.
2. Connect the two batteries and then turn the switch on
3. The VESCs located on the suspension arms should light up blue if power is successfully connected.

4. Turn on the Jetson by flipping the switch on the UPS Power Module from off to on.
5. Connect the USB serial ports to the rover starting with the left-side motors and then the right-side motors.
6. Verify that all motors have been connected by using the following command in the ssh terminal:

```
ls /dev/ttyACM
```

The output should list all connected devices as /dev/ttyACM[0-5]. Additionally, the command:

```
lsusb
```

can be used to show all listed devices. If a USB hub is utilized, the code can be modified to negate the usage of the /dev/ttyACM* address, which will make the order of which the usb devices are connected unnecessary. See Utlizing udev Rules for more.

Turning off the Rover

1. To turn off the rover, first flip the switch to the off position and remove the batteries
2. In the ssh terminal connected to the rover, type the following command:

```
sudo shutdown –h now
```

Alternatively, if a reboot is required,

```
sudo reboot
```

3. Once the green led on the jetson turns off, close the switch on the power module
4. Depending on how the rover is being stored, it may be best to remove the Jetson and the batteries and store them elsewhere.

Updating Code on the Jetson

1. Updating the code on the Jetson can be done in several ways, see methods below:

Method 1: Update Remote Jode Through SSH

1. Existing code on the Jetson can be modified remotely through ssh. First establish an ssh connection.
2. Go into the directory that the code is located in.

```
cd testserver
```

3. Use the vim editor to begin editing code. This example will use main.cpp, but it can be replaced with any file. In the command terminal:

```
vi main.cpp
```

4. The program can now be modified through the terminal. Commands need be input into the terminal before any actions may be performed. Some important commands are:

i	his is the INSERT command, which allows for modification of the file. The bottom left of the terminal will say --INSERT-- when this mode is active. Press esc to exit this mode.
:w	This command writes/saves any changes.
:q	This command quits out of the vim editor.
:x OR :wq	This command saves and exits the vim editor.
u	undos the last edit
ctrl + r	redo

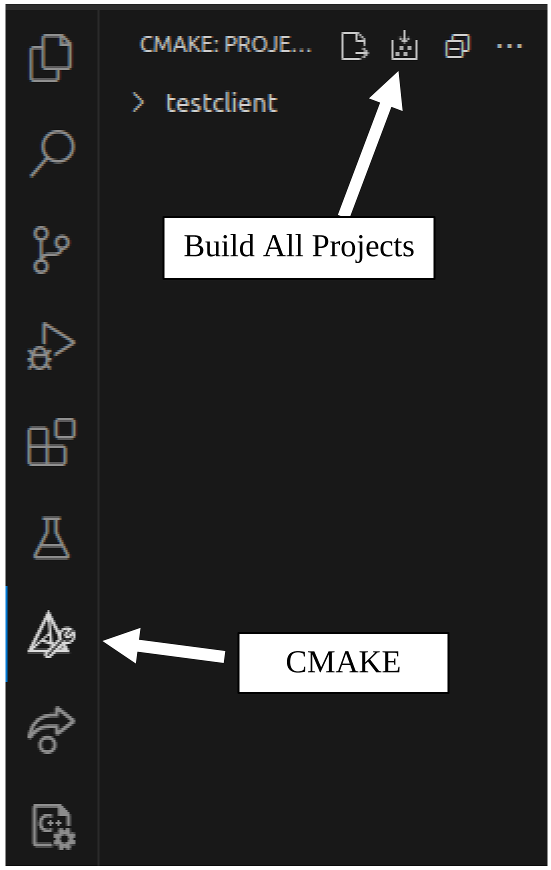
Method 2: Update Local Code and Move to Jetson Through SSH

1. Make changes to the code locally and then copy that code into the Jetson. First edit the code and make changes.
2. Establish an ssh connection.
3. Follow the instructions:
   Copy Files From One Machine to Another Using SSH (stackexchange)

Method 3: Connect Jetson to External Monitor and Edit

1. Connect the Jetson to an external monitor using its HDMI or DP.
2. Open Visual Studio Code and open the working directory (or alternatively, through command terminal type: code testserver)
3. Make changes to the files and save

2. Once changes have been made to the files, it needs to be compiled. If the changes were made using Method 3, find the CMAKE icon on the left and then press the “Build All Project” icon.



