Solar-Powered Rover

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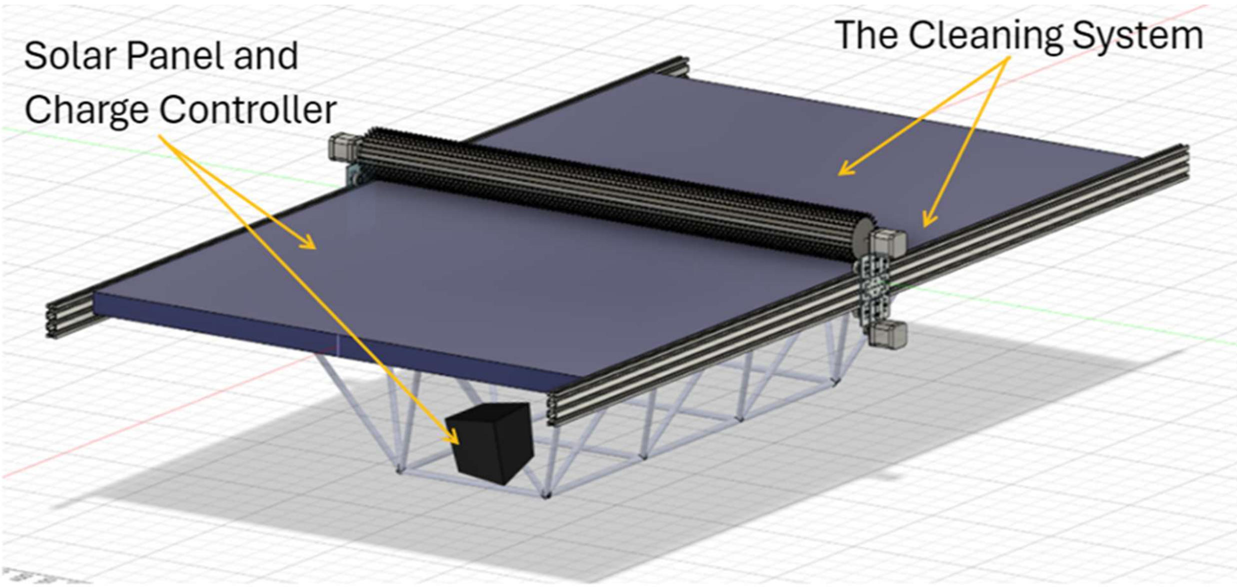

I. Abstract

Expanding on a previous senior design project that had built a rover for educational purposes, this project intends to enhance LOUIS, the rover, by integrating a solar panel to the rover, creating autonomous switching between solar and battery power, and developing a cleaning system for the solar panels. With a $4,000 budget, the project will have to consider the limited leftover chassis space and the maximum additional load capacity of 36.3kg. The cleaning system will have to be gentle on the solar panels, so as not to scratch or damage it, thus maximizing the energy output. The various components should be able to withstand the different weather conditions in Louisiana, such as winds, precipitation, and heat. The project aims to have a system that switches to battery power if the solar panels are not receiving adequate sunlight due to clouds or nighttime conditions. With regards to deliverables, the sponsor requested proof of concept. For this, the group will need to make sure to maintain the current functions, despite the additions. Additionally, if time and resources allow, the project will seek to improve the object avoidance system.

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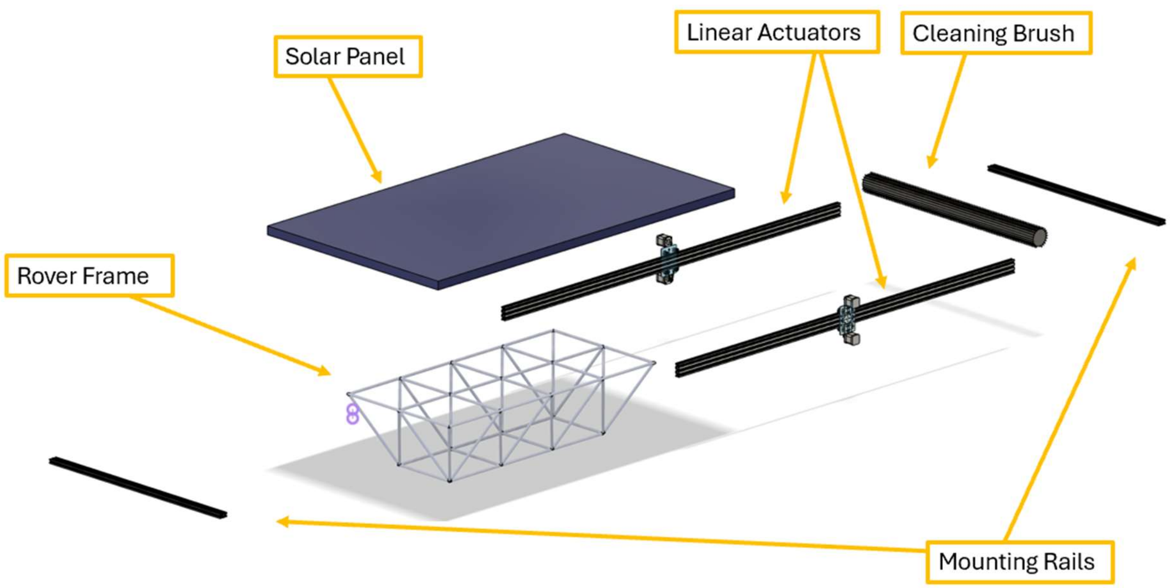
II. Executive Summary

<u>Objectives and Problem Definition</u>: The main objective of this project is enhancing the previously built rover, which is battery powered, by integrating solar power, autonomous power switching between solar and battery power, and an independent cleaning system for the solar panel.

<u>Key Engineering Specifications:</u> The rover must convert solar power into useable energy for the rover, autonomously switch between solar and battery power, and clean the solar panel.

<u>Product/System Description:</u> In this system, the solar panel absorbs solar energy that is then converted to useable power. The charge controller, which is attached to the solar panel, battery, and rover, then regulates the voltage to be sent at a constant level to the rover. When not needing power, the charge controller sends the extra voltage to charge the battery. If the solar panel is too dirty or sunlight conditions are poor, the charge controller can detect the power output loss. Through this detection, the charge controller can switch to battery power only. A timer-based activation system then initiates the cleaning system, where a brush rolls across the panel.



Exploded View Solid Model

<u>Engineering Analysis Result Summary:</u> The project had many considerations such as the current draw of all new subsystems being added. The team also needs to consider the power supplied from the addition of the solar panel.

<u>Manufacturing/Assembly Summary:</u> This project has more assembly than manufacturing, most of the parts are sourced from vendors and will need to be assembled together using bolts and screws to secure the design to the rover frame. Some components will also need to be cut to length, like the mounting rails and wiring.

Statement of Expected Performance: The team expects the incorporation of our design to increase battery life and driving distance of the rover.
Design-Phase Testing Results: Team 66 did not conduct any testing during the design phase.
Validation Test Plan Summary: The team plans to mainly test the cleaning system and the state of charge of the battery with the addition of the solar panel.

III. Engineering Specification

III.A. Objective Statement

The main objective of this project is enhancing the previously built rover, which is battery powered, by integrating solar power, autonomous power switching between solar and battery power, and an independent cleaning system for the solar panel.

III. B. Introduction

III.B.1. Background Information

The original inspiration behind the creation of LOUIS was to expose young engineers to the development and design of rovers, as it can easily be seen that space exploration will continue to be a prominent area of work for engineers in the future. We intend to build upon that idea by incorporating solar power into the design of LOUIS. As an educational proof of concept, we will also design a power switching system to autonomously switch between battery and solar power, depending on the environment. As many NASA rovers also use solar power, this addition will push the rover one step closer to the design of rovers currently being used in space exploration missions. This will make LOUIS an increasingly relevant tool for future students who are interested in working in this field.

Picture of LOUIS:

III.B.2. Problem Description and Motivation for the Project

The motivation for our project is to make power improvements to a space rover engineered by a previous group of Senior Design students. We hope that our solar-oriented improvements will enable enhancement opportunities for future students. Overall, our teams' motivation is to improve upon a platform that can be used as a vessel for teaching students about space rovers and solar panel systems.

III.B.3. Existing/Competing Technologies

- SolarEdge Monitoring Portal: SolarEdge offers a cloud-based monitoring platform that provides real-time data on solar system performance, energy consumption, and grid interaction. The team is planning on doing something similar with a charge controller just on a smaller scale. Instead of grid integration we would be looking at solar panel voltage and current output and calculating the load needed to operate the rover.
- Nanosolar Coating**:** This advanced nanotechnology-based coating repels water and dirt, ensuring that rainwater washes away debris without leaving residues. This is a viable way to have a passive cleaning system for solar panels.
- Ecoppia E4: This autonomous robot uses soft brushes to clean panels without water. It can navigate arrays independently and is designed for large-scale solar farms. This robot uses a similar waterless brush system that the team is currently considering using to clean the solar panel. The main difference is that it is designed for a solar farm.
- NASA's Spirit and Opportunity Rovers: These are rovers launched by NASA in 2003. They both used solar panels to generate power. The panels collected sunlight and charged the rovers' batteries. This will be similar to what the team plans to do by adding solar panels to the existing rover. However, the team's solar panels will be able to both charge the existing battery as well as take on the electrical load of the rover.

III.B.4. Potential Customers

<u>Primary:</u> The LSU Electrical Engineering Department can utilize LOUIS for research, development, and educational purposes for their students.
<u>Secondary:</u> Future senior design students can enhance LOUIS's capabilities to learn more about the design and building process. Additionally, companies can use and adapt this technology for their own purposes, like energy companies adapting the technology to have access to unreachable areas.

III.C. Functional Requirements

Table 0-1: Required Functions

#	Weight	Function	Explanation
F1	0.40	Convert solar energy to power the rover.	Utilize solar panels to absorb sunlight as an additional power source to the battery power.
F2	0.35	Autonomously switch power between power sources.	Autonomously switch between battery and solar power.
F3	0.25	Clean the solar panels.	Intermittently clean off debris from solar panels to maximize energy absorption and efficiency.

The above functions were chosen based on the demands of the sponsor.

III.D. Qualitative Constraints

Table 0-2: Required Qualitative Constraints

#	Weight	Qualitative Constraint	Explanation
Q1	0.40	Compatibility with Existing Design	Make sure that the new implementations to the previous rover are compliant with each other. The additions should merge with the existing design seamlessly.
Q2	0.35	Weatherproof Design	The solar panel system should be built to withstand the elements of Louisiana such as wind, precipitation, and heat.
Q3	0.25	Portability	Make sure that the system doesn't hinder the transportation of the rover. It should be convenient to maneuver without disassembly.

The above qualitative constraints were chosen based on optimal functionality of the rover, given its potential vulnerability to the weather, necessity for seamlessness between the new and old design, and previous constraints from the last project.

III.E. Measurable Engineering Specifications

Table 0-3: Required Measurable Engineering Specifications

#	Weight	Name	Symbol	Units	Value(s)	Explanation
M1	0.50	Budget	B	$	4000	A budget of $4000 was decided upon by the sponsor.
M2	0.40	Interior Space	S	M^3	0.977	This is the amount of available space inside the rover's chassis to install new electronic components.
M3	0.10	Weight Limit	W	Kg	<36.3	The max additional weight load was measured at 36.3kg. The team would like to stay under this variable.

The above measurable engineering specifications were chosen based on the financial constraint given by our sponsor and the limitations of the already-built rover.

III.F. Deliverables

Upon completion of our project, we will be delivering a functional solar power system which will be added onto the existing planetary exploration rover LOUIS. This solar power system will have autonomous power switching between battery and solar power, depending on available sunlight and user preference. We will also have an autonomous cleaning system incorporated into our design to clean the solar panel of dust or debris intermittently. Our team will ensure that the additions we make will only be improvements to the rover, without losing any of the general functionality existing prior to our additions. Other deliverables include comprehensive reports and presentations, as well as complete engineering analyses detailing the technical aspects of the project.

IV. Embodiment

IV.A. Functional Breakdown - Objective Tree(s)

One of our three main functions is to be able to clean our solar panels. To achieve this, our brush cleaning system is using a timer-based activation outputted from an Arduino Uno. This signal activates the brush cleaning system which clears debris from the surface of the solar panels. This function affects the other two functions since debris greatly reduces the efficiency of power generation of solar panels, and since debris build up results in power loss it can lead to a switch between power sources. The second function is to be able to generate solar power utilizing the solar panel that is going to be attached to the rover. This solar panel will absorb sun rays and convert them to electricity which will then be used to power the rover and the battery. These affect the two other functions because the power from the solar panel will be used to power the two other functions. The third function is to be able to autonomously switch power sources. Using a charge controller, the rover should be able to detect power consumption and execute a pre-programmed action to be able to prioritize a more suitable power source. This affects the solar power generation function because it may result in a change in power source priority when the solar panels are not adequately supplying enough power due to lack of sunlight.

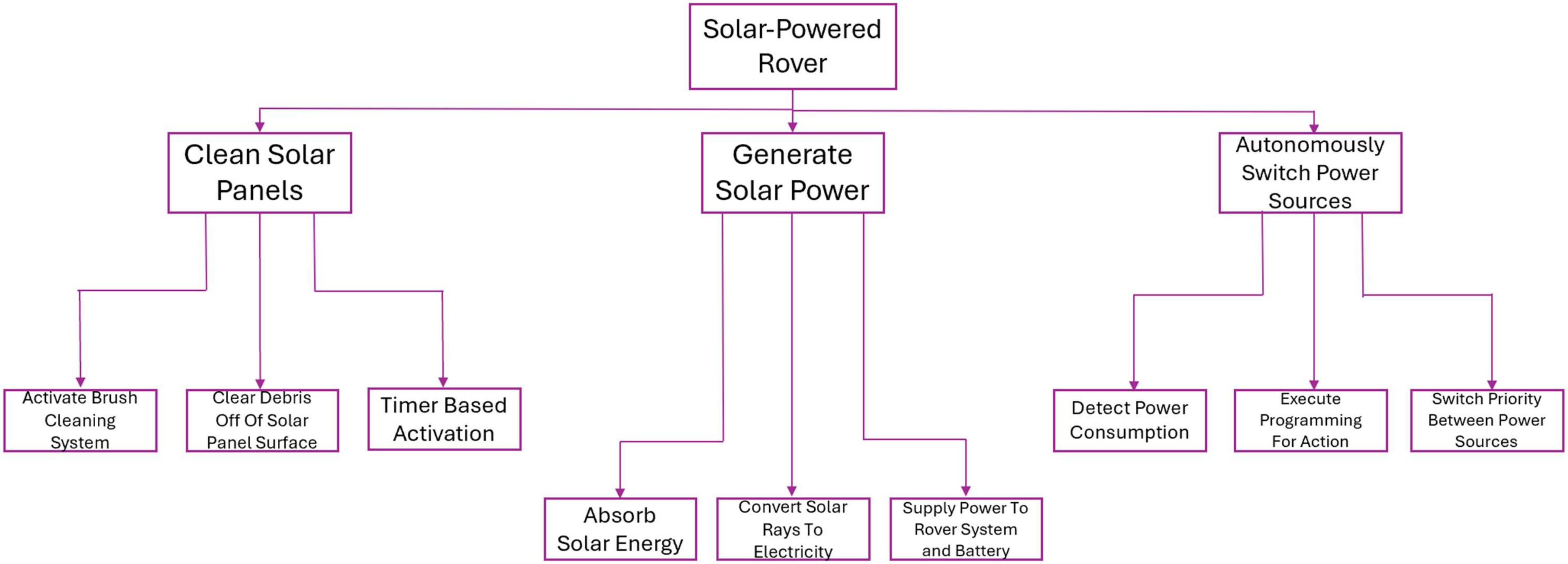


Figure 0-1: Project Objective Tree

IV. B. Concept/Solution Generation, Evaluation and Selection

IV.B.1. Concept/Solution Generation Method(s) Used

In general, each of the team members researched different pieces of the project and presented the material to one another to discuss the best options when proceeding forward. From here, we made sure to have a person or two to challenge the consensus by offering potential difficulties with each of our decisions to see if there was a potential alternative we should investigate that offered the desired solutions. We also drew inspiration from existing technologies, like the Lotus P4000 and Geva Bot, which are shown below.

Image 1: GEVA Bot

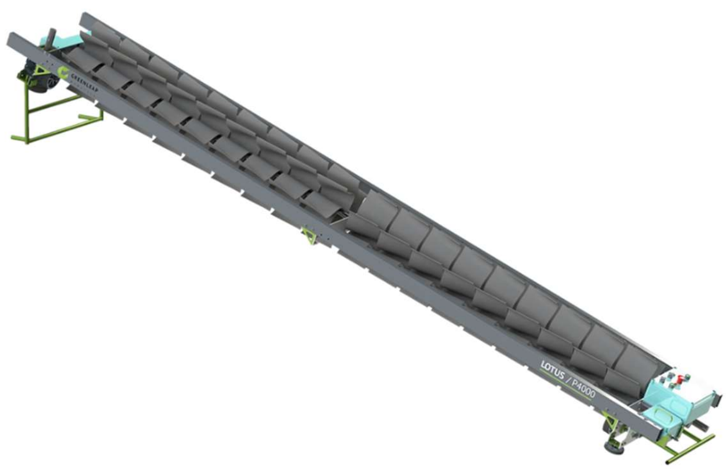


Image 2: LOTUS P4000

IV.B.2. Concept/Solution Evaluation Method(s) Used

We originally drew up a pros and cons list for each of our functions: the solar power, the autonomous power switching, and the cleaning system. After this, a decision matrix was made for each function to ensure our decisions were properly made, rather than by bias. The decision matrices matched what we had thought was the best option for each.

IV.B.3. Concept/Solution for Function F#1 – Convert Solar Energy for Power

IV.B.3.a. Concept/Solution Selected for Function F#1

The team is proceeding with a design incorporating the monocrystalline solar panel. This is a solar panel whose PV cells are made from a singular silicon crystal. This allows for higher efficiency because the single silicon crystal used allows for electrons to move more freely generating more electricity. The lower temperature coefficient of a monocrystalline panel makes it more suited for the Louisiana environment allowing it a longer life span. As for the cons, this type of solar panel is the most expensive. It is also heavier than some of the other options.

IV.B.3.b. Concepts/Solutions Considered for Function F#1

The other option we considered was the polycrystalline panel. A polycrystalline uses cells constructed from multiple silicon crystals making electron motion. The polycrystalline panel does have the second highest power output at about 300W, while weighing the same and being the same size as a Monocrystalline. This being the same weight and size while achieving a lower power output did not fit well with the team's design.

IV.B.3.c. Concepts/Solutions Considered for Function F#1

The thin- film panels are made by depositing one or more thin layers of photovoltaic material onto a substrate, such as glass, plastic or metal. This is the least efficient design of a solar panel, only achieving a power production of less than 200 W. Although the thin-film panel is smaller and lighter, having two would still be about the same size but with lower power output.

IV.B.4. Concept/Solution for Function F#2- Autonomously Switch Power Between Power Sources

IV.B.4.a. Concept/Solution Selected for Function F#2

The team decided for this function, autonomous power switching, to move forward with the solar charge controller. This method uses a preprogrammed piece of hardware that would automatically pull power from the battery and the solar panel, while also charging the battery with any influx of power. This method is the most expensive of the options, however, provides the most reliable and precise technology and is very much worth the price.

IV.B.4.b. Concept/Solutions Considered for Function F#2

One of the other options we had for this function was a DC/DC converter paired with an Arduino. This option would attempt to replicate the charge controllers' functions and would pull power from the battery as needed. The advantage of using this method would be it would be much cheaper. However, this is heavily outweighed by the difficulty of designing a solar charge controller and its pulse width modulation system. This would also mean that the Arduino would have to be coded to use maximum power point tracking, which companies keep as proprietary information, making research on the topic very difficult. Due to this we decided to not to move forward with this function.

IV.B.4.c. Concept/Solutions Considered for Function F#2

The final option we considered was a voltage regulator that is paired with an Arduino. This would be the cheapest of all the options. However, it wouldn't have the ability to do the pulse width modulation like the other two options. This would likely lead to overcharging of the battery, decreasing its lifespan. It would also have inaccurate power switching.

IV.B.5. Concept/Solution for Function F#3 – Clean the Solar Panels

IV.B.5.a. Concept/Solution Selected for Function F#3

The team decided to proceed with the brush cleaning system method. This method entails a rotating, soft-bristle brush that rolls across the solar panel in order to wipe off the collected debris. This was likely to be the cheapest method along with the lightest one, both of which coincided with quantitative constraints. Regarding the cons, it may potentially scratch the solar panel, since physical contact will be made to clean the panel. Additionally, the brush may trap debris and redeposit it when cleaning once again.

IV.B.5.b. Concept/Solutions Considered for Function F#3

One of the other options considered was the air compressor method, where an air compressor would blow into a perforated pipe that would move across the panel. Ultimately, the weight/weight distribution of this method, high-power consumption, and lacking cleaning effectiveness due to the spacing in between the holes of the perforated pipe led us to choose an alternative.

IV.B.5.c. Concept/Solutions Considered for Function F#3

The last option we considered was the electrostatic method. In this system, indium tin oxide (ITO) glass sits on top of the solar panel and has a charge. An electrode, or piece of metal, that is oppositely charged passes over the ITO glass, which causes an electric field to form. This causes the debris on the glass to be attracted to the electrode, which then gets deposited off the side of the panel through discharging the electrode. This method proved to be too expensive due to the cost of materials. The ITO glass alone costs around $4000, which is the entirety of our budget. The picture of MIT's electrostatic repulsion method is shown below:

MIT's Electrostatic Repulsion Method

IV.C. System Description/Product Architecture

Solar energy will be converted into usable power for the rover by the solar panel as a new primary power source. A programmable solar charge controller will perform power switching based on power consumption of the rover and power available from the solar panel. If solar power is insufficient for the rover to function, the rover will switch to battery power. The solar panel will be cleaned using a rotating brush. The brush will be driven along the length of the solar panel by two DC stepper motors along a rail system. Another DC motor will rotate the brush as it moves along the rails. A timer code using an Arduino will be used to start a cleaning cycle, sending inputs to the three DC motor controllers which will drive the DC motors to clean the solar panel.

