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GENG5511/12 MPE Research Project
Final Report

Planetary Rover Design & Build Project

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Abstract

In this design and build project, a six-wheel vehicular platform was constructed with the capability to perform driving and navigation tasks in uneven terrain. The planetary rover is programmable, with the ability to drive under manual control and the potential to drive autonomously, and possesses the capability to drive over a variety of surfaces. It has redundant chassis volume and was designed to support up to 20kg of additional payload. Tests performed after build completion demonstrated the rover's driving capabilities. This included an initial drive test on a carpet floor, a field test on a hardened clay surface in the Perth Hills, and a slope driving test up an artificial grass ramp.

The project commenced with researching previous and current successful planetary rovers, as well as other Earth-based research project rovers from relevant published papers, informing an achievable rover layout, given the low budget and two-semester timeframe. Then, basic design parameters were defined, and a 3D CAD model was created in SolidWorks to visualise this. Next, electronic, and mechanical component selections were suggested and selected. These were later reselected as additional constraints were realised through more detailed design. A comprehensive SolidWorks assembly of the rover was made with all components fully defined as purchasable or manufacturable parts, ensuing functionality, strength, and constructability before making the required purchases.
During the second semester, the chassis, rocker-bogie suspension, steering gearboxes, drivetrains and wheels were all assembled following CNC manufacturing from the UWA Mechanical Workshop and PCBway. Electronics were tested and appropriately wired, following a rough connection diagram. Software was written on the Raspberry Pi computer in C++ for manual driving with a Bluetooth PS4 controller.

This rover has opened a multitude of exciting projects for future engineering students wishing to pursue autonomous navigation or space robotics. Some possible future improvements and applications for this rover are suggested, providing options from which future students may select from.

Table of Contents

1. Introduction

1.1. Project Goals & Aim

The goal of this project was to design and construct a planetary rover, with the functionality to drive over uneven terrain and perform basic navigation tasks. It was to be designed as though it will be built for the Lunar or Martian surface, however with cheaper, Earth rated components. It also aimed to demonstrate that it is possible for a single dedicated student engineer to design, delegate assistance and produce a functioning planetary rover with a two-semester timeframe.

The motivation for this project originated from UWA's interest to get a foot in the door of the space robotics industry. Currently, UWA has not delivered any major projects within this industry, leading to a reluctancy for outside investors to sponsor such projects. This rover project aimed to provide a demonstration of the university's commitment to research within this industry, opening an avenue for sponsorship for future projects.

The presence of the rover has generated a multitude of future projects for students in robotics and automation. For example, students with a background in software engineering and interest in computer vision would be suited to a project programming the rover to perform advanced navigation and path finding to find the best route across a field of rough terrain. Other students, with a more mechanical engineering background and interested in robot mechanics, would be otherwise suited for a project designing and building a robotic arm for the rover, perhaps to attach a mineral analysis tool, or to act as sample collection mechanism, for which a sample return mission could be simulated.

There is also the potential for the required adaptions to be made for the rover to be entered into the Australian Rover Challenge. These adaptions would include a robotic arm and longer-range wireless control.

The timeframe for the build was two semesters; however, the budget was not fixed. This is because it was agreed that the rover would have a lot of variable costs, and so if it could be justified alongside the bill of materials that selected components are required for proper and safe functioning of the rover, and that sufficient research was done to ensure that the given component was the cheapest reasonable choice, then suitable funds were sourced to support the purchase.

1.2. Project Timeline

The schedule which was planned and subsequently followed for this project was conceptualization, design, and purchasing in semester 1, and construction, programming and testing in semester 2.

The project commenced with a literature review of all the planetary rovers that had successfully traversed terrain on other planetary bodies, as well as other earth-based research and university rovers, to get an idea of the design features common to the most successful rovers. Following these findings, concept designs were drawn, with the most promising sketched on SolidWorks to consider its feasibility.

After gaining approval for this concept design, the main features of the rover were chosen, and the SolidWorks assemblies were gradually defined and iterated as the motors, servos and other components were selected. By the end of semester 1, the assembly was fully defined for all mechanical components, and a bill of materials was created, allowing the large component purchases to be made with confidence. Following this, during the mid-year break, parts from the SolidWorks assembly requiring manufacturing where converted to technical drawings, and given to the UWA mechanical workshop in both printed and digital formats.

Construction commenced two weeks before studies resumed as the purchased components arrived and the aluminium extrusion for the chassis frame was cut. A solar panel was attached to the top of the frame with hinges to act as the lid of the rover, and acrylic panels were laser cut for the walls and floor.

The electronics were then tested and carefully wired and mounted on a MDF board, which then slipped inside the chassis. A previously used Raspeberry Pi 3 was flashed with a new operating system allowing a C++ program to be written to communicate with the motors, servos, encoder readers and a PS4 controller.

During the semester 2 mid-year study break, the rover was constructed using temporary 3D printed components, to ensure the correct fitting and functionality. It also allowed the drive code to be written and tested with real-world feedback.

In week 9, all the machined aluminium components arrived from PCB way, allowing the final construction to occur. The first ground driving test was performed immediately following the project seminar presentation on the 3 October 2023. That weekend, the rover was taken to the Statham Wetlands in Glen Forrest WA for a field test on hardened clay. A design oversight was recognised during that test, however enough footage was taken of the driving to create a promotional video, showing the design and build process in addition to the rover driving. The design oversight was fixed in week 11 and a slope driving test was performed.

A Gantt chart is included in Appendix A which shows this timeline.

1.3. Risk Management & Contingency Planning

Risks to the project may have included:

- Components arriving late.
- Design failing to work in some way.
- Delays causing timeline to stretch.
- Issues during construction causing late redesign.
- Major illness or injuring preventing progress.
- The restatement of COVID-19 lockdowns preventing university access for construction.

At the beginning of the project risk assessment was made against a risk matrix where the residual risk was identified, and the resulting risk is determined after the instatement of control measures. This risk assessment is attached in Appendix B.

All the considered risks – except for the reinstatement of COVID-19 lockdowns – occurred in some form, however, having considered the risks early, and taking appropriate actions as they occurred, meant that the project was able to reach completion without these issues causing major delay. Starting early and keeping ahead of schedule was the key factor that allowed the project timeline to ‘absorb’ these issues.

2. Literature Review

Planetary rovers form an important part of human exploration off earth, acting as our first mobile scouts before we eventually arrive. While not specifically true – the first humans on the moon arrived before the first rover – this is the desired legacy of the past and current rovers on Mars and the Moon's south polar region.

There have been 6 rovers that have successfully been deployed on Mars, with 5 of these being from NASA's sequence of Martian rovers and the last being China's Zhurong rover. On the Moon, the recent Indian Pragyan rover as well as 4 other robotic rovers have roamed the surface, with the additional notable mentions of the manned Apollo Lunar Roving Vehicles [1]. Figure 1 shows on overview of all the successful extraterrestrial planetary rovers.

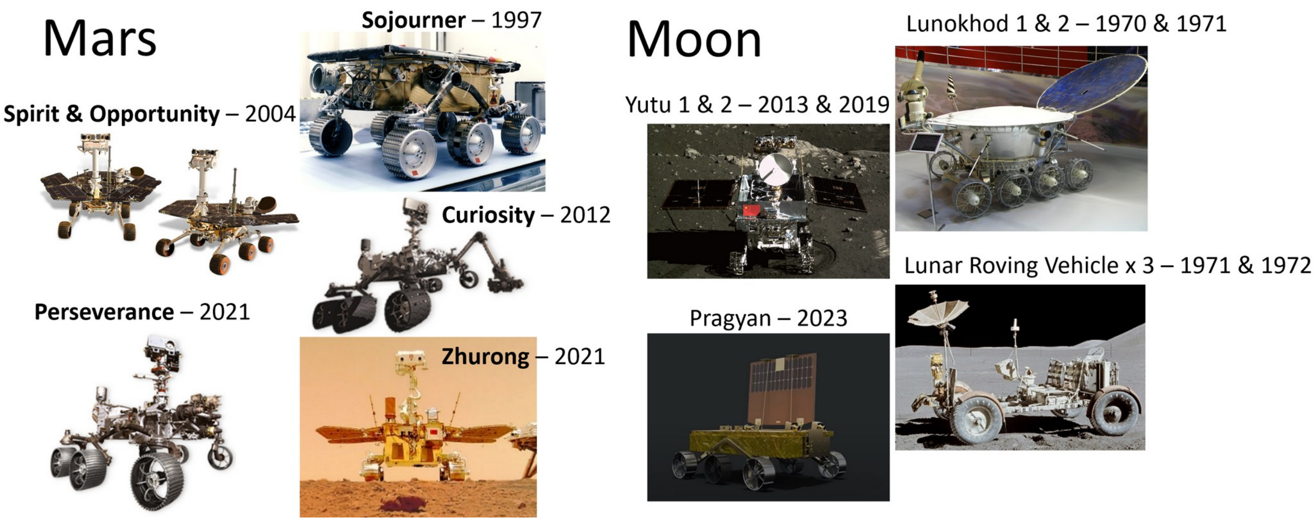

Figure 1: *A collage of images showing the list of successful extra-terrestrial planetary rovers. [2], [3], [4], [5], [6], [7] & [8].*

Of all these rovers, perhaps the most influential for this project was NASA's Sojourner rover, which formed part of the Pathfinder mission in 1997. It was the first planetary rover on Mars and the first to demonstrate the rocker bogie suspension on an extra-terrestrial surface, with its success paving the way for its use in the design of all subsequent rovers. It's low-profile design with a single rectangular solar panel atop is akin to the design of this project's rover. It's mission, however, was quite short at 85 days, and it was limited in its exploration ability by its small size – just 11.5 kg [9]. Figure 2 shows a concept sketch of Sojourner, while figure 3 shows a photograph of the rover days before launch.

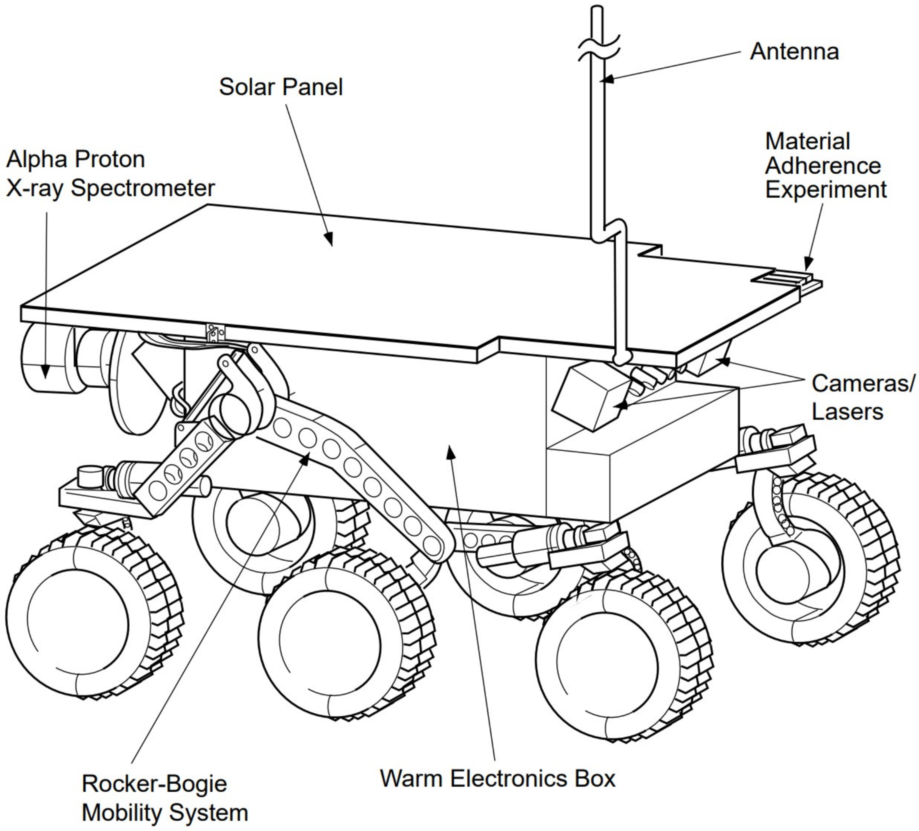

Figure 2: *A concept drawing of the Sojourner rover. [10]*

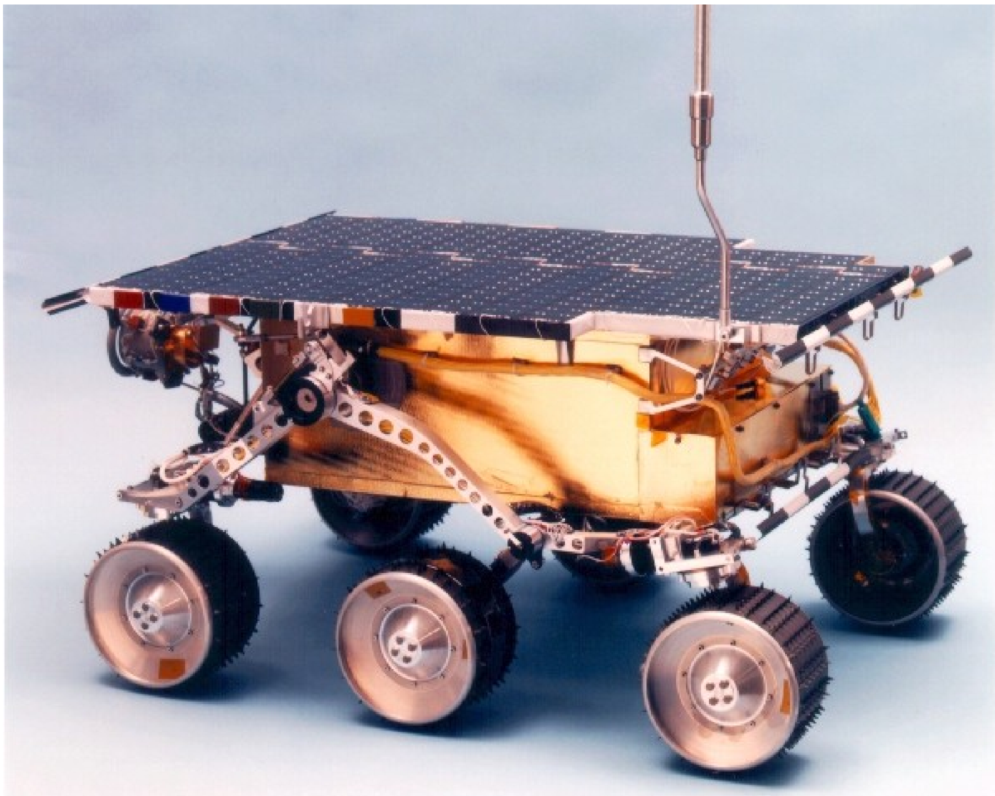

Figure 3: *A photograph of the Sojourner rover a few days before launch. [11]*

Following the success of their older cousin, NASA's twin Spirit and Opportunity rovers were deployed in 2003. Kitted with a suite of scientific instruments, these rovers went down in history as perhaps the most inspiring planetary rovers. These rovers however were not without their issues, and after extended mission journeys, they fell short of the Martian elements – Spirit getting stuck in soft sand in 2009 [12] and Opportunity losing power due to dust on the solar panels in 2018 [13]. Figure 4 below shows an image of the two rovers.

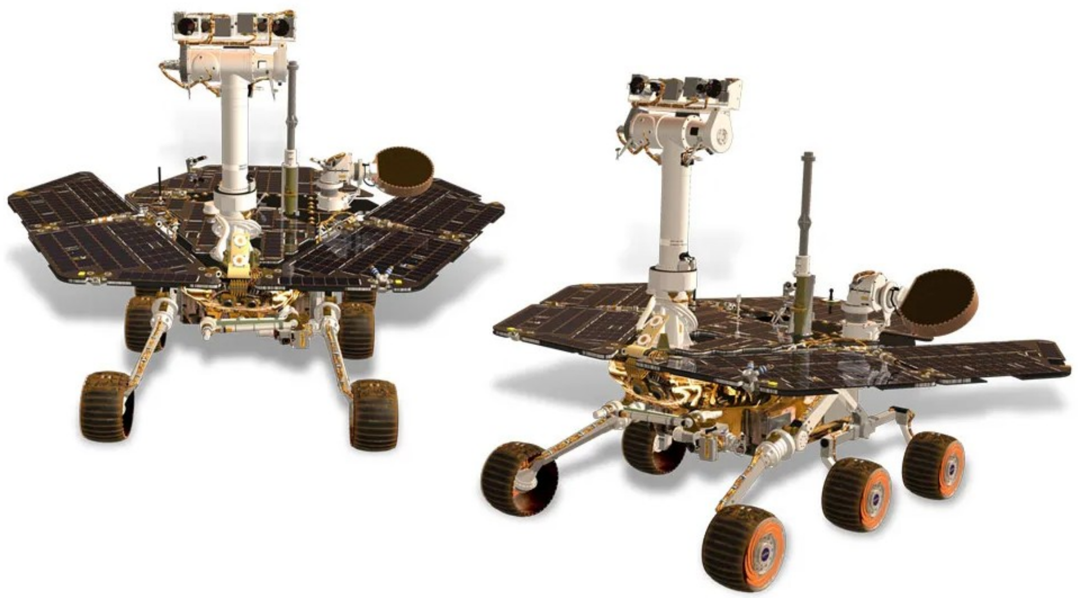

Figure 4: *An illustration of the twin Spirit and Opportunity rovers. [3]*

Curiosity improved upon the issues of the twin rovers by being larger and more capable with updated equipment. It also lost the solar panels in favour of nuclear decay thermal energy. It was launched in 2011 and is currently active on Mars, though it has been having issues with its thin tyre treads wearing out, with the formation of large holes visible in more recent photographs [5]. Figure 5 shows a selfie photograph of the Curiosity rover taken on November 12, 2020, where the worn-out tyres are visible.

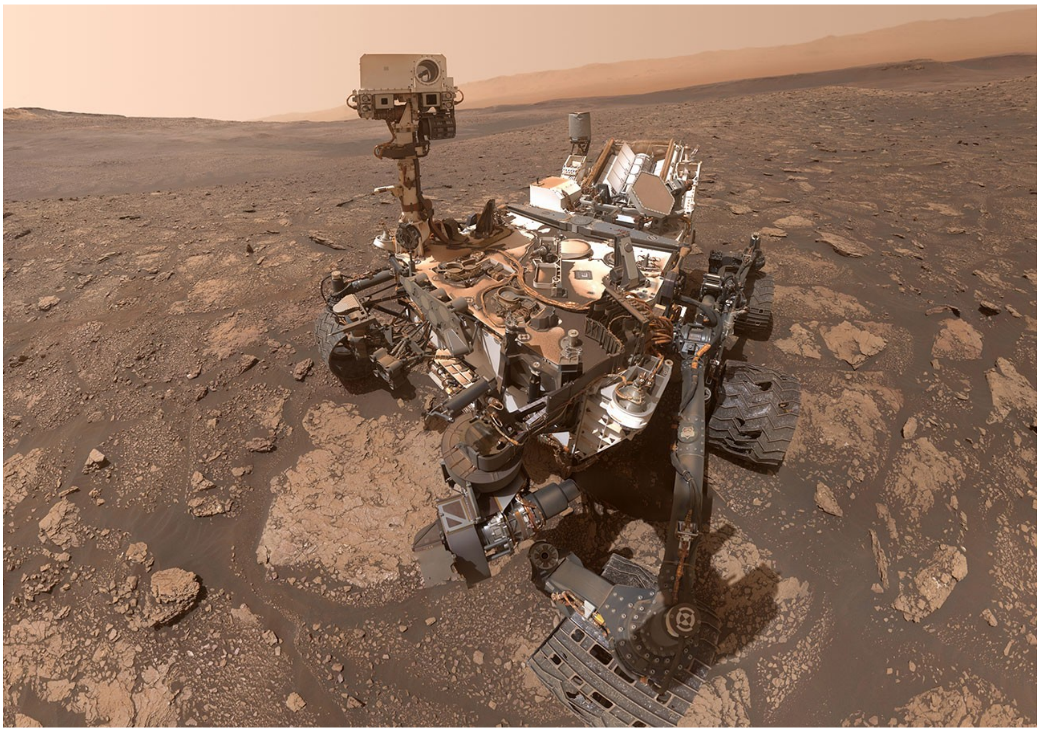

Figure 5: *A selfie Photograph of the Curiosity rover taken on November 12, 2020. [14]*

The Perseverance rover was launched in 2020. It improves once more upon the previous rovers with more updated equipment and more robust wheels. It deposited its companion helicopter Ingenuity, which has performed beyond initial expectations and currently scouts ahead of Perseverance, assessing the upcoming terrain from a birds-eye perspective [6]. A selfie photograph of the Perseverance rover is shown below in figure 6.

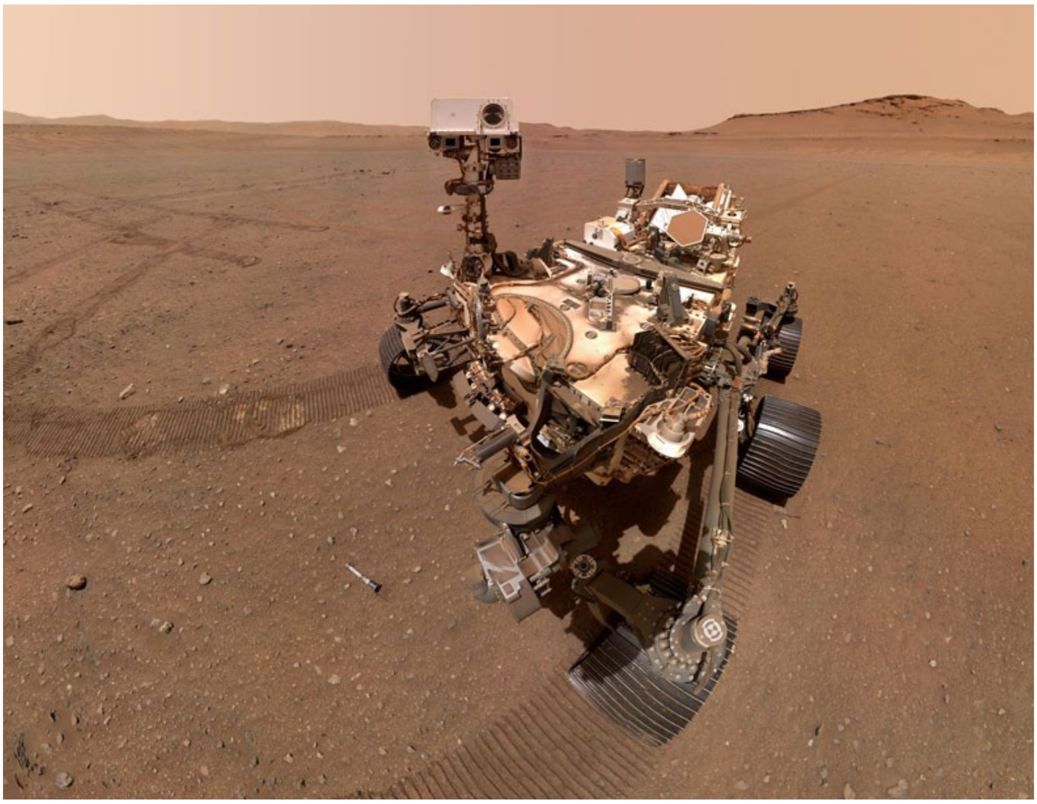

Figure 6: *A selfie image of the Perseverance Rover taken January 24, 2023. [15]*

Most recently, on the moon, the Pragyan rover was deployed in August of 2023, following India's historic successful touchdown of the Vikram lander on the lunar South Pole. The six wheeled rover much resembles the appearance of my rover, with a shallow box shaped chassis and rocker bogie suspension. The hinged lid of my rover, when opened, also resembles the hinged solar panel of the Pragyan rover. Notable differences to my rover include the use of a gearbox, rather than a bar differential, the central wheels being fixed forward unlike my independently steered wheels, and a heated compartment for the electronics (which of course mine does not require, being on earth).