If changes were made using Methods 1 or 2, then this can be done through ssh as well.

1. Enter the build directory:

```
cd /testserver/build
```

2. Then enter the following commands sequentially:

```
cmake ..
cmake --build .
```

If there are no errors within the code, the following output should be displayed for all methods: [build] Build finished with exit code 0

Fixing Clock Skew Error When Compiling Code

1. When using cmake to compile the code through ssh, a clock skew error may occur. To fix this, first cd into the main code directory on the Jetson:

```
cd testserver
```

2. Then enter the following command:

```
find . -type f | xargs -n 5 touch
```

3. cd into the build directory and type the following commands in sequence:

```
make clean
cmake ..
cmake --build .
```

Utilizing udev Rules

1. If an usb hub is used, then the need to define the addresses of the devices using ttyACM* is unnecessary. Instead, custom addresses can be used to associate the port connection to the device. This will allow for the connection of the vescs to the Jetson to happen in any order, as long as the port that they are connected to stays the same. First, cd in the rules.d directory with ssh using the command:

   ```
   cd /etc/udev/rules.d
   ```

2. Edit the already created rule with superuser control:

   ```
   sudo vi 99-serial-port-rules.d
   ```

3. Edit the devpath in the rules. The devpath can be found using:

   ```
   udevadm info -q all -n /dev/ttyACM* --attribute-walk
   ```

   replacing the * with the target device path.
4. Save the file and reload to rules with:

   ```
   sudo udevadm control --reload-rules && sudo service udev restart && sudo udevadm trigger
   ```

5. Instructions based on:
   https://askubuntu.com/questions/1132542/create-udev-rule-for-device-with-multiple-tty-ports
   https://answers.ros.org/question/224028/permanently-set-permissions-for-devttyacm0-port-using-udev/

Appendix B – Risk Assessment

PDR Design Hazard Checklist **F56 - University Rover Challenge**

Y	N	
	✔	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	✔	2. Can any part of the design undergo high accelerations/decelerations?
	✔	3. Will the system have any large moving masses or large forces?
	✔	4. Will the system produce a projectile?
	✔	5. Would it be possible for the system to fall under gravity creating injury?
	✔	6. Will a user be exposed to overhanging weights as part of the design?
	✔	7. Will the system have any sharp edges?
	✔	8. Will any part of the electrical systems not be grounded?
	✔	9. Will there be any large batteries or electrical voltage in the system above 40 V?
✔		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	✔	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	✔	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	✔	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	✔	14. Can the system generate high levels of noise?
	✔	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
✔		16. Is it possible for the system to be used in an unsafe manner?
	✔	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Stored energy is present in the form of a battery	Integrate mechanical and software emergency stop to kill all power if necessary	4/20/23	
Rover can be mishandled and cause bodily harm if misused	Integrate mechanical and software emergency stop to kill all power and all stop motion	4/20/23	

Appendix C – Final Project Budget

MECHANICAL ENGINEERING SENIOR PROJECT - UNIVERSITY ROVER CHALLENGE BUDGET TRACKER		
System	Subsystem	Net Cost
Structural		$1,652.90
	Chassis	$443.40
	Rocker-Bogie (Suspension)	$263.06
	Differential	$764.02
	Multi-Purpose Fasteners + Brackets	$182.42
Electronics		$2,573.45
	Computer + Communications System	$352.11
	Motors + Controllers	$1,271.00
	Wiring + Power Distribution System	$501.87
	Batteries	$448.47
	Total Cost	$4,226.35
	Senior Project Budget	$3,000.00
	MEDAC Funding	$1,509.08
	Remaining Funds	$282.73

Appendix D – Design Verification Plan & Report (DVPR)

DVP&R - Design Verification Plan (& Report)