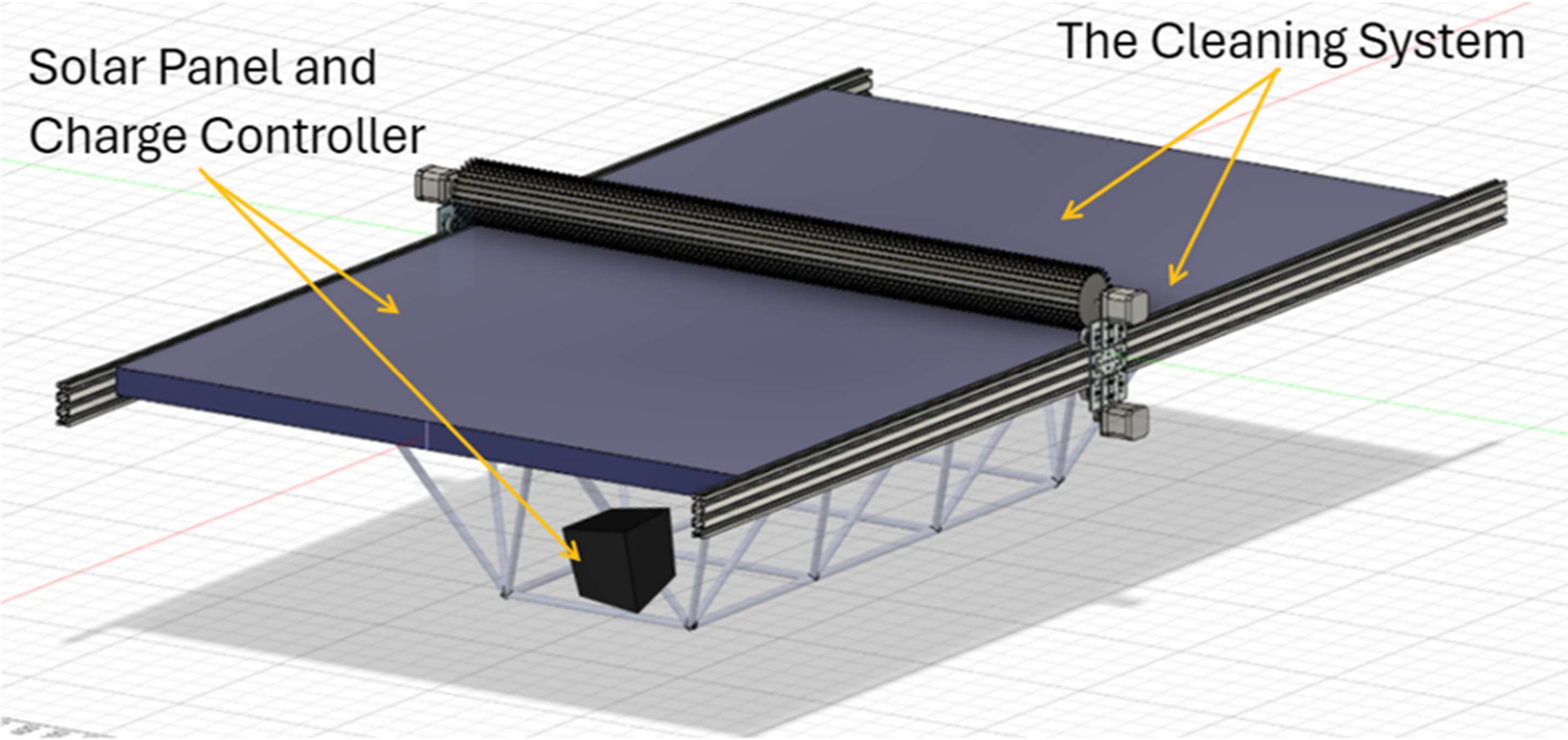


Figure 0-2: Assembled Prototype Drawing

Table 0-1: List of Sub-Systems

#	Name	Brief Description of Sub-System Functionality
SS1	Solar Panel and Charge Controller	Provide solar power, voltage regulation, and power distribution to the rover.
SS2	The Cleaning System	The linear actuators run alongside the solar panel to cause the brush to move across the panel. There are additionally motors that will cause the brush to roll.

IV.C.1. Description of Sub-System SS1 – Solar Panel and Charge Controller

This subsystem of the project is the newly added power system. The solar panel will be used to generate power for the system. It will do this by absorbing solar radiation, and then converting those solar rays to electricity. This will then be used to power the rover and the battery. This last function will be a part of the autonomous power switching. To do this we will be using a solar charge controller, this controller is preprogrammed by the manufacturer. It will detect the power consumption and decide whether to use the solar power alone or pull power from the battery. It has the capability to swap between whichever power source is necessary. It also has multiple different priority settings depending on the user's need.

IV.C.2. Description of Sub-System SS2 – The Cleaning System

This sub-system of the rover is designed to clean the surface of the solar panel intermittently to maximize the efficiency of the power generated by the solar panel. This sub-system is composed of a pair of linear actuators with stepper motors and a DC motor for the brush which are housed on rails on the sides of the solar panel. Both of these motors are driven by their motor drivers and a microcontroller in the form of an Arduino Uno. The Arduino Uno is coded to act as a timer and outputs signals used to activate the stepper motors and the DC motor. After the desired amount of time has elapsed, the brush cleaning system is activated, and the cleaning process occurs over the top of the solar panel. Our code is designed to run once every rover activation to reduce redundancy, but allow for the operator to control when they want to clean the solar panel. This sub-system ensures that the rover can receive efficient yet controlled cleaning.

V. Engineering Analysis and Materials Selection

V.A.1. Engineering Analysis for SS#1.1 - Solar Panel and Charge Controller

Types of Engineering Analysis Conducted:

- MATLAB Simulink
    - State of Charge
    - Temperature vs Efficiency
    - Solar Radiation vs Power Generation

V.A.1.a. Engineering Analysis & Materials Selection for SS#1.1 – Solar Panel and Charge Controller

Bowen Williamson and William Mancuso

For this analysis we used MATLAB Simulink to model the solar panel and charge controller system. The model used the exact parameters of the solar panel and the battery used for this project. This model used maximum power point tracking as well giving us a very close look at how our controller will work. Since this tech is proprietary, we were unable to gain complete access to all of it. Finally the model also has the load of all of the electronics to track the overall power consumption. All of this allowed us to look into many forms of analysis like state of charge, temperature vs efficiency, and solar radiation vs power generation.

The most notable simulation conducted was comparing the decline in battery state of charge with and without the addition of solar power. The same load and battery specifications were used in both simulations. From the results of this simulation, considering full and direct sunlight, we expect a substantial increase in the life of the battery. Across a 5-minute simulation, the state of charge of the battery with the solar panel decreased at a rate of about 0.25 times the rate without the addition of solar power.

A simulation was conducted analyzing the efficiency of the solar panel as the cell temperature was gradually increased across the range of operating temperatures for the solar panel, which was -40°C to 85°C. The resulting graph of the tracked efficiency of the solar panel peaks at the nominal operating temperature for the solar panel, which is 44°C.

Another simulation shows the proportional increase and decrease in power generated by the solar panel with a variable solar radiation input to the solar cell. This can be likened to the power that could be generated across different times of day, depending on the location of the sun in the sky. During midday, when the sun is directly overhead, would correspond to when there is a 1000W/m^2 solar radiation input in the MATLAB model. Any lower values of solar radiation input simulate other times of day when direct sunlight would not be available.

V.A.1.a. Engineering Analysis & Materials Selection for SS#1.2 – Overall Circuit

Kenny Bui

For the analysis of the overall circuit, we utilized MATLAB Simulink to simulate and visualize how the existing battery on the rover reacts to the additional load that we will be adding to the rover system. To do so, we used the previous group's load calculation to demonstrate an accurate depiction of the load that existed before us. We also did a load calculation for the additional components and loads that we will be adding based on their nominal Ah consumption. Using these two load calculations, I can simulate the overall circuit with our battery parameters and observe the state of charge over the course of one hour. The Simulink model is composed of two loads (in the form of duty cycle blocks) input into a controlled current source block (which acts as the load to the battery) and then the battery block outputs to a bus selector where we can see SOC, voltage, and current using scope blocks. In the SOC scope, we can see the SOC percentage over an elapsed time of 1 hour. This percentage is reduced, which is to be expected due to the added load to the battery circuit. In conclusion, we determined that our battery can power the additional load without a significant reduction in battery SOC.

V.A.2. Engineering Analysis for SS#2- The Cleaning System

Types of Engineering Analysis Conducted:

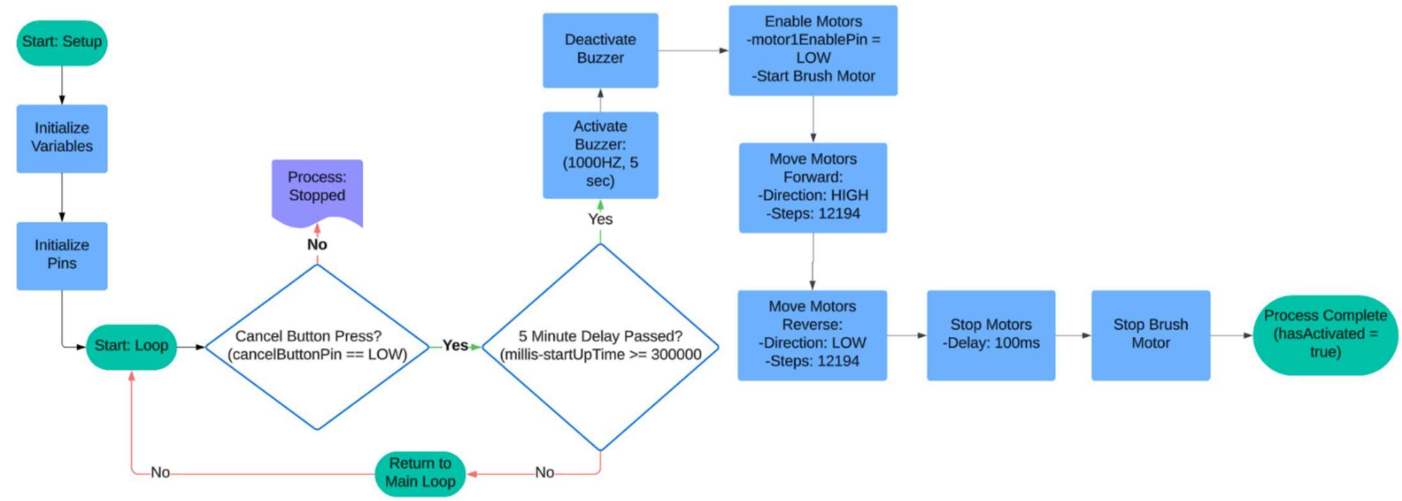
- The current draw of the stepper motor was measured to determine the load requirements and ensure cohesion with our solar panel system. Additionally, this is to see how the stepper motor driver should be configured to match the motor's requirements, optimize performance, and prevent overheating/inefficiencies.
- The current draw of the geared DC motor was measured to determine over all cohesion with the existing power system along with the addition of the solar panel. The torque to shaft speed along with the amount of current draw to achieve the desired speed to extend the motor life and achieve cleaning.

V.A.2.a. Engineering Analysis & Materials Selection for SS#2-P#1-Arduino Uno

Kenny Bui

Below is the flowchart for the Arduino code:

Arduino Uno Code Flowchart:



V.A.2.b. Engineering Analysis & Materials Selection for SS#2-P#2-NEMA 23 Stepper Motor

Margaret Burkes

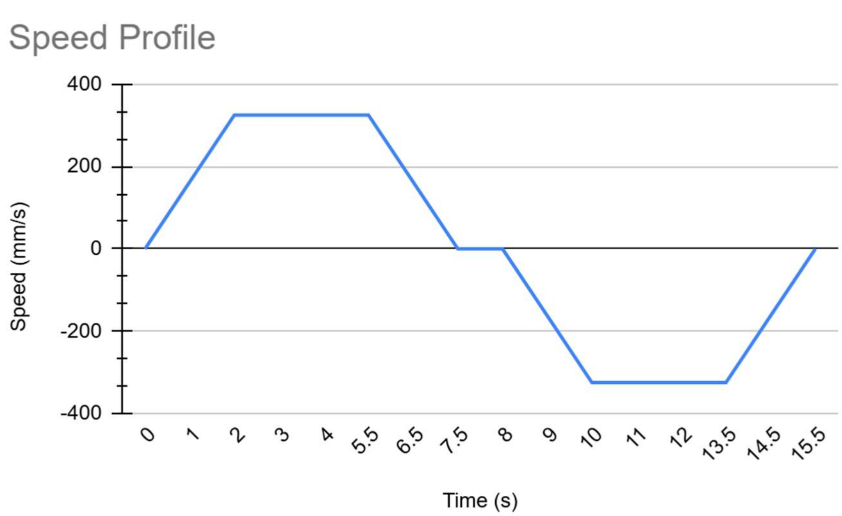
Calculations:

Mass of stepper motor: 0.75kg

Mass of gear motor: 0.5 kg

Mass of brush: 2.1 kg

Total mass: 3.35 kg

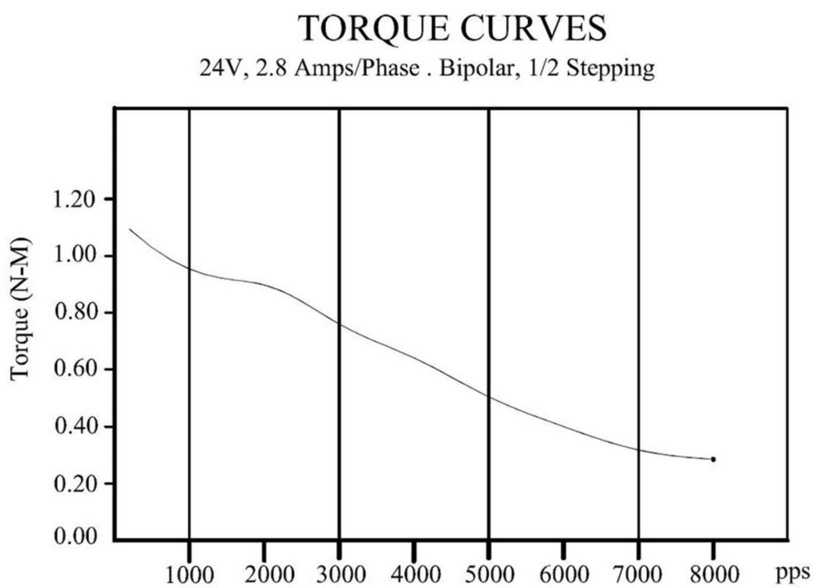


$$r = \frac{(\#\ of\ teeth)(pitch)}{2\pi} = \frac{20 \times 3mm}{2\pi} = 9.5mm$$

$$\omega_1 = \frac{v}{r} = \frac{162.5mm/s}{9.5mm} = 17.02\ rad/s$$

$$\omega_2 = \frac{v}{r} = \frac{325mm/s}{9.5mm} = 34.03\, rad/s$$
$$\frac{d\omega}{dt} = \frac{\Delta\omega}{\Delta t} = \frac{34.03 - 17.02}{2 - 1} = 17.01\, rad/s$$
$$T_{em} = \frac{1}{2}Mr^2\frac{d\omega}{dt} + r^2M\frac{d\omega}{dt} + rf_l = 0.32Nm$$

Selected Motor Torque Curve:



After running a MATLAB simulation, the team measured the current draw to be 2.5A. For more information on this simulation, refer to the appendix.

V.A.2.c. Engineering Analysis & Materials Selection for SS#2-P#3-TB6600 Stepper Motor Driver

Margaret Burkes

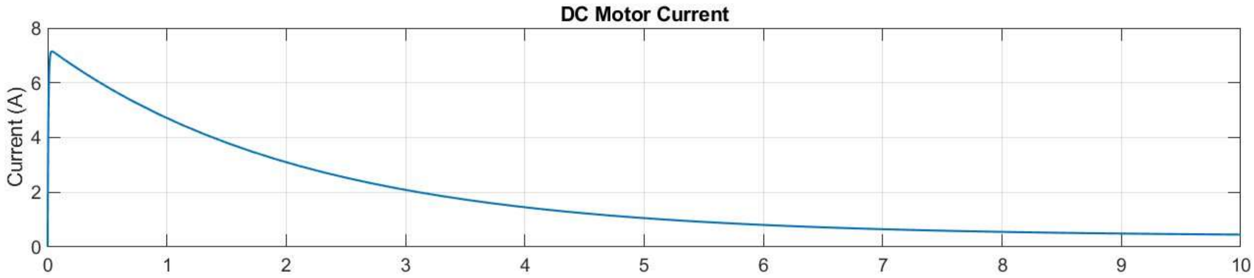
TB6600 Stepper Motor Driver Specs:

Operating Voltage	9-42V
Input Current	1-4A
Max Output Current	3.5A
Input Control Voltage	5-24V
Max Subdivision	32 Microsteps

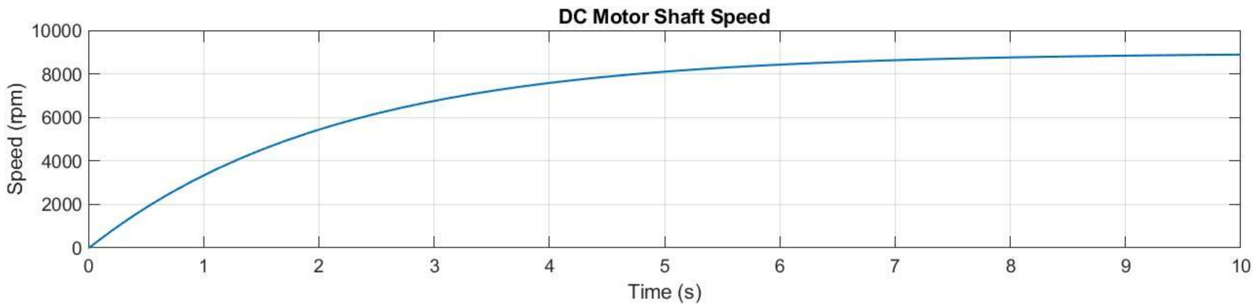
The above chart shows how the operating voltage was within the operating voltage of the NEMA 23 stepper motor. The max output current is a little high for the NEMA 23 stepper motor, however, the microstepping option allows us to be able to control the output current.

V.A.2.d. Engineering Analysis & Materials Selection for SS#2-P#4-Gearmotor

Keldon Ngo



Shown above is a current to time graph. Current is highest at start up, then levels out to 0.33A.



Shown above is the shaft speed to time. The DC geared motor begins to spin faster as time goes on, topping out at about 8500RPM.

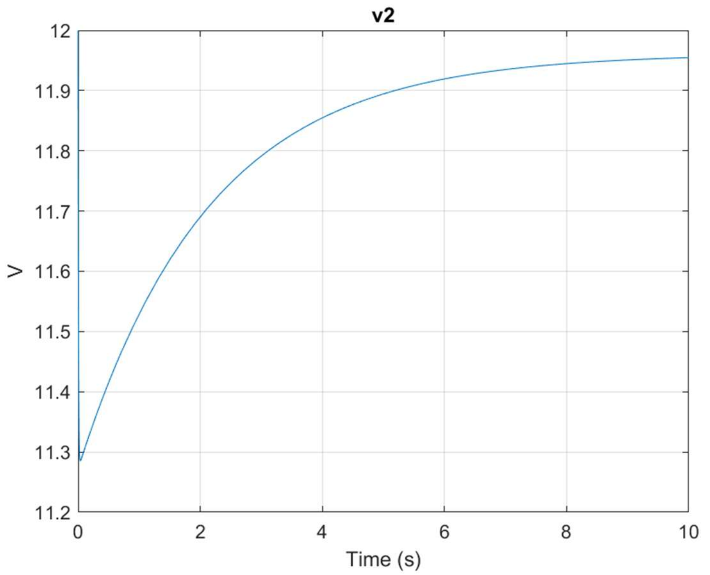
V.A.2.e. Engineering Analysis & Materials Selection for SS#2-P#5-L298N Dual H-Bridge

Keldon Ngo

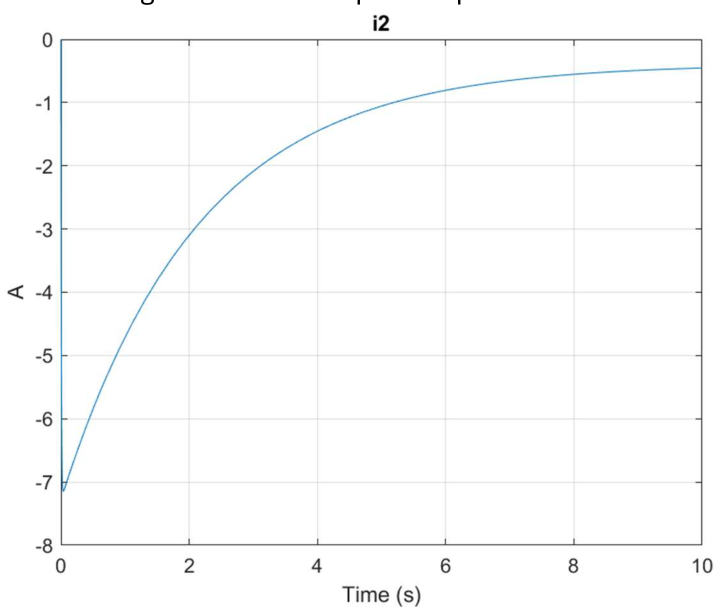
<u>L298N Dual H-bridge Motor Driver Specs:</u>

Operating Voltage	3.2-40V
Input Current	0-36mA
Max Output Current	2A
Input Control Voltage	3.2-24V
Max Power Consumption	20W

The above chart shows how the operating voltage was within the operating voltage of the L298N Dual H-Bridge Motor Driver.



Shown above is a voltage to time of the motor controller. As we can see, the controller slowly draws more voltage as the motor speeds up.



Shown above is a current to time of the motor controller. As we can see, the controller slowly draws more current as the motor speeds up.

VI. Manufacturing & Assembly

VI.A. Manufacturing Processes

For the manufacturing of this project, gear for welding will be used to weld to the frame of the solar panel to install rails used for mounting the system. These rails will also need to be cut to length so since they are made of aluminum, the group will need an angle grinder. We will also need a drill to tap a threaded hole through the rails of the cleaning system and the welded rails. Once again, an angle grinder will be needed to grind the installed screws of the newly tapped holes to be sure they do not inhibit the movement of the gantry plate sliding back and forth on the cleaning system. There will also need to be a threaded hole drilled into the core of the brush we are getting to install the flange coupling; this way we can secure the brush to the rotational motor.