Figure 7 is an image of the rover mounted onto the ramp of the Vikram lander.

Figure 7: *Image by Indian Space Research Organisation (GODL-India) of the Pragyan rover mounted on the ramp of the Vikram lander. [16]*

Back on earth, many rovers have been created for demonstration and research purposes. For example, the four wheeled LUVMI-X [7] and the six wheeled rover from Delhi Technological University [8]. These are shown in figures 8 and 9 respectively.

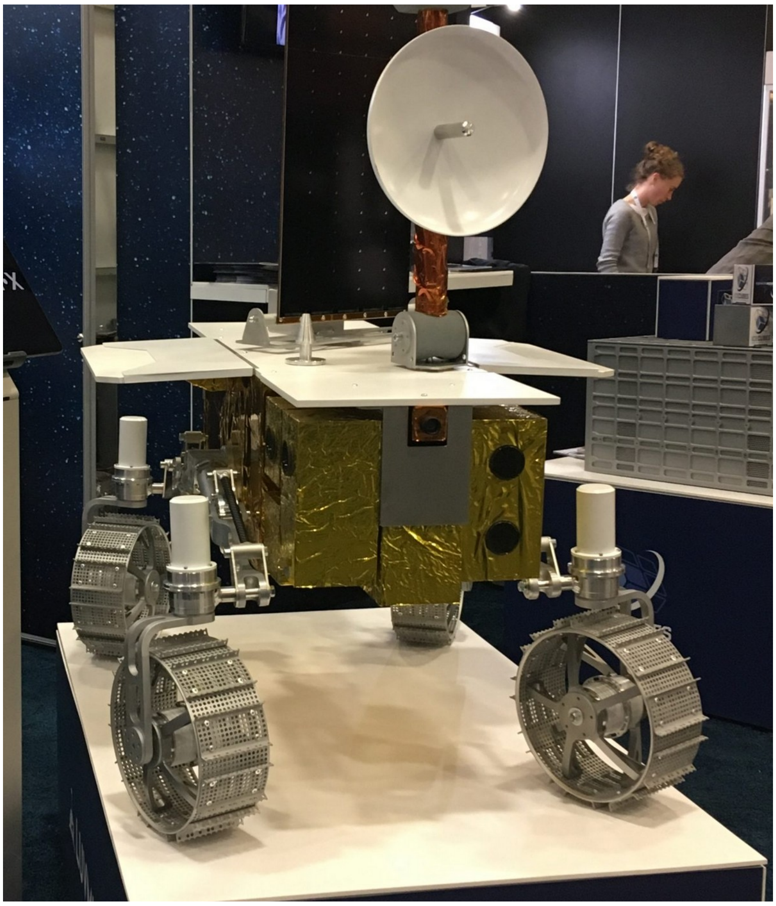

Figure 8: *Image of the LUVMI-X rover. [17]*

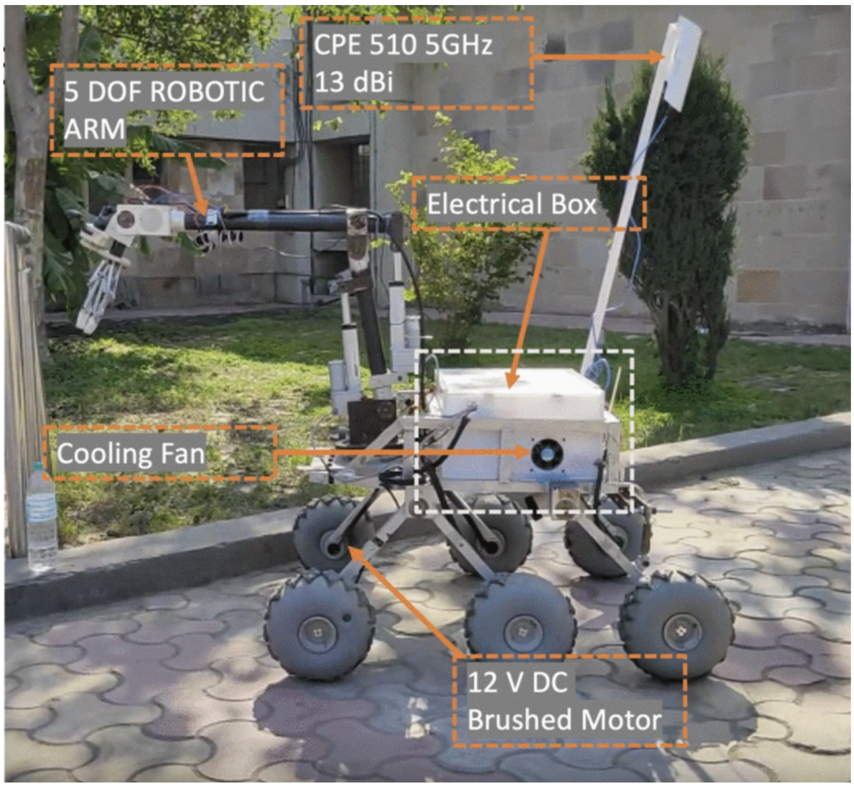

Figure 9: *Image of the rover built by V. Sharma, S. Sangwan and K. S. Bora at Delhi Technological University [18].*

Many other rovers have been developed by universities around the world for regional and national rover challenges. For example, the Australian Rover Challenge is held yearly at the university of Adelaide. The 2023 challenge winner was the Monash University's Nova Rover [9], designed and build by a well organised team of several dozen students. Having a large team of many people, split into specific subtasks with a strong leadership team makes it possible for a more complex and capable rover to be build. An illustration of Monash University's 2023 Waratah Nova rover is shown below in figure 10.

Figure 10: *Monash University's 2023 Waratah Nova rover. [19]*

Other papers were studied, including [20], [21] and [22] which all modelled alternative rover designs with advanced kinematics and simulation. While these papers presented interesting alternative rover designs, they were all technically complex and sub-optimal, and would have been difficult to implement in practice.

An image of the rover comparison spreadsheet in included in the Appendix C which outlines some of the rovers studied.

3. Design Process

3.1. Defining Requirements

As outlined in the aim of this document, the requirements and desirables of the rover were defined before construction. These were outlined early in the semester, and then later refined. The reason behind each decision is outlined below:

- Have six independently driven wheels.

Many of the rovers implemented by other universities use only 4 wheels. We believe this to be too much like a regular RC car, too simple looking and less capable over uneven terrain. It was preferred to build something that looks more like the rovers seen on Mars, with a six wheeled rocker bogie design.

- Have independently steered wheels.

While the rover could steer with just the outer 4 wheels turning, it was decided that independent steering on every wheel would be implemented, because it makes it possible to turn the rover with minimal wheel slippage using the correct driving control of the rover geometry. It also gives the option for sideways ‘crab walk’ driving for greater manoeuvrability.

- Have modular wheels that can be removed and swapped.

We wanted to be able to swap the wheels out with ease. We intend for the final rover to have wheels made from CNC aluminium, however due to the high cost, 3D printed carbon fibre reinforced nylon wheel were used instead. Swappable wheels present the opportunity to test different wheels with alternative grouser designs, to test which design is best over a variety of test surfaces.

- Be able to carry at least 10kg of payload, ideally 20kg.

We wished for this rover to be able to support the additional weight of future student projects. While 10kg is likely plenty of mass for this, 20kg gives additional freedom of design for future students.

- Have additional chassis volume to fit future projects.

The future projects will need an unknown amount of room. This extra chassis space will allow plenty of volume for this.

- Be easily programable with an onboard computer system.

A Raspberry Pi 3 was selected. It has reasonable computing power and is capable enough for the basic driving functions and additional functionalities. Should a project need greater computing power (such as for more advanced computer vision), this can be added separately in parallel to the Raspberry Pi.

- Have sensors capable of supporting autonomous navigation. (Camera, Lidar, Motor encoders)

The rover has an Oak d S2 depth camera, as well as encoders on the motors to estimate driving distance and speed. The addition of a Lidar either underneath or on a mast is also proposed. An IMU and a GPS unit would also be simple additions that would enhance the navigation capabilities of the rover; however, this will be left to future students to add.

- Have a solar panel for self-charging.

A large 1080 x 710mm fixed frame solar panel has determined the dimensions of the rover. The solar panel acts as the lid of the rover and is on hinges so that it can be opened to access the electronics inside.

- Have a battery that lasts at least 2 hours of continuous driving.

A 12.8V 25Ah lithium battery is installed in the rover that should keep the rover driving continuously for at least 2 hours. A timed continuous drive test still needs to be performed to confirm this. The addition of a solar charge regulator means that it is capable of charging via solar panel whist in sunlight and operating.

- Have an emergency stop button and appropriate fuse.

An e-stop is located on the back of the rover, so one can turn off the rover from behind and not stand in its path. This e-stop cuts the power to all the electronics including the raspberry pi, to ensure that all processes stop in an emergency. This e-stop is wired in series with the 'on' button and turns on a 60A relay that connects the power a fuse box, which distributes the power to the peripherals. As well as every peripheral having a separate fuse, the main power line into the relay also has a fuse.

- Look reasonably impressive and not look like a toy.

The size of the rover is large enough that it looks impressive at first glance. The choice of 6 over 4 wheels also contributes to this impression. Additionally, the large CNC Aluminium components look impressive alongside the exposed aluminium extrusion frame and legs.

3.2. Concept Design

After defining these requirements, the basic rover layout was decided.

Given that a 6-wheel design was selected, next was to consider whether to simplify the full 6-wheel rocker bogie design to an independent lever suspension for each wheel, or further to a more car like design with though axels. While it appears at first that simplifying the rocker bogie design would decrease the overall complexity of the design, it turns out to not be the case, because it would lead to greater complexity to achieve the same functionality. For example, a full rocker bogie design – due to its clever geometry - can always maintain equal force ground contact with every wheel and thus maintains the full traction of all wheels, doing so without an active suspension system. A simplified design, while appearing on the surface easier to construct, leads itself to more complication, as each lever would need its own active suspension system, such as a spring or hydraulic strut. A similar problem of requiring an active suspension system is also required on a car type design.

Ultimately it was decided that to make something that looks impressive with excellent performance, a proper minimally simplified version of the rocker bogie mechanism should be implemented.

An initial concept design of this rover was drawn up on SolidWorks. This initial design is shown below in figure 11.

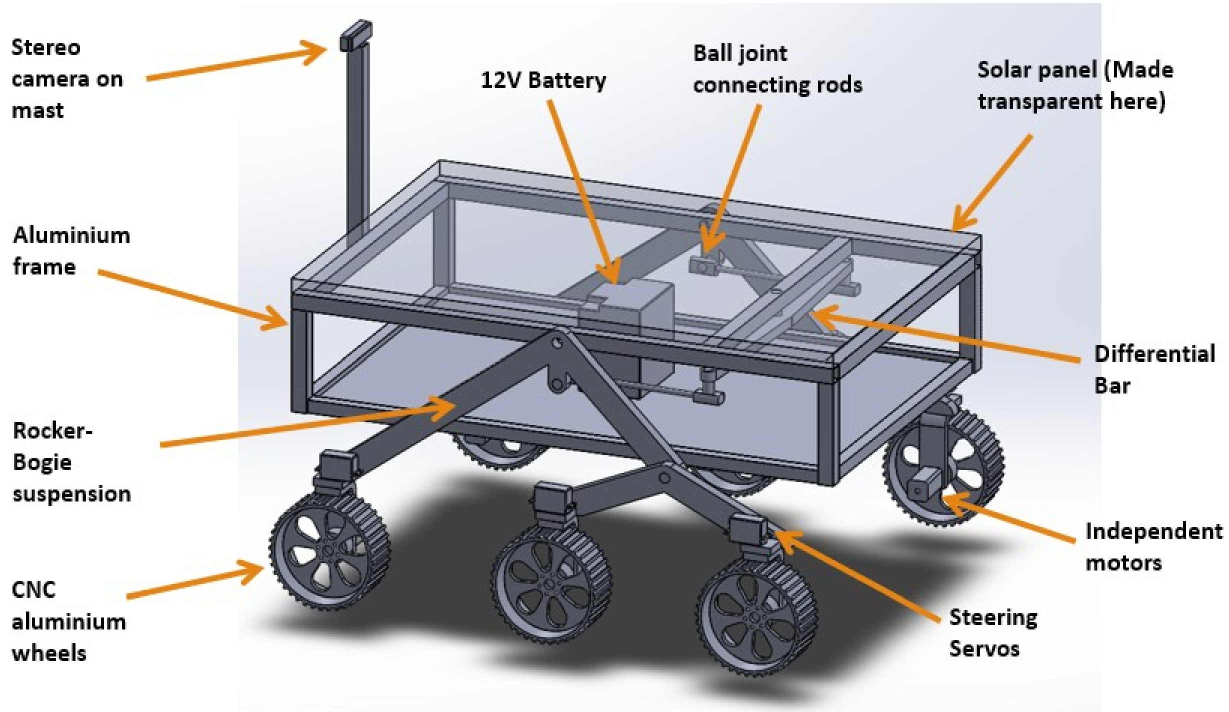

Figure 11: *Initial concept SolidWorks drawing.*

3.3. Component Selection

Following the concept design, more refined choices and the selection of components were made. Some of the major design decisions – the differential, wheels, motors and steering servos – are listed below.

3.3.1. Differential

Vehicles using a rocker bogie suspension require the use of a differential mechanism to maintain a level chassis.

There are two main types of differentials used in planetary rovers: gearbox differentials and bar differentials. These two options use alternative designs to achieve the same mechanical output, and each has their own strengths and weaknesses.

After some research, a bar differential was chosen for this project because it discovered to be easier to construct than a gearbox differential, which require precisely machined gears to work optimally. Bar differential allows some adjustability in the lengths of the linkages and the level of the chassis can be trimmed post installation. While the rover will not actually be sent to the moon or mars, dust could be an issue with a gearbox differential if dust gets trapped in the gears with nobody or no way to clean it out. The bar mechanism is less susceptible to this.

Figure 12 shows the differential bar mechanism on a near complete 3D model.

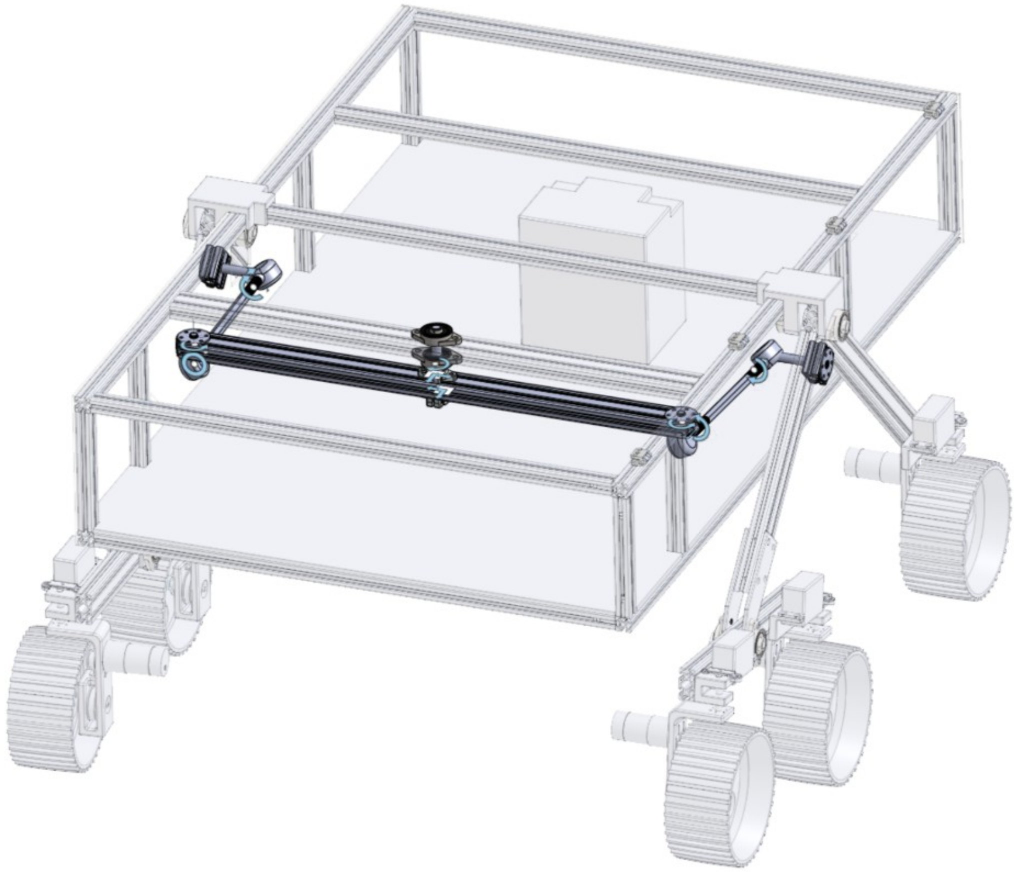

Figure 12: *The differential bar mechanism highlighted on the rover model.*

3.3.2. Wheels

The choice of wheels was another major design choice.

From the beginning, it was decided to not use rubber tyres due to its narrow functional temperature range, (rubber gets brittle at low temperatures, making it unsuitable for space missions), instead opting for aluminium alloy wheels with grousers, making the project look more like a genuine planetary rover.

However due to the long 10 to 12-week lead time and price for CNC aluminium, the wheels were 3D printed out of carbon fibre reinforced nylon on UWA Mechanical Workshop's industrial 3D.

Figure 13 below shows an image of one of these wheels.

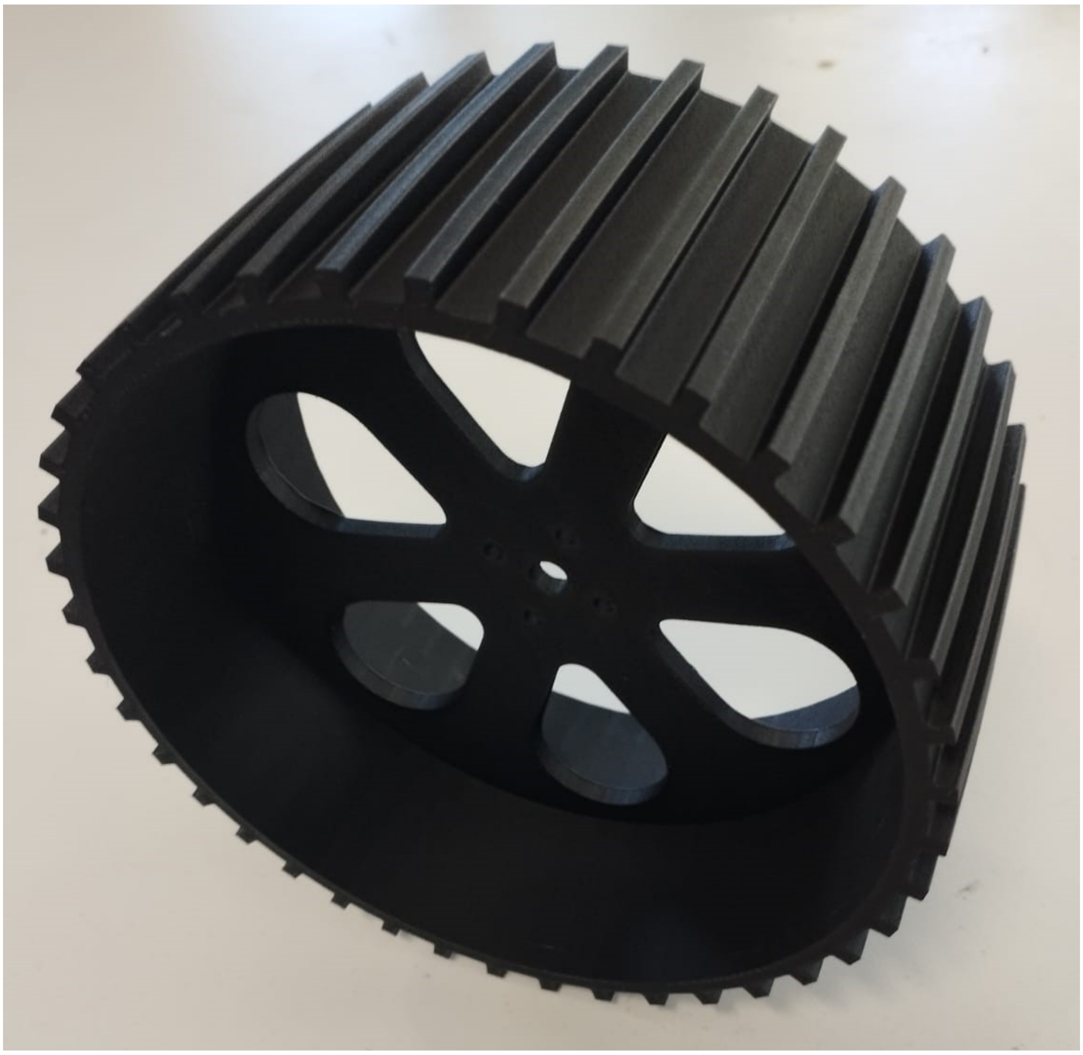

Figure 13: *One of the carbon fibre reinforced 3D printed nylon wheels.*

3.3.3. Motors & Motor Drivers

Selection of the motors was a challenging aspect of the project. To select the motors, the torque required needed to be known, however, to know the torque required, the mass of the vehicle, as well as other factors need to be estimated. Of course, the mass of the vehicle has a lot to do with the chosen motors. This circular reasoning led to confusion early in the project development.

An Engineering Stack exchange post was found, which outlines a method of how to estimate the torque and power required of the motors for a given vehicle mass, speed, wheel size and friction coefficient [23].

Using a rough mass estimate of a 40kg rover with 20kg of payloads, this method was followed and formulated in an Excel spreadsheet, allowing for the ability to change input variables and see how those effect the output torque and power requirements. An image of this Excel spreadsheet is included in Appendix D.

At 60kg, 0.5m/s, and a 1:1 gear ratio, the required torque per motor is 3.2 Nm and Power is 19.5 W at a rotational speed of 47.7 RPM. Several weeks were spent trying to find the correct motors, with encoders, to perform to these characteristics. A few were found that almost fit the task, however, none were perfect.