Project:	University Rover Challenge Team Impassability		Sponsor:							Edit Date:	6/1/2023
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Motors must move 50 kg	Motor Torque Test: Testing 1 motor to move 1/6 of final rover weight. Based on designed wheel size of 8 in and desired speed, motor will be required to produce 7Nm of torque. We will utilized weighted level arm	Speed at which motor can move weight	7>Nm torque	24V Power Supply	BLDC Motor, Scale,	Dylan	2/22/2023	5/23/2023	Inconclusive	Motors have an irreversible safety feature that does not allow for documenting of torque.
2	Suspension system's ability to overcome obstacles, including rocks, boulders, and steep inclines which may be	Rocker-bogie Suspension Test: Test rover at varying speeds and pproach angles for small, medium, and large rocks. Additionally the tests will involve terrain surfaces of sand and gravel	Pass/Fail, Max/Min speed	Manueverbility in all obstacles	Cal Poly Beach Volleyball Courts, Arboredum	Fully Assembled Rover, Various Rocks	Logan	5/9/2023	--/--/--	Fail	Due to failure of several of the ESCs and lack of treads on the wheels, full operation of the rover was unable to be achieved. Replacement of damaged ESCs, use of better usb cables, and utilizing better wheels with more traction would likely allow this test to be passed.
3	Rover Angle Climb	Rover Angle Climb Test: Start with a slope of 5 degrees and increase it by 5 degrees with every successful test. Continue incrementing the tested slope until the rover fails to climb (MAX 45 degrees)	Pass/Fail, Max/Min speed	>15 degree incline	Cal Poly Campus	Fully Assembled Rover	Logan	5/16/2023	--/--/--	Fail	Due to failure of several of the ESCs and lack of treads on the wheels, full operation of the rover was unable to be achieved. Replacement of damaged ESCs, use of better usb cables, and utilizing better wheels with more traction would likely allow this test to be passed.
4	Capable of being able to communicate instructions	Ensure communication system between computer and rover over Wifi/Bluetooth	Pass/Fail	Computer and rover communicate	N/A	Nvidia Jetson, Camera Module Laptop	Daniel	2/14/2023	5/14/2023	Pass	Testing indicated that the instructions were able to be fully communicated to the motor.
5	Live video feed from rover with ability to discern details	Live Video Streaming Test: Ensure control computer can receive a low latency live video feed from the video stream on the rover	Pass/Fail	Computer recieves video from onboard camera	N/A	Nvidia Jetson, Camera Module Laptop	Daniel	2/14/2023	5/14/2023	Pass	While testing is a success, the quality of video left much to be desired. Current method sends encoded frames. However, it would be better if the livestream video was encoded in something like H.264 with audio. This would allow for higher quality video to be transmitted with less delay.
6	Test to see how long the system can operate at different levels of operation	Battery Life Test: Charge Batteries to full Power on system, and Start timer and record how long the system lasts idle with just communications. -Repeat and record how long the system lasts with motors running continuously	Hours, minutes, seconds		Mechatronics Laboratory (192-118)	Fully Assembled Rover	Dylan	5/14/2023		Pass	

Appendix E – Test Procedures

Test 1: Motor Torque Test

Test Name: Motor Torque Test
Purpose:
The objective of these procedures is to assess the torque output of the motors, ensuring that they satisfy the established criterion of 7.5 Nm.
Scope: (Defines what feature or function the test is for)
The scope of this test encompasses the evaluation and data collection related to the rover's mobility and driving performance, as dictated by the motor's constraints and capabilities.
Equipment: (List of equipment necessary, diagram of apparatus from Experimental Design Planning Form)

- Scale
- Motor
- Controller
- Test Mount and Test adapter
- Power supply
- Wires/Connectors

Hazards: (list hazards associated with the test)

- Uncontrollable motor
- Electrical hazards
- Mechanical/Rotational motion

PPE Requirements: (e.g. safety goggles, respirators)

- Safety glasses
- Protective gloves

Facility: (Where the test should occur)

- Mechatronics Laboratory (192-118)

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

1. Place the torque lever on the force transducer and zero the scale.
2. Select a Duty Cycle for the motor using the controller.
3. Monitor and document motor's current draw and force.
4. Compute torque by multiplying force and lever arm length.
5. Test different Duty Cycles, evaluate motor performance, and perform a numerical analysis on the data.

Results: Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.

Motor Test Data				
Test #	Scale Reading (N)	Power Supply Voltage (V)	Power Supply Current (A)	Length of Lever Arm (m)
1	-	-	-	-
2	-	-	-	-

3	-	-	-	-
4	-	-	-	-
5	-	-	-	-

Test Date(s):
Test Results:

Motor Test Results		
Test #	Input Power (W)	Produced Torque (Nm)
1	-	-
2	-	-
3	-	-
4	-	-
5	-	-
Average	-	-

Impact Test Results	
Time (s)	Scale Reading (g)
1	0
2	-3
3	-88
4	-61
5	139
6	184
7	-38
8	189
9	-60
10	149
11	185
12	136
13	158
14	146
15	199
16	188
17	191

Notes: Due to safety mechanism on motors, anticipated motor-torque test could not be conducted and an impact torque test for uncertainty analysis was conducted but will not be used for verification.