VI.B. Assembly Process

The assembly of the new additions to the rover will start with the solar panel. The two 20x20 rails will be welded to the bottom of the solar panel frame. These rails have tracks that will fit t-track bolts. These bolts will secure a two-hole electrical strap around the frame using nuts on the other end. This will secure the solar panel to the frame of the rover. Next to be added are the cleaning system rails. Those will be secured to the sides of the solar panel and be screwed into the rails that were welded underneath. The rails will be tapped through to add threads for the screws. The screws will then be grinded down to make sure they are flush for the gantry plate to roll over

For the electrical wiring the plan is to add on to the existing design. Shown below is the picture of the add-ons with the old wiring document. The white boxes are the old stuff, the blue boxes are new components, blue arrows are new electrical wiring and the red wiring is new signal wiring. The solar panels will be connected to the charge controller with the included wiring. The same will happen for the battery. The charge controller will then hook up to the bus bar with 4 AWG wiring. The bus bars will be connected to the motor controllers via 16 awg wiring. Those motor controller will also us 16 awg wiring to connect the motors. The H-Bridge motor controller also have a 5-volt output that will power the Arduino. Finally, the Arduino will send signal to the controllers telling them how to operate.

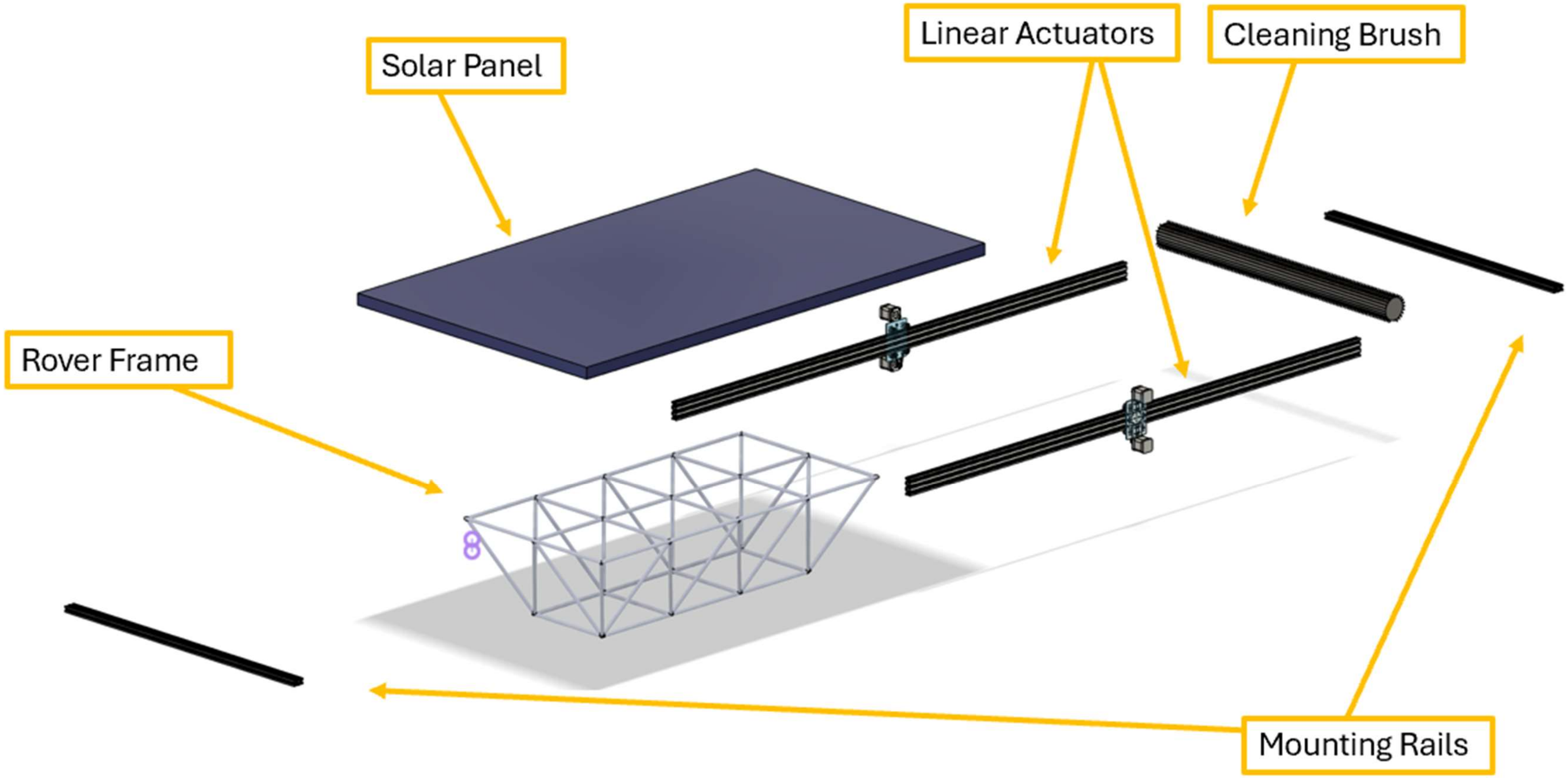


Figure 0-1: Exploded View Assembly Drawing of Prototype – Sub-System Level

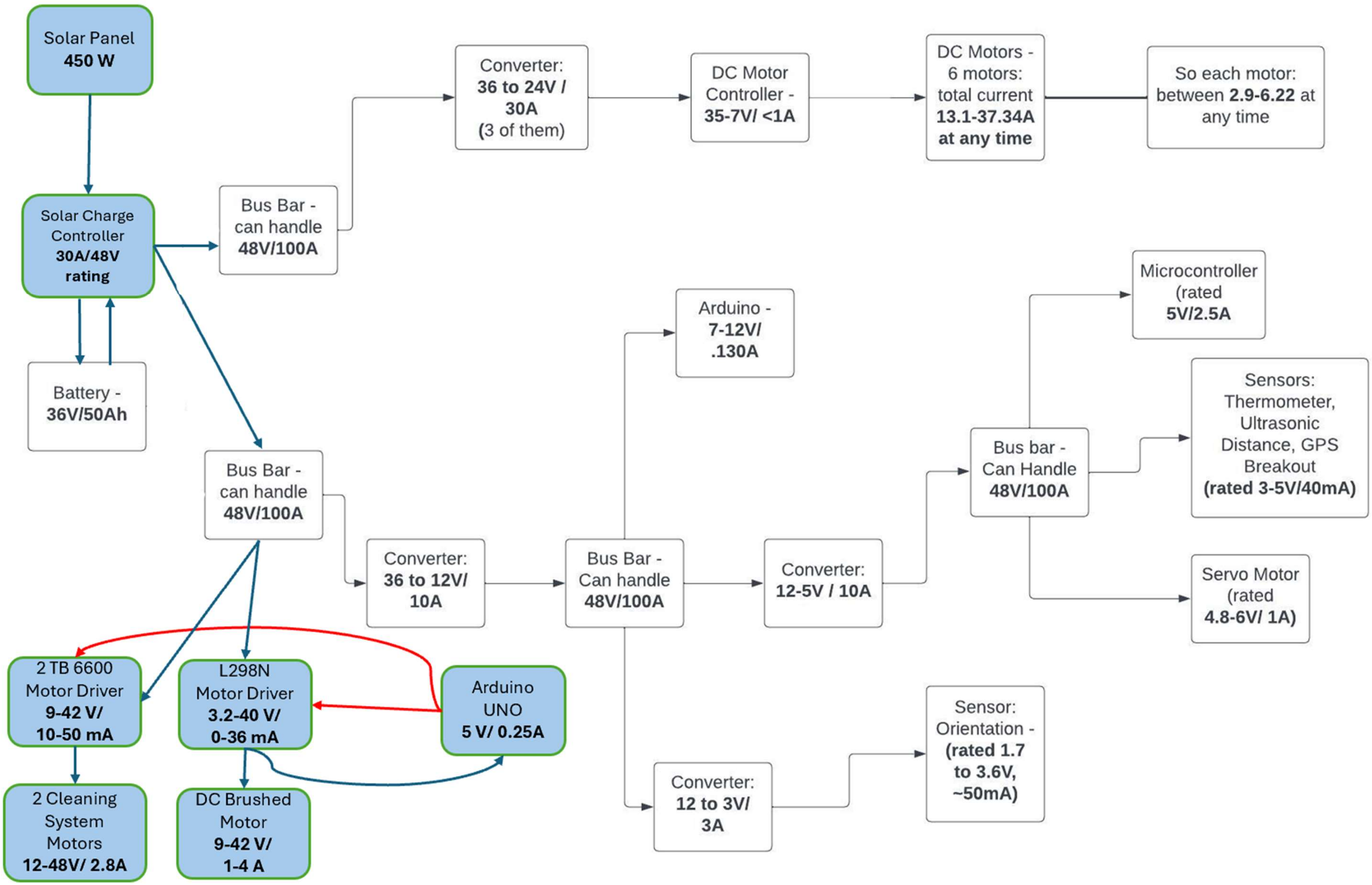


Figure 0-2: Electrical Diagram– Sub-System Level

VII. Safety Considerations

VII.A. Operational Safety

During our project process, our group thought about various safety concerns during operation that we have provided solutions to. The first concern is an electrical shock and arc flash hazard. To prevent this hazard, we have made sure that all of our electrical connections are grounded properly and that any bus bars are insulated to prevent a short across the terminals. We also implemented properly sized fuse connections to important electrical connections to prevent overcurrent damages. We were also concerned with the moving parts of the brush cleaning system causing a hazard, so we added a cancel button and a buzzer to create a system to stop the process of the cleaning system and add an auditory warning to those nearby. Lastly, in the case of emergencies, we have kill-switches on the battery terminals to completely de-energize the rover. These factors were thought out to ensure operational safety for our rover and systems.

VII.B. Safety During Manufacturing, Assembly and Testing

For safety during manufacturing, assembly, and testing, we are planning to utilize all of the safety considerations from operating the rover, but we also have additional safety considerations. For manufacturing and assembly, our group will most likely be in a work shop, so making sure that we acknowledge proper work shop safety is essential. For example, proper PPE for our tasks as well as making sure to be aware of our surroundings are essential safety considerations that we should have. For testing, our group should ensure that the tests being run are setup correctly to prevent any unexpected results that may be deemed dangerous. With these safety considerations in mind, our safety during manufacturing, assembly, and testing should be fulfilled.

VIII. Environmental Impact Assessment

VIII.A. Related to Manufacturing

The manufacturing plan includes many components however all the components are recyclable. The largest environment impact coming from manufacturing will be the welding of some components for mounting purposes. This includes air pollution such as metal fumes and gaseous emissions. Welding also generates waste such as electrodes and filler metals. These can be mitigated with proper ventilation and eco-friendly materials.

VIII.B. Related to Operation

It is expected that the addition of solar power to the rover will increase the intervals between charging the onboard battery, decreasing the total energy required from a utility company for charging during the life of the battery. The main advertised advantage for using solar power is that you will not have to consume as much power from the grid. There should not be any negative environmental impacts from the operation of the solar power system.

VIII.C. End-of-Life

The motors and electronics we use for the self-cleaning system should be recycled at their end-of-life, as they can be reused in the manufacturing of new devices. The solar panel should also be recycled once it becomes obsolete or no longer produces sufficient power. Solar panels contain heavy metals such as cadmium and lead, which will become hazardous materials if a solar panel is simply thrown away in a landfill. Recycling can also repurpose the rare elements used in photovoltaic cells such as gallium and indium, which could be used in the production of new solar panels.

IX. Testing, Validation, and/or Implementation

IX.A. Design-Phase Testing

Team 66 did not conduct design-phase testing.

IX.B. Preliminary Testing, Validation and/or Implementation Plan

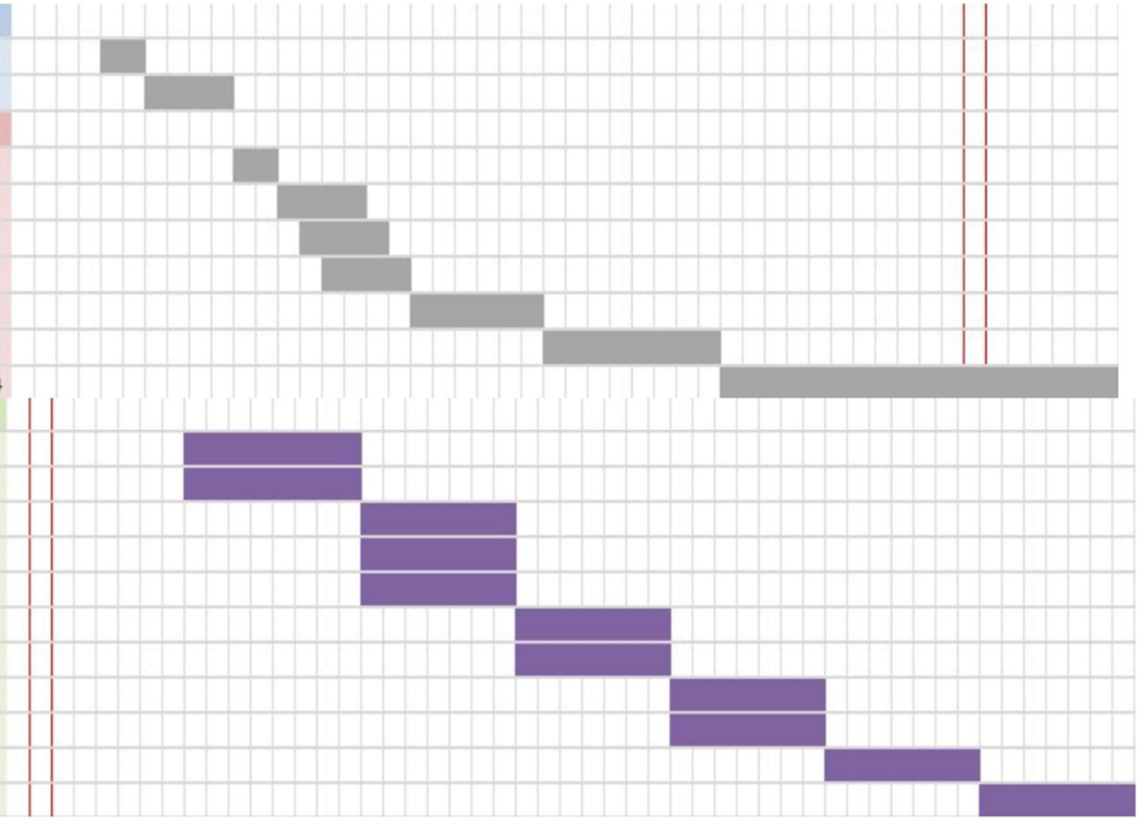
The team is planning on testing the battery runtime with the additional source of the solar panel. As for environmental performance we plan to bring the solar panel outside during peak sun irradiation and measure the power output of the panel under ideal conditions. The testing plans for the cleaning system is to test the effectiveness of the brush and also validate that the several systems work before combination.

X. Project Management

X.A. Schedule and Milestones

Our Project starts with our Project Preview milestone. During this period, our group did a lot of preparation and introduction for our project. This involved meeting with our sponsor and choosing a faculty advisor we thought would have the most expertise in our area. We also were able to do an interpretation of our project and assign each team member with their own role that would be beneficial to the entire team. We then move on to the Planning and Design portion of our project. During this time, we begin researching the main functions of our project. This includes solar panels, a solar panel cleaning system, and autonomous power switching system. From our research we were able to turn our ideas into concept generations. Using these concept generations, our group was able to make selections on the concepts that we deemed would be most suitable and beneficial to our rover design. To visualize these, we created 3D rendering in Fusion. Next, our group will move into the Analysis phase of our project. During this phase, our group will run simulations and experiments to ensure that our functions and subfunctions will in fact work when we assemble and run them. This is also the time to make sure that our functions will be compatible with the previous rover's system, and to make any necessary changes to our functions. This is identified as our critical failure point and critical path. Without proper analysis our ideas could fail if they prove to not be feasible. We must ensure that proper analyses are done to prove that our system does work. Once we have verified that our functions are feasible, we can now look into ordering the components needed to manufacture our function systems. That leads us to the next semester, where we will begin assembling our function systems once the essential parts arrive during the Manufacturing and Testing stage. Once we have assembled each function system, our group will make sure to test that specific function to make sure that it works properly and how we planned it to. Once we have thoroughly built and tested each function, we will implement all our systems onto the pre-built rover. From then we will run another series of tests to make sure that our system is working properly with the original system. This testing allows us to fine tune our systems to ensure that they are working the best that they can be. Once fine tuning and one final round of testing is completed, our team will be ready to give our final presentation. After completing the analysis phase of our project, we have discovered that our battery is capable of supporting the additional load that we will add, our solar panel will generate the adequate power to aid in the longevity of the rover run time, the proper sizing of stepper motors and DC motors to execute a brush cleaning system, and constructed a code to activate the brush cleaning system. Using simulations and calculations, we confirmed that our functions are feasible. We will now move onto our manufacturing phase, where the proper assembly of our functions is a new critical path and critical failure point. If our functions are not assembled properly, our whole project scope and functions will fail causing a long delay or possibly failure. That is why it is critical that we stay on the right path for assembly and ensure that our functions are suitable for the testing phase.

Project Preview			
Met Sponsor/Decide Faculty Advisor	100%	9/5/24	9/6/24
Project Interpretation and Team Roles	100%	9/7/24	9/10/24
Planning and Design			
Research Previous Rover Project	100%	9/11/24	9/12/24
Research Solar Panel Cleaning	100%	9/13/24	9/16/24
Research Methods to Autonomously Switch	100%	9/14/24	9/17/24
Research Solar Panels & Connections	100%	9/15/24	9/18/24
Create Concept Generations for Each Functio	100%	9/19/24	9/24/24
Decide/Select Ideal Concept Generations	100%	9/25/24	10/2/24
Create 3D Models in Fusion for Each Functio	100%	10/3/24	10/20/24
Analysis			
Simulations to See Power Capabilities of Solar Panel		10/21/24	10/28/24
Solar Panel with Rover System as Load Test		10/21/24	10/28/24
Run Analysis on Charge Controller for Power Switching		10/29/24	11/4/24
Analysis on DC Brush Motor for Cleaning Brush		10/29/24	11/4/24
MATLAB Stepper Motor Analysis		10/29/24	11/4/24
Construct Code and Analyze For Cleaning System Activatio		11/5/24	11/11/24
Experiment with Physical Model with Real Debris		11/5/24	11/11/24
Load Analysis for New Electrical Components		11/12/24	11/18/24
Evaluate Results and Adjust Concepts Accordingly		11/12/24	11/18/24
Verify Compatibility With Previous Rover System		11/19/24	11/25/24
Order Necessary Parts For Manufacturing		11/26/24	12/7/24



Task	Start	End
Manufacturing		
Plan Out Part Assembly For Functions	1/13/25	1/20/25
Assemble Brush Cleaning System	1/21/25	2/5/25
Connect Motors and Brush to Rails	1/21/25	2/5/25
Mount Solar Panel to Rover Frame	1/21/25	2/5/25
Assemble Solar Panel Connections	2/6/25	2/20/25
Assemble Charge Controller For Power Switching	2/21/25	3/5/25
Implemement All Functions to Rover	3/30/25	4/10/25
All Appropriate Electrical Connections Made	4/11/25	4/13/25
Testing		
Solo Test Brush Cleaning System	3/6/25	3/13/25
Ensure Motors Actuate	3/6/25	3/13/25
Solo Test Solar Panel Power Generation	3/14/25	3/21/25
Test Production During Different Scenarios	3/14/25	3/21/25
Solo Test Charge Controller Autonomous Power Switching	3/22/25	3/29/25
Test Power Switching With Different Battery SOC	3/22/25	3/29/25
Test Rover with Total Integration	4/14/25	4/17/25
Make Final Adjustments	4/18/25	4/25/25
Final Rover Test	4/26/25	5/3/25