Later, the decision was made to reduce the required torque and isolate the weight of the rover from the motor shaft by introducing a 2:1 ratio belt-pully drivetrain. This allowed the selection of a smaller motor with half the required torque.

The final motor selection was the FIT0185 DF Robot Motor shown below in figure 14.

Figure 14: *FIT0185 DF Robot Motor. [24]*

Two Sabertooth dual channel regenerative motor drivers were selected to drive the motors. These drivers allow a high peak current rating of 12A and are currently being used on the omnidirectional wheelchair in the UWA Robotics Lab.

Figure 15 below shows an image of this motor driver.

Figure 15: *Sabertooth Dual 12A 6V-24V Regenerative Motor Driver. [25]*

3.3.4. Steering Servos & Servo Controllers

Shown below in figure 16 is the 150kgcm 12V servos that were selected to independently steer the wheels. The 270-degree version was used to ensure that a greater than 180-degree range of motion could be achieved, essential for the side driving capability. The 12V input also means it can be run straight off the chosen battery.

Figure 16: *DS51150 150kgcm servo [26].*

These servo motors are controlled via a Micro Maestro 6-Channel USB servo controller. These convert the serial output from the Raspberry Pi to the Pulse Width Modulation (PWM) required for the servo position commands. This component is shown below in figure 17.

Figure 17: *Micro Maestro 6-Channel USB Servo Controller [27].*

3.4. SolidWorks 3D CAD Model

After the initial concept drawings, a to-scale detailed model of the rover was created to fully define the assembly. It defined the length of all the aluminium extrusion, ensured all joints were braced by bearings appropriately, demonstrated the proper mobility of the bar differential and rocker bogie suspension, and detailed the precise measurements required for the drivetrain and steering gearbox, while also confirming that it is constructable and functional. A screenshot of the SolidWorks model is shown below in figure 18.

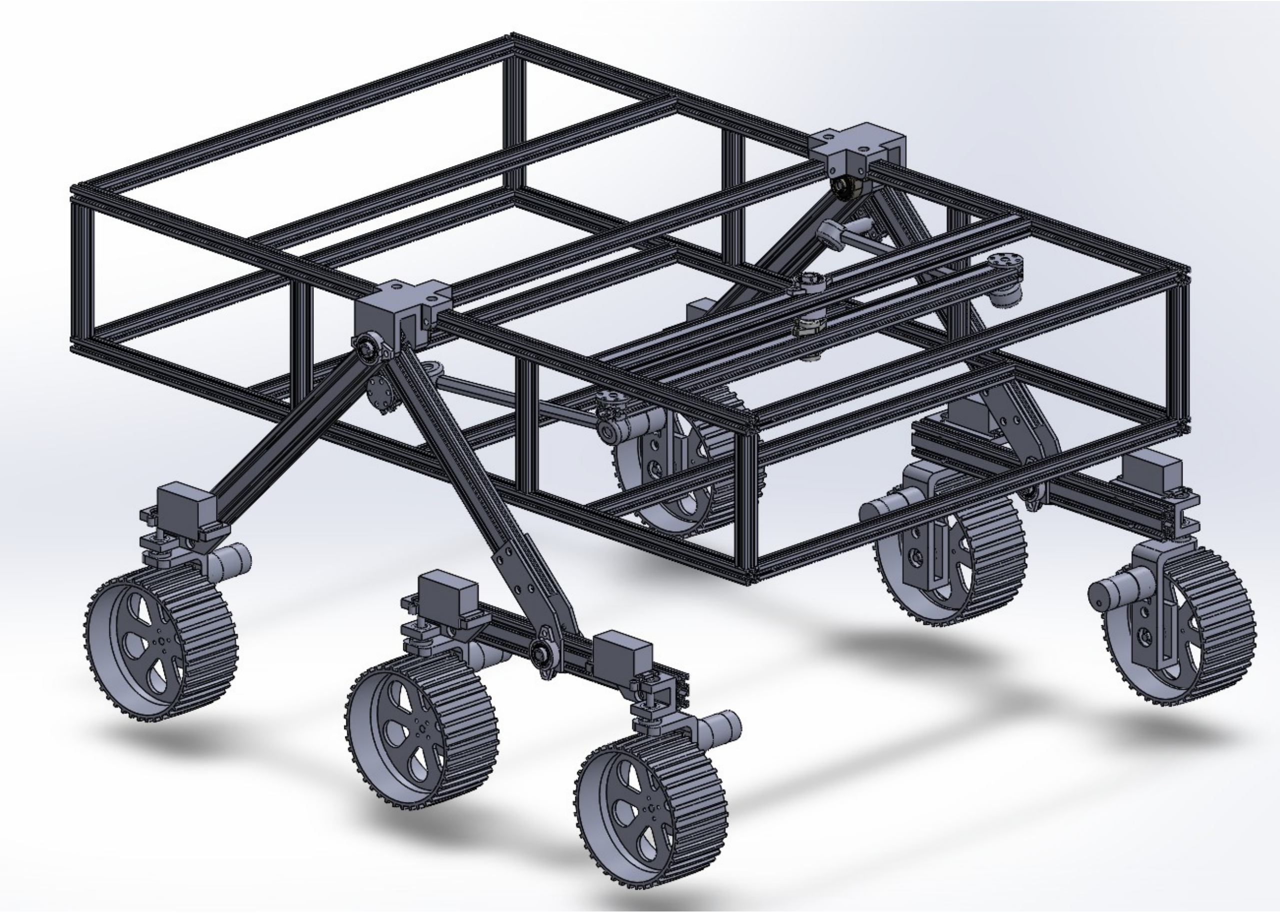

Figure 18: *Detailed SolidWorks assembly of the rover.*

Technical design drawings of all components detailing all critical dimensions were created. These were given to the UWA Mechanical Workshop to allow them to manufacture the components. For the components that the workshop were unable to produce, the corresponding drawings were sent to PCBway alongside the 3D models for CNC milling. The complete set of these technical drawings is included in Appendix F.

3.5. Electrical Component Layout

Also completed during the design of the rover was a basic electrical component layout. This was used to work out how many of what types of connections were required based on the components selected, and what they must communicate with or draw power from.

Figure 19 below shows an abstraction of the connections between each of the essential electrical and electronic components of the rover. The higher voltage 12.8V lines are represented as thicker lines, and low voltage signal lines are shown as thin lines.

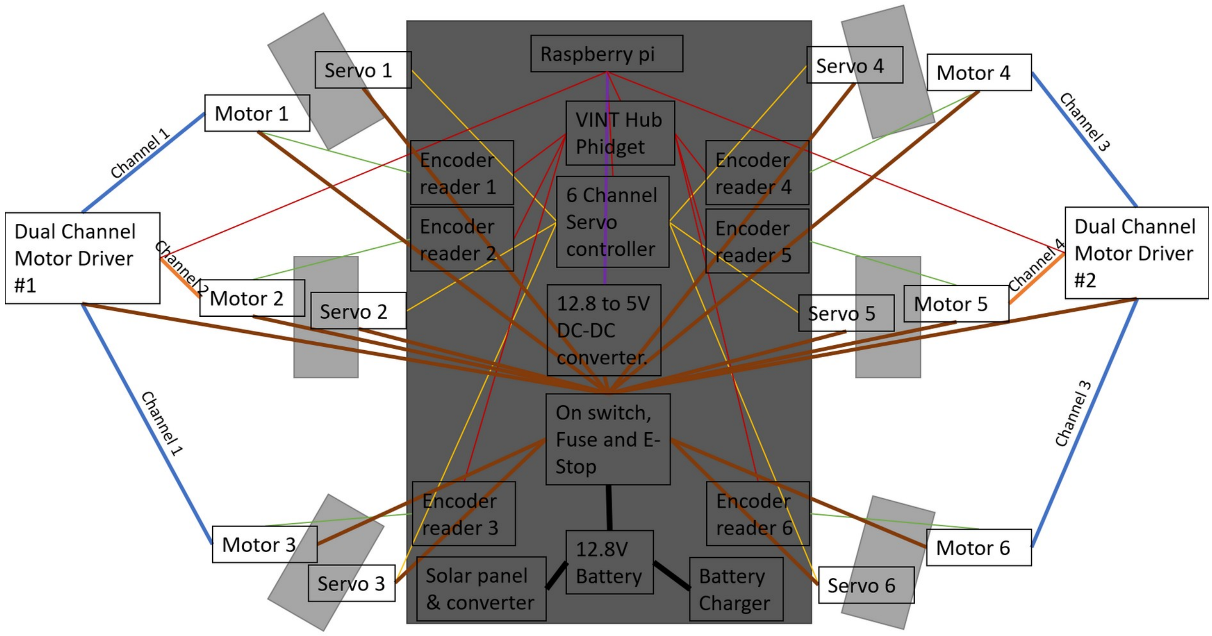

Figure 19: *Planetary Rover Component Connection Diagram.*

4. Construction

Construction of the rover occurred in stages over second semester. Majority of the construction involved the assembly of parts produced by the UWA Mechanical workshop. They were given a list outlining the priority of each component and aimed to produce the components in this order. While the list changed over the course of the second semester, the workshop generally followed the list and components were produced on schedule.

First out of production was the chassis frame, cold saw cut to allow for a tight and precise fitting assembly. The choice of ITEM Profile 5 aluminium extrusion allowed for simple assembly using Automatic-Fastening Set 5 fasteners. Figure 20 below shows how the extrusion joins using these fasteners.

Figure 20: *Image showing how the automatic fasteners join the ITEM Profile 5 aluminium extrusion. [28]*

A 1080mm x 710mm 22V solar panel was modified, becoming the lid of the rover, with hinges, gas struts and latches to lock it closed. Handles were attached on either side of the frame to allow for safe two person carry.

The short and long threaded inserts, alongside the differential bar were completed early, allowing the differential bar mechanism to be assembled and attached to the chassis frame.

Acrylic panels were cut to seal the walls of the chassis and to act as the floor of the chassis. 4.5mm transparent acrylic was selected because it was the perfect thickness to slide into the channels of the aluminium extrusion acting as windows to allow the interior to be viewed.

Figure 21 below shows the frame complete, with the solar panel lid and the acrylic side panels and floor. The differential bar mechanism can also be seen inside the frame.

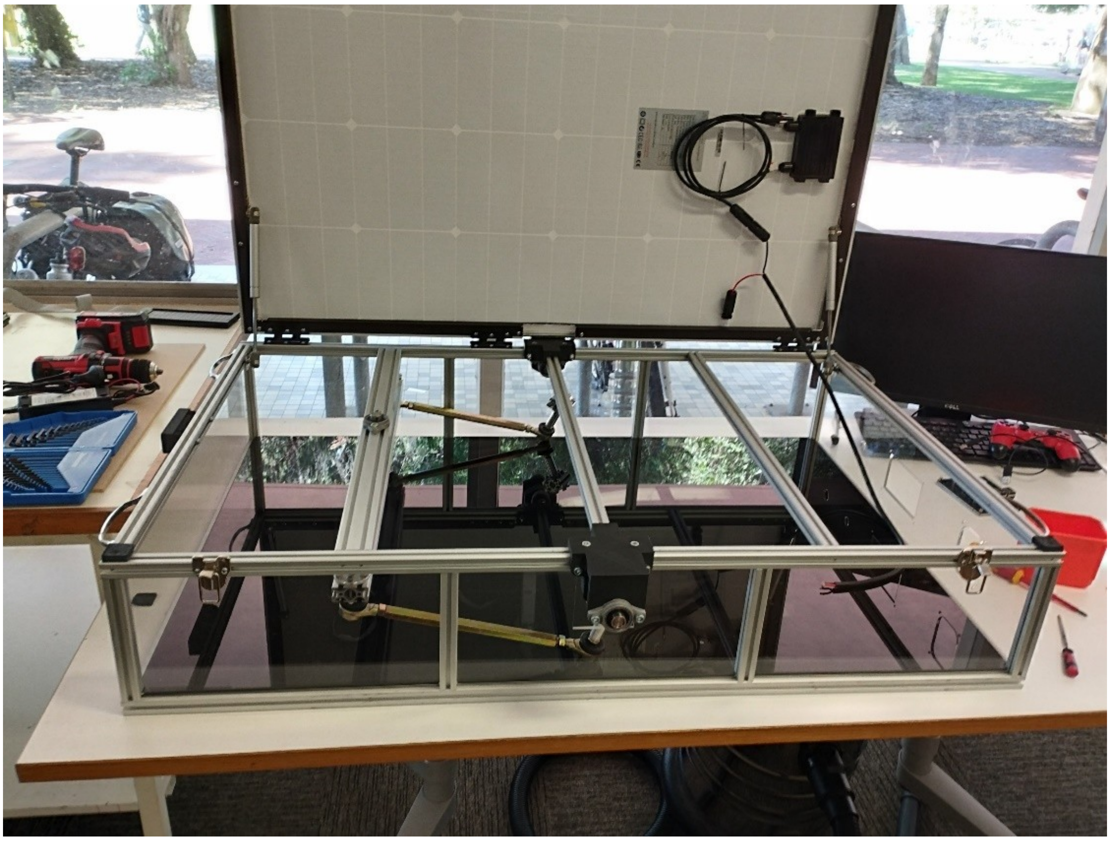

Figure 21: *Image showing the chassis frame complete with acrylic side panels and solar panel lid.*

Next, MDF board was cut to fit inside the chassis, on which all the electronic components were mounted. Care was taken to ensure that the wiring was done correctly, to prevent damage to any of the components due to short circuits of incorrect wiring. The 3.6 kg battery was centrally mounted to reduce the pitching torque the differential bar must compensate for. Power from the battery was directed to a fuse box, where each component is distributed 12V through individual fuses. The motors were connected to the appropriate pins on the Sabertooth motor drivers following the Sabertooth2x12 User Manual [29]. Similarly, the servos were connected following the instructions in the Pololu Maestro Servo Controller User's Guide [30]. A LM2596 DC-DC step down module was used to decrease the voltage to 5.2V appropriate to power the Raspberry Pi.

A latching 'power on' button, as well as an emergency stop button, were connected via a 60A relay which would then cut off the power to the fuse box. This ensured that all electrical components are turned off during an emergency, including the Raspberry Pi computer in the case of a software issue.

The battery is charged from the solar panel via a solar charge converter, which steps down the 22V from the solar panel down an appropriate voltage level to charge the battery safely. It also has a display that shows the battery voltage, and an estimate of the charge left in the battery. The battery can also be charged though a regular wall charger, adapted to a caravan type wall plug, onto which a regular extension lead can be connected. The data lines for the servo controllers, and encoder readers were directed to the Raspberry Pi through USB serial, while the motor driver data lines were connected to the appropriate serial pins.

Figure 22 below shows inside the chassis after completion of all wiring.

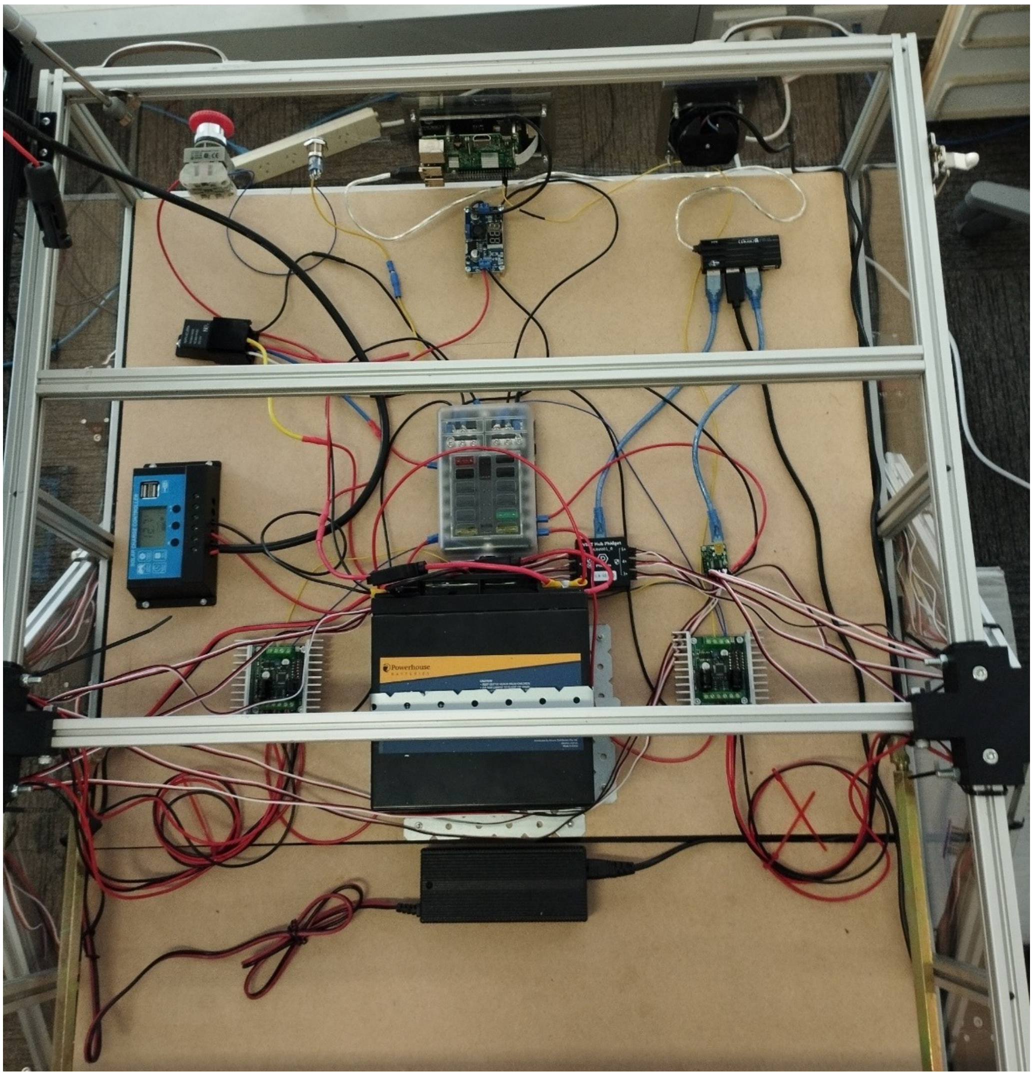

Figure 22: *Top view inside the chassis after completion of all wiring.*

Figure 23 below shows the back of the rover where the Raspberry Pi Screen, ‘power on’ button, emergency stop button and caravan plug are mounted.

Figure 23: *View of the back of the rover with the Raspberry Pi screen, buttons and charging plug mounted.*

3D printed versions of the complex metal brackets were created in order the test the fit against the real components. After the rover legs were cut, a temporary first construction of the rocker bogie mechanism, including the legs, motor belt drive assemblies, steering assemblies and wheels was completed.

Figures 24 and 25 below show the one of the motor and belt drive assemblies and one of the steering gearbox assemblies respectively.

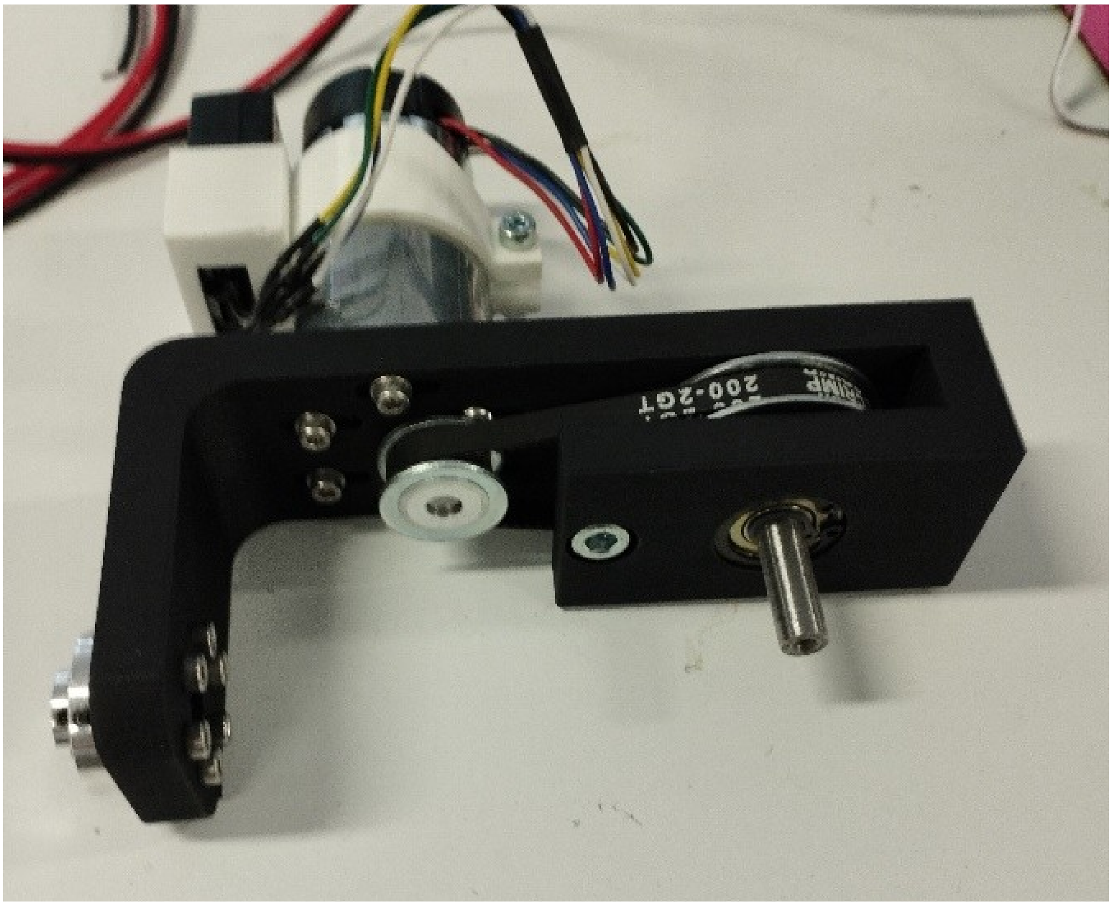

Figure 24: *One of the six belt drive assemblies*.