Test 2: Rocker Bogie Suspension Test
Test Name: Rocker Bogie Suspension Test
Purpose:
To evaluate the rocker bogie suspension system's ability to overcome obstacles, including rocks, boulders, and steep inclines which may be encountered during the competition.
Scope:
To test the ability of the rocker bogie suspension system to overcome obstacles encountered during competition. The test will be conducted using a rover prototype and an obstacle course designed to simulate difficult terrain.
Equipment:

- Mars rover prototype equipped with a rocker bogie suspension system
- Obstacle course consisting of rocks, boulders, and steep inclines and slopes
- Hal Sensors to measure the rover's speed (included on motors)
- Phone camera to capture the rover's movements and record video footage of the test

Hazards: (list hazards associated with the test)

- Slip, trip, and fall hazards: The terrain of the obstacle course can be uneven and may pose a slip, trip, and fall hazard
- Dust exposure: The test may generate dust and debris which can be harmful to inhale
- Electrical hazards: The rover prototype will be powered by electricity, which can pose an electrical hazard if uncontrolled

PPE Requirements:

- Non-slip boots should be worn to reduce the risk of falls
- Face masks could be worn to reduce the risk of dust exposure
- Insulated gloves could be worn by team members working with the electrical systems of the rover

Facility:
This testing will occur outside of the Engineering IV building and in between the Bonderson shop on the Cal Poly campus.
Procedure:

1. Set up the obstacle course that incorporates environmental hazards that we will be expected to see. This will include small rocks (5-10 cm), medium sized rocks (10-15 cm), and large rocks (15-30cm). Measurements indicated are of the height of the rock. Additionally, sand and gravel will be put into the terrain. Ensure that the obstacles are placed randomly to simulate the actual terrain conditions that will be encountered during the competition.
2. Place the rover prototype at the starting point of the obstacle course.
3. Power the rover’s electrical system and engage the rocker bogie suspension.
4. Drive the rover through the obstacle course at a predetermined speed, ensuring that the rover traverses over all the obstacles.
5. Record video footage of the test to document the rover's movements and measure the rover's speed.
6. Repeat the test multiple times, varying the speed and approach angles, to ensure that the suspension system can overcome obstacles under different conditions.
7. Inspect the rover and the suspension system after each test run to detect any damage or wear and tear.
8. Analyze the test data and video footage to assess the suspension system's ability to overcome obstacles and climb steep inclines and slopes.

9. Identify any issues or areas for improvement and make necessary adjustments to the suspension system or other rover systems as required.
10. Document the test results and provide a report outlining the rover's performance during the obstacle test.

Test Date(s):
Test Results:

Suspension Test Data				
Obstacle	Rover Successfully Traversed Obstacle (Y/N)	Dimensions of Obstacle	Max Speed Recorded	Min Speed Recorded
Small Rocks	-	-	-	-
Medium Rocks	-	-	-	-
Large Rocks	-	-	-	-
Sand	-	-	-	-
Gravel	-	-	-	-

Notes: Unable to be conducted due to electronics issues

Test 3: Rover Angle Climb

Test Name: Rover Angle Climb
Purpose:
The objective of these procedures is to assess the rover's capabilities of climbing slopes.
Scope: (Defines what feature or function the test is for)
The scope of this test encompasses the evaluation and data collection of the rover's capabilities to drive uphill in varying slopes.
Equipment: (List of equipment necessary, diagram of apparatus from Experimental Design Planning Form)

- Mars rover prototype
- Phone with app that can determine the angle of the phone

Hazards: (list hazards associated with the test)

- Uncontrollable motor
- Electrical hazards
- Mechanical/Rotational motion

PPE Requirements: (e.g. safety goggles, respirators)

- Safety glasses

Facility: (Where the test should occur)

- Testing will occur around Cal Poly Campus

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

1. Cal Poly campus is full of slopes of varying steepness. Find slopes around the campus, and using the phone app, determine the angle of the slope. Start with a slope of 5 degrees and increase it by 5 degrees with every successful test.
2. Drive the rover up the slope and record the max power output of the rover. This data is automatically recorded and saved by the rover program.
3. Record if the rover successfully climbed the slope.
4. Continue incrementing the tested slope until the rover fails to climb (MAX 45 degrees)

Results: Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.