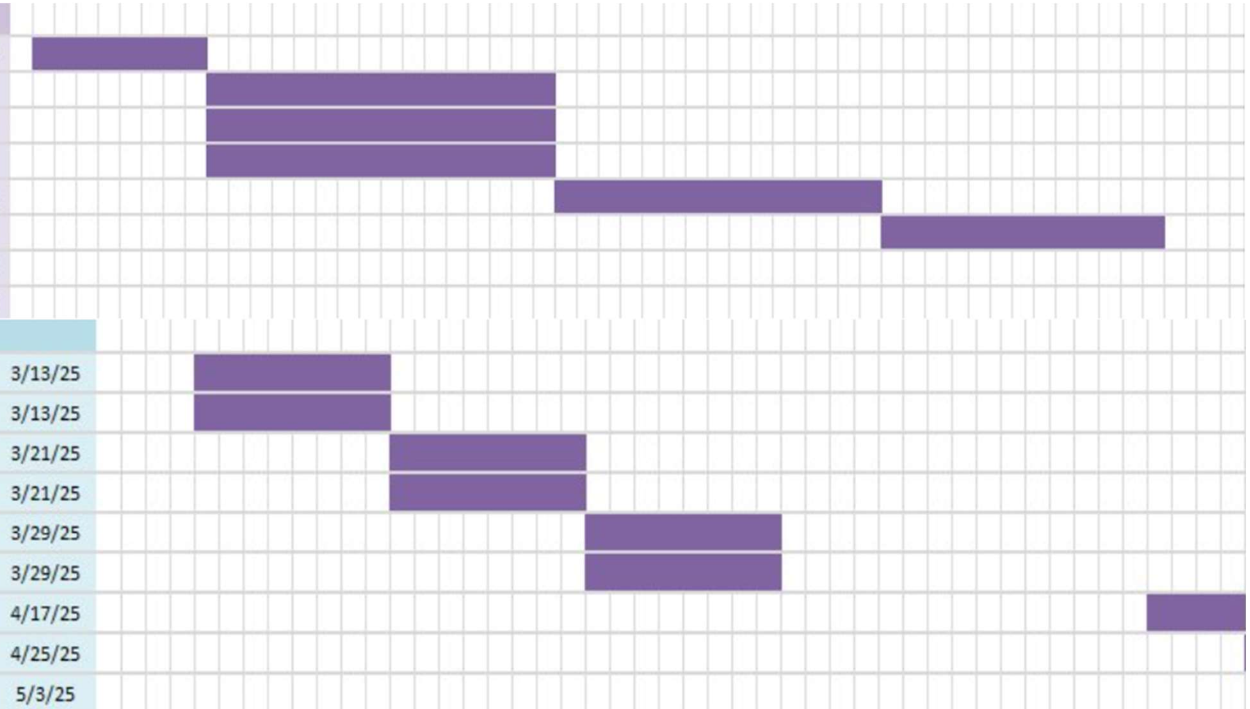
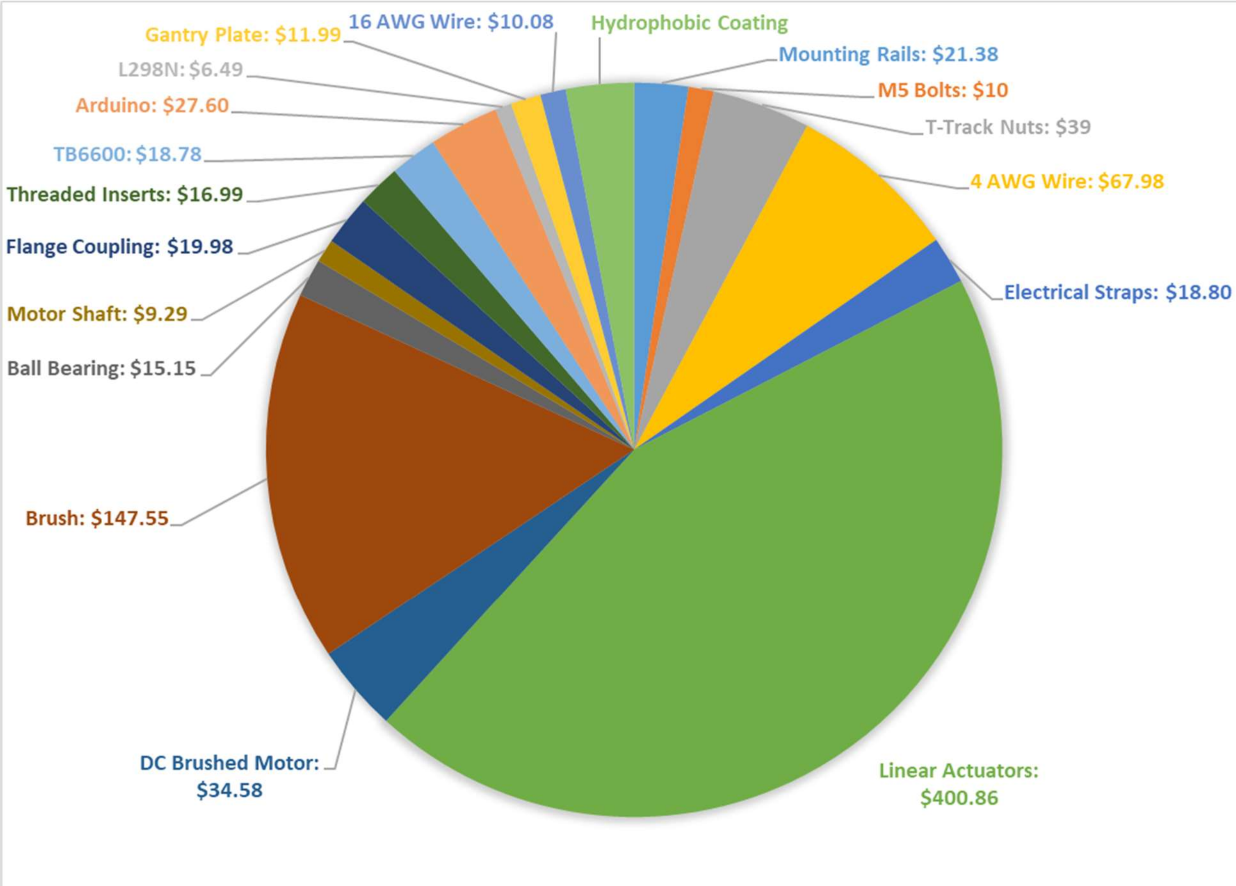


Figure 0-1: Gantt Chart with Project Time-Line

X.B. Budget



The chart above shows the estimated budget for our project. More details will be included in the Budget Details (Appendix XIII.D.2).

XI. Summary and Conclusions

Our project aims to enhance LOUIS's battery life, while also staying safely under budget ($4,000) and meeting the sponsor's requirements. We will integrate a solar panel as the primary power source, implement autonomous power switching to optimize power input, and develop a cleaning system to maximize solar panel efficiency. The chosen solar panel, the monocrystalline REC Pure-RX, delivers a power output of 450W and efficiency of 21.6%. Autonomous power switching will be overseen by the MorningStar TriStar-MPPT-30 charge controller, which utilizes maximum power point tracking to alternate between solar and battery power. The cleaning system will consist of linear actuators with a stepper motor for linear motion and a gearmotor for rotational motion of the brush. Future testing will focus on the battery runtime after the additions, environmental performance given varying weather conditions, and the cleaning system’s activation and effectiveness.

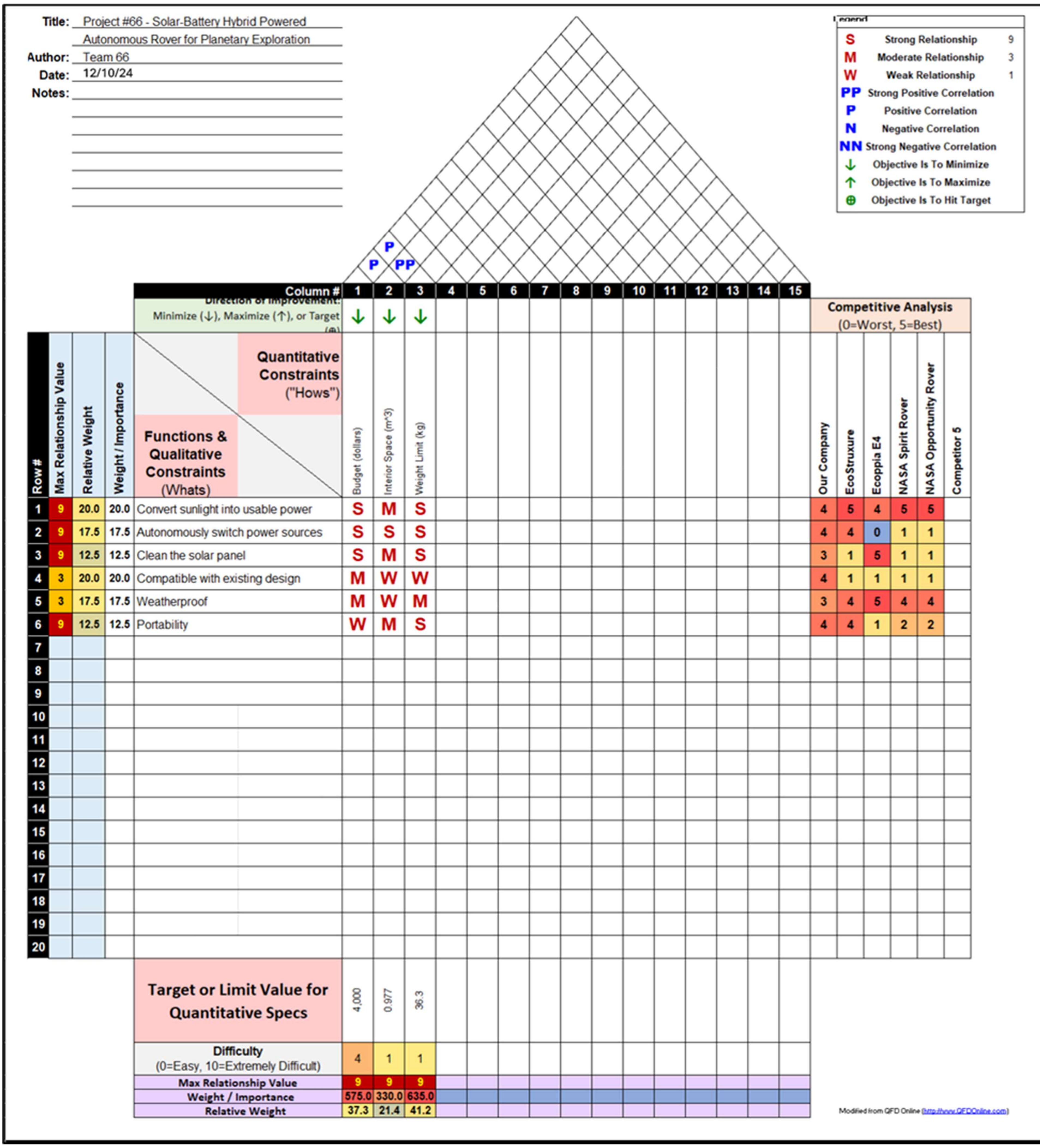
XII. Appendix

XII.A. Quality Function Deployment (QFD) - HoQ

The House of Quality pictured below demonstrates the relationships between the functions of the project and constraints that must be met to accomplish these functions. Weights were assigned in ranking of importance from the perspective of the sponsor's desired results. Values of 1, 3, or 9 were assigned to the relationships between functions and constraints to show these relationships as weak, moderate, or strong. The relative weights for the functions and qualitative constraints in the House of Quality were determined by taking the relative weights of each function and quantitative constraint from the tables in the Engineering Specification and dividing them by 2, since they are grouped together in the House of Quality but are two separate tables in the Engineering Specification.

Quantitative constraints are those that can be assigned specific values for physical limitations on the project. As this project is desired by the sponsor to be more of a proof of concept, we have very few quantitative constraints, giving us great flexibility in our design. The only sponsor-assigned quantitative constraint is that the project should remain within a budget of $4,000. Upon visual inspection and measurements of the rover, it was determined that we must fit any additional electronics or components within a $0.977m^3$ space to ensure that the electronics are contained within the chassis of the rover. The tested additional load of the rover was 36.3kg, so we cannot exceed this weight when adding the solar power and power switching systems.

The more components that are required to accomplish our goals with this project, the higher our costs and the more weight capacity and space will be taken up. This results in positive correlations between cost and available space/weight. There is a strong positive correlation between space being used and added weight to the rover, as taking up more of the available space in the chassis with electronic components will increase the weight of the rover as well.



Title: Project #66 - Solar-Battery Hybrid Powered Autonomous Rover for Planetary Exploration
Author: Team 66
Date: 12/10/24
Notes:

Legend

S	Strong Relationship	9
M	Moderate Relationship	3
W	Weak Relationship	1
PP	Strong Positive Correlation	
P	Positive Correlation	
N	Negative Correlation	
NN	Strong Negative Correlation	
↓	Objective Is To Minimize	
↑	Objective Is To Maximize	
⊕	Objective Is To Hit Target	

P
P PP

Row #	Max Relationship Value	Relative Weight	Weight / Importance	Functions & Qualitative Constraints (Whats) / Quantitative Constraints ("Hows")	1 Budget (dollars)	2 Interior Space (m^3)	3 Weight Limit (kg)	4	5	6	7	8	9	10	11	12	13	14	15	Our Company	EcoStruxure	Ecoppia E4	NASA Spirit Rover	NASA Opportunity Rover	Competitor 5
				Direction of Improvement: Minimize (↓), Maximize (↑), or Target (⊕)	↓	↓	↓													Competitive Analysis (0=Worst, 5=Best)					
1	9	20.0	20.0	Convert sunlight into usable power	S	M	S													4	5	4	5	5	
2	9	17.5	17.5	Autonomously switch power sources	S	S	S													4	4	0	1	1	
3	9	12.5	12.5	Clean the solar panel	S	M	S													3	1	5	1	1	
4	3	20.0	20.0	Compatible with existing design	M	W	W													4	1	1	1	1	
5	3	17.5	17.5	Weatherproof	M	W	M													3	4	5	4	4	
6	9	12.5	12.5	Portability	W	M	S													4	4	1	2	2	
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				Target or Limit Value for Quantitative Specs	4,000	0.977	36.3																		
				Difficulty (0=Easy, 10=Extremely Difficult)	4	1	1																		
				Max Relationship Value	9	9	9																		
				Weight / Importance	575.0	330.0	635.0																		
				Relative Weight	37.3	21.4	41.2																		

Modified from QFD Online (http://www.QFDOnline.com)

Figure 0-1: The House of Quality for the project .

XII.B. Concept/Solution Evaluation and Selection Supplement

XII.B.1. Concept/Solution for Function F#1 – Convert Solar Energy for Power

XII.B.1.a. Concept Selected - Details

The monocrystalline solar panel was selected after completing a pros and cons chart along with a decision matrix. The monocrystalline solar panel was the most efficiency is much higher than both of the other options. This allows for a smaller panel saving space. Although it is the highest cost this is weighed by its efficiency. The weight was similar to a polycrystalline panel.

XII.B.1.b. Concepts Considered - Details

Decision matric for F1:

		Concepts		
Criterion	Weights	Thin Film	Polycrystalline	Monocrystalline
Efficiency	40	-1	0	1
Cost	25	1	0	-1
Weight	20	1	-1	-1
Life-span	15	-1	1	1
Weighted Total	100	-.1	-.05	0.1

Pros and Cons of solar panel types.

	Monocrystalline	**Polycrystalline**	**Thin-Film**
Pros	• High Efficiency: 20-23% • Space-Saving • Longer Lifespan	• Good Efficiency • Cost-Effective • Decent Space Utilization	• Lightweight and Flexible • Performance in High Temperatures • Lower Cost
Cons	• Expensive • Production	• Space • Shorter Life-span • Less efficient	• Low Efficiency: 13-15% • Consume lots of space • Not Durable

Above is both our decision matrix and pros/cons chart for function 1. the evaluation and selection of solar panel types. We were deciding between thin-film, polycrystalline and mono crystalline panels.

We weighted efficiency the highest at 40 percent because having a higher efficiency solar panel will also cut down on the size of solar panel needed to provide appropriate power to the rover and we don't want the rover to lose any capability due to size of panel. Cost is weighted 25 percent as this is going to be the most important component because it is the basis of our project. We placed weight at 20 percent because the rover does have a maximum load weight of about 36 kilograms the panels will be the heaviest component added. The lifespan of the solar panels is rated at 15 percent as this will allow future teams to work with the panel. This led us to the decision of a monocrystalline solar panel because it was the only panel that had high enough efficiency to power the rover and charge the battery.

XII.B.2. Concept/Solution for Function F#2 – Autonomously Switch Power

XII.B.2.a. Concept Selected - Details

The charge controller was selected after completing the decision matrix. The charge controller method was much more accurate, efficient, and user-friendly, than the voltage regulator or DC/DC converter. The price was a concern for the charge controller because it was the most expensive option, however with our budget of $4,000 the group felt confident it was the right purchase. This was further validated when Morningstar donated the charge controller to us. The charge controllers ease of use and ability to hook right up to the system made it the perfect choice for our application.

XII.B.2.b. Concepts Considered - Details

		Concepts		
Criterion	*Weights*	*Voltage Regulator with Arduino*	*DC/DC Converter with Arduino*	*Solar Charge Controller*
Functional Accuracy	*45*	*-1*	*0*	*1*
Simplicity	*25*	*0*	*-1*	*1*
Programmability	*20*	*-1*	*0*	*1*
Cost	*10*	*1*	*0*	*-1*
Weighted Total	*100*	*-0.55*	*-0.25*	*0.8*

Above is the decision matrix for function 2. For the decision matrix, the most important criteria we decided on was functional accuracy. This was weighted 40% because the main goal of this concept is that it can accurately swap between solar and battery power, because of this it was weighted 40%. Simplicity was weighted at 25% because it was important that the switching be easy to operate and understand. Following that was programmability, which as stated before is sort of a subcategory of simplicity. We weighted this 20% because we wanted to make sure that the power switching was able to be set to parameters of our choosing, while also being easy to do. Lastly, the cost was decided to be weighted at 10% because it was decided that of course the $4000 budget cannot be exceeded, there is enough in the budget to ensure that the best quality item is chosen. For the calculations, 0 meant the "standard" compared to the other methods, -1 meant "poor", and 1 meant "good" and the weight of the criteria was multiplied across and then each concept was added up accordingly.

XII.B.3. Concept/Solution for Function F#3 – Clean the Solar Panel

XII.B.3.a. Concept Selected - Details

The brush method was selected after completing a pros and cons chart and a decision matrix. The brush method was far cheaper than the electrostatic method, and cleaned relatively effectively, despite concerns over potential scratching. The solar panel we selected should be able to withstand that level of friction. The brush would be a lighter system, and given our weight constraint, this was a necessity. It is a potentially abrasive system, as stated earlier, but the risk is low if we use soft bristle brushes and a monocrystalline panel. Maintenance wise, the brush will likely have to be replaced every few years, which is not as often as potential air compressor repairs.

XII.B.3.b. Concepts Considered - Details

Decision Matrix for F3:

		Concepts		
Criterion	*Weights*	*Air Compressor*	*Electrostatic Method*	*Brush Method*
Cost	*30*	*0*	*-1*	*1*
Cleans Effectively	*25*	*-1*	*1*	*0*
Mass	*20*	*-1*	*0*	*1*
Non-abrasive	*20*	*0*	*1*	*-1*
Maintenance	*5*	*-1*	*1*	*0*
Weighted Total	*100*	*-0.5*	*0.2*	*0.3*

Pros and Cons for F3:

	Air Compressor	**Electrostatic Method**	**Brush**
Pros	- Less likely to scratch	- Requires humidity - No scratch - 90% effective	- Easily obtainable parts - Within budget - Low power consumption
Cons	- Weight distribution - Large power consumption - Potentially less effective due to spacing between holes	- Too expensive - May not clean heavier debris	- May scratch - May trap debris

Above is both our decision matrix and pros/cons chart for function 3. For the decision matrix, the main criteria we selected was the cost to stay under the $4000 budget. This was weighed 30% due to the quantitative constraint. An effective cleaning system was weighed 25% to ensure maximum power absorption. A lower mass was weighed 20% to stay under the 36.3kg quantitative constraint. Non-abrasiveness was 20% to, again, maximize that power absorption. This is a little lower than the effective cleaning since the solar panel we selected is relatively durable. Lastly, ease of maintenance to have minimal repair issues was 5% since the rover will be for educational purposes, rather than for space. For the calculations wise, 0 meant the “standard” compared to the other methods, -1 meant “poor”, and 1 meant “good”.

For the pros and cons chart, the air compressor would not scratch the panel because there would be no physical contact. However, it would have a high density and might disrupt the weight balance. Additionally, it would consume larger amounts of power to complete the same task. Lastly, the effectiveness of cleaning is in question due to the spacing between the holes of the perforated pipe. With regards to the electrostatic method, it works most effectively in humid environments due to its reliance upon electrical conductivity in the air. It wouldn’t scratch since there would be no physical contact, and MIT researchers have reported that it is 90% effective. However, the indium tin oxide (ITO) alone was around $4000, which would be too much for our budget. We might need to also supply a higher voltage to pick up the heavier debris, which might lead to more power loss than necessary. For the brush method, the parts are much more obtainable than some of the more niche components and lie within budget. This method also did not require lots of power, but it might trap debris within its bristles and scratch the panel.

XII.C. System Description/Product Architecture Supplement

XII.C.1. Sub-System SS#1 – Solar Panel and Charge Controller

The most critical component for this project, the 450W solar panel will absorb solar energy and act as the main power source for the rover when sunlight is available. The chosen solar panel measures 46 inches wide, 68 inches long, and 1.2 inches thick, and weighs 50 pounds. The panel is composed of 88 heterojunction cells with gapless technology. An MPPT solar charge controller will be used to regulate the power output of the solar panel while drawing the appropriate current to extract maximum power from the panel. The charge controller will be sending the power from the panel to the existing electrical system of the rover, including the battery. This charge controller will be programmed to output 36V to safely and efficiently work in conjunction with the 36V battery currently onboard the rover, charging the battery when solar power produced exceeds that which the rover needs to function at that time. The rover itself will play an important role in the design of the project. This is because every component added must be mounted or fastened securely to the rover. The frame, which consists of a series of skeletal struts made of small cylindrical steel pipe, will provide mounting locations for all of those added components. The rails supporting the solar panel will be mounted to the frame by two-hole electrical straps. The straps will wrap around the circumference of the cylindrical frame struts. The rails have slots that will accommodate T-track bolts, which will be used to bolt the ends of the electrical straps to the rails.

XII.C.2. Sub-System SS#2 – The Cleaning System

The brush will move across the length of the panel via linear actuators, while simultaneously rotating to sweep debris off the panel. This rotation will be accomplished using a DC brushed motor mounted on the gantry cart of one of the linear actuators at end of the cleaning brush. The other end of the brush will be supported by a bearing in a bearing housing mounted to the other gantry cart, so this end of the brush will be free spinning. The cleaning brush will ride on linear actuators to move back and forth along the length of the solar panel. These linear actuators will be mounted on the sides of the solar panel. The linear movement will be accomplished by stepper motors on a belt-and-pinion system. The stepper motors are mounted on gantry carts that roll along linear rails. The pinion on the stepper motor shaft moves along a stationary synchronous belt as the motor shaft spins. This belt has teeth that engage with the teeth of the pinion, allowing the motor to drive the gantry cart along the belt. An Arduino microcontroller will be used to control the movement of the stepper motors. In the spring we will determine how to program the cleaning system to autonomously activate when power production of the solar panel drops below a certain threshold.