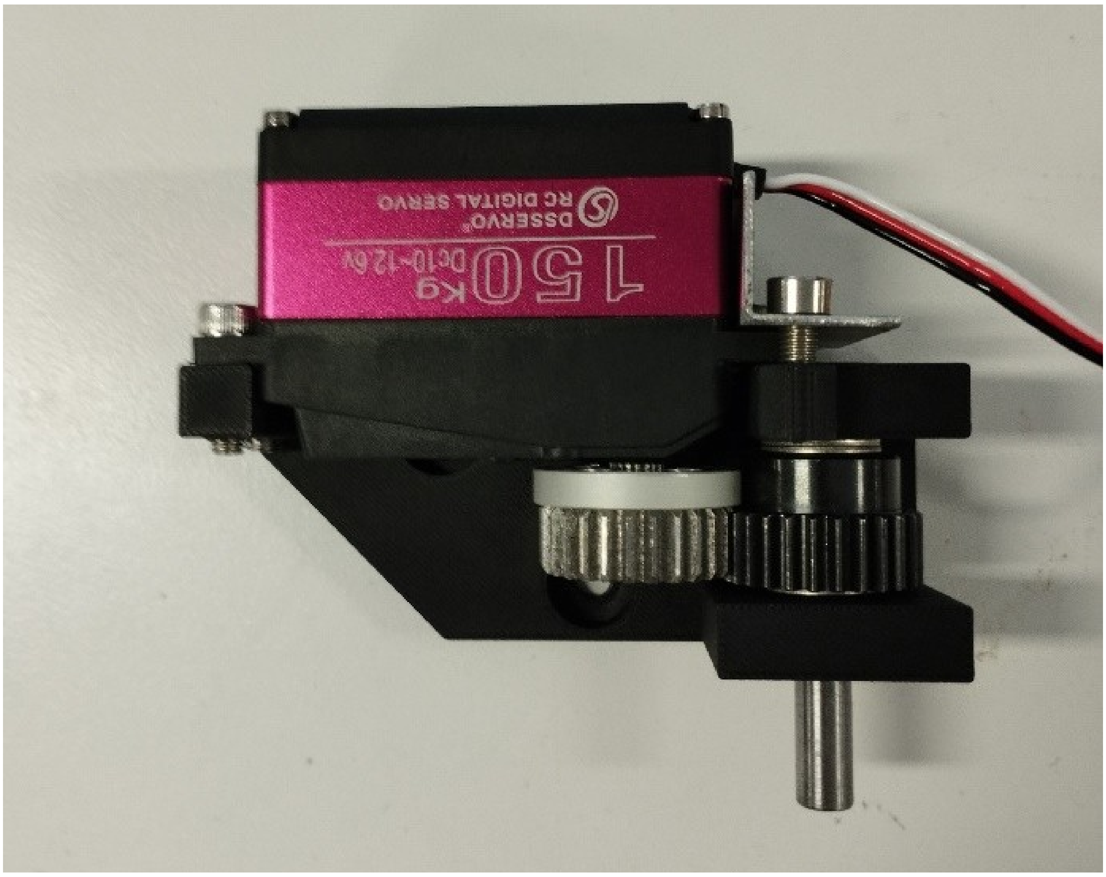

Figure 25: *One of the six steering assemblies.*

Figure 26 shows a side view of the rover after the temporary assembly.

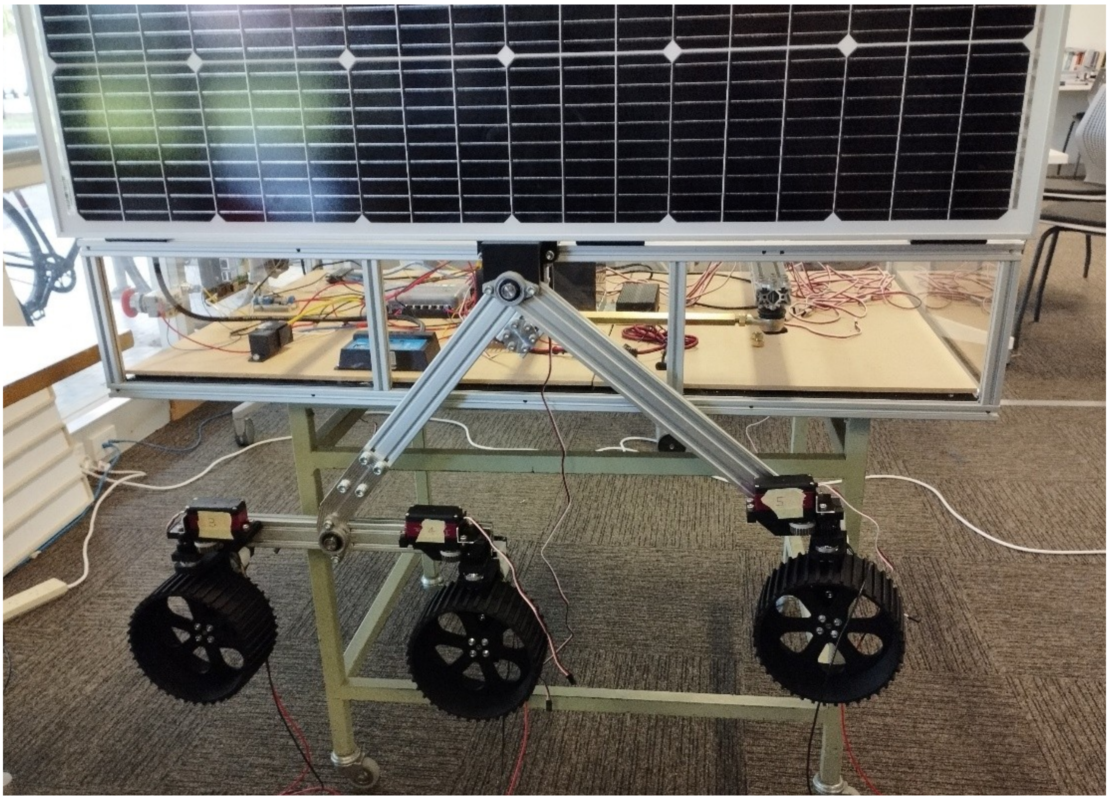

Figure 26: *Side view of the rover after the initial temporary construction.*

The successful temporary construction demonstrated that the parts were designed correctly, however the 3D printed components would not be strong enough to support the mass of the rover.

The busy schedule of the UWA Mechanical Workshop, tasked with other clients, meant that they could not produce the final CNC machined parts by the end of the semester. Therefore, this manufacturing was outsourced.

While many local Perth based machining service companies were contacted for quotes, the decision was made to order the mounts to be CNC machined and delivered by the online company PCBway. Quick manufacturing and delivery time meant the parts were delivered in under 3 weeks from ordering.

Figures 27 through 30 show examples of each part upon delivery.

Figure 27: *One of the six wheel mounts.*

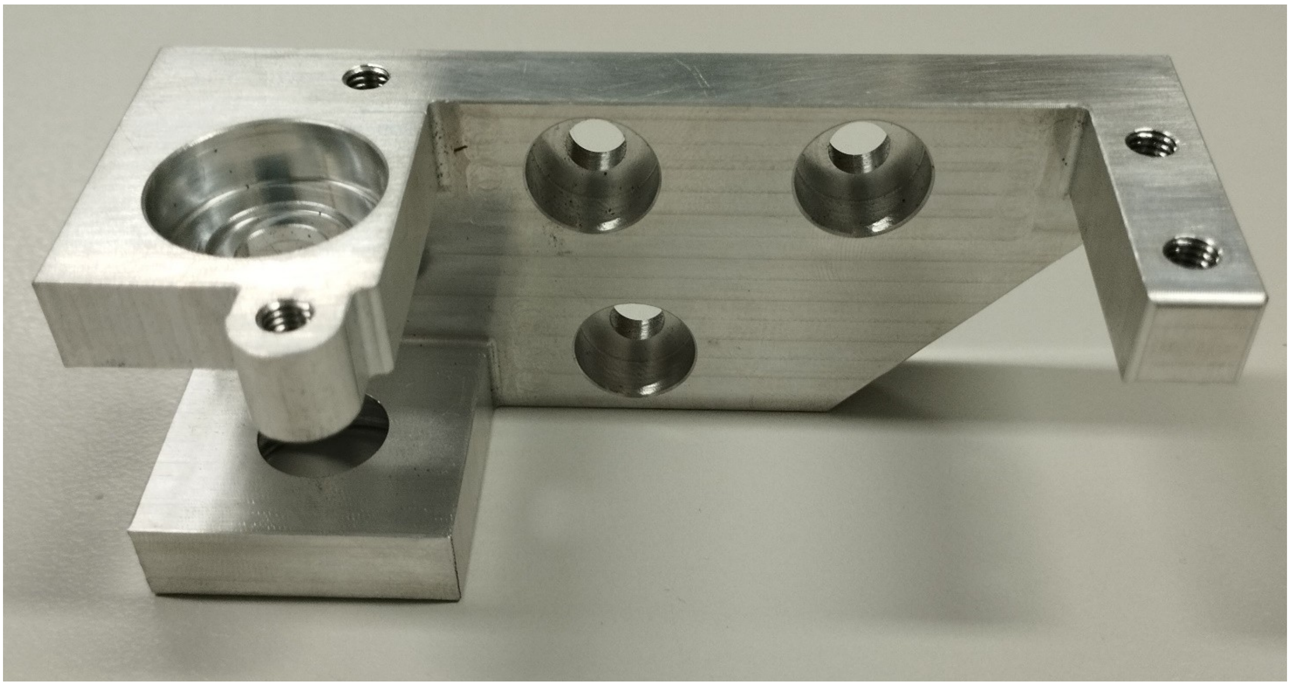

Figure 28: *The one of the three servo mounts.*

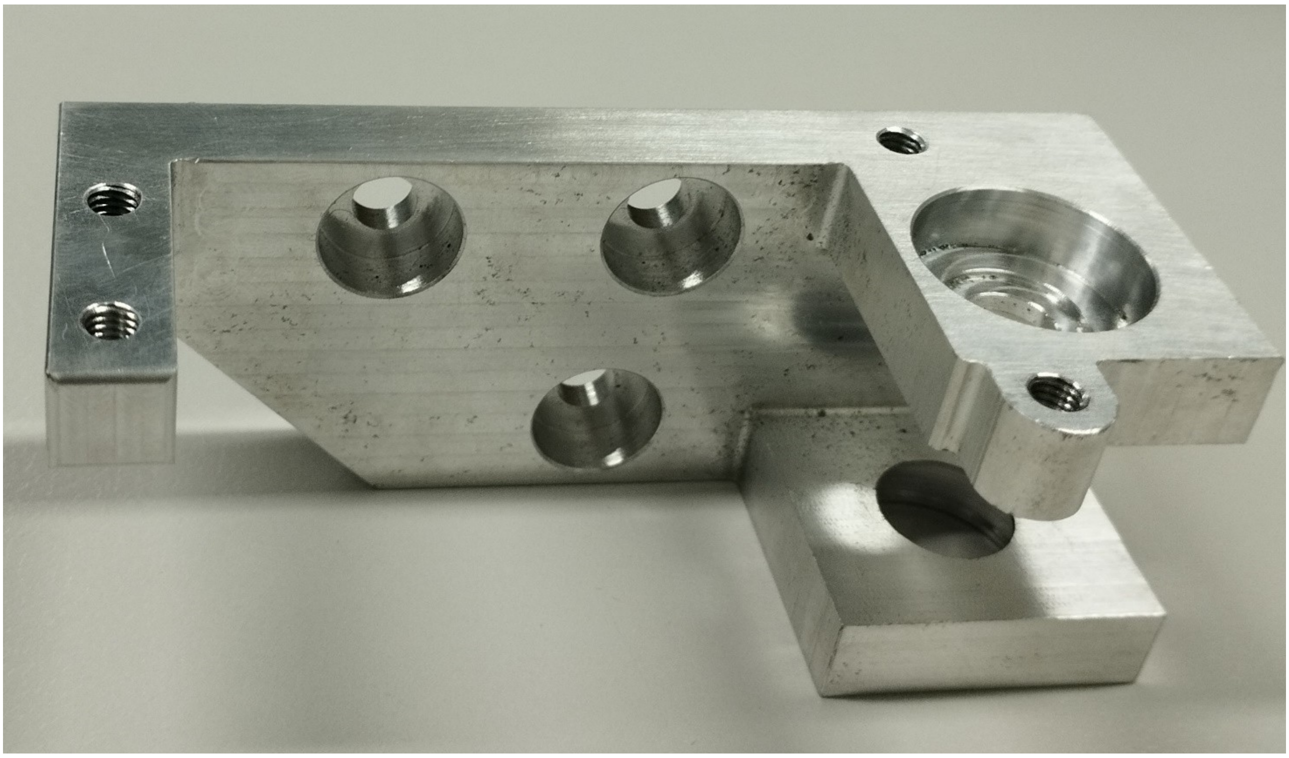

Figure 29: *The one of the three inverted servo mounts.*

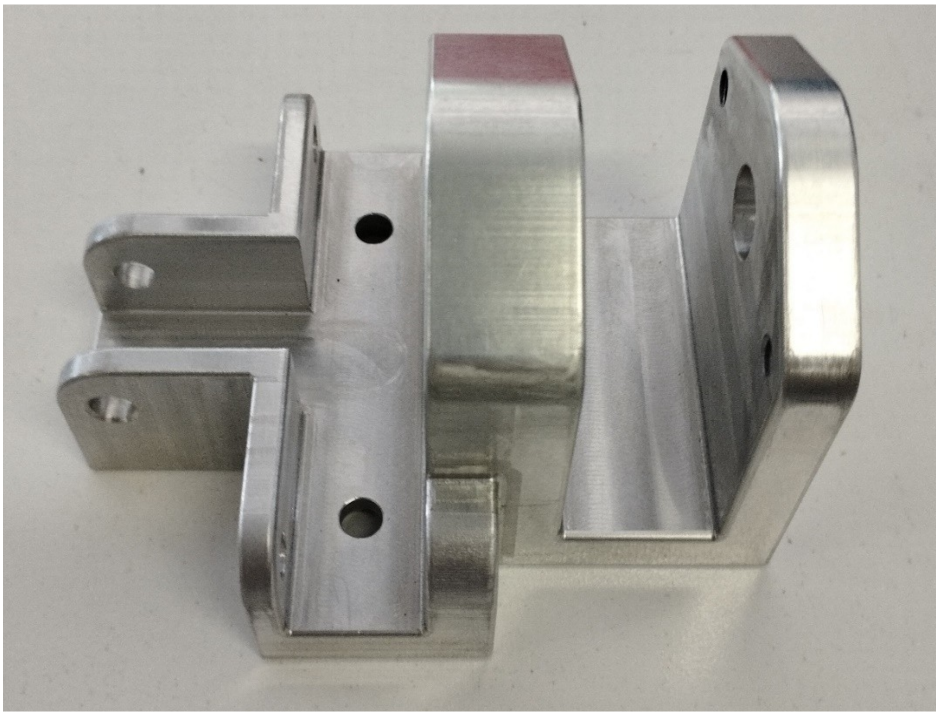

Figure 30: *One of the two Rocker Joint Brackets.*

Figure 31 shows the completed rover standing on the ground for the first time.

Figure 31: *The rover on the ground after the completed construction.*

5. Operation

5.1. Software

First step in the design of the control software was to ensure that all the peripheral components could interface with the Raspberry Pi. Ideally the libraries used would all be in the same programming language to allow functionalities to run on a single executable program. It was found that the language supported by all systems was C++. A benefit of C++ is that it is a compiled language, therefore, the code cannot be run until all errors are fixed, making it less likely for hidden errors in the code to slip through.

A Bluetooth PS4 controller was selected for the use of demonstrating manual driving control, due to its simplicity and ease of use in the C++ program.

The top-level structure of the code involves two main stages. An initialization stage sets up the connection with all the peripherals and presets all the required variables. A sequential movement of the motors and servos was included in the test code, however, is removed in the final version.

Then, repetitively inside a while loop, values from button presses and joystick movements from the PS4 controller are received. These are then mapped to the appropriate commands to send to the motors and servos, from which the desired driving motion of the rover is achieved. Steering control is explained in the next section. Pressing ‘OPTIONS’ on the controller exits the while loop, after which the motors are commanded to stop, and the program is terminated.

5.2. Steering Control

Manual control of the rover was achieved by mapping the analogue values from the PS4 controller joysticks to the motor and servo commands.

Linear control of the rover simply involved mapping the vertical movement of the left analogue joystick proportionally to the speed command of all the motors. Additionally side and angled driving involved sending the equal steering commands to all servos.

Implementing swerve steering, however, was a more involved task.

The geared motors cannot freely be back driven; therefore, excessive use of skid steering could cause damage. However, with six independently driven and steered swerve modules, the rover has a high enough degree of freedom to make possible swerve steering. For this drive type, the inverse kinematics required for the motor speeds, and concurrent servo steering angles to turn the rover without slipping needed to be calculated.

Shown in figure 32 below is a SolidWorks sketch of the geometric layout of the wheel contact points on flat level ground. Co-centric circles are shown, which represent the driving path of each of the wheels at a given rover turning circle.

When the rover turns, the outermost wheels need to turn faster that the inner wheels. The percentage of the speed that a particular wheel needs to spin in relation to any other wheel is proportional to the ratio of the radius of their circular paths at a given rover turning circle.

Additionally, the concurrent angle to turn the servo was achieved by measuring the angle between the horizontal centre line to the radius line to each wheel. Through the equivalent angle's theorem, this is the same as the angle that the wheel module needs to turn.

While the desired functionality was to have a variable turning radius proportional to the right joystick's horizontal movement, this was found to be very difficult to implement in practice. Therefore, only a single turning radius was implemented for each turning direction, significantly simplifying the implementation.

Figure 32 below illustrates linear driving, side driving, and swerve steering.

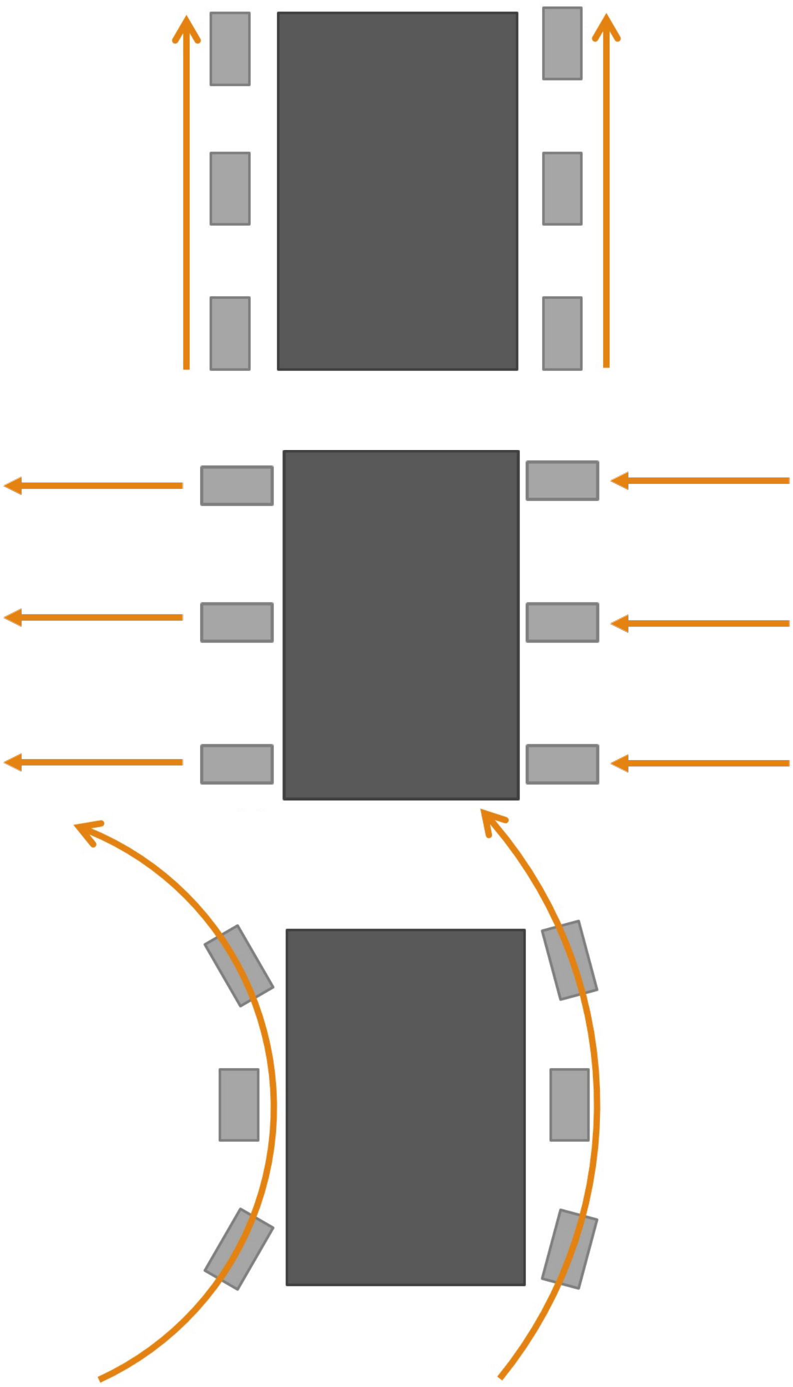

Figure 32: *An illustration linear driving, side driving, and swerve steering.*

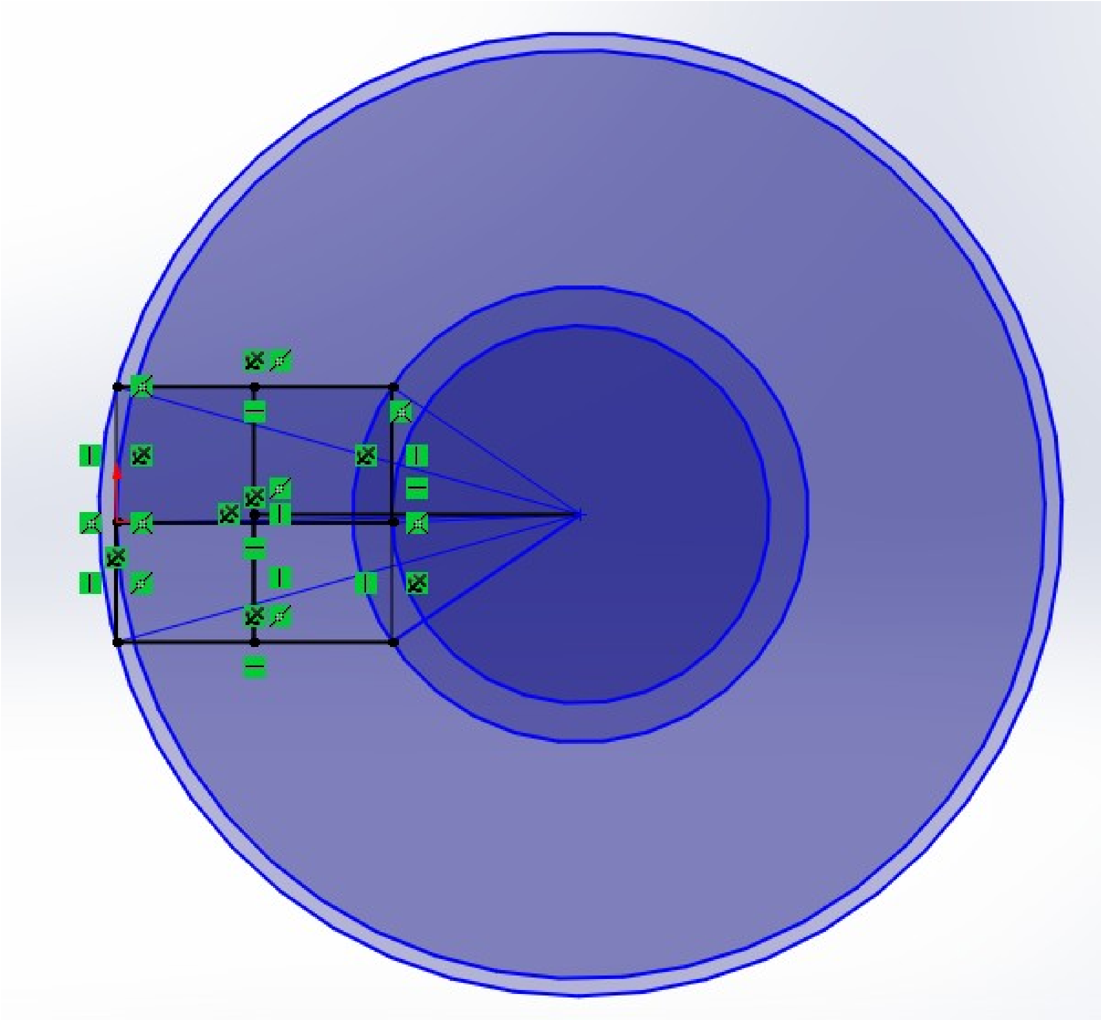

Figure 33: *The SolidWorks sketch used to calculate the motors speeds and turning angles for swerve steering.*

6. Experiments & Results

6.1. Test Driving

Construction of the rover was completed at the end of week 9, with the first test drive on 3 October 2023. This first test drive provided insight into the performance of the rover.