Test Date(s):
Test Results:

Slope Test Data			
Test #	Slope Steepness [degrees]	Power Output [W]	Pass/Fail
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-

Notes: Unable to be conducted due to electronics issues

Test 4: Live Video Streaming Test
Test Name: Live Video Streaming Test
Purpose:
To evaluate the rover's capabilities to send live video-feed that is both low latency and high enough quality to discern any possible details.
Scope:
The scope of this test encompasses the video streaming capabilities to ensure that the operator can drive the rover remotely.
Equipment:

- Mars rover prototype
- Ground station computer and controller
- Measuring Tape
- Paper signs with directional instructions on them with varying levels of details. This will encompass low detailed signs (just arrows), medium detailed signs (smaller sized arrows), and high detailed signs (text instructions).

Hazards: (list hazards associated with the test)

- Electrical hazards: The rover prototype will be powered by electricity, which can pose an electrical hazard if uncontrolled

PPE Requirements:

- None

Facility:
This testing will occur outside of the Engineering IV building and in between the Bonderson shop on the Cal Poly campus.
Procedure:

1. Configure the Rover so that it is in remote operation mode. Designate an operator to be at the base station to view the camera output.
2. Turn on the rover (code may be configured so that only the camera is running). Have another member of the team hold text-based signs in front of the rover. Have the team member holding the sign move towards the camera until the operator is able to discern the details.
3. Measure and record the distance between the sign and the rover.
4. Once the distance is measured, indicate to the operator to perform the action, and record if the operator was able to successfully make out the details.
5. Continue with the different signs of different levels of details. Details is determined by font size used on the sign (low being a large font size, high being a small font size).

Results:

Camera Test Data			
Sign #	Level of Detail (low, medium, high)	Distance between rover and sign [m]	Pass/Fail
1	low	1	Pass
2	low	1	Pass
3	low	1	Pass
4	low	1	Pass
5	medium	0.2	Pass

6	medium	0.2	Pass
7	medium	0.2	Pass
8	medium	0.2	Fail
9	high	0	Fail
10	high	0	fail

Notes:
The video compression is very high, (scaled down from 1080 to 192) which makes image details hard to decipher.

Test 5: Test Procedure for Communications

Test Name: Communications Test

Purpose:
Test to see if system is capable of being able to communicate instructions at varying distances
Scope: (Defines what feature or function the test is for)
Test to see if system is capable of being able to communicate instructions to and from the ground station to the rover.
Equipment: (List of equipment necessary, diagram of apparatus from Experimental Design Planning Form)

- Raspberry Pi
- Laptop
- Controller

Hazards: (list hazards associated with the test)

- Electrical hazards

PPE Requirements: (e.g. safety goggles, respirators)
Facility: (Where the test should occur)

- Mechatronics Laboratory (192-118)

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

- 1. Power on Laptop and Raspberry Pi
- 2. Connect the controller to the laptop
- 3. Connect Laptop and Raspberry Pi via communications protocol
- 4. Determine whether connection has been established
- 5. Repeat for different distances

Results: Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.

Test Data		
Test #	Distance (m)	Connected (P/F)
1	0	Pass
2	5	Pass
3	10	Pass

Test Date(s):
Performed By:

Test 6: Battery Life Test

Test Name: Battery Life Test
Purpose:
Test to see how long the system can operate at different levels of operation
Scope: (Defines what feature or function the test is for)
Test to quantify the system power capabilities throughout different intensities of operation
Equipment: (List of equipment necessary, diagram of apparatus from Experimental Design Planning Form)

- Electronics and Controls System
- Laptop
- Controller
- Timer

Hazards: (list hazards associated with the test)

- Electrical hazards

PPE Requirements: (e.g. safety goggles, respirators)

- N/A

Facility: (Where the test should occur)

- Mechatronics Laboratory (192-118)