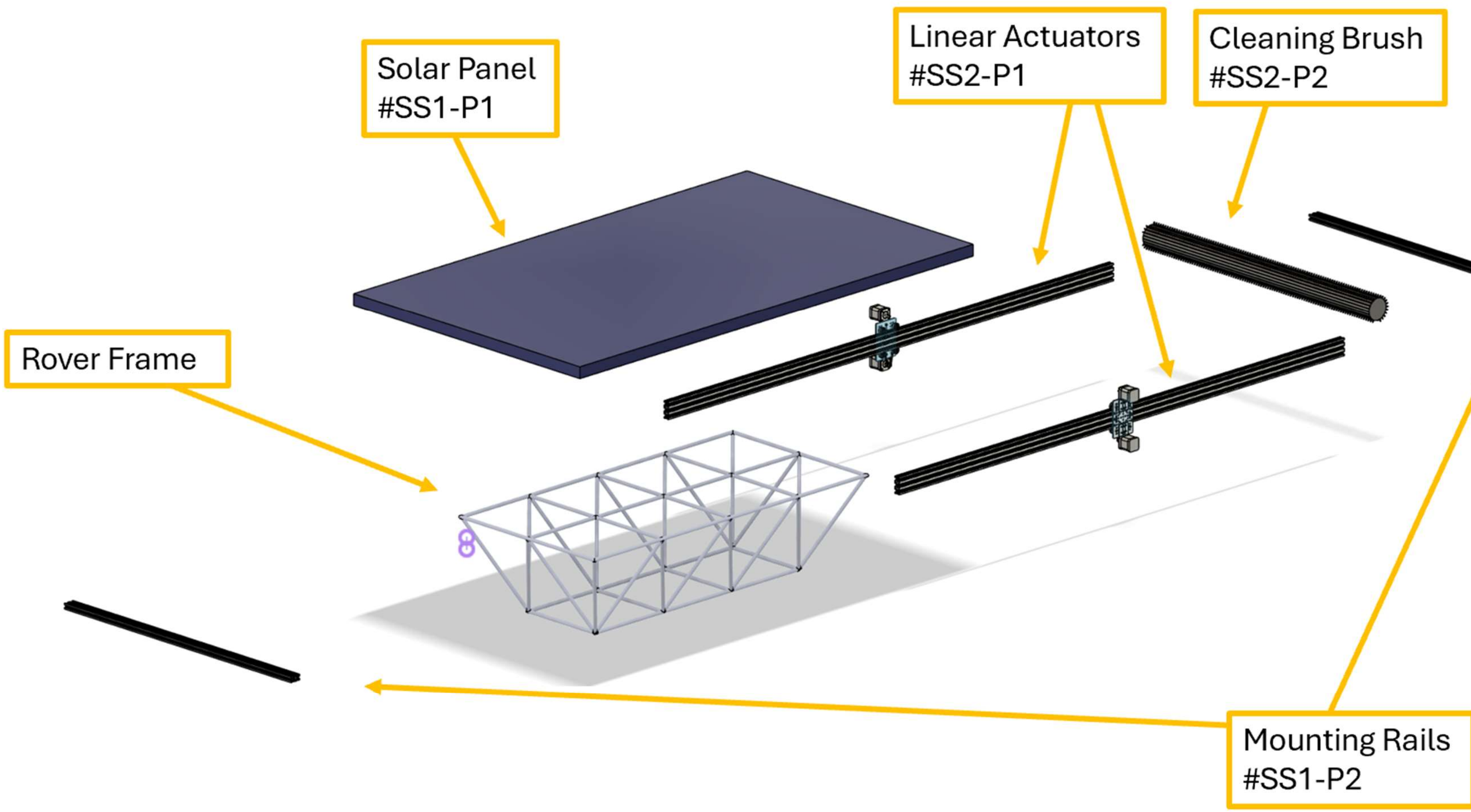


Figure 0-2: Exploded View Assembly Drawing of Sub-System SS#1&2-The Overall System

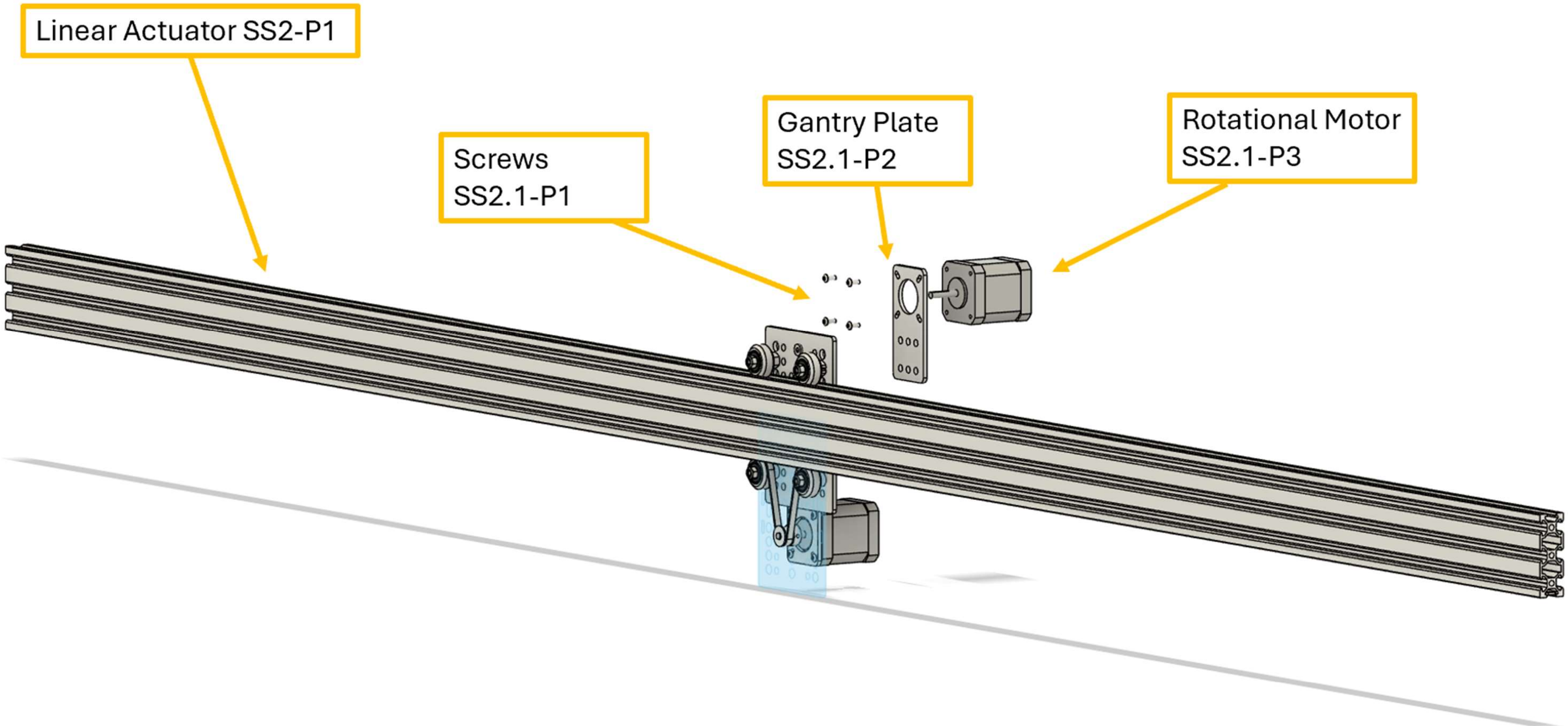


Figure 0-3: Exploded View Assembly Drawing of Sub-System SS# 2.1-The Linear Actuator

XII.C.1.a. Comprehensive Parts List for SS#1 – Solar Panel and Charge Controller

Table 0-1: List of Parts for Sub-System SS#1

Part #	Quantity	Material	Name
SS1-P1	1	N/A	Solar Panel
SS1-P2	2	Aluminum	Mounting Rails

XII.C.1.b. Comprehensive Parts List for SS#2 – The Cleaning System

Table 02: List of Parts for Sub-System SS#2

Part #	Quantity	Material	Name
SS2-P1	2	N/A	Linear Actuators
SS2.1-P1	4	N/A	Screws
SS2.1-P2	1	Aluminum	Gantry Plate
SS2.1-P3	1	N/A	Rotational Motor
SS2-P2	1	Nylon	Cleaning Brush

XII.C.1.c. *Off-The-Shelf Parts and Component Specifications for SS#1 – Solar Panel and Charge Controller*

Solar Panel Specs:

Power Output	450 W
Efficiency	21.6%
Power Density	20.1 W/m^2
Nominal Power Voltage	54.3 V
Nominal Power Current	8.29 A

Charge Controller Specs:

Operating Voltage	9 V
Nominal Battery Voltage	12, 24, 36, or 48 V
Charge Rating	30 A
Max PV Power	1200 W
Max PV Voc	150 V

XII.C.1.d. Off-The-Shelf Parts and Component Specifications for SS#2 – The Cleaning System

Arduino Uno R3 Specs:

Name	Arduino Uno R3
I/O Voltage	5V
Input voltage (nominal)	7-12V
DC Current per I/O Pin	20 mA
Power Supply Connector	Barrel Plug
Weight	25 g
Width	53.4 mm
Length	68.6 mm

NEMA 23 Stepper Motor Specs:

Items	Specs	Items	Specs
Phase Number	2 phases	Step Angle	1.8°±5%
Driving Voltage	24-48VDC (Recommended)	Rated Current	DC 2.8A/phase
Resistance (20℃)	1.1±10% Ω/phase	Inductance	3.0±20% mH/phase
Holding Torque	≥12.6Kg-cm(175 Oz.in)	Detent Torque	400 g-cm REF
Rotate Direction	ABCDA CW	MAX Starting PPS	2500 PPS
Max Slewing PPS	5000 PPS	Insulation Resistance	≥100 MΩ (DC 500V)
HI POT	AC600V/1mA/1S	Insulation Class	Class B
Rotor Inertia	300 g.cm2	Weight	0.75 Kg REF

TB6600 Stepper Motor Driver Specs:

Operating Voltage	9-42V
Input Current	1-4A
Max Output Current	3.5A
Input Control Voltage	5-24V
Max Subdivision	32 Microsteps

DC Gearmotor Specs:

Operating Voltage	1-12 V
Input Current	0.09-2.5 A
Max Current at Stall	2.5A
Toque	0.196 Nm
Speed(Rated)	7812RPM

L298N Dual H-Bridge:

Operating Voltage	3.2-40 V
Input Current	0-36 mA
Max Output Current	2 A
Input Control Voltage	3.2-40 V
Max power consumption	20W

XII.C.1.e. Engineering (Manufacturing) Drawings of All Parts of SS#1 – Solar Panel and Charge Controller

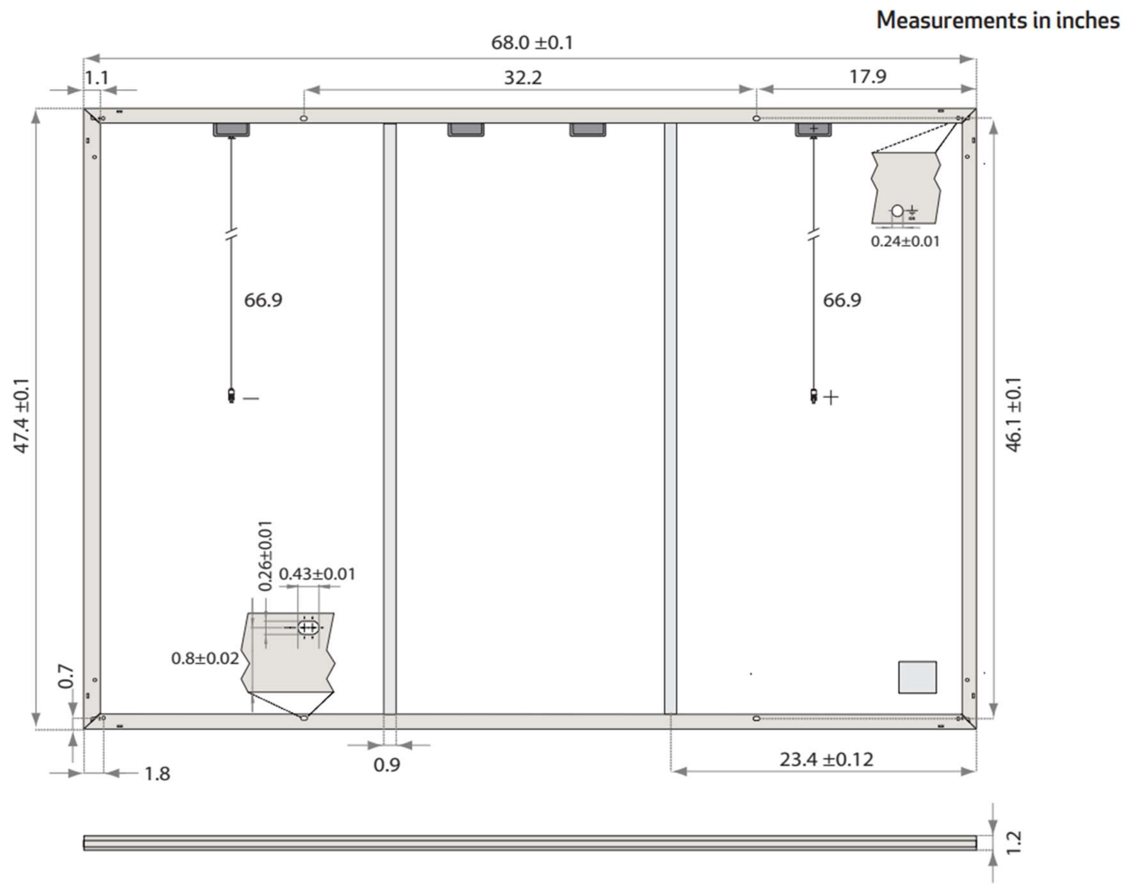


Figure 0-4: Manufacturing Drawing of part SS#1-P#1 – Solar Panel

XII.C.1.f. Engineering (Manufacturing) Drawings of All Parts of SS#2 – The Cleaning System

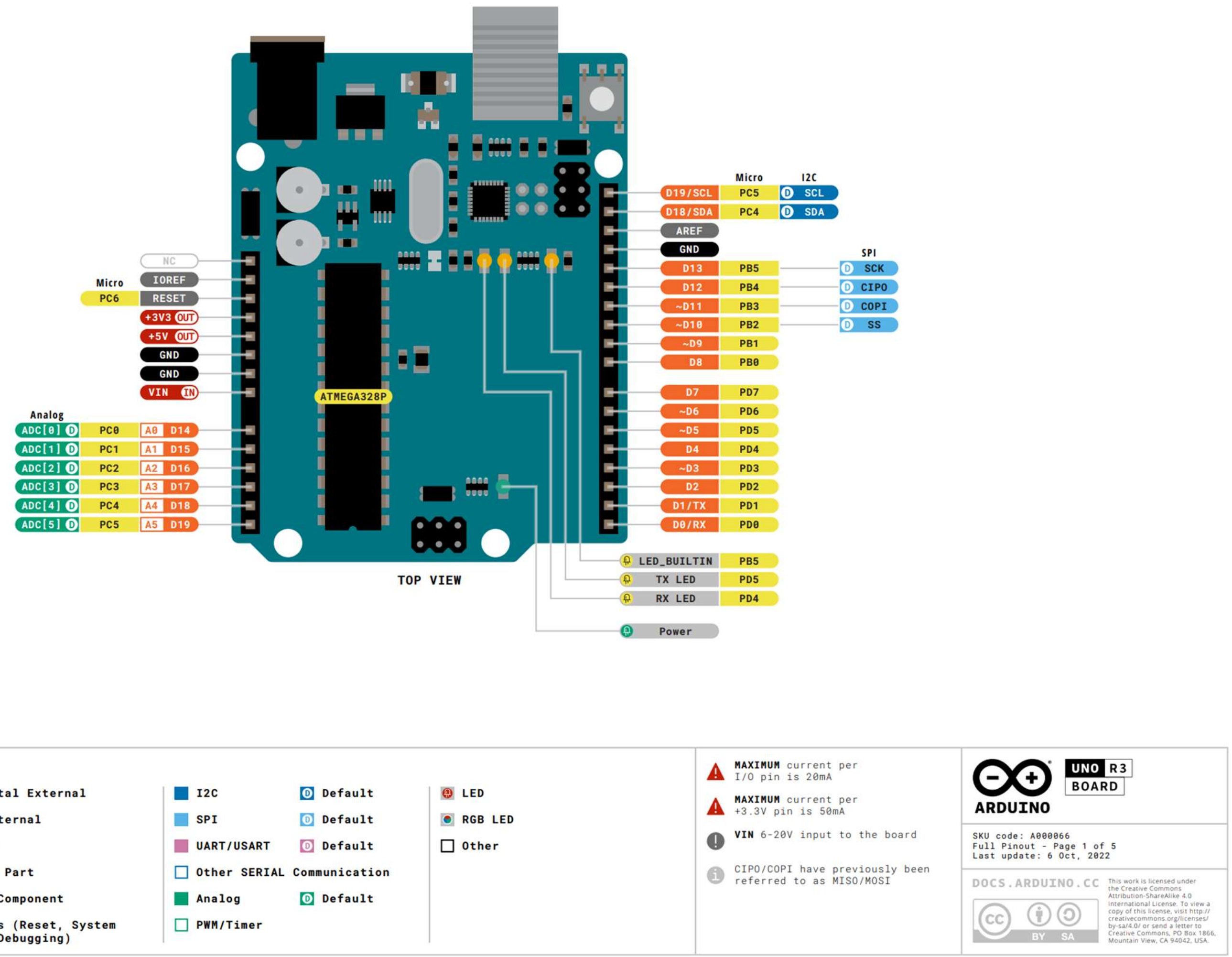
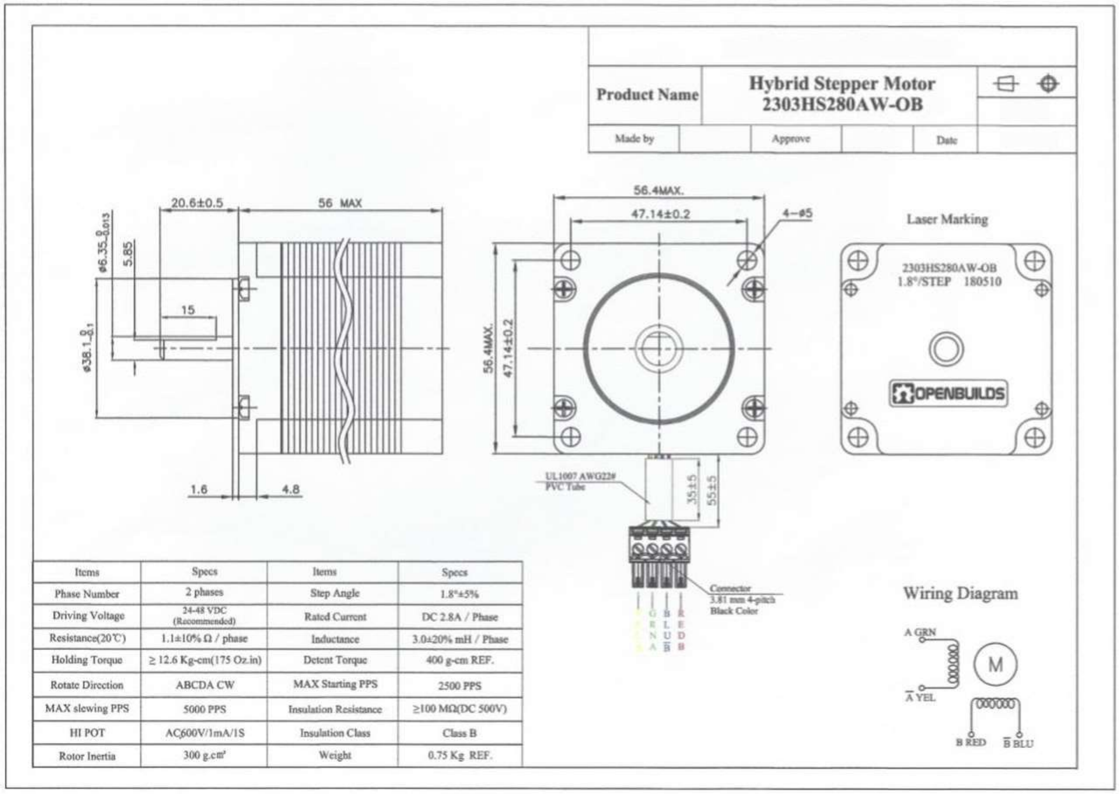


Figure 0-5: Manufacturing Drawing of part SS#2-P#1 – Arduino Uno



Items	Specs	Items	Specs
Phase Number	2 phases	Step Angle	1.8°±5%
Driving Voltage	24-48 VDC (Recommended)	Rated Current	DC 2.8A / Phase
Resistance(20℃)	1.1±10% Ω / phase	Inductance	3.0±20% mH / Phase
Holding Torque	≥ 12.6 Kg-cm(175 Oz.in)	Detent Torque	400 g-cm REF.
Rotate Direction	ABCDA CW	MAX Starting PPS	2500 PPS
MAX slewing PPS	5000 PPS	Insulation Resistance	≥100 MΩ(DC 500V)
HI POT	AC600V/1mA/1S	Insulation Class	Class B
Rotor Inertia	300 g.cm²	Weight	0.75 Kg REF.