Upon putting the rover on the ground, it became immediately obvious that the chassis had significant movement in the pitch direction. While the differential bar mechanism does do an excellent job in keeping the chassis level, the cross beam mounting the differential bar has a small but non-negligible twisting movement. This movement is amplified over the length of the differential linkage to a noticeable movement of the chassis when the rover accelerates and decelerates. While this has no effect on the driving capabilities of the rover, it will make the image from the depth camera instable, with the potential for significant motion blur. A potential fix is to brace the cross beam more effectively, to reduce the twisting movement.

When driving manually, the rover is quite responsive to commands by the PS4 controller. Having a linear mapping to the steering angle means that the joysticks are quite sensitive, and the driver must be precise to hold a fixed angle whist side driving. However, the simplified swerve driving, with a fixed turning radius for left and right allow the driver to be less precise with the driving control. This may be a reason to suggest that implementing variable radius turning may not be necessary.

On 7 October 2023, the rover was taken out to the Statham Wetlands in Glen Forrest for a field test and videography session. This test demonstrated the rover’s ability to drive on a hardened clay surface.

While it drove reasonably well on the level ground, the grub screws holding the pullies to the wheel shafts did not hold during the uphill tests, meaning that the pullies spun in place and did not deliver the full torque from the motors to the wheels. To fix this, a flat section was machined off the shafts to form a D shaped cross-section. This ensured the grub screws cannot slip, creating a positive drive on all sections of the drive chain to transfer the full torque from the motors to the wheels.

The rocker bogie suspension worked as designed, absorbing the contours of the terrain, ensuring every wheel remained in contact with the ground. The bearings braced this mechanism appropriately, however, the rocker legs have a tendency to splay outwards, which is ultimately due to the width of the rocker joint bracket causing insufficient bracing of the legs.

A montage video including images from the construction, initial drive tests, and the field test was created as a summary of the project and what was achieved.

Figure 34 shows a photograph of the rover at the Statham Wetlands in Glen Forrest WA.

Figure 34: *A photograph of the rover at the Statham Wetlands in Glen Forrest, Western Australia.*

After the wheel shafts were modified with a flat to create D shaped shafts, a slope driving test was performed in the robotics lab. Two wooden ramps were placed back-to-back with an artificial grass mat laid on the top for traction and aesthetics. Unfortunately, the rover was not able to drive up the slope without assistance. As the rover drove up the slope, the belts of the drive train slipped over the pully of the motor, meaning that the torque from the motors did not transfer to the wheels.

An easy fix for this may be to tension the belt more by pulling the up the motor on the slotted holes. If this doesn't work, other solutions involving redesign include adding an idler pully, to wrap the belt more around the motor pully, or to use a bigger belt, with corresponding larger pullies.

Figure 35 shows the rover on a ramp during the slope drive test.

Figure 35: *Image of the rover on the ramp during the slope drive test.*

6.2. Cost

At the beginning of the project, it was estimated that cost of all components would come to around $4000. During the project, all spending was recorded on a bill of material Excel spreadsheet. The final bill of materials – attached in Appendix D – shows that the overall spending totalled to $5,365.32. The pie chart in figure 36 shows the proportion of the spending on each component category.

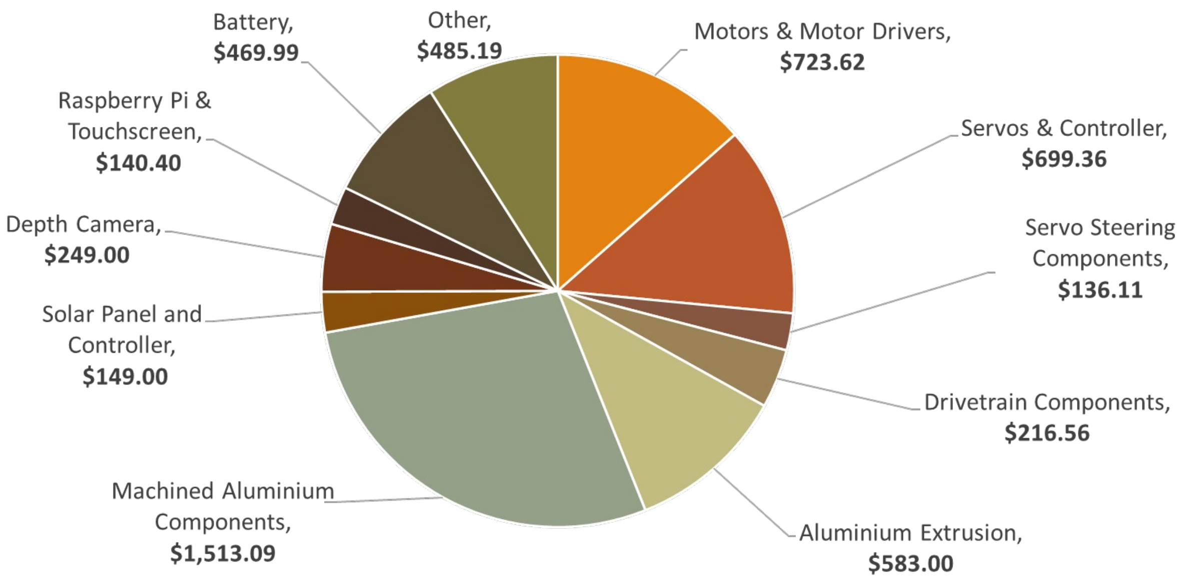

Figure 36: *The proportion of spending on each component category of the rover.*

The pie chart shows that the largest spending item was the machined aluminium components. The cost of this was more than originally estimated due to outsourcing some of the parts to PCBway, with the additional shipping costs included. The other major expenditures were on the upper end of the original estimates, with the motors, motor driver, servos and servo controllers being the next highest expenditure as expected.

Considering the exceptionally high price of spacefaring planetary rovers, and even comparing to other university build rovers, the cost of this rover is very low and shows that such a rover can be made with limited budget, time and resources.

7. Future Goals & Conclusion

7.1. Future Goals

The completion of construction is only the beginning of the life of the rover. The rover will be given to the next cohort of students, to improve the driving performance and to integrate more advanced software to allow for autonomous driving abilities.

The additional chassis space can be used to house a more powerful computer, additional sensors or other additional hardware that may be desired in the future.

Upon gaining suitable funding, it is hoped that in March 2024, the rover will be entered into the Australian Rover Challenge. While it has not been specifically built for the challenge, and won't be able to compete in all events, it will be a great way to demonstrate the rover to a wider interested audience.

7.2. Conclusion

This planetary rover project was a challenging yet exciting final year honours project, and I am grateful to have been given the opportunity to undertake it. The experience gained from undertaking the entirety of this project, from conception to demonstrations, was invaluable. In the robotics community, the saying goes that you don't truly understand a system unless you built it. I have learned more about robotics, construction, electronics and software than I ever would have just by looking at other pre-made systems. By doing everything myself, I have encountered all the problems one faces as a robotics engineer, felt the pain of things not working, the tedious work required to fix mistakes, and the joy when a complex system finally performs as intended.

I am grateful that I set aside the entire first semester to planning. It ensured that I spent time optimising the components, ensuring that everything was manufacturable, constructable, and most importantly, worked.

I was very fortunate to have a supportive professor, Thomas Bräunl, who was willing to fund this project right the way through, despite the unfortunate unsuccessful attempts at gaining sponsorships. I also owe my success to the time and capabilities of John Hitching and his staff at the UWA Mechanical Workshop. Without them, I simply would have not had the resources to pull this project off.

I hope this rover inspires future students of UWA Engineering to build something amazing of their own. I am excited to find out what the next cohort of students come up with to improve the construction, I hope that fully autonomous driving can be achieved.

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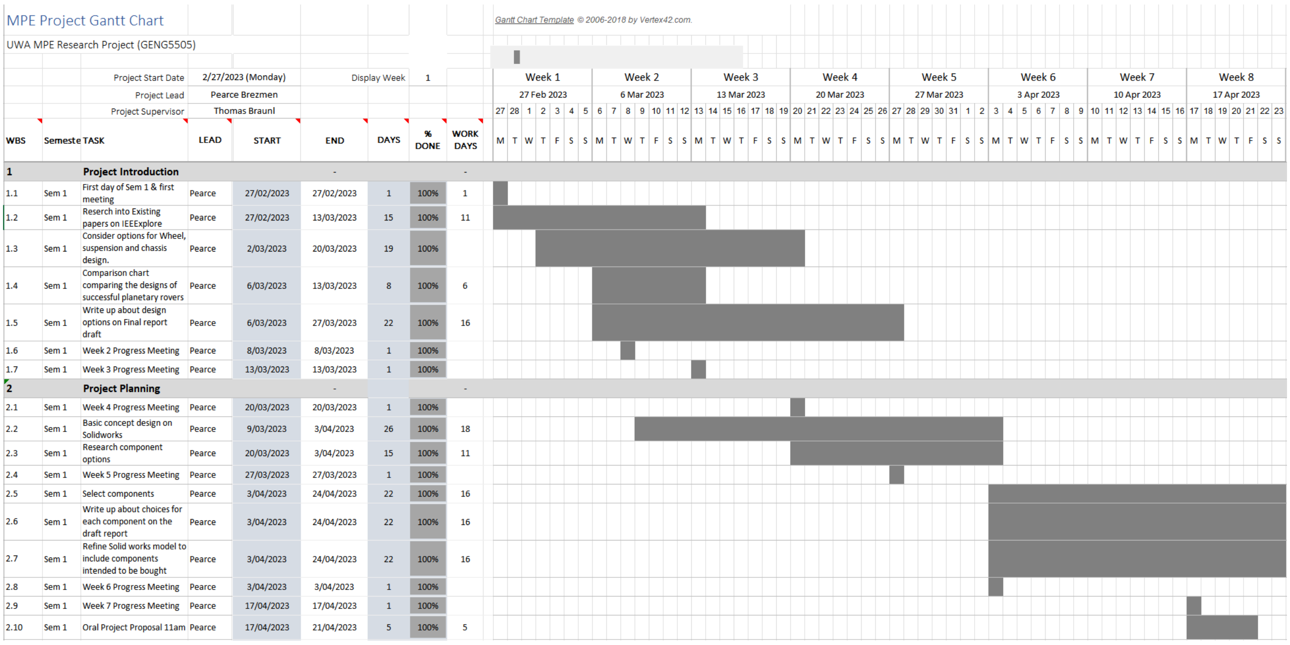
Appendices

Appendix A – Gantt Chart

Shown below is the Gantt chart for the project. To fit the chart onto one page, it is shown as 4 separate images, with sections scrolled to different positions.

Gantt chart image 1:



MPE Project Gantt Chart

UWA MPE Research Project (GENG5505)

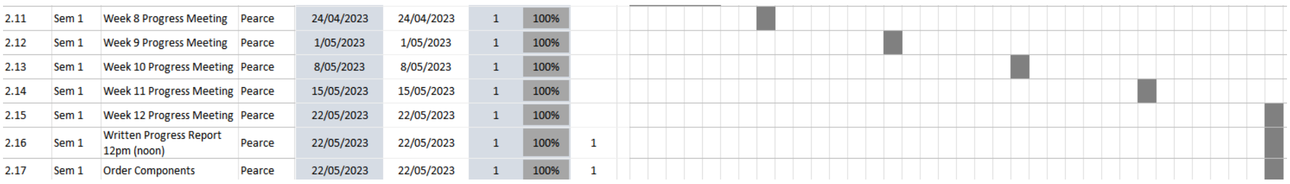
Project Start Date: 2/27/2023 (Monday) Display Week: 1

Project Lead: Pearce Brezmen

Project Supervisor: Thomas Braunl

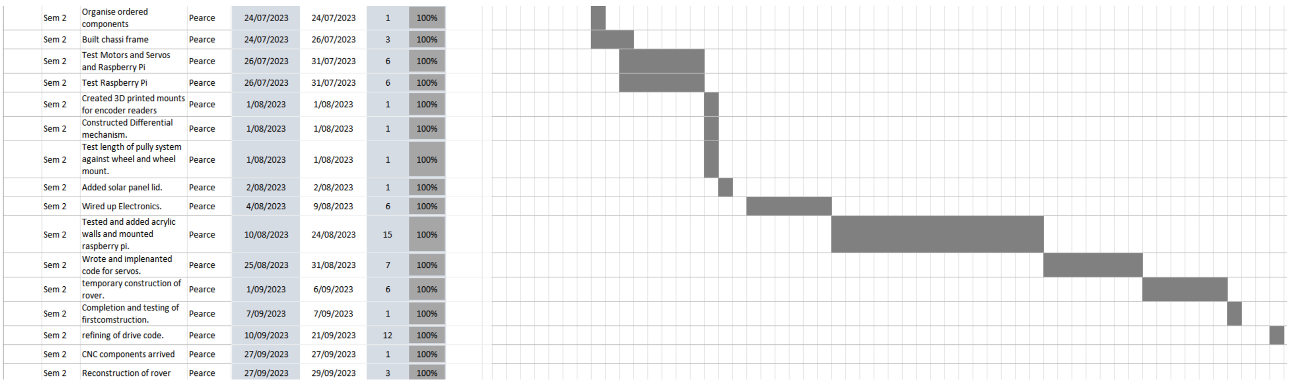
WBS	Semeste	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1		**Project Introduction**			-			-
1.1	Sem 1	First day of Sem 1 & first meeting	Pearce	27/02/2023	27/02/2023	1	100%	1
1.2	Sem 1	Reserch into Existing papers on IEEExplore	Pearce	27/02/2023	13/03/2023	15	100%	11
1.3	Sem 1	Consider options for Wheel, suspension and chassis design.	Pearce	2/03/2023	20/03/2023	19	100%	
1.4	Sem 1	Comparison chart comparing the designs of successful planetary rovers	Pearce	6/03/2023	13/03/2023	8	100%	6
1.5	Sem 1	Write up about design options on Final report draft	Pearce	6/03/2023	27/03/2023	22	100%	16
1.6	Sem 1	Week 2 Progress Meeting	Pearce	8/03/2023	8/03/2023	1	100%	
1.7	Sem 1	Week 3 Progress Meeting	Pearce	13/03/2023	13/03/2023	1	100%	
2		**Project Planning**			-			-
2.1	Sem 1	Week 4 Progress Meeting	Pearce	20/03/2023	20/03/2023	1	100%	
2.2	Sem 1	Basic concept design on Solidworks	Pearce	9/03/2023	3/04/2023	26	100%	18
2.3	Sem 1	Research component options	Pearce	20/03/2023	3/04/2023	15	100%	11
2.4	Sem 1	Week 5 Progress Meeting	Pearce	27/03/2023	27/03/2023	1	100%	
2.5	Sem 1	Select components	Pearce	3/04/2023	24/04/2023	22	100%	16
2.6	Sem 1	Write up about choices for each component on the draft report	Pearce	3/04/2023	24/04/2023	22	100%	16
2.7	Sem 1	Refine Solid works model to include components intended to be bought	Pearce	3/04/2023	24/04/2023	22	100%	16
2.8	Sem 1	Week 6 Progress Meeting	Pearce	3/04/2023	3/04/2023	1	100%	
2.9	Sem 1	Week 7 Progress Meeting	Pearce	17/04/2023	17/04/2023	1	100%	
2.10	Sem 1	Oral Project Proposal 11am	Pearce	17/04/2023	21/04/2023	5	100%	5

Gantt chart image 2:



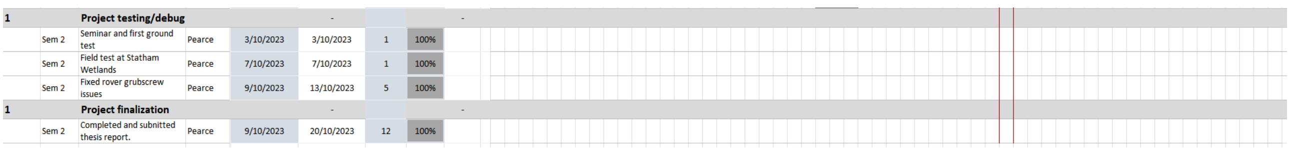
2.11	Sem 1	Week 8 Progress Meeting	Pearce	24/04/2023	24/04/2023	1	100%	
2.12	Sem 1	Week 9 Progress Meeting	Pearce	1/05/2023	1/05/2023	1	100%	
2.13	Sem 1	Week 10 Progress Meeting	Pearce	8/05/2023	8/05/2023	1	100%	
2.14	Sem 1	Week 11 Progress Meeting	Pearce	15/05/2023	15/05/2023	1	100%	
2.15	Sem 1	Week 12 Progress Meeting	Pearce	22/05/2023	22/05/2023	1	100%	
2.16	Sem 1	Written Progress Report 12pm (noon)	Pearce	22/05/2023	22/05/2023	1	100%	1
2.17	Sem 1	Order Components	Pearce	22/05/2023	22/05/2023	1	100%	1

Gantt chart image 3:



	Sem 2	Organise ordered components	Pearce	24/07/2023	24/07/2023	1	100%
	Sem 2	Built chassi frame	Pearce	24/07/2023	26/07/2023	3	100%
	Sem 2	Test Motors and Servos and Raspberry Pi	Pearce	26/07/2023	31/07/2023	6	100%
	Sem 2	Test Raspberry Pi	Pearce	26/07/2023	31/07/2023	6	100%
	Sem 2	Created 3D printed mounts for encoder readers	Pearce	1/08/2023	1/08/2023	1	100%
	Sem 2	Constructed Differential mechanism.	Pearce	1/08/2023	1/08/2023	1	100%
	Sem 2	Test length of pully system against wheel and wheel mount.	Pearce	1/08/2023	1/08/2023	1	100%
	Sem 2	Added solar panel lid.	Pearce	2/08/2023	2/08/2023	1	100%
	Sem 2	Wired up Electronics.	Pearce	4/08/2023	9/08/2023	6	100%
	Sem 2	Tested and added acrylic walls and mounted raspberry pi.	Pearce	10/08/2023	24/08/2023	15	100%
	Sem 2	Wrote and implenanted code for servos.	Pearce	25/08/2023	31/08/2023	7	100%
	Sem 2	temporary construction of rover.	Pearce	1/09/2023	6/09/2023	6	100%
	Sem 2	Completion and testing of firstcomstruction.	Pearce	7/09/2023	7/09/2023	1	100%
	Sem 2	refining of drive code.	Pearce	10/09/2023	21/09/2023	12	100%
	Sem 2	CNC components arrived	Pearce	27/09/2023	27/09/2023	1	100%
	Sem 2	Reconstruction of rover	Pearce	27/09/2023	29/09/2023	3	100%

Gantt chart image 4:



1		**Project testing/debug**			-			-
	Sem 2	Seminar and first ground test	Pearce	3/10/2023	3/10/2023	1	100%	
	Sem 2	Field test at Statham Wetlands	Pearce	7/10/2023	7/10/2023	1	100%	
	Sem 2	Fixed rover grubscrew issues	Pearce	9/10/2023	13/10/2023	5	100%	
1		**Project finalization**			-			-
	Sem 2	Completed and subnitted thesis report.	Pearce	9/10/2023	20/10/2023	12	100%	

Appendix B – Risk assessment

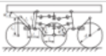
Included below is an image of the risk assessment done at the beginning of the project, considering risks that may have affected the project timeline and potential ways to mitigate these risks. Each has a likelihood and consequence rated out of 5 and these are combined by multiplication to get the final rating. Lower risk ratings are more ideal, and as can be seen, all the risks have been reduced some amount by a mitigation strategy.

Risk	Likelyhood	consequence	Risk rating	mitigation strategy	new likelyhood	new concequence	new risk rating
Components arriving late.	3	4	12	Order components early, have a back up plan for if components to arrived in time, only order from local and reliable sources or purchase in store, especially later in the year.	2	4	8
Design failing to work in some way	4	4	16	Ensure careful designing in the early stages, don't move onto construction until all parts of design have been considered.	2	4	8
Delays causing timeline to stretch	3	3	9	Allow extra time in the timeline for delays, maintain progress with project whereever possible, if delay is only on one section of the project, work on a different section.	2	3	6
Major illness or injuring preventing progress	2	4	8	Don't do anything stupid that could cause injury, maintain good rest and sleep. Eat healthy and continue to exersise.	1	3	3
The restatement of covid lockdowns.	2	3	6	Follow all recomendantions and maintain covid imunisation	2	3	6
Issues during construction causing late redesign.	3	3	9	Ensure careful designing in the early stages, don't move onto construction until all parts of design have been considered.	2	2	4
Budget is exceded	4	3	12	Write down all planned spending into budget spreadsheet to keep track of spending. Spend extra time finding a better deal on components, order early so shipping cost is less, look for ways to do things cheaper where possible.	2	3	6

Appendix C – Rover comparison Excel spreadsheet.

The three images below show the comparison chart used to visualize the comparisons between planetary rovers.