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

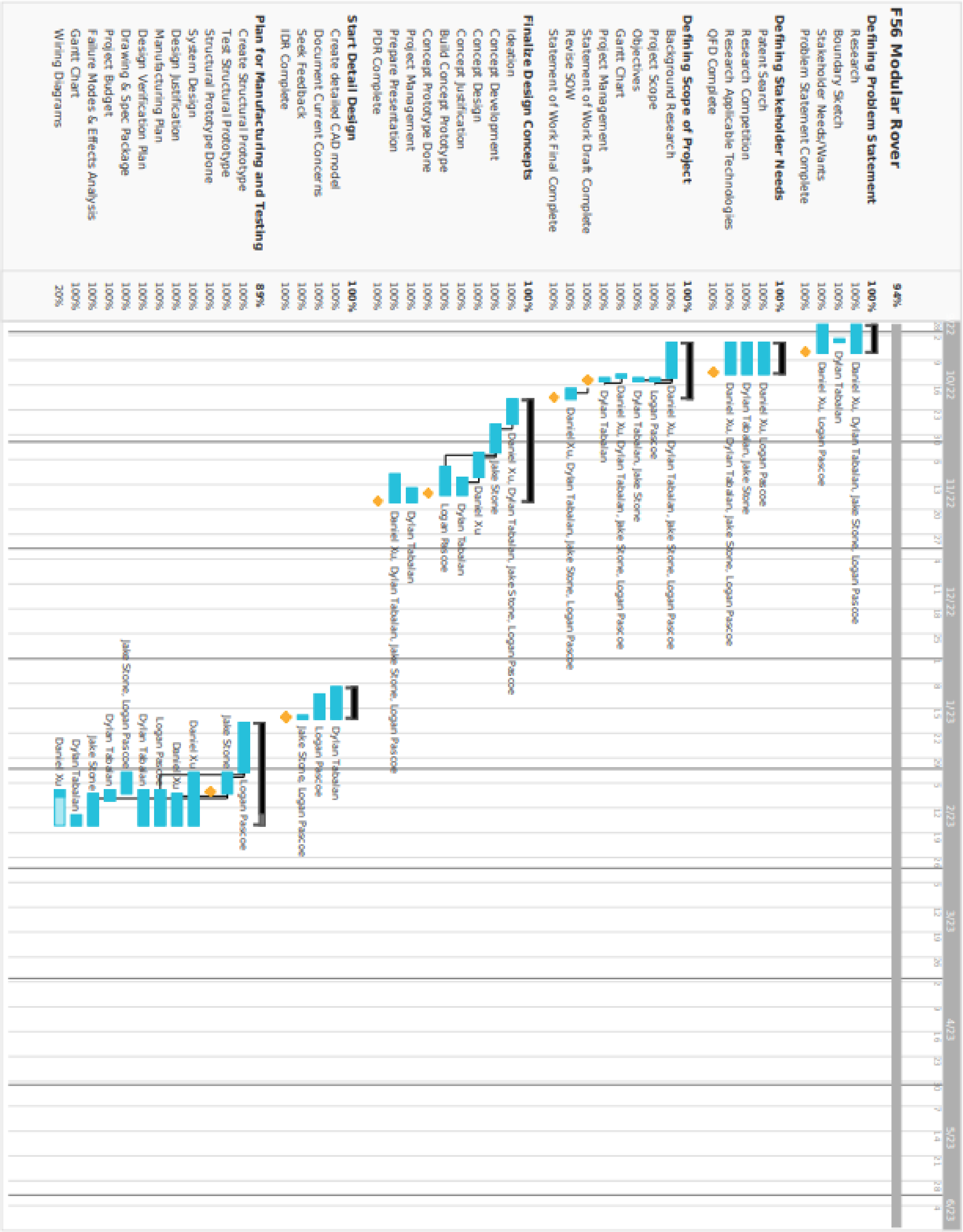
- 1. Charge Batteries to full
- 2. Power on system
- 3. Start timer and record how long the system lasts idle with just communications
- 4. Repeat and record how long the system lasts with motors running continuously