Figure 0-6: Manufacturing Drawing of part SS#2-P#2 – NEMA 23 Stepper Motor

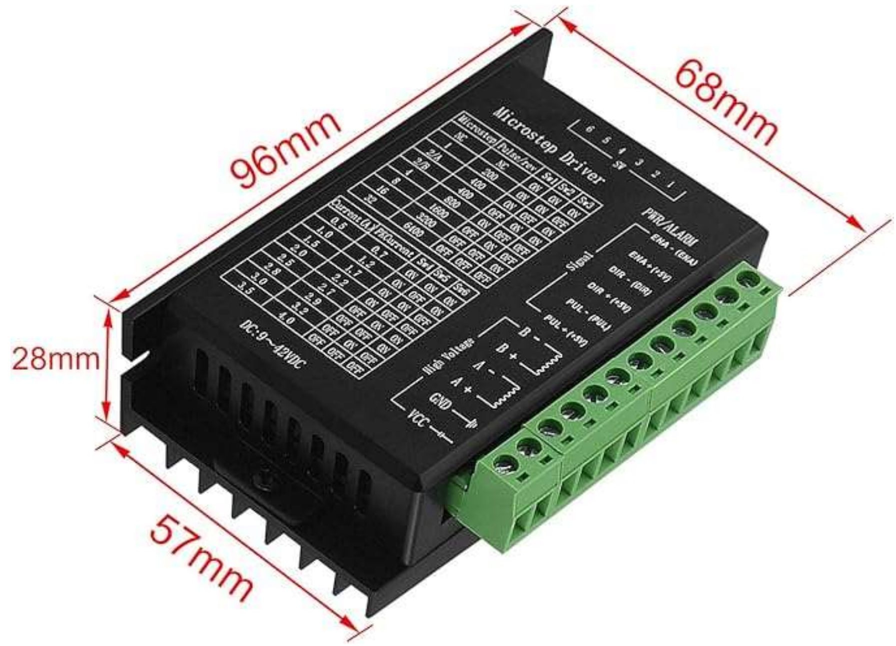


Figure 0-7: Manufacturing Drawing of part SS#2-P#3 – TB6600 Stepper Motor Driver

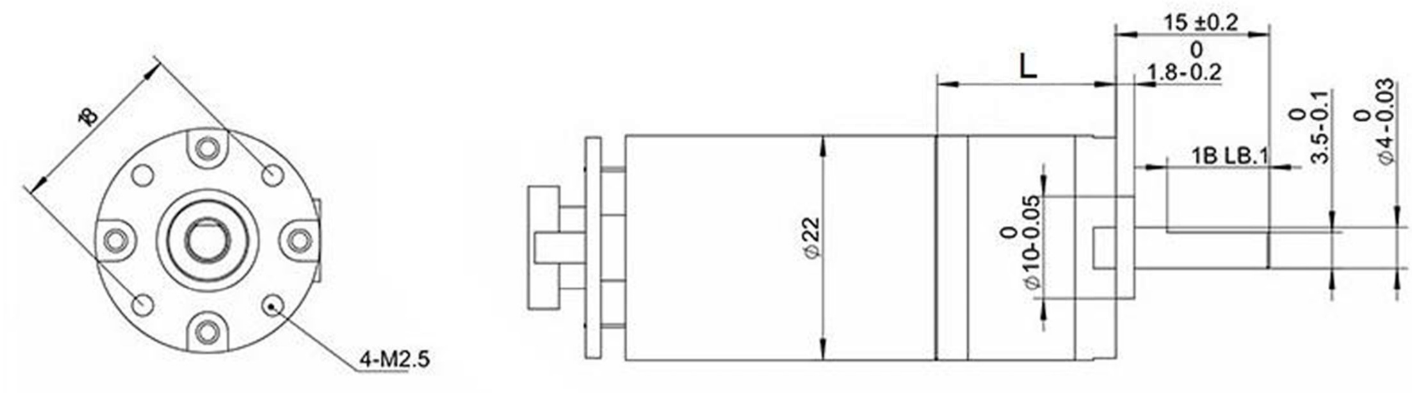


Figure 0-8: Manufacturing Drawing of part SS#2-P#4 – DC Gearmotor

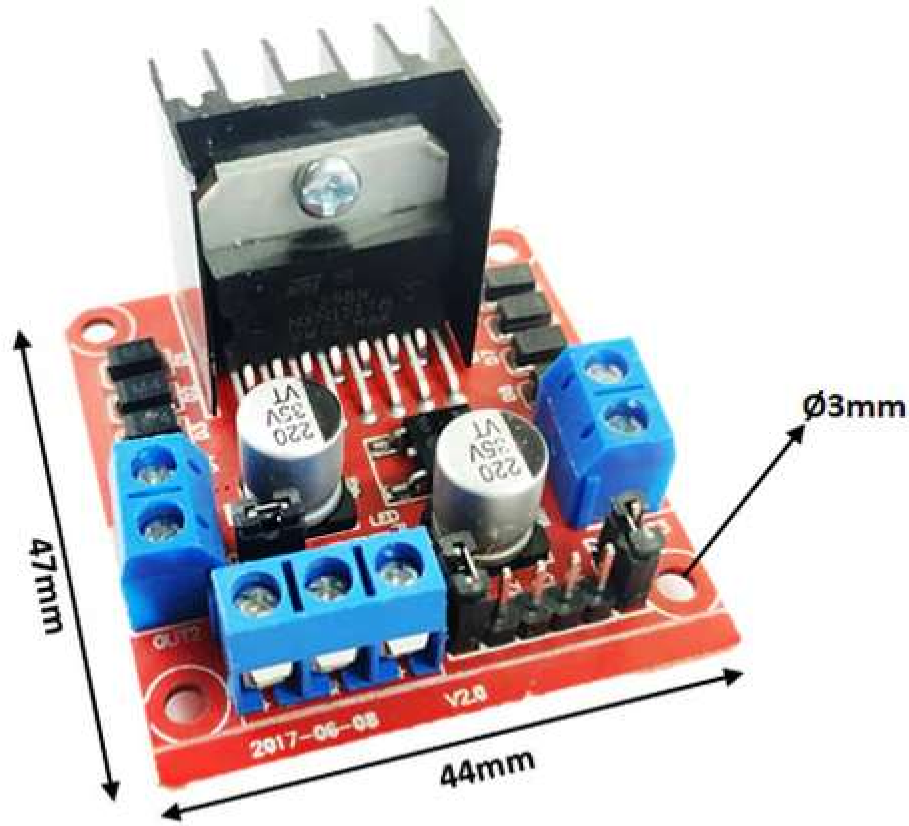


Figure 0-9: Manufacturing Drawing of part SS#2-P#5 – L298N Dual H-Bridge

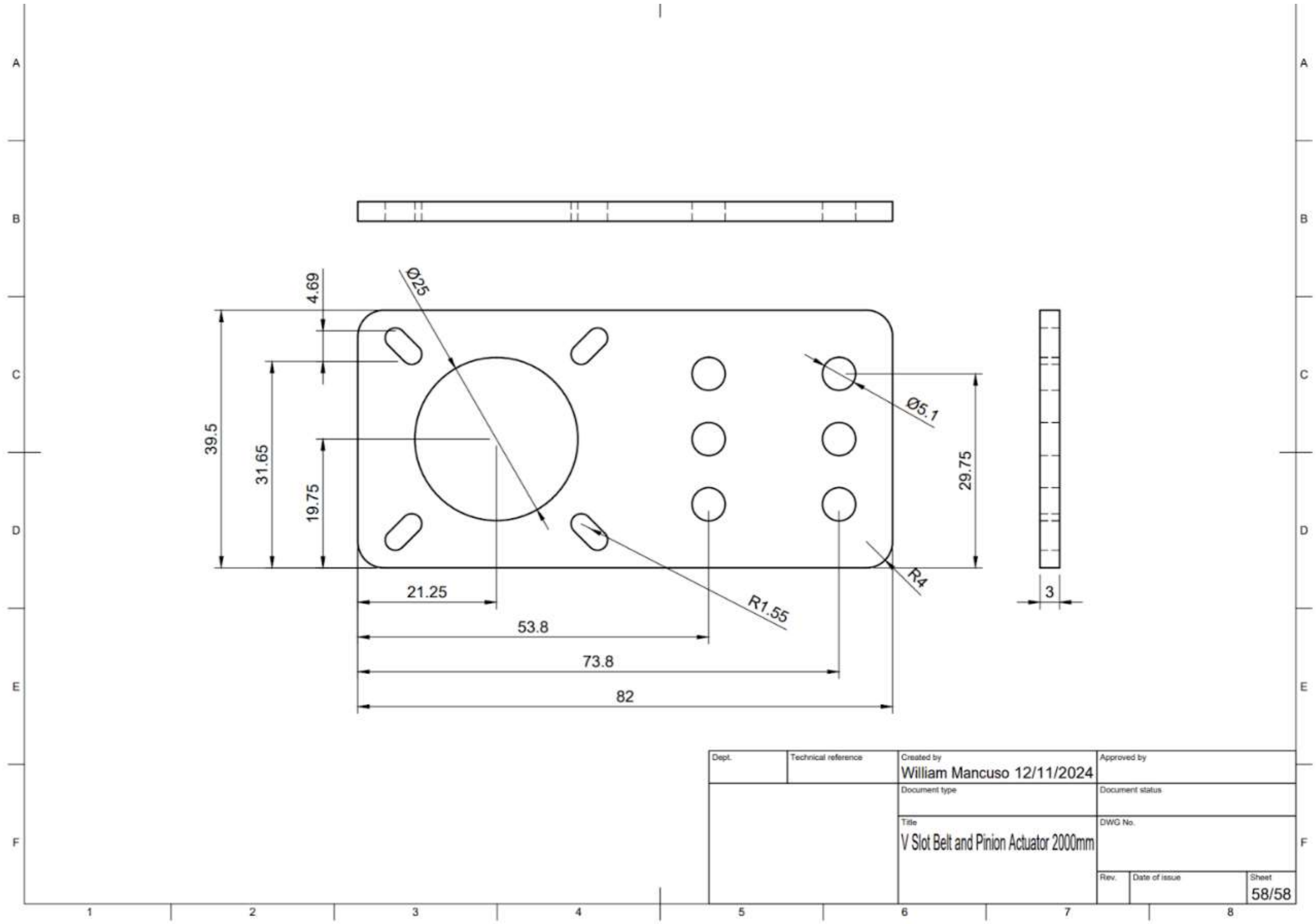


Figure 0-10: Manufacturing Drawing of part SS#2.1-P#2 – Secondary Gantry Plate

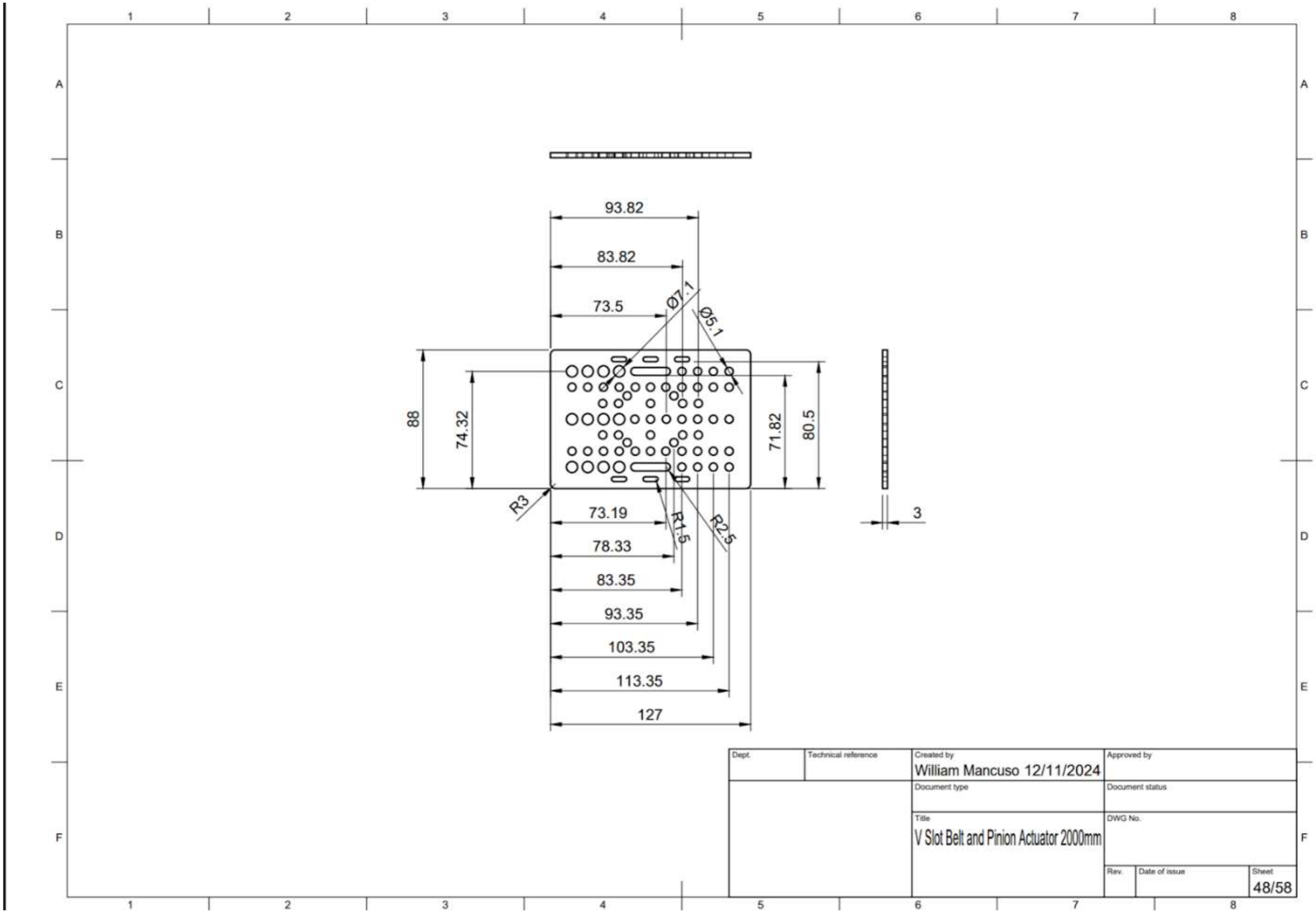


Figure 0-11: Manufacturing Drawing of part SS#2-P#6 – Main Gantry Plate

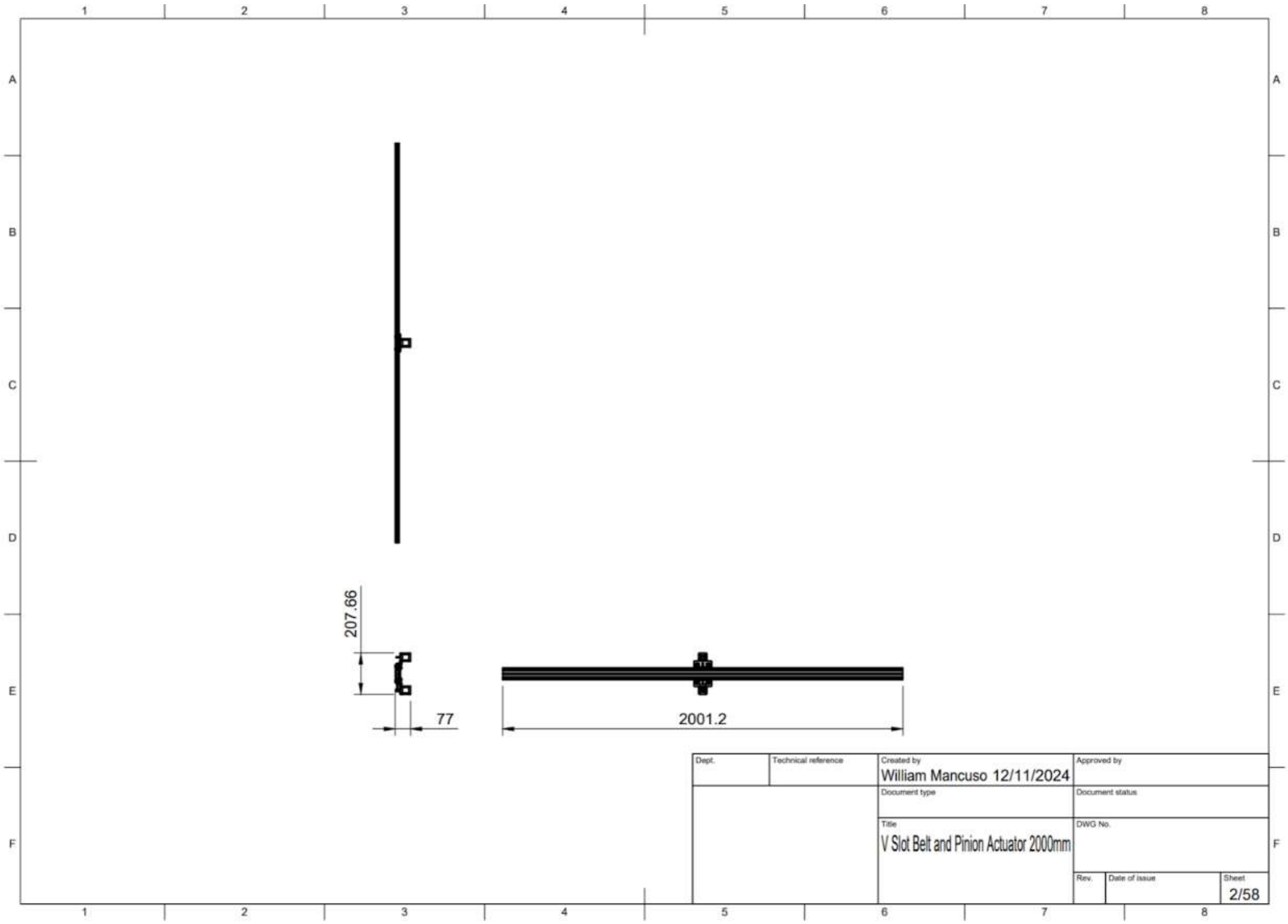


Figure 0-12: Manufacturing Drawing of part SS#2-P#1- Linear Actuators

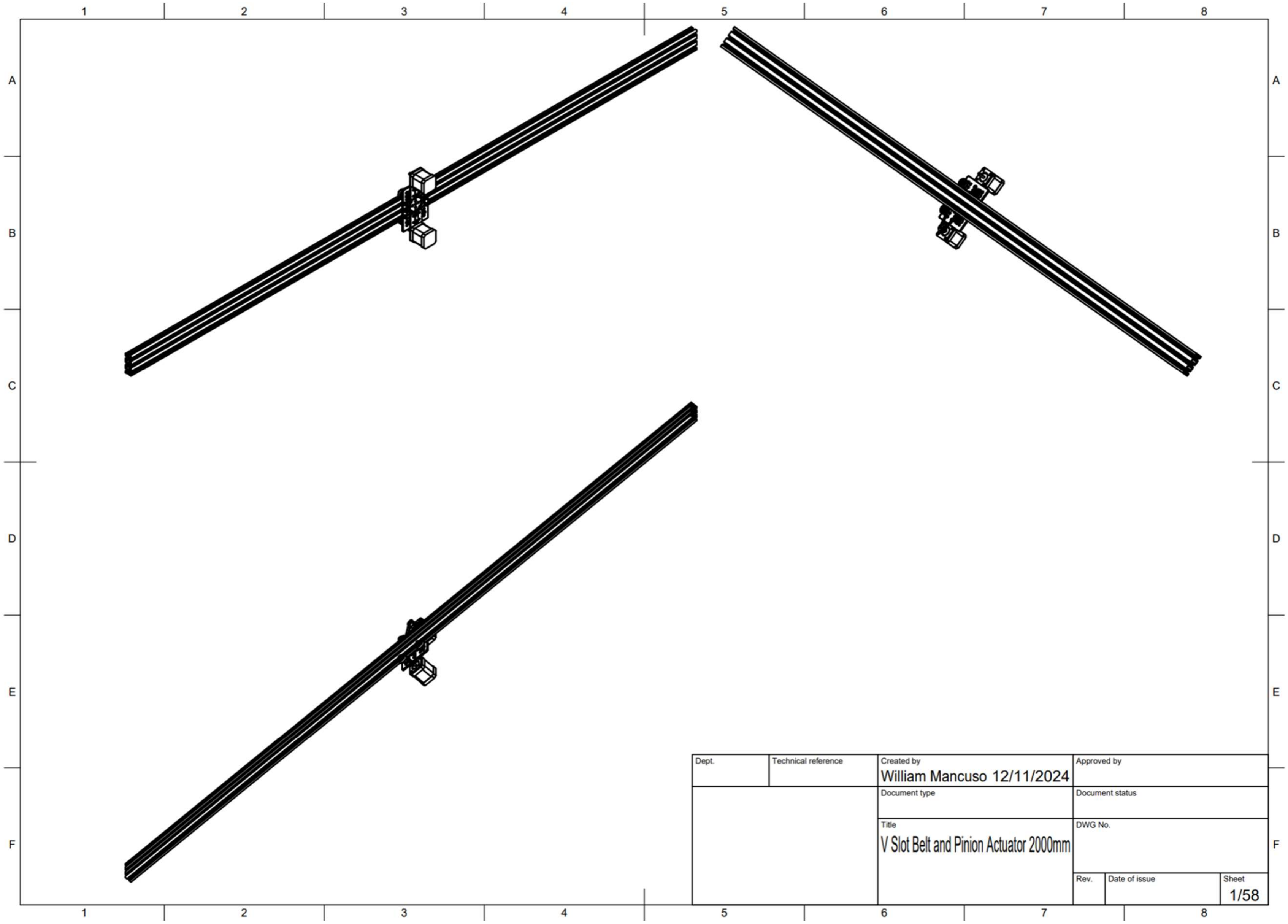


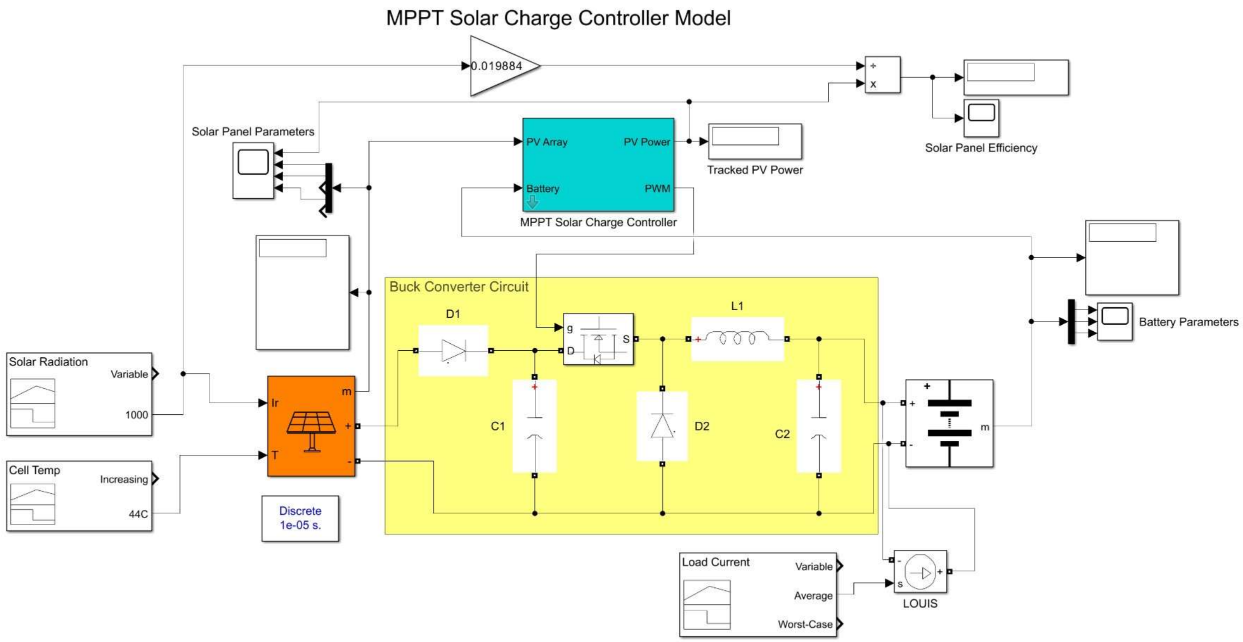
Figure 0-13: Manufacturing Drawing of part SS#2-P#1- Linear Actuators