	Name	Authors/ Organisation	year	Image	Number of wheels	Wheel Design	Suspension Design	Benifits	Costs	comments	DoF	Joints	Links	actuators
Successful planetary rovers - Mars														
	Sojourner,	NASA (USA)	1997		6	Aluminum	Rocker Bog	Simple but effective rocker bogie design		Sojourner (rover) - Wikipedia				
	Spirit and Opportunity	NASA (USA)	2004		6	Aluminum	Rocker Bog	Improved design from Sojourner changed lengths and proportions of linkages.		Spirit (rover) - Wikipedia				
	Curiosity	NASA (USA)	2012		6	Aluminium	Rocker Bog	Capable of rolling over rocks the size of one of its wheels		Wheels I Rover – NASA Mars Exploration				
	Perseverance	NASA (USA)	2021		6	Aluminium	Rocker Bog	Enable the rover to drive over knee-high rocks as tall as 15.75 inches (40 centimeters).		Rover Wheels - NASA Mars				
	Zhurong	CNSA (China)	2021			aluminum	Rocker Bogie (lower profile than NASA rovers but			https://global.chinadaily.com.cn/a/202207/06/WS62c540b8a310fd2b29e6ac2b.html				

Successful planetary rovers - Moon	Name	Authors/ Organisation	year	Image	Number of wheels	Wheel Design	Suspension Design	Benifits	Costs					
	Lunokhod 1&	USSR	1970		8		each wheel s	Simple design to demonstarate the first planetary rover on the moon. 8 Wheels provide redudancy.	Inability to climb large obsticles. Therefore limited to flat tarain of landing site.					
	Yutu (1&2)	CNSA (China)	2013		6		Rocker Bogie							
	Apollo Lunar Roving Vehicle	NASA (USA)			4	two alumi	Ackermann	Simple 4 wheel dune buggy design makes driving simple for the astronauts, who would be able to avoid large		https://en.wikipedia.org/wiki/Lunar_Roving_Vehicle How Lunar Rovers Work	HowStuffWorks				
Other Projects	Name	Authors/ Organisation	year	Image	Number of wheels	Wheel Design	Suspension Design	Benifits	Costs					
	LUVMI-X	Scientists and engineers from a consortium of public and private-	2020		4		For wheels e	Simpler design with 4 wheels. (It appears that the designers wanted to propose and alternative design to the well established rocker						
IEEE														
	Design of Six-Wheeled Planetary Rover with a Novel Hybrid Suspension	Sanfeng Hu; Guoxing Wang; Jianguo Tao	2021		6			Novel design, capable of complex movement.	Higly complex with many joints and linkages. Therefore would be difficult to produce.	It would be great to test out this theoretical design on a real world prototype, hower the complexity is cost and time prohibative.	2	34 + 6 wheels	26	6 wheels, 4 steering, 2 suspension lock actuators.
	Study on the dynamics and motion capability of the planetary rover with	Jianjun Du; Mingjun Ren; Jianjun Zhu; Dun	2010		6			Able to traverse gaps and climb simple obsticales better than a simple rocker bogie design.	Weird design,	Has potential, however the tests were done with obsticles dirven into perpendicularly, may make navigating uneven terrain more complicated due to asymetry.	1	6 + 6 wheels	7	6 wheels
	Design, Development and Control of a Planetary Rover using ROS	V. Sharma, S. Sangwan and K. S. Bora	2021		6			Successful project by 3 students in India. Simple suspension design.	Simplified version of rocker bogie is less capable.	Simple mechanical design however this team did a good job at producing an working product with electrical, communication and software design.	2	4 + 6 wheels	9	6 wheels + 5 dof robotic arm

Appendix D – Motor Torque Estimation

This is an image of the interactive Excel spreadsheet made to calculate the torque and power requirements for the motors. It was essential for deciding the final motor choice.

[How can I calculate the power and torque required for the motor on a wheeled robot/vehicle? - Engineering Stack Exchange]

Estimate variable	Symbol	Calculation	value	units	Notes
coefficient of rolling	μ		0.25		Considering soft terrain Values estimated from Fi Pala Gir https://iopscience.iop.org/article/10.1088/1757-899X/330/1/012127/pdf
Rover maximum speed	v		0.5	m/s	Slow speed
maximum continuous	θ		0	°	Considering driving up a 5 degree slope continuously
Gravitational acceleration	g		9.81	m/s^2	For Earth rated rover
mass of the vehicle	m		60	kg	Calculated in mass estimate tab
Weight of vehicle	W Vehicle	m*g	588.6	N	
Perpendicular weight of vehicle on max slope	W⊥Vehicle	W Vehicle * cos(θ)	588.6	N	
radius of wheel	r		0.1	m	
drivetrain ratio	N		1	:1	We would like a motor with an inbuilt gearbox, so setting N = 1 will get the estimate for the torque and power required on the output shaft.
number of wheels	n		6	wheels	
drivetrain efficiency	η drivetrain		0.9		direct drive only losses in bearings and inbuilt gearbox
motor efficiency	η motor		0.7		Conservative motor estimate
Force of rolling friction	F roll	W⊥Vehicle * μ	147.2	N	
Force to overcome gravity on max incline	F Incline	W Vehicle * sin(θ)	0	N	
number of seconds to reach top speed	t		1.2	second	
acceleration from rest to top speed	a	v/t	0.417	m/s^2	
Constant force to accelerate to top speed	F accelerat	m*a	25	N	
Angular velocity of wheel	ω	v/r	5	rad/s	
Angular velocity of wheel in RPS	RPS	(ω/(2π))	0.796	rev/s	
Angular velocity of wheel in RPM	RPM	(ω/(2π))*60	47.75	rev/min	
Combined wheel torque to overcome rolling friction on level surface	τ roll	F roll * r	14.72	Nm	
Combined wheel torque to overcome gravity on max incline	τ incline	F incline * r	0	Nm	
Combined wheel torque to accelerate	τ accelerate	F accelerate * r	2.5	Nm	
Combine wheel torque to maintain constant speed on max incline	τ constant	τ roll + τ incline	14.72	Nm	
total torque required	τ wheel	τ constant + τ acceleration	17.22	Nm	
combined motor torque	τ motors	(1/η drivetrain)*(τ wheel/N)	19.13	Nm	
Torque required per	τ per motor	τ motors / n	3.188	Nm	32.51 kgcm 451.5 oz in
required to maintain speed	P continuou	(1/η motor)*(1/η drivetrain))	116.8	W	
Peak power reached when accelerating	P peak	P continuous + (F accelerate * v * (1/η motor)*(1/η drivetrain))	136.6	W	
Contuous power per motor	P continuous per motor	P continuous/n	19.46	W	
Peak power per motor	P peak per	P peak/n	22.77	W	
Supply Voltage	V		12	V	
Current draw per motor	I	P continuous per motor / V	1.622		

Appendix E – Bill of Materials

Shown below is the final bill of materials for the project. It contains all the components that were ordered for this project and calculates the over expenditure for the project. The full website URL's have been cropped out in this image to save space.

Rover Project Bill of Materials

Pearce Brezmen 22968227

To be bought

	Component	Name	Quantity	Price each	Total Price	Notes	Website
Motors & components	Motor	FIT0185	4	$48.17	$192.68	Only 4 more required. 2 already bought and tested.	https://au.element14.com/dfrobot/fit0185/dc-geared-motor-brushed-131-
	Motor Driver	Sabertooth Dual 12A 6V-24V	2	$120.28	$240.56	Only need 2 Dual motor drivers because there are 4 channels required not six.	https://www.robotshop.com/products/sabertooth-dual-regenerative-motc
	Encoder reader	Quadrature Encoder Phidge	6	$22.57	$135.40		Quadrature Encoder Phidget - ENC1000_0 at Phidgets
	VINT Hub Phidget	VINT Hub Phidget	1	$45.13	$45.13	This is a 6 way phidget reaquired for the connection between the encoder readers and the raspberry pi.	VINT Hub Phidget - HUB0001_0 at Phidgets
	VINT Cables	Phidget Cable 120cm	6	$2.25	$13.50	Required for the connection between the encoder readers and the VINT hub.	
Servos & Components	Servo	RC Servo for 1/5 RC Car Serv	6	$100.86	$605.16	Ensure to get the 150Kgcm 270 degree servos. Can get one of these for $58.49 as a first order price.	Baja 1/5 Servo Steering | Rc Baja Servo Steering | Rc Car Steering Servo - Rc
	Servo controller	Micro Maestro 6-Channel U:	1	$49.70	$49.70	This is a 6 channel controller, just the correct number for our application.	Micro Maestro 6-Channel USB Servo Controller (Assembled) | POLOLU-135(
Servo steering	8mm bore Mounting hub	Pololu Universal Aluminum	3	$15.95	$47.85	2 pack comes with gub screws and an allen key	Pololu Universal Aluminum Mounting Hub for 8mm Shaft, M3 Holes (2-Pack
	32 tooth Spur Gear to servo					Will get Mech workshop to manufacture	
	32 tooth Spur gear to steering axle					Will get Mech workshop to manufacture.	
	26 tooth Spur gear 8mm bore		6	5.19	$31.14	Mod 1 Profile	https://www.ebay.com.au/itm/313483206769?var=612326191080
	26 tooth Spur gear flat		6	3.95	$23.70	Mod 1 Profile	https://www.ebay.com.au/itm/313483207103?var=612326191357
	Mounting disk to connect with the servos.	DSSERVO 18T Metal Servo A	6	$5.57	$33.42	Ensure to get the disks not the arms.	https://au.banggood.com/DSSERVO-18T-Metal-Servo-Arm-Servo-Disc-For-[
pully Drivetrain	pully 40 tooth + belt	2Pack GT2 Timing Belt Pulle	3	$4.94	$14.82	2 pack comes with correct length belt	https://www.aliexpress.com/item/1005004354835176.html?spm=a2g0o.de
	pully 28 tooth	2GT/GT2 28 Teeth Tooth Idl	6	$5.32	$31.92	Required for 2:1 ratio	2GT/GT2 28 Teeth Tooth Idler Timing Pulley Bore 45/6/6.35/8/10/12/12.7m
	60 tooth pully	2GT-60Teeth, 7mm, Bore	6	$5.76	$34.56	Had to order these because the previous order was wrong.	2GT 34 80Teeth Timing Pulley Without Step Bore 4/5/6/6.35/8/10/12/12.7/
	28-tooth pulley	28-tooth pulley, Bore Diar	6	$5.15	$30.90	Had to order these because the previous order was wrong.	2GT/GT2 28 Teeth Tooth Idler Timing Pulley Bore 45/6/6.35/8/10/12/12.7m
	8mm shaft	Linear shaft long diameter d	2	$23.98	$47.96	Ensure to get the 400mm long, 8mm diameter shaft (One shaft for steering axi	https://www.aliexpress.com/item/1005004104816559.html?pdp_npi=2%4(
	8mm bore hub Connector	8mm Shaft Universal Alumir	6	$9.40	$56.40	Will connect the wheel to the hub. DISLIKE PRICE	https://www.aliexpress.com/item/32897216951.html?&_t=pvid:e2afa43a-(
Rocker Bogie + differential joints	22*7*8mm bore ball bearings		3	$0.98	$2.94	24 bearings rquired, Get 3 packs of 10	https://www.aliexpress.com/item/32949333808.html?pdp_npi=2%40dis%2
	Flat bearing pillow block 12mm bore KFL001	KFL001 12mm Bore Diamete	8	$1.20	$9.60		https://www.aliexpress.com/item/4000150146292.html?pdp_npi=2%40dis
	Vertical mount pillow block 12mm bore	2x 12mm Diameter Bore Bal	1	$9.98	$9.98	one 2 pack required	
	SHF12 12mm bore clamp end	SHF12 aluminum linear Rod	2	$2.09	$4.18		https://www.aliexpress.com/item/32946096241.html?pdp_npi=2%40dis%2
	12mm shaft	1pc 12mm linear shaft Rail 4	1	$12.43	$12.43		https://www.aliexpress.com/item/1005003215184406.html?pdp_npi=2%4(
	Washers		8				
Differential	Ball joint tie rods		1	$38.68	$38.68	Comes as a set of 2	https://www.aliexpress.com/i/1005001555511982.html
Chassis	3 meter lengths profile 5 20x20mm aluminiu	Profile 5 20x20, natural	4	$58.00	$232.00	ITEM 11.16 meters worth of extrusion is required. Therefore order 12 meters	https://www.item24.com/en-de/profile-5-20x20-natural-37003/
	2 meter length cut profile 5 40x20mm alumi	Profile 5 40x20, natural	2	$72.00	$144.00	ITEM 3.7 meters worth required. Will order a single 4m length so we have a little bit of spare	https://www.item24.com/en-de/profile-5-40x20-natural-37004/
	Standard-Fastening Set 5, stainless	Automatic-Fastening Set 5, s	40	$2.30	$92.00	ITEM Double check this number before ordering.	https://www.item24.com/en-de/standard-fastening-set-5-stainless-43749/
	cutting fee		6	$2.50	$15.00	As quoted by state wide bearings	
	Delivery				$100	As quoted by state wide bearings	
	Chassis floor		1			ITEM 1080 X 710 X 4mm composite panel from ITEM.	
	Perspex acrylic side panels	Acrylic CAST Clear Sheet 2m	1	$65.00	$65.00	Will get one large sheet and laser cut to size	https://www.ebay.com.au/itm/114742132836?chn=ps&_ul=AU&norover=1

Bolts	Wheel to hub		36			Need to choose appropiate size for each attachment point.	
	motor to ankle		36			Found the right ones in Makers Lab M3	
	ankle to steering axel hub		36				
	Servo to servo mount		12				
	Servo ribbon to servo mount		12				
	servo mount to bogie (or rocker)		24			Assuming 4 per servo mount	
	Pillow block to rocker bogie plate		8				
	Rocker bogie plate to rocker through bolt		8			Requires nuts	
	Pillow block to rocker joint bracket		4				
	Vertical pillow block to chassis		4				
	Rocker joint mount to chassis		12			Assuming 6 each	
	Threaded insert to third leg		24				
	Pillow block to chassis (differential axis)		4				
	Shaft clamp to differential bar		4				
Other	Hinges for Solar panel		3				
	Lock/latch fro solar panel lid						
	On/off switch						
	Wiring for 12V lines						
	Wiring for data lines						
	3D print filament for various components						
	Extra Bearings		1	$24.44	$24.44	30pk 22x7x8 bearings	30pcs 608zz Ball Bearings,metal Double Shielded Speed Bearings Quality Ba
	Rubber mat and angle brackets		1	25.68	$25.68	Bunnings Warehouse	
	MDF, rubber strips, brackets		1	59.49	$59.49	Bunnings Warehouse	
	Servo wires		1	39.06	$39.06	Ali Express	
	Servo Controller - Replacement		1	44.5	$44.50	Core electronics	
	MPF boards and Latches		1	28.34	$28.34	Bunnings Warehouse	
	Aluminium, screws, handles		1	68.88	$68.88	Bunnings Warehouse	
	Hinges, handles, gas strut		1	61.07	$61.07	Bunnings Warehouse	
	Gears 26t Mod 1		1	30.54	$30.54	ebay	
					$0.00		
	CNC Components		1	1191	$1,191.00	US 766.31	
			1	322.09	$322.09	US 207.24	
				total	$4,255.71		

For Mechnical Workshop to manufacture

		One piece CNC wheel with b	6		$ 2,700.00	Quote from mech workshop to manufacture wheels (Was not manufactured)
	Wheels	Acts as the 'castor' for the w	6			
	'Ankle' wheel mount	Right parity	3			Need to make 3 of each parity
	servo and steering mount	Left parity	3			Need to make 3 of each parity
			4			
	Rocker to bogie plates		2			
	Rocker Joint mount	long nose	2			Long and short refers to the length of the threaded section.
	Threaded insert	short nose	2			
			6			
	Spur gear to servo		6			
	spur gear to steering axle					

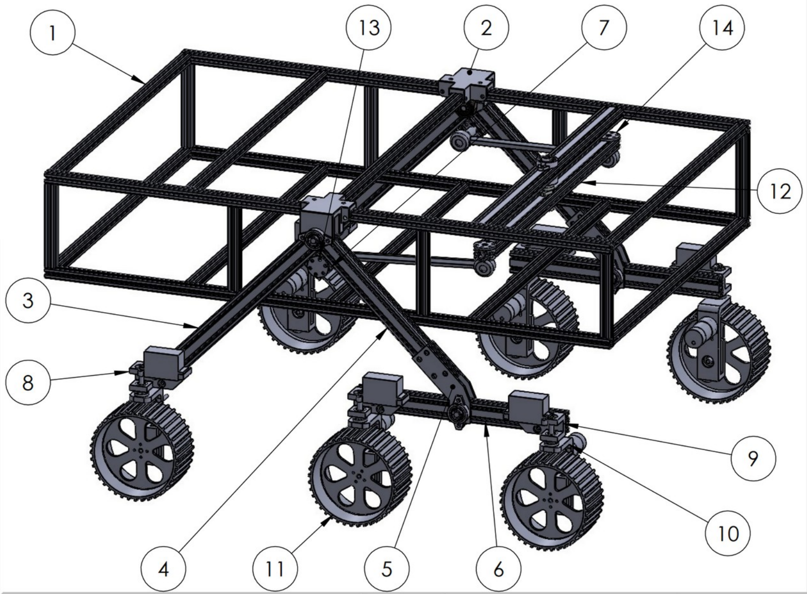
Already purchased

		Name	Quantity	Price each	Total Price	Notes	Website
	Component		1	$ 149.00	$ 149.00		
	700 X 1000mm solar panel + Controller		1	$ 249.00	$ 249.00		
	Luxonis Oak D S2		1	$ 58.10	$ 58.10		
	Raspberry Pi 3		1	$ 82.30	$ 82.30		
	Touchscreen		1	$ 469.99	$ 469.99		
	Battery		1				
	e stop		1				
	fuse case and fuse		1				
	Lidar	FIT0185	2	$48.17	$96.34		
	Motor	LM2596	1	$4.88	$4.88		
	DC-DC step down power modual						
				Total purchas	$ 1,109.61		
				total overall	$ 5,365.32	This does not include the Aluminium and parts from ITEM or some of the Mech Workshop parts to manufacture.	

Appendix F – Technical Drawings

Images of all the technical drawings for the rover components are included below.

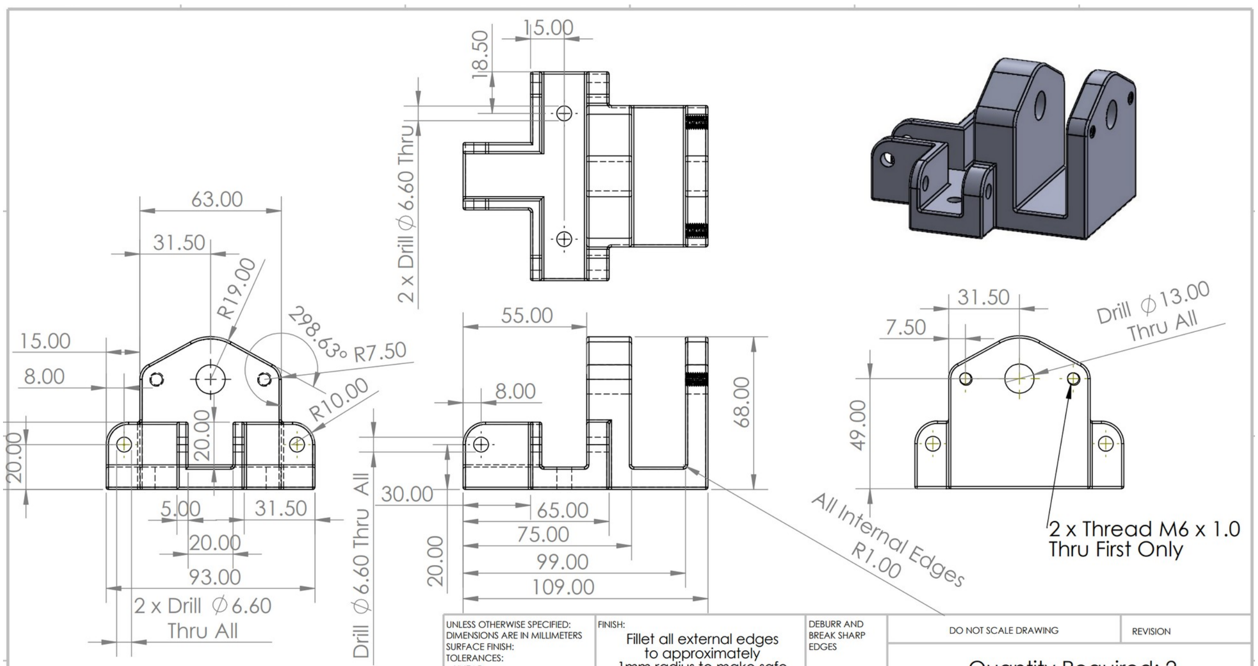
ITEM NO.	PART NUMBER	QTY.
1	Chassis Extrusion Cutting List	1
2	Rocker Joint Bracket	2
3	Rocker Leg	2
4	Rocker Short Leg	2
5	Rocker to Bogie Plate	4
6	Bogie	2
7	Rocker Attachment	2
8	Servo Mount	3
9	Servo Mount Inverted	3
10	Wheel Mount	6
11	Rover Wheel	6
12	Differential Bar	1
13	Threaded Insert - Longer	2
11	Threaded insert - shorter	2



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Please see drawing of all labled components.