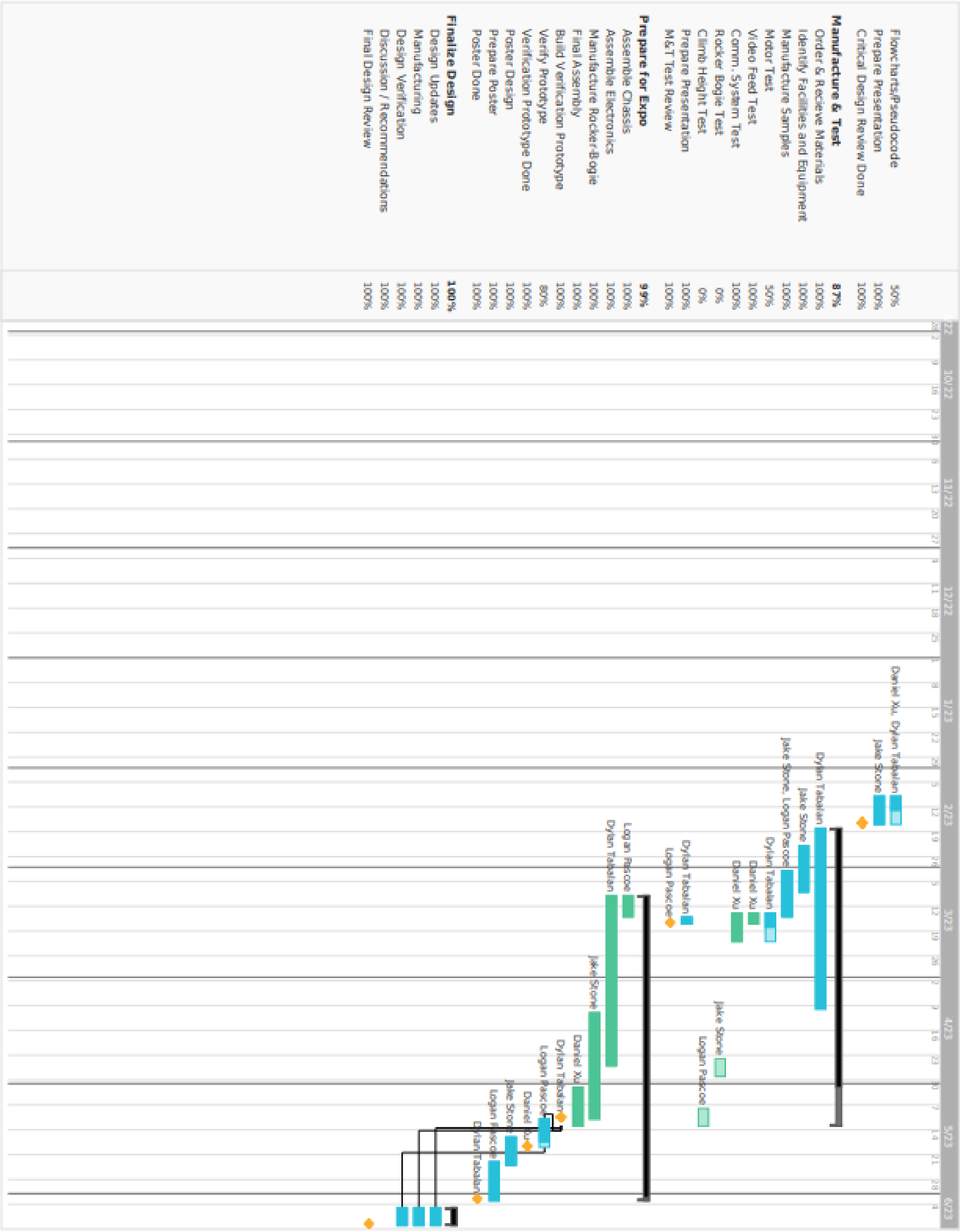
Results: Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.

Test Data	
Test	Time (Hour:Min:Seconds)
Idle	3+ hours
Motors Active	3+ hours

Test Date(s):

Appendix F – Gantt Chart




Flowcharts/Pseudocode 50%
Prepare Presentation 100%
Critical Design Review Done 100%
Manufacture & Test 87%
Order & Recieve Materials 100%
Identify Facilities and Equipment 100%
Manufacture Samples 100%
Motor Test 50%
Video Feed Test 100%
Comm. System Test 100%
Rocker Bogie Test 0%
Climb Height Test 0%
Prepare Presentation 100%
M&T Test Review 100%
Prepare for Expo 99%
Assemble Chassis 100%
Assemble Electronics 100%
Manufacture Rocker-Bogie 100%
Final Assembly 100%
Build Verification Prototype 100%
Verify Prototype 80%
Verification Prototype Done 100%
Poster Design 100%
Prepare Poster 100%
Poster Done 100%
Finalize Design 100%
Design Updates 100%
Manufacturing 100%
Design Verification 100%
Discussion / Recommendations 100%
Final Design Review 100%
10/22
11/22
12/22
1/23
2/23
3/23
4/23
5/23
6/23