XII.D. Engineering Analysis and Materials Selection Supplement

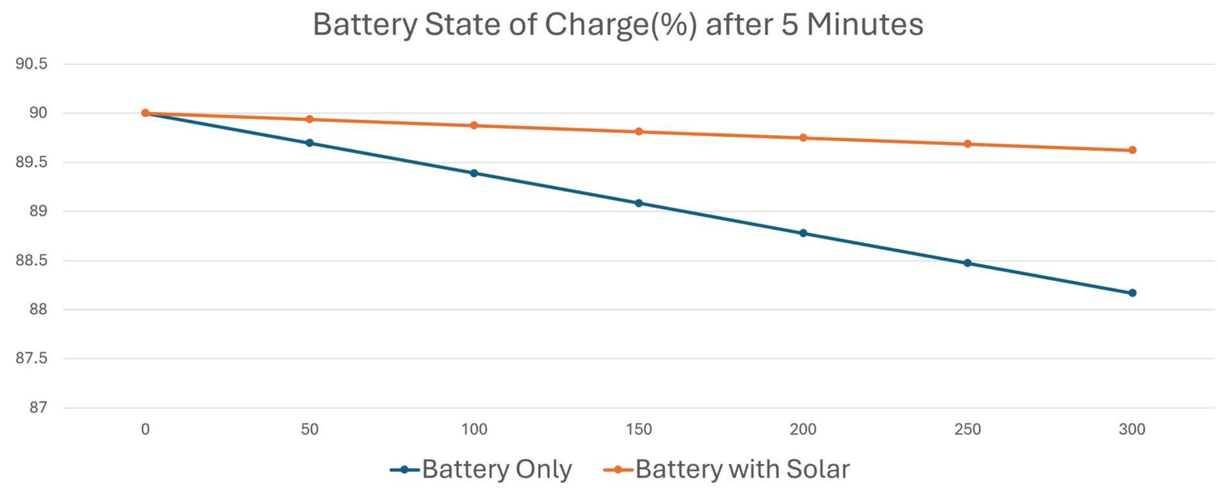
XII.D.1. Eng. Analysis Details for SS#1 – Solar Panel and Charge Controller

XII.D.1.a. Eng. Analysis and Materials Selection Details for SS#1.1 - Solar Panel and Charge Controller

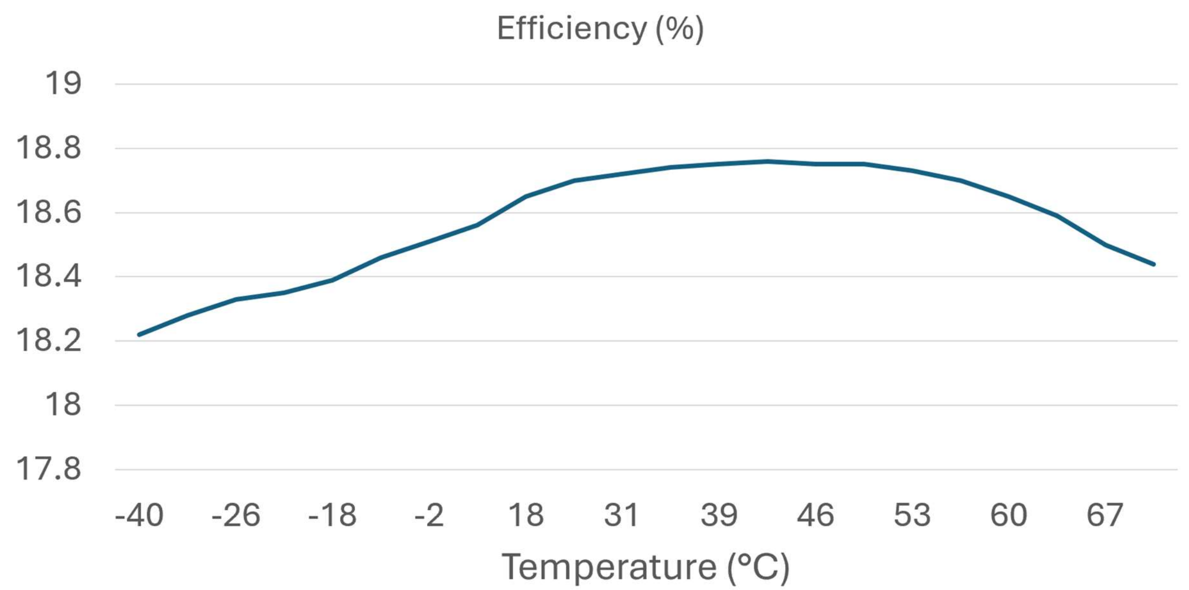
Bowen Williamson and William Mancuso



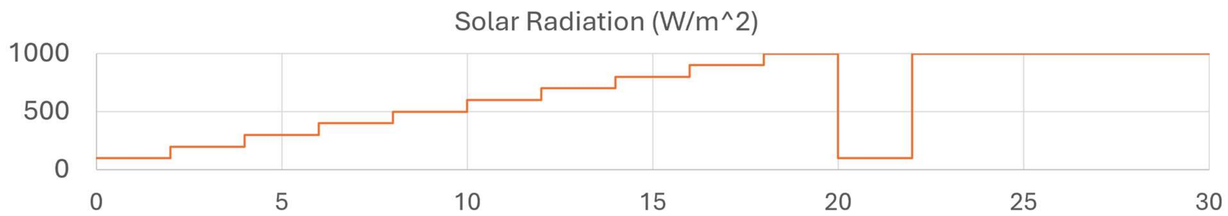
The graph below displays a decline in the state of charge of the battery during 5 minutes of runtime. The blue line depicts the state of charge before the addition of the solar panel, and the orange line shows the state of charge once the solar power is added. Given these results, the battery should last approximately 4 times as long as before between recharging.

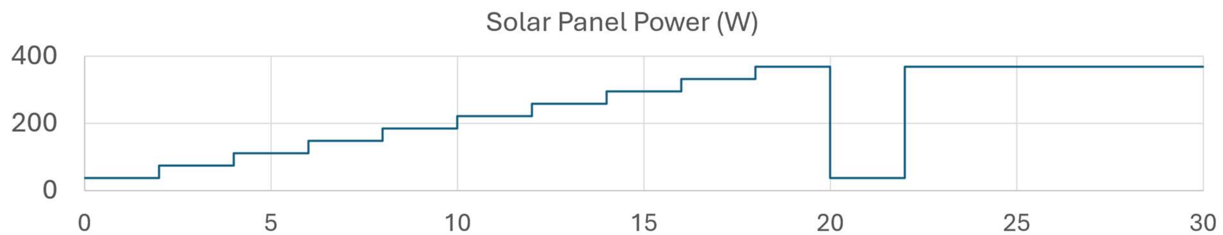


This is the plot of efficiency of the specific solar panel that will be used for the project. This shows the effects of temperature on the efficiency of the panel. The range of temperature matches the range of operating temperatures given by the manufacturers. This graph reaches a maximum where expected, near the nominal operating temperature of 44°C given by the manufacturer.



In the lower graph shown, the solar radiation input for this simulation is shown. The lower graph shows the proportional increase and decrease in generated solar power. During full solar radiation of 1000W/m^2, a tracked power output of 370W was attained during this simulation.

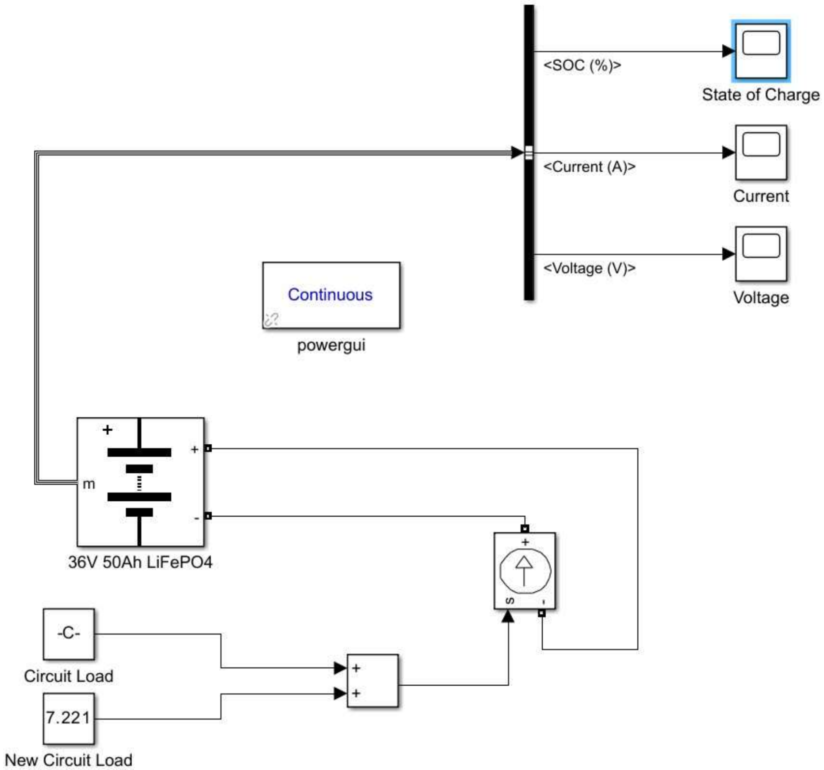




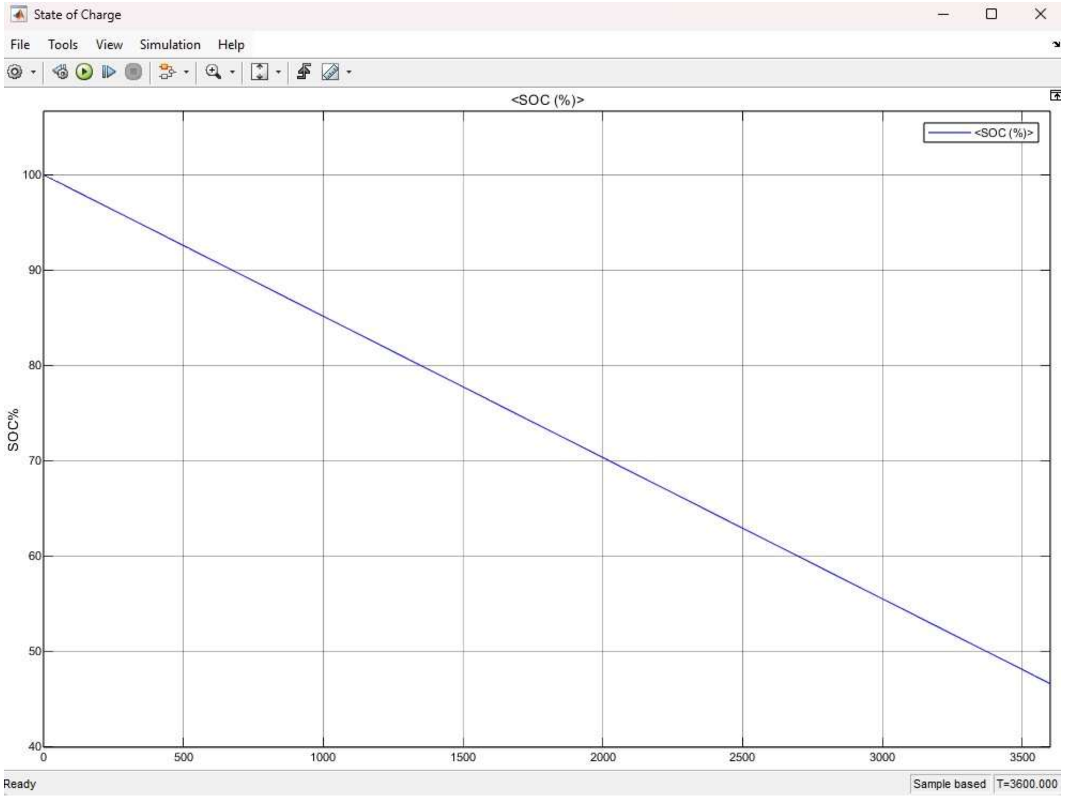
XII.D.1.b. Eng. Analysis and Materials Selection Details for SS#1.2 - Overall Circuit

Kenny Bui

This is the MATLAB simulation I used to conduct my simulation:



Below are the results of the simulation. Here, you can see how the state of charge decreases more quickly than the previous design, which makes sense since there is more load. This is not including the solar panel.



Below are the load calculations that the previous group conducted. I pulled from this information to conduct our final calculations.

Load #	A*min	Ah
1	65.5	1.0916667
2	74.5	1.2416667
3	43.32	0.722
4	37.34	0.6223333
5	131	2.1833333
6	149	2.4833333
7	36.46	0.6076667
8	131	2.1833333
9	36.46	0.6076667
10	131	2.1833333
11	100.045	1.6674167
12	18.44	0.3073333
13-21	33.402	0.5567
22	48	0.8
23	150	2.5
Total		**19.757783**

Below are the load calculations that were calculated and found for our additions, taking into consideration the previous group's calculations.

Load		A*min	Ah
Arduino Uno		30	0.5
NEMA 23 Stepper Motors(Idle)		336	5.6
NEMA 23 Stepper Motors(Running)		33.6	0.56
TB6600 Motor Drivers		24	0.4
DC Brush Motor		7.5	0.125
L298N Motor Driver		1.08	0.036
Charge Controller		0	0
			7.221

XII.D.2. Eng. Analysis Details for SS#2 – The Cleaning System

XII.D.2.a. Eng. Analysis and Materials Selection Details for SS#1-P#1 - Arduino

Kenny Bui

The code to initiate the cleaning system is below:

```
// Pin Definitions for Motor 1 (TB6600 Driver)
const int motor1StepPin = 2;       // Step signal
const int motor1DirPin = 3;        // Direction signal
const int motor1EnablePin = 4;     // Enable signal

// Pin Definitions for Motor 2 (TB6600 Driver)
const int motor2StepPin = 5;       // Step signal
const int motor2DirPin = 6;        // Direction signal
const int motor2EnablePin = 7;     // Enable signal

// Pin Definition for Brush Motor
const int brushMotorPin = 9;

// Pin Definition for Buzzer
const int buzzerPin = 10;

// Cancel Button
const int cancelButtonPin = 8;

// Motion Parameters
const int stepDelay = 1000000;     // Microseconds between steps
const int totalSteps = 12270;       // Number of steps for the movement
const unsigned long delayBeforeStart = 300000;

// State Variables
bool hasActivated = false;         // Ensures the process occurs only once
bool isCancelPressed = false;
unsigned long startUpTime = 0;     // Time when the device is powered on
```

```
void setup() {
  // Initialize motor pins
  pinMode(motor1StepPin, OUTPUT);
  pinMode(motor1DirPin, OUTPUT);
  pinMode(motor1EnablePin, OUTPUT);
  pinMode(motor2StepPin, OUTPUT);
  pinMode(motor2DirPin, OUTPUT);
  pinMode(motor2EnablePin, OUTPUT);
  pinMode(brushMotorPin, OUTPUT);
  pinMode(buzzerPin, OUTPUT);
  pinMode(cancelButtonPin, INPUT_PULLUP);

  // Disable motors initially
  digitalWrite(motor1EnablePin, HIGH);
  digitalWrite(motor2EnablePin, HIGH);
  digitalWrite(brushMotorPin, LOW);

  // Record the time when the device is powered on
  startUpTime = millis();
}

void loop() {
  // Check if the cancel button is pressed
  if (digitalRead(cancelButtonPin) == LOW) {
    isCancelPressed = true;
    Serial.println("CancelPressed");
    disableMotors();
    stopBrushMotor();
    stopBuzzer();
```

```
  // Timer before process starts
  if (!hasActivated && !isCancelPressed && (millis() - startUpTime >= delayBeforeStart)) {
    // Activate buzzer for 5 seconds before starting the motors
    activateBuzzer();
    delay(5000);  // Wait for 5 seconds while buzzer is active
    stopBuzzer(); // Turn off the buzzer

    // Enable motors and start brush motor
    enableMotors();
    startBrushMotor();

    // Move motors forward
    Serial.println("Motors moving forward...");
    moveMotors(true); // true for forward direction

    // Reverse motors immediately after forward motion
    Serial.println("Motors reversing...");
    moveMotors(false); // false for reverse direction

    // Stop and disable motors
    stopMotors();
    disableMotors();
    stopBrushMotor();

    hasActivated = true; // Ensure the process runs only once
    Serial.println("Process completed.");
  }
}

// Function to move motors
void moveMotors(bool forward) {
  // Set direction
  digitalWrite(motor1DirPin, forward ? HIGH : LOW);
  digitalWrite(motor2DirPin, forward ? HIGH : LOW);
```

```
  // Step motors
  for (int i = 0; i < totalSteps; i++) {
    if (isCancelPressed) break;

    digitalWrite(motor1StepPin, HIGH);
    digitalWrite(motor2StepPin, HIGH);
    delayMicroseconds(stepDelay);

    digitalWrite(motor1StepPin, LOW);
    digitalWrite(motor2StepPin, LOW);
    delayMicroseconds(stepDelay);
  }
}

// Function to start the brush motor
void startBrushMotor() {
  digitalWrite(brushMotorPin, HIGH); // Turn on brush motor
  Serial.println("Brush motor started.");
}

// Function to stop the brush motor
void stopBrushMotor() {
  digitalWrite(brushMotorPin, LOW); // Turn off brush motor
  Serial.println("Brush motor stopped.");
}

// Function to stop motors
void stopMotors() {
  Serial.println("Motors stopped.");
  delay(100);
}

// Function to enable motors
void enableMotors() {
  digitalWrite(motor1EnablePin, LOW); // Enable signal is active LOW
  digitalWrite(motor2EnablePin, LOW);
  Serial.println("Motors enabled.");
}
```

```
// Function to disable motors
void disableMotors() {
  digitalWrite(motor1EnablePin, HIGH); // Disable signal is active HIGH
  digitalWrite(motor2EnablePin, HIGH);
  Serial.println("Motors disabled.");
}

// Function to activate the buzzer
void activateBuzzer() {
  tone(buzzerPin, 1000);  // Activate buzzer at 1000 Hz
  Serial.println("Buzzer activated.");
}

// Function to stop the buzzer
void stopBuzzer() {
  noTone(buzzerPin);  // Deactivate buzzer
  Serial.println("Buzzer stopped.");
}
```

XII.D.2.b. Eng. Analysis and Materials Selection Details for SS#2-P#2&3 – NEMA 23 Stepper Motor and TB6600 Stepper Motor Driver

Margaret Burkes

To determine the current draw, I used the Simulink file entitled “Stepper Motor with Control” on MATLAB’s website. It works as follows:

1. Demand: is the demand speed in revolutions per second. Ours was 2.7088 RPS due to the following equations:

$$\omega = \frac{v}{r} = \frac{\frac{162.5mm}{s}}{9.5mm} = 17.02\frac{rad}{s}$$

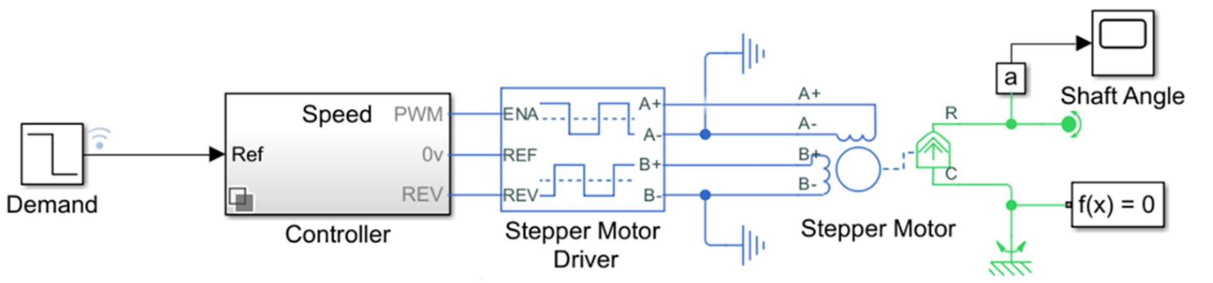
$$RPS = \frac{\omega}{2\pi} = \frac{17.02\ rad/s}{2\pi} = 2.7088\ RPS$$

2. Controller: is set in speed mode. This means it uses the speed demand signal and converts the command into a pulse train that controls the stepper motor driver. This is representing our Arduino Uno.
3. Stepper Motor Driver: is set in microstepping mode at 2 steps per full step. This is to be able to control the current output to protect the motor. The motor is rated for 2.8A/phase, and the TB6600 can be set to 2.5A/phase. Therefore, the maximum continuous current per phase on the block

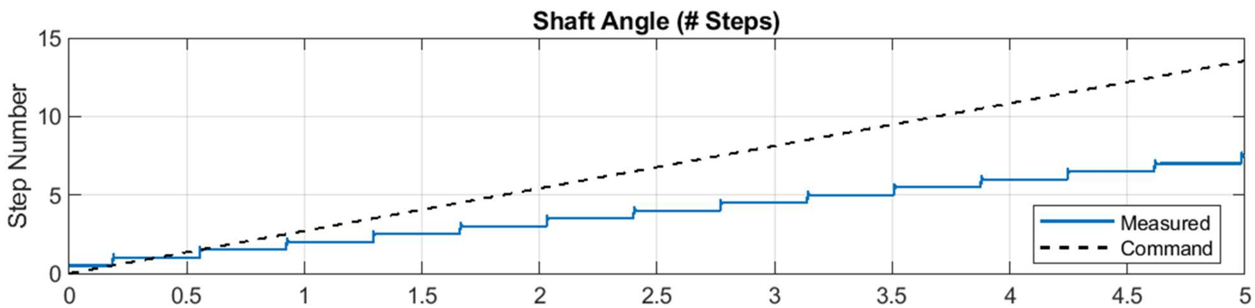
is set to 2.5A. In general, the driver is responsible for converting the low-power input signals from the controller into high-power electrical pulses to drive the motor.

4. Stepper Motor: is the NEMA 23 stepper motor that the team will be using. The information used in the block is directly from the datasheet.