	NAME	SIGNATURE	DATE
DRAWN	Pearce Brezmen		2/Jul/23
CHK'D			
APPV'D			
MFG			
Q.A			

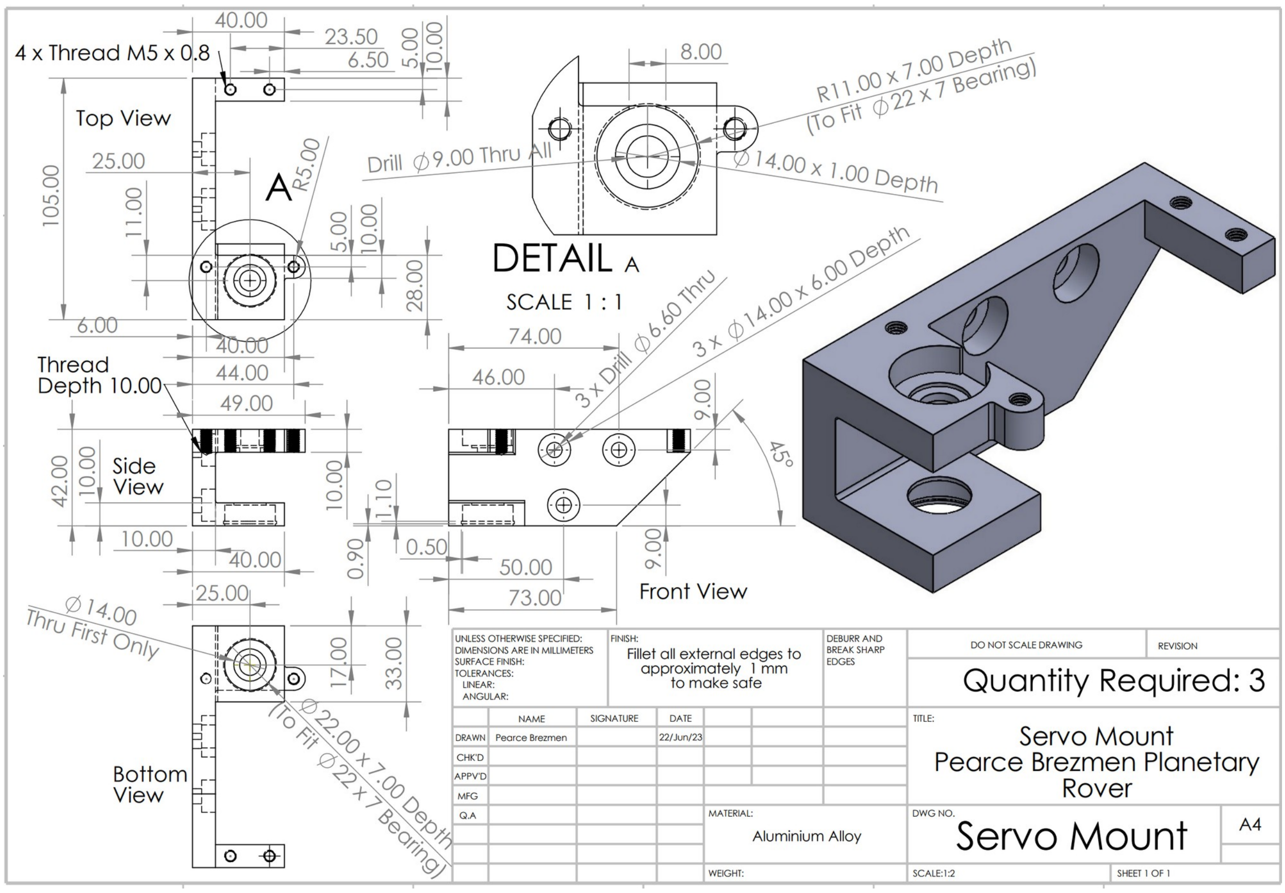
TITLE: Planetary Rover Pearce Brezmen
MATERIAL:
DWG NO. Planetary Rover Overall View
A4
WEIGHT:
SCALE:1:20
SHEET 1 OF 1



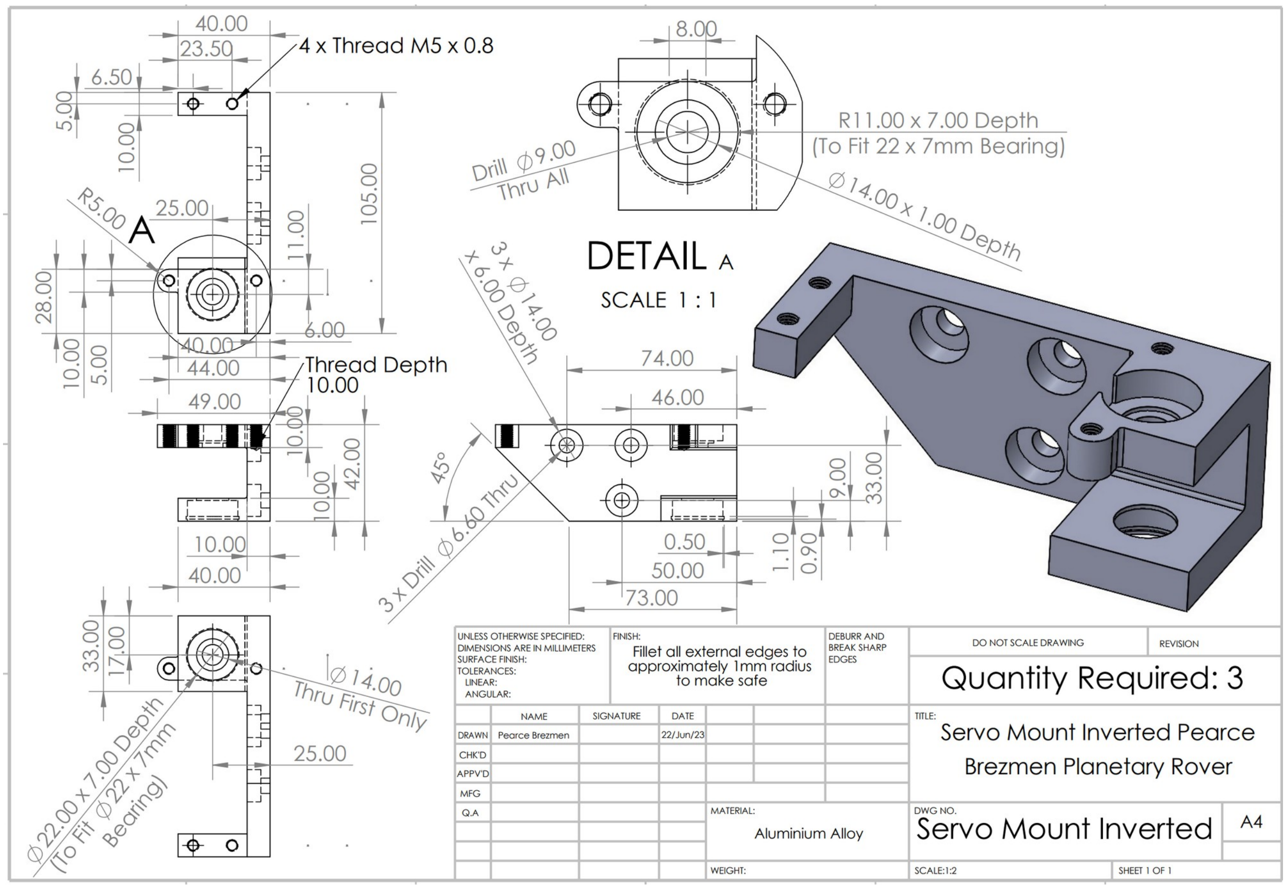
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH: Fillet all external edges to approximately 1mm radius to make safe.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2

	NAME	SIGNATURE	DATE
DRAWN	Pearce Brezmen		19/Jun/23
CHK'D			
APPV'D			
MFG			
Q.A			

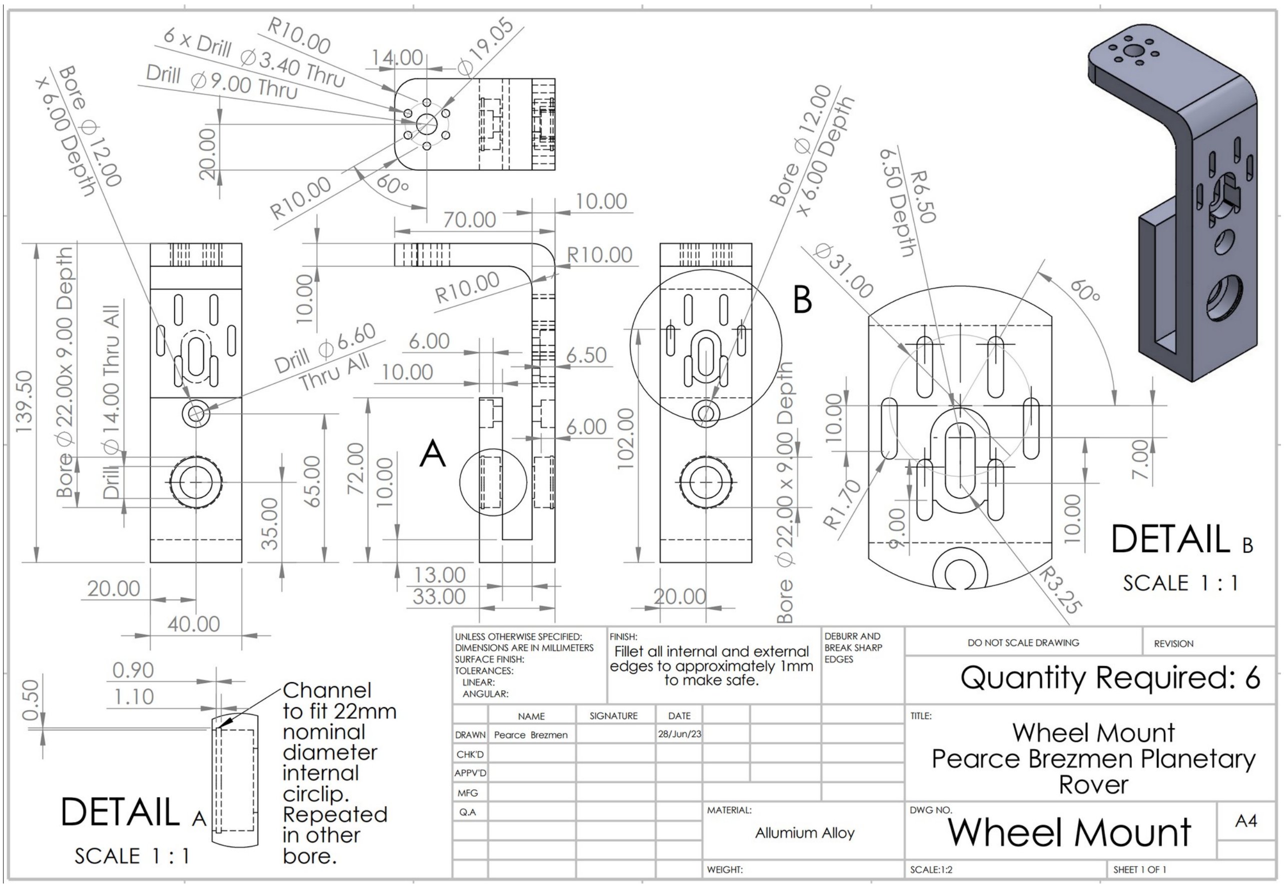
TITLE: Rocker Joint Bracket Pearce Brezmen Planetary Rover
MATERIAL: Aluminium Alloy
DWG NO. Rocker Joint Bracket
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

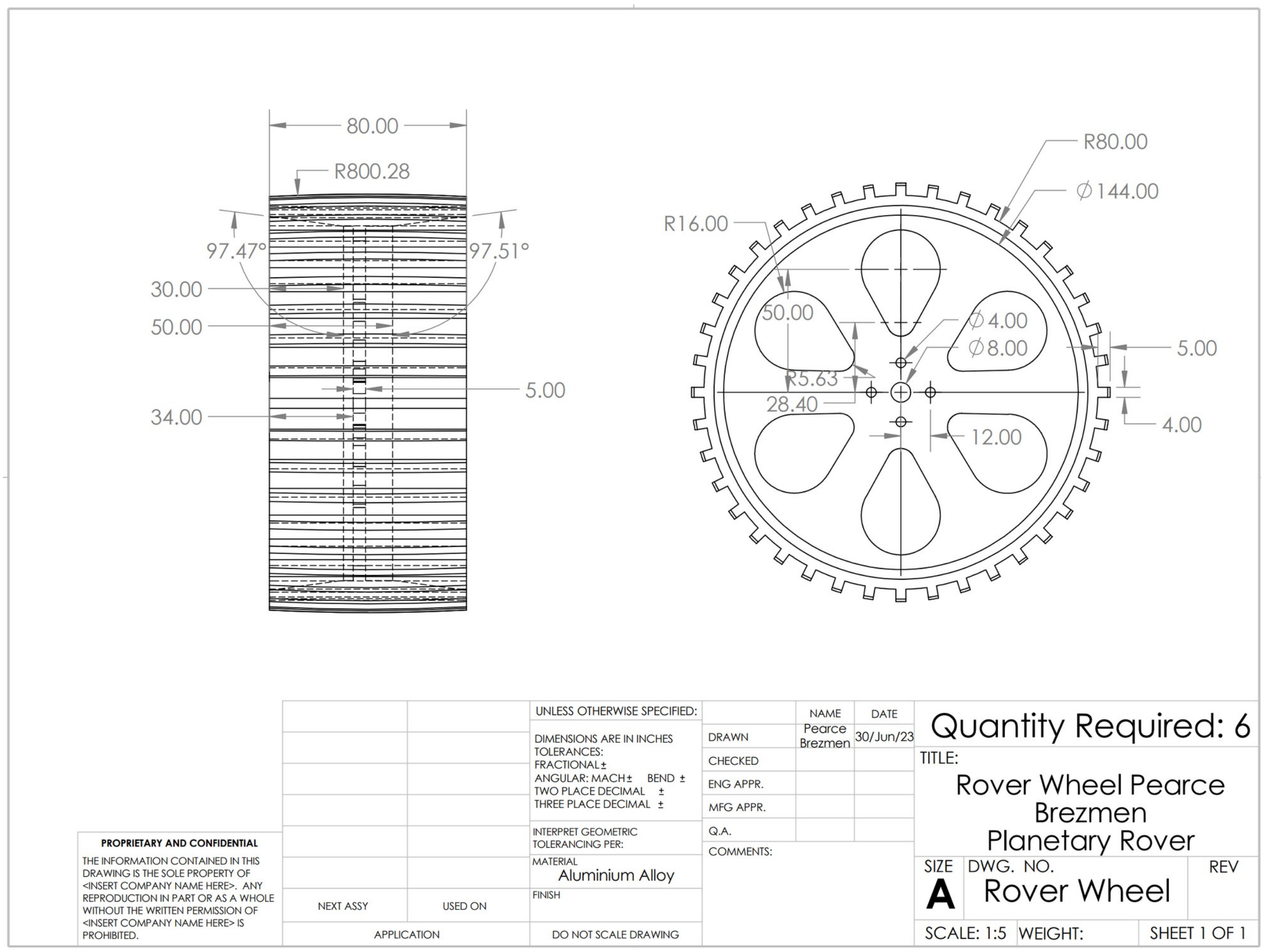


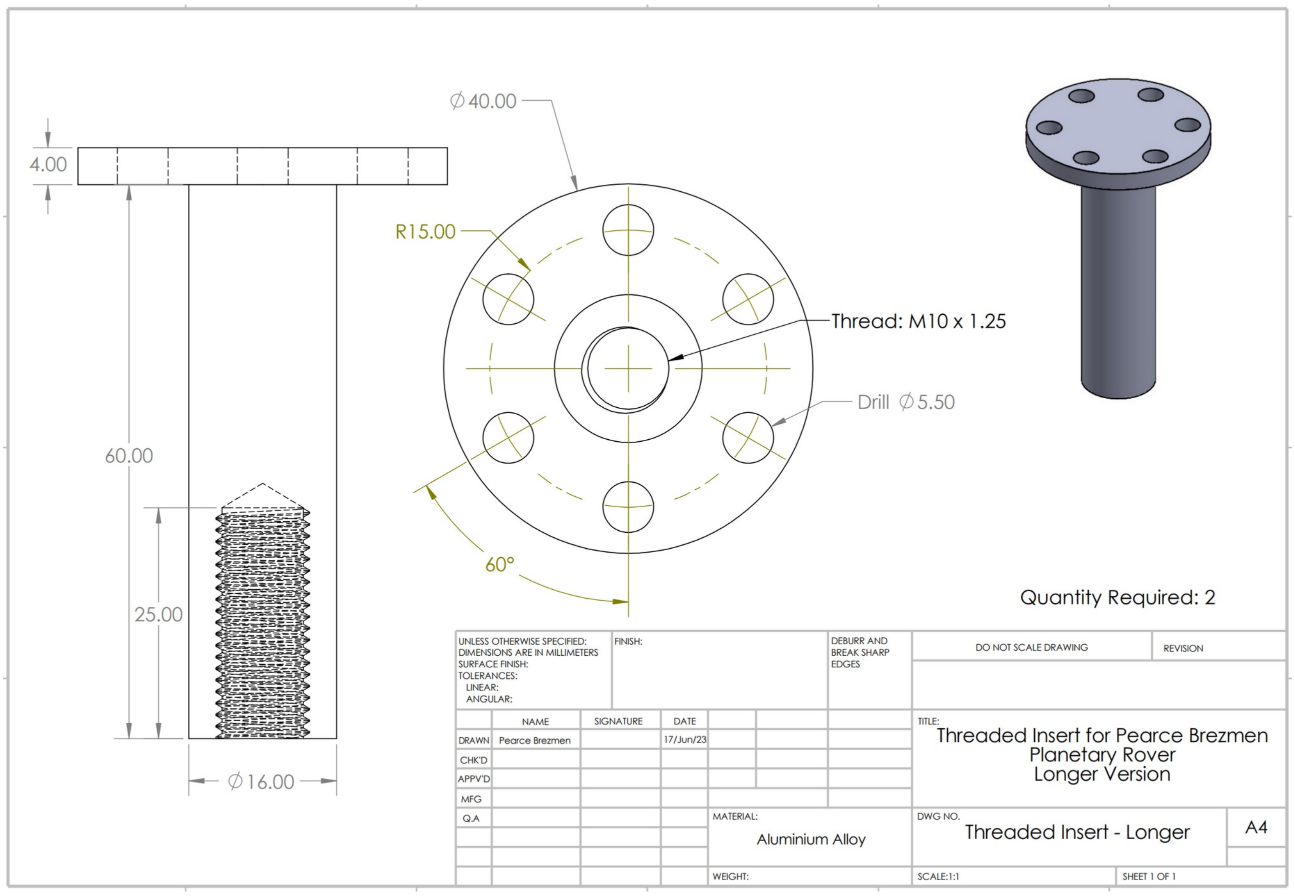
4 x Thread M5 x 0.8
Top View
A
R5.00
DETAIL A
SCALE 1 : 1
Drill Ø9.00 Thru All
R11.00 x 7.00 Depth
(To Fit Ø22 x 7 Bearing)
Ø14.00 x 1.00 Depth
3 x Drill Ø6.60 Thru
3 x Ø14.00 x 6.00 Depth
Thread
Depth 10.00
Side
View
Front View
45°
Ø14.00
Thru First Only
Ø22.00 x 7.00 Depth
(To Fit Ø22 x 7 Bearing)
Bottom
View
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
Fillet all external edges to approximately 1 mm to make safe
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 3
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
22/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Servo Mount
Pearce Brezmen Planetary
Rover
MATERIAL:
Aluminium Alloy
DWG NO.
Servo Mount
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

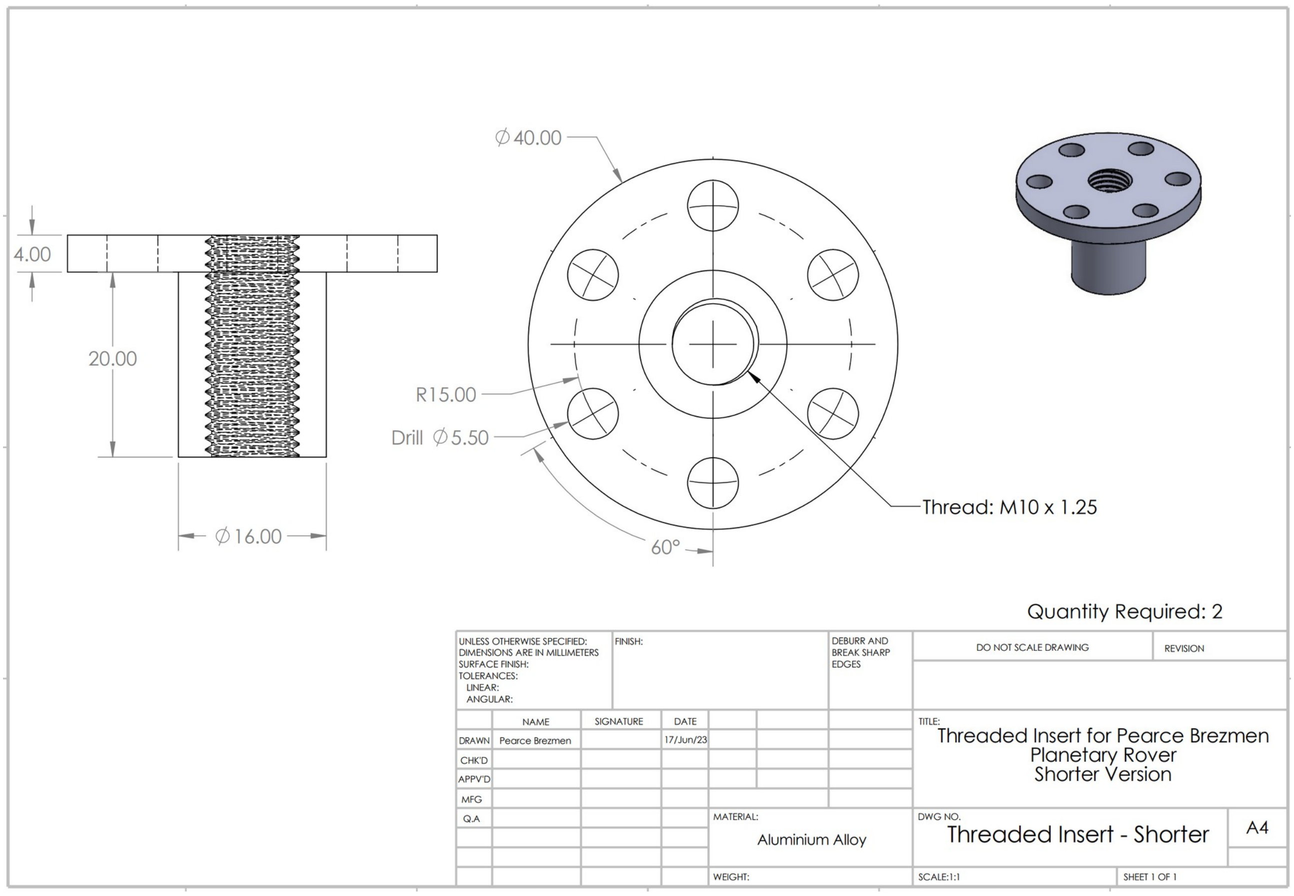


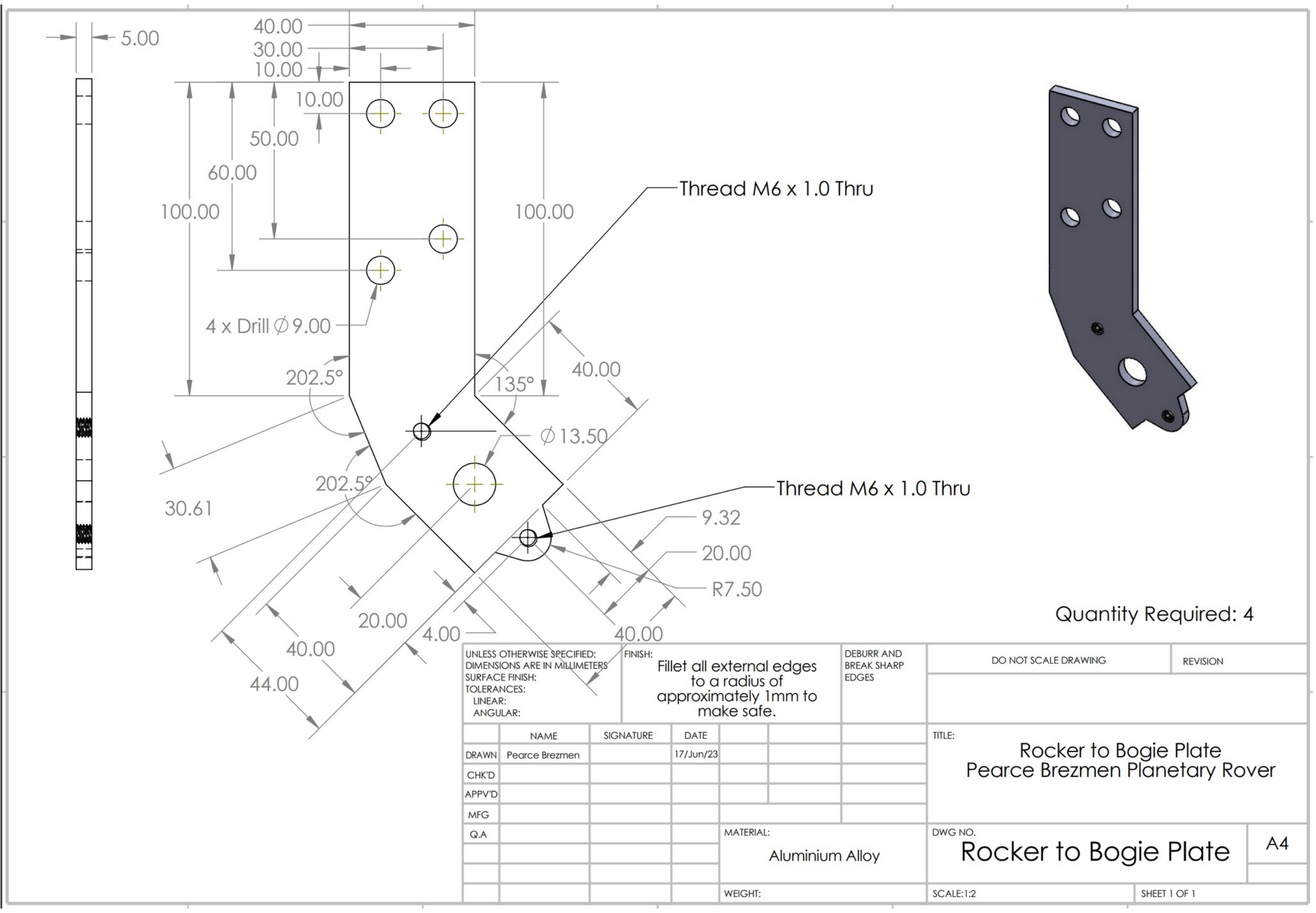
4 x Thread M5 x 0.8
R5.00
A
DETAIL A
SCALE 1 : 1
Drill Ø9.00
Thru All
R11.00 x 7.00 Depth
(To Fit 22 x 7mm Bearing)
Ø14.00 x 1.00 Depth
3 x Ø14.00
x 6.00 Depth
Thread Depth
10.00
45°
3 x Drill Ø6.60 Thru
Ø14.00
Thru First Only
Ø22.00 x 7.00 Depth
(To Fit Ø22 x 7mm
Bearing)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
Fillet all external edges to approximately 1mm radius to make safe
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 3
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
22/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Servo Mount Inverted Pearce
Brezmen Planetary Rover
MATERIAL:
Aluminium Alloy
DWG NO.
Servo Mount Inverted
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