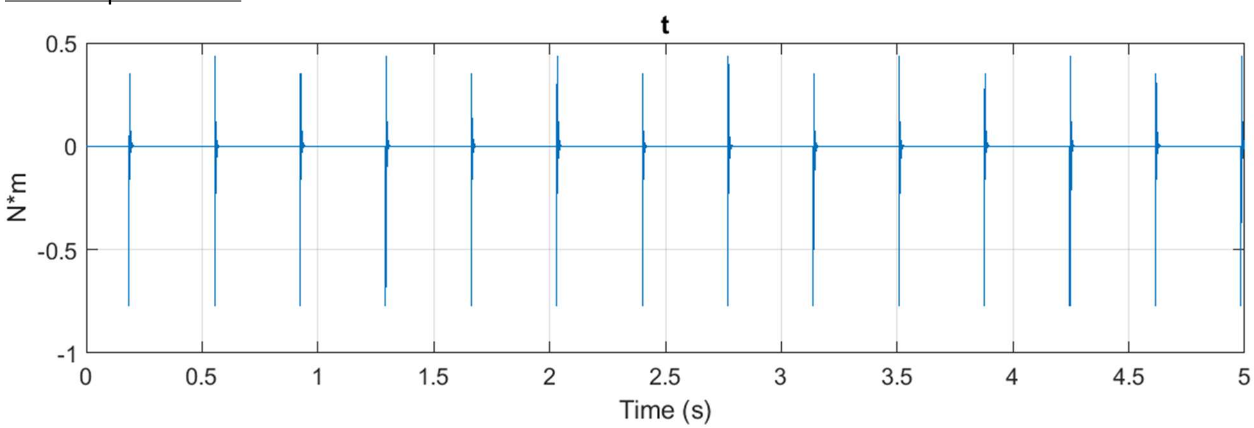
Stepper Motor with Control Simulation



The Commanded vs Measured Speed Profile:

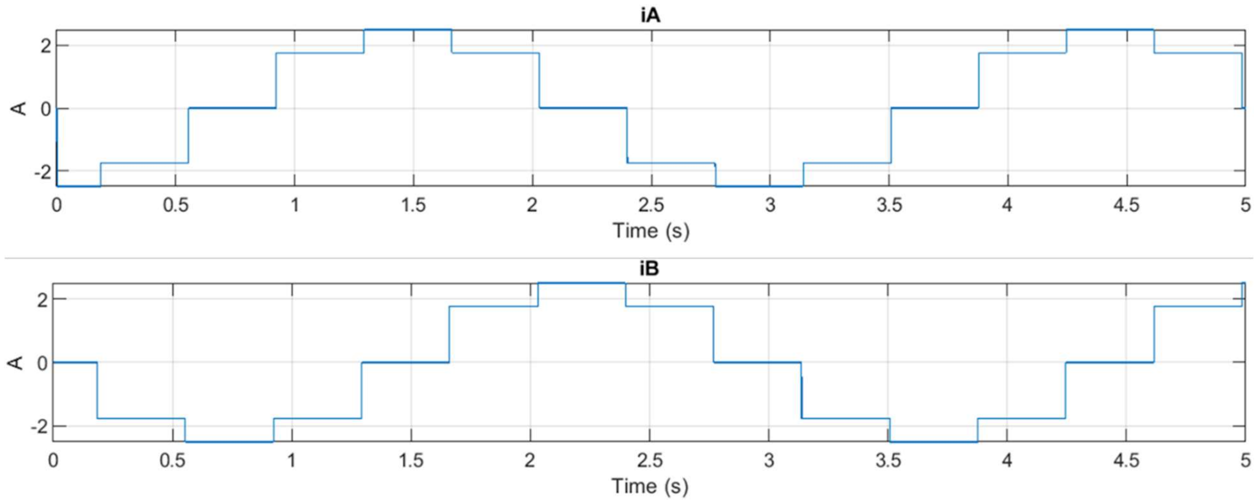


The Torque Profile:



The maximum torque required shown in the graph above is 0.4386 Nm, which the NEMA 23 stepper motor is more than rated for.

The Current Draw Profile:

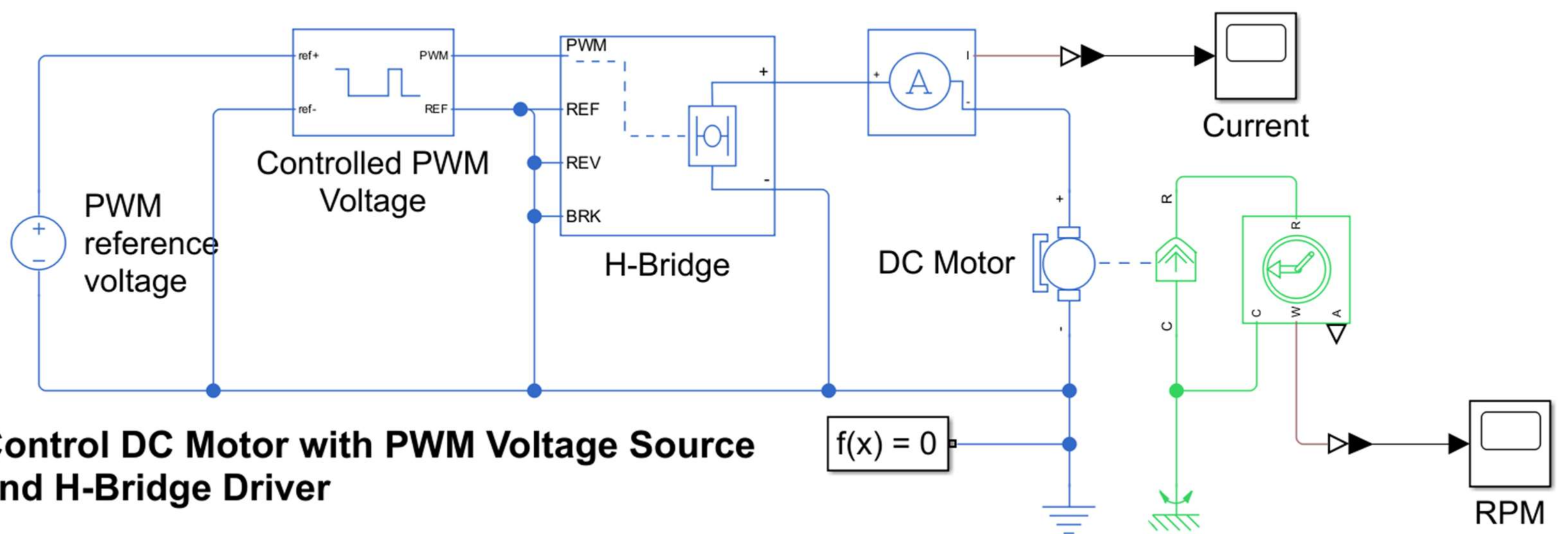


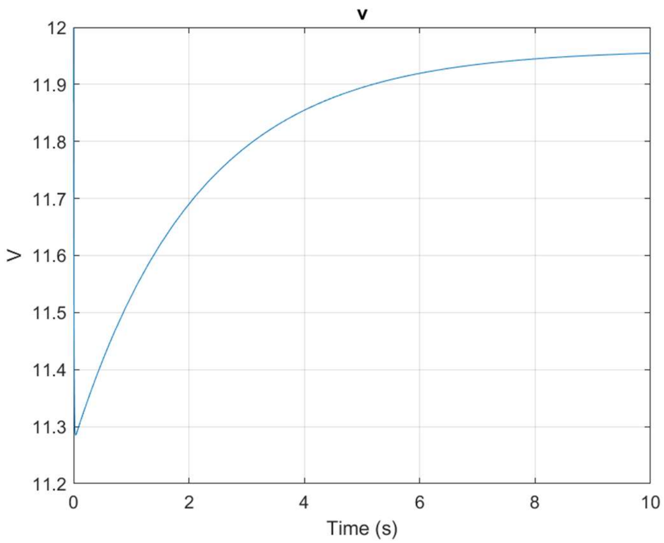
As seen here, the current being drawn is a maximum of 2.5A/phase when the speed demand is 2.7088 revolutions/second.

XII.D.2.c. Eng. Analysis and Materials Selection Details for SS#2-P#4&5 – DC Gearmotor

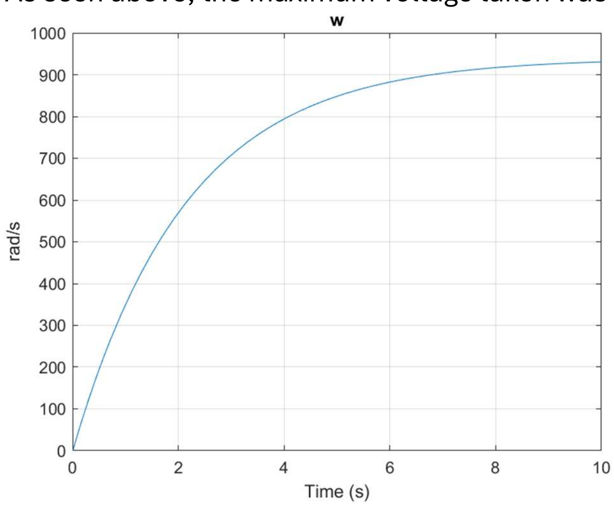
Keldon Ngo

Shown below is the Simulink model I used to conduct my calculations.

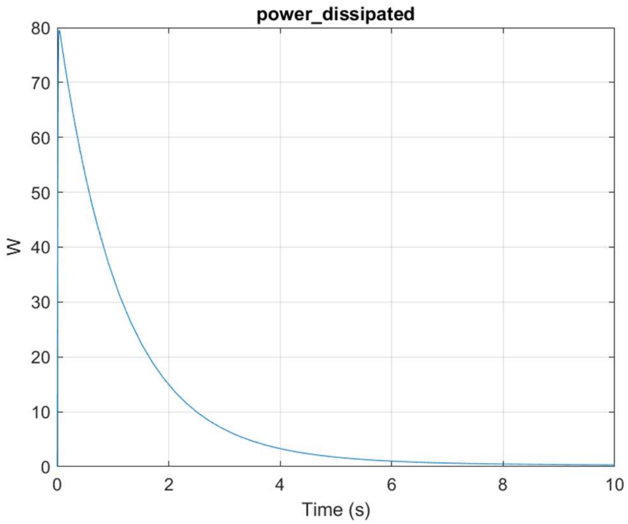




As seen above, the maximum voltage taken was less than the 12v that the motor is rated for.



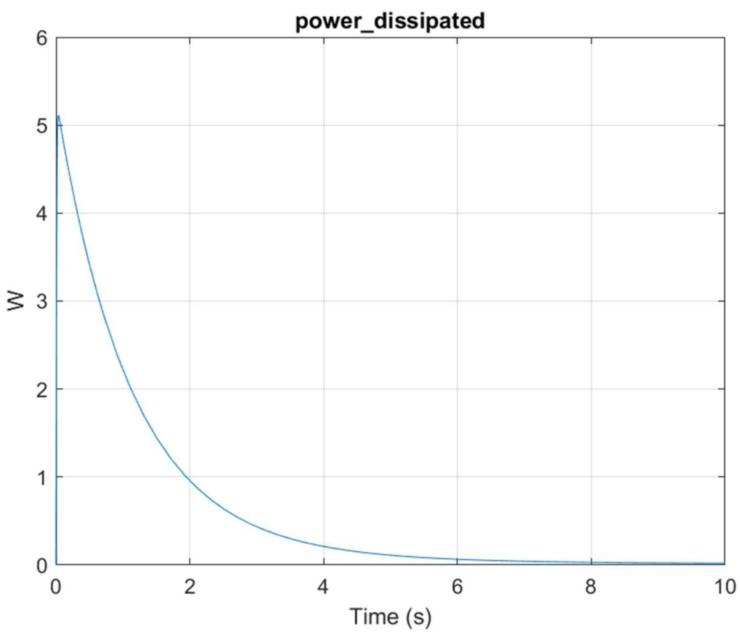
The rad/s progressively gets higher as the motor begins to spin and more current is drawn, topping out at about 930rad/s.



The power dissipation is at its highest on startup at about 80W then drops rapidly.

XII.D.2.c. Eng. Analysis and Materials Selection Details for SS#2-P#4&5 – L298N Dual H-Bridge

Keldon Ngo



The power dissipation maxes out at 5 W for the L298N, as seen above, and is concurrent with the max displayed on the data sheet.

XIII. Manufacturing & Assembly Supplement

XIII.A. Manufacturing Processes

Table 0-1: Manufacturing Processes for Parts of Sub-Systems

Part #	Manufacturing Process
SS#1-P1	Purchased/ Welded
SS#1-P2	Angle Grinder (Cut to Length), Drill Tapped, Welded
SS#2-P1	Purchased/ Drill tapped
SS#2.1-P1	Purchased
SS#2.1-P2	Purchased
SS#2.1-P3	Purchased
SS#2-P2	Purchased

XIII.B. Assembly Processes

XIII.B.1. Assembly Process for Sub-System SS#1- Solar Panel and Charge Controller

In sub-system one, P1 the solar panel will have the mounting rails (SS1-P2) that are cut to length, welded to the back of it. These bars will also be used to connect the whole system to the rover frame. They have tracks on them that will be used to slide t-track bolts. These tracked bolts will secure a 2 hole electrical strap around the bars of the frame using nuts. The rest of the sub-system is all electronics. The solar panel will be hooked up to the charge controller. Which will be connected with both the battery and the panel, as well as feeding power to all of the rest of the electronics through the bus bars.

XIII.B.2. Assembly Process for Sub-System SS#2- The Cleaning System

Sub-System 2 is the cleaning system, which will be assembled with mostly purchased parts. Starting with P1, the linear actuators will be mounted via tapped holes to the mounting rails(SS1-P2). These will be screwed securing them to the panel and rest of the system. The screws will also be made to be flush on the rails so the gantry plate can slide right over it. Quickly jumping to Sub-System 2.1 are the linear actuators these will be purchased from open build, and added to them will be another gantry plate and rotational motor with pre-tapped holes screwed in. Back to sub-system 2, the cleaning brush will be mounted using a flange coupling that will connect it to the motor.

XIII.C. Testing & Validation Supplement

XIII.C.1. Design Phase Testing Methods and Details

Team 66 conducted no design-phase testing.

XIII.C.2. Design Phase Testing Results

Team 66 conducted no design-phase testing.

XIII.C.3. Preliminary Validation Testing Methods and Details

The team is planning on testing the battery runtime with the additional source of the solar panel. As for environmental performance, we plan to bring the solar panel outside during peak sun irradiation and measure the power output of the panel under ideal conditions. The testing plan for the cleaning system is to arbitrarily add debris to the panel to test the effectiveness of the brush. the team will also be running the cleaning system without attachment to the solar panel to ensure all the separate subsystems such as the rotation of the brush and the linear actuation systems; within the cleaning system work independently before combining them.

XIII.D. Project Management Supplement

XIII.D.1. Schedule and Milestones Details

During our project analysis phase, our group did have some realizations. These involved running simulations and calculations for our stepper motors, DC motor, battery state of charge with additional load, a code for brush cleaning system activation, and solar panel power generation. These were all crucial realizations because these analyses were additional factors that our group did not realize would play a major part in the complete picture of our individual function objectives. For manufacturing, we also realized that we needed to figure out how to connect motors to the rails for the brush cleaning system, mount the solar panel to the rover frame, and program the solar charge controller for use. For the testing phase, our group realized that we need to make sure that our brush cleaning system motors actuate properly, test the power generation of the solar panel in different weather types, and test the solar charge controller switching with different battery state of charge. All these realizations are very beneficial as they play a role in determining the overall success of our project. They also help our group make the proper adjustments needed in terms of decisions to get us closer to the success of our project.

Project Preview			
Met Sponsor/Decide Faculty Advisor	100%	9/5/24	9/6/24
Project Interpretation and Team Roles	100%	9/7/24	9/10/24
Planning and Design			
Research Previous Rover Project	100%	9/11/24	9/12/24
Research Solar Panel Cleaning	100%	9/13/24	9/16/24
Research Methods to Autonomously Switch	100%	9/14/24	9/17/24
Research Solar Panels & Connections	100%	9/15/24	9/18/24
Create Concept Generations for Each Functio	100%	9/19/24	9/24/24
Decide/Select Ideal Concept Generations	100%	9/25/24	10/2/24
Create 3D Models in Fusion for Each Functio	100%	10/3/24	10/20/24
Analysis			
Simulations to See Power Capabilities of Solar Panel		10/21/24	10/28/24
Solar Panel with Rover System as Load Test		10/21/24	10/28/24
Run Analysis on Charge Controller for Power Switching		10/29/24	11/4/24
Analysis on DC Brush Motor for Cleaning Brush		10/29/24	11/4/24
MATLAB Stepper Motor Analysis		10/29/24	11/4/24
Construct Code and Analyze For Cleaning System Activatio		11/5/24	11/11/24
Experiment with Physical Model with Real Debris		11/5/24	11/11/24
Load Analysis for New Electrical Components		11/12/24	11/18/24
Evaluate Results and Adjust Concepts Accordingly		11/12/24	11/18/24
Verify Compatibility With Previous Rover System		11/19/24	11/25/24
Order Necessary Parts For Manufacturing		11/26/24	12/7/24

Manufacturing		
Plan Out Part Assembly For Functions	1/13/25	1/20/25
Assemble Brush Cleaning System	1/21/25	2/5/25
Connect Motors and Brush to Rails	1/21/25	2/5/25
Mount Solar Panel to Rover Frame	1/21/25	2/5/25
Assemble Solar Panel Connections	2/6/25	2/20/25
Assemble Charge Controller For Power Switching	2/21/25	3/5/25
Implemement All Functions to Rover	3/30/25	4/10/25
All Appropriate Electrical Connections Made	4/11/25	4/13/25
Testing		
Solo Test Brush Cleaning System	3/6/25	3/13/25
Ensure Motors Actuate	3/6/25	3/13/25
Solo Test Solar Panel Power Generation	3/14/25	3/21/25
Test Production During Different Scenarios	3/14/25	3/21/25
Solo Test Charge Controller Autonomous Power Switching	3/22/25	3/29/25
Test Power Switching With Different Battery SOC	3/22/25	3/29/25
Test Rover with Total Integration	4/14/25	4/17/25
Make Final Adjustments	4/18/25	4/25/25
Final Rover Test	4/26/25	5/3/25

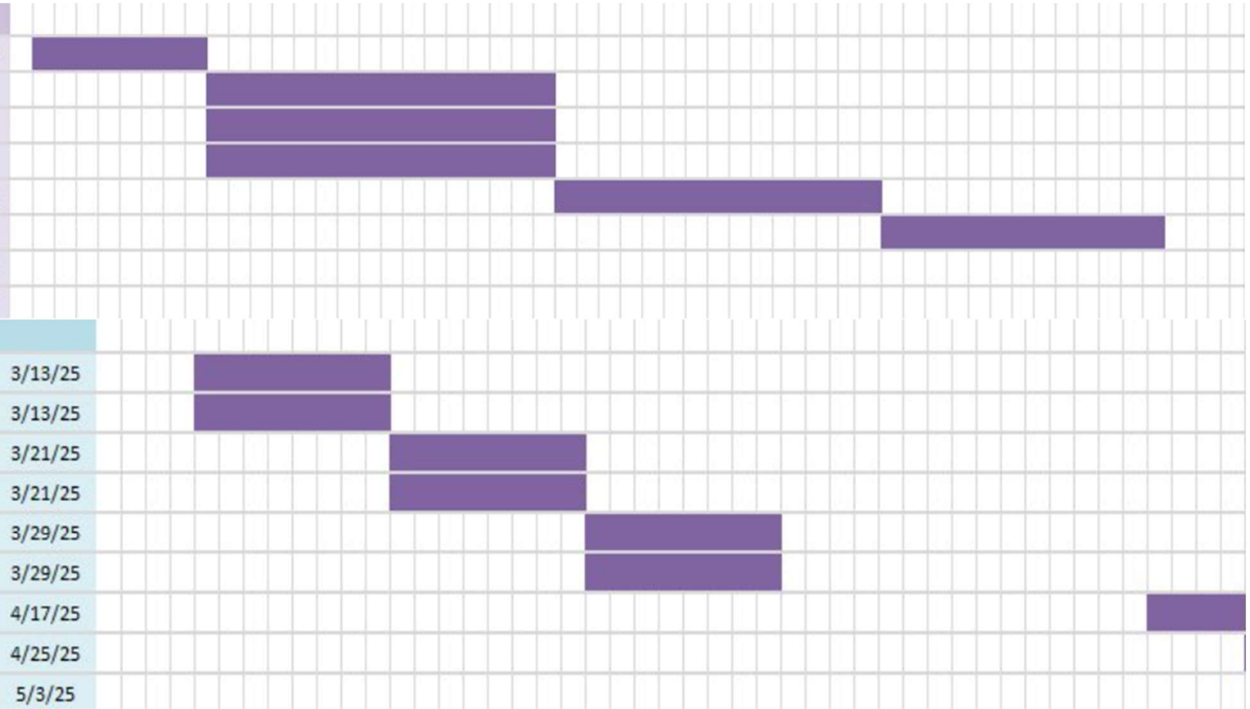


Figure 0-1: Gantt Chart with Detailed Project Time-Line

XIII.D.2. Budget Details

The total spending for this project is expected to be $903.45. The budget of the project is $4000, so we have a large buffer for unexpected costs that could occur during manufacturing and assembly, such as parts that could be manufactured. The Bill of Materials below shows a full breakdown of the costs for both subsystems.

Table 0-2: Bill of Materials/Parts

Subsystem	Components	Quantity	Cost/Item	Total Cost	Manufacturer
Solar Panel & Solar Charge Controller	Solar Panel	1	Donated	0	REC Solar
	Solar Charge Controller	1	Donated	0	MorningStar
	1000mm Mounting Rails	2	10.69	21.38	OpenBuilds
	M5 Bolts	8	1.25	10.00	Home Depot
	T-Track Nuts	10	3.90	39.00	OpenBuilds
	4 AWG Wire, 8ft	2	33.99	67.98	End Game
	Two-Hole Electrical Strap	4	4.70	18.80	Grainger
Cleaning System	2000mm Linear Actuators	2	200.43	400.86	OpenBuilds
	DC Brushed Motor	1	34.58	34.58	RobotShop
	Custom Radial Brush	1	147.55	147.55	Industrial Brush Corp.
	Ball Bearing	1	15.15	15.15	MSC
	Motor Shaft	1	9.29	9.29	Enlybee
	Flange Coupling	2	9.99	19.98	Daier
	Threaded Inserts	1	16.99	16.99	Amazon
	TB6600 Motor Driver	2	9.39	18.78	Jusnboir
	Arduino Uno REV3	1	27.60	27.60	Arduino
	L298N Motor Driver	1	6.49	6.49	DIYmall
	Gantry Plate	1	11.99	11.99	OpenBuilds
	16 AWG Wire (Red), 25ft	1	5.04	5.04	Grainger
	16 AWG Wire (Black), 25ft	1	5.04	5.04	Grainger
	Hydrophobic Coating	1	26.95	26.95	Ducky Products
Total Cost				903.45	

XIII.E. Reference Materials

XIII.E.1. Codes and Standards

The following codes will be considered in the design and execution process:

1. NEC: This lays out the proper sizing of wiring and overcurrent protection, grounding, disconnects, proper labeling of equipment, and solar photovoltaic systems designs and considerations.
2. UL 9540A: This highlights different ways to test to protect against thermal runaway risk.
3. UL 1703/UL 61730: This describes PV module safety standards, including heat, cold, and humidity tolerance.
4. UL 1742: This details how to safely integrate charge controllers into solar systems.
5. EPA Guidelines: This details how to dispose of electrical components and restricts the use of lead, mercury, or cadmium for environmental safety.
6. IEC 61508: This standard ensures that a given control system can detect faults and act appropriately.
7. ISO 13849: This standard assesses the mechanical safety of the system with regards to emergency stops or other means of protecting the user and/or the rover.
8. ISO 14120: This code shows how to ensure safeguards, like barriers, within mechanical systems for the safety of the user.
9. IEC 61850: This code lays out communication protocols between intelligent electronic devices (IEDs) to ensure synchronization and reliability.

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