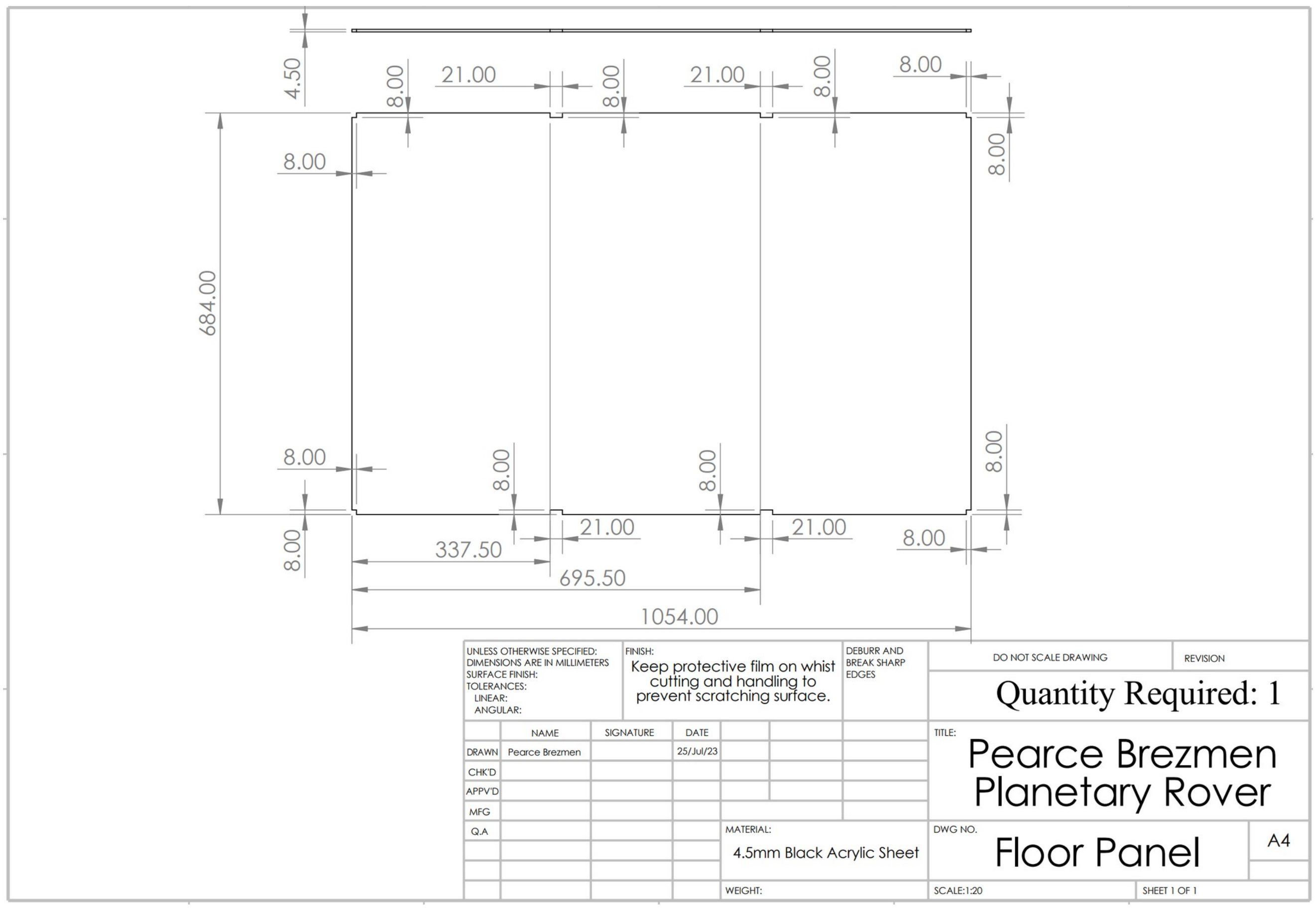

6 x Drill ∅3.40 Thru
Drill ∅9.00 Thru
R10.00
14.00
∅19.05
20.00
60°
Bore ∅12.00 x 6.00 Depth
139.50
Bore ∅22.00x 9.00 Depth
Drill ∅14.00 Thru All
Drill ∅6.60 Thru All
70.00
10.00
R10.00
6.00
6.50
102.00
72.00
65.00
35.00
13.00
33.00
20.00
40.00
A
B
6.50 Depth
R6.50
∅31.00
R1.70
9.00
7.00
R3.25
DETAIL B
SCALE 1 : 1
0.90
1.10
0.50
Channel to fit 22mm nominal diameter internal circlip. Repeated in other bore.
DETAIL A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH: Fillet all internal and external edges to approximately 1mm to make safe.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 6
NAME SIGNATURE DATE
DRAWN Pearce Brezmen 28/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Wheel Mount
Pearce Brezmen Planetary Rover
MATERIAL:
Allumium Alloy
DWG NO.
Wheel Mount
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

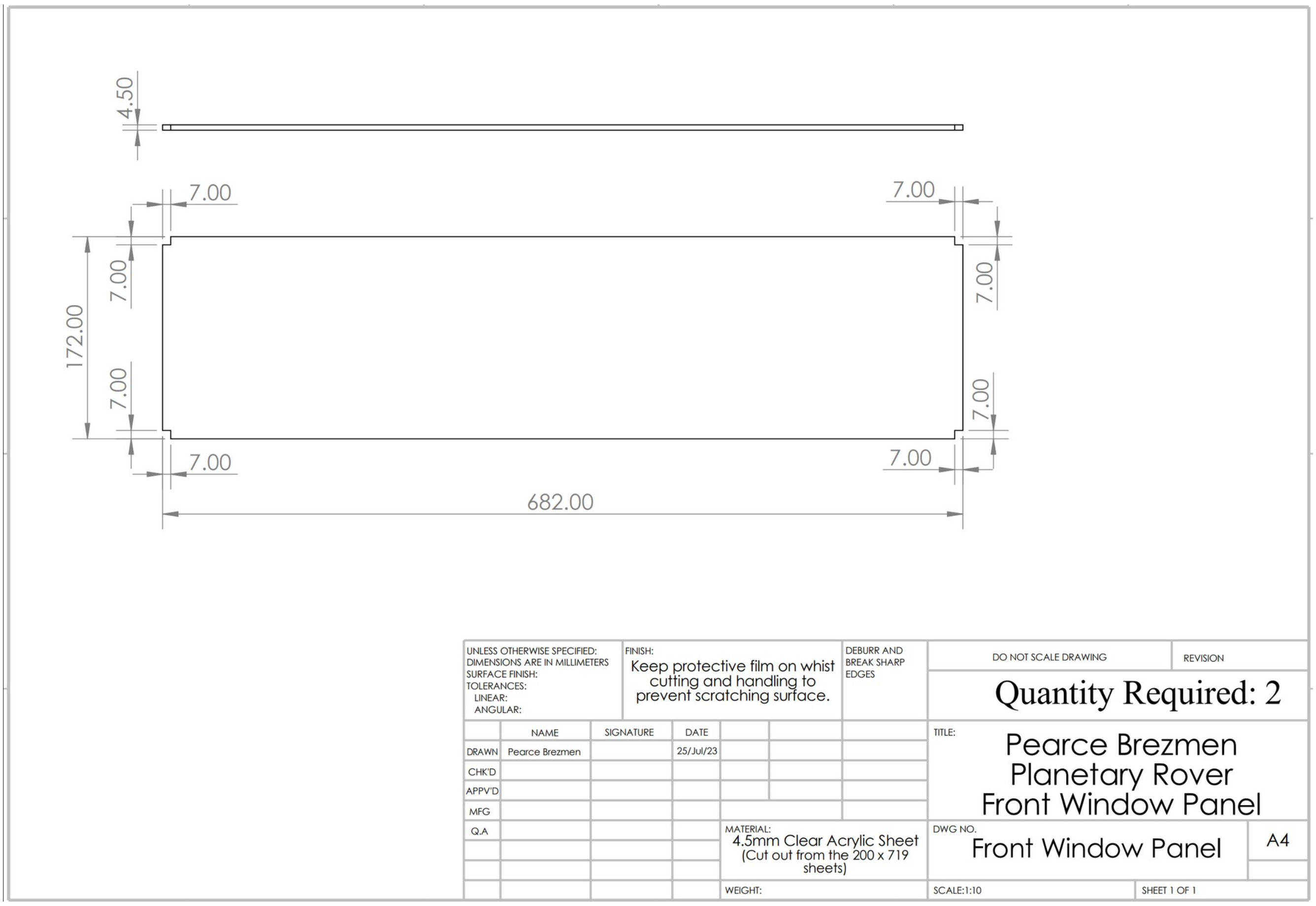

80.00
R800.28
97.47°
97.51°
30.00
50.00
34.00
5.00
R80.00
∅144.00
R16.00
50.00
∅4.00
∅8.00
R5.63
28.40
12.00
5.00
4.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminium Alloy
FINISH
NAME DATE
DRAWN Pearce Brezmen 30/Jun/23
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity Required: 6
TITLE:
Rover Wheel Pearce Brezmen Planetary Rover
SIZE A
DWG. NO.
Rover Wheel
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

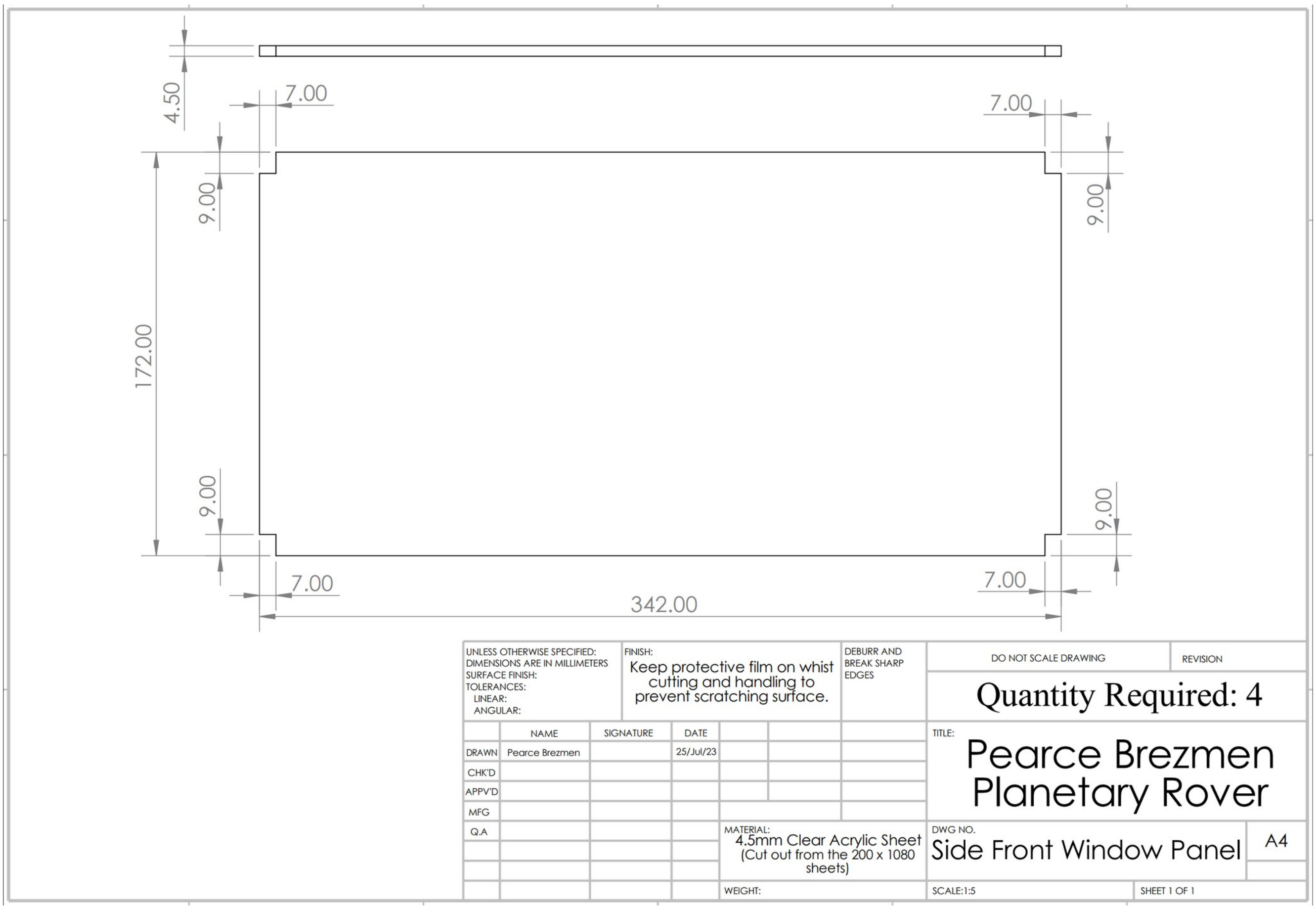

∅40.00
4.00
R15.00
Thread: M10 x 1.25
Drill ∅5.50
60.00
25.00
60°
∅16.00
Quantity Required: 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
17/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Threaded Insert for Pearce Brezmen
Planetary Rover
Longer Version
MATERIAL:
Aluminium Alloy
DWG NO.
Threaded Insert - Longer
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1

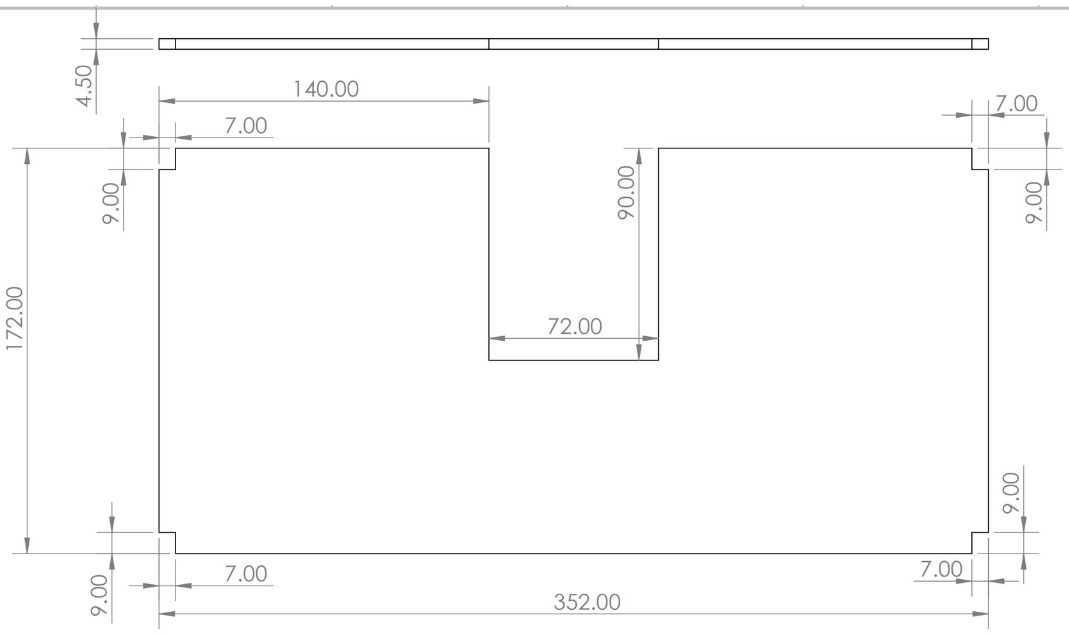

∅40.00
4.00
20.00
R15.00
Drill ∅5.50
Thread: M10 x 1.25
60°
∅16.00
Quantity Required: 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
17/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Threaded Insert for Pearce Brezmen
Planetary Rover
Shorter Version
MATERIAL:
Aluminium Alloy
DWG NO.
Threaded Insert - Shorter
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


5.00
40.00
30.00
10.00
10.00
50.00
60.00
100.00
100.00
Thread M6 x 1.0 Thru
4 x Drill ∅9.00
202.5°
135°
40.00
∅13.50
30.61
202.5°
Thread M6 x 1.0 Thru
9.32
20.00
R7.50
20.00
4.00
40.00
40.00
44.00
Quantity Required: 4
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH: Fillet all external edges to a radius of approximately 1mm to make safe.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN Pearce Brezmen 17/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE: Rocker to Bogie Plate Pearce Brezmen Planetary Rover
MATERIAL: Aluminium Alloy
DWG NO. Rocker to Bogie Plate
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1


4.50
8.00
21.00
8.00
21.00
8.00
8.00
8.00
8.00
684.00
8.00
8.00
8.00
8.00
8.00
21.00
21.00
8.00
337.50
695.50
1054.00
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH: Keep protective film on whist cutting and handling to prevent scratching surface.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 1
NAME
SIGNATURE
DATE
DRAWN Pearce Brezmen 25/Jul/23
CHK'D
APPV'D
MFG
Q.A
TITLE: Pearce Brezmen Planetary Rover
MATERIAL: 4.5mm Black Acrylic Sheet
DWG NO. Floor Panel
A4
WEIGHT:
SCALE:1:20
SHEET 1 OF 1


4.50
7.00
7.00
172.00
7.00
7.00
7.00
7.00
7.00
7.00
7.00
682.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
Keep protective film on whist cutting and handling to prevent scratching surface.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
25/Jul/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Pearce Brezmen Planetary Rover Front Window Panel
MATERIAL:
4.5mm Clear Acrylic Sheet (Cut out from the 200 x 719 sheets)
DWG NO.
Front Window Panel
A4
WEIGHT:
SCALE:1:10
SHEET 1 OF 1


4.50
7.00
7.00
9.00
9.00
172.00
9.00
9.00
7.00
7.00
342.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
Keep protective film on whist cutting and handling to prevent scratching surface.
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 4
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
25/Jul/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Pearce Brezmen Planetary Rover
MATERIAL:
4.5mm Clear Acrylic Sheet (Cut out from the 200 x 1080 sheets)
DWG NO.
Side Front Window Panel
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: Keep protective film on whist cutting and handling to prevent scratching surface.

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Quantity Required: 2

	NAME	SIGNATURE	DATE
DRAWN	Pearce Brezmen		25/Jul/23
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: 4.5mm Clear Acrylic Sheet (Cut out from the 200 x 1080 sheets)

WEIGHT:

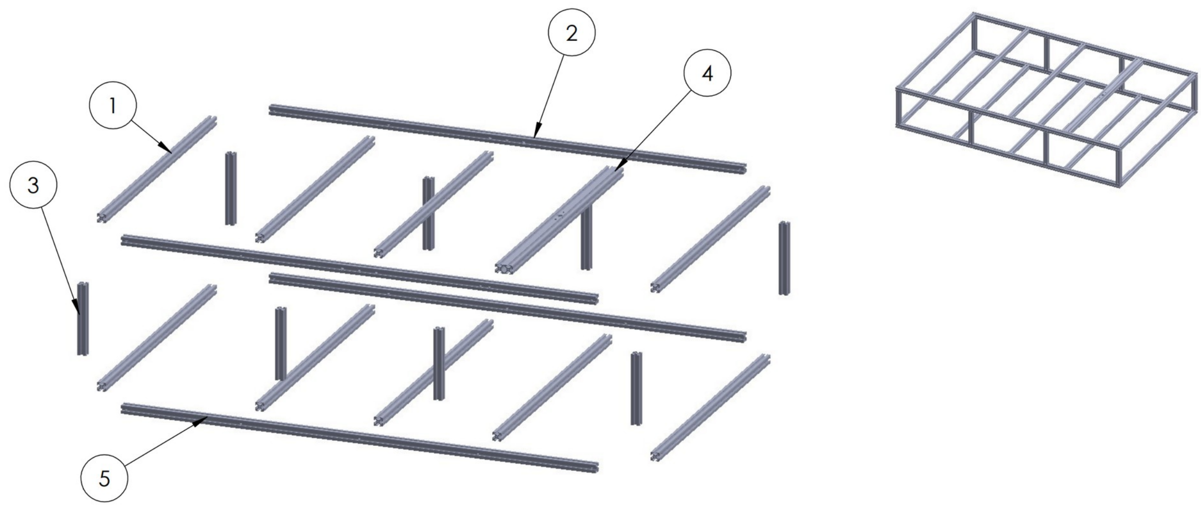
TITLE: Pearce Brezmen Planetary Rover

DWG NO. Side Middle Window Panel

A4

SCALE:1:5

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Chassis front top V slot		9
2	Chassis side top V slot		2
3	Chassis vertical V slot		8
4	Chassis cross beam for diff		1
5	Chassis side bottom V slot		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Please see the assosciated drawing for each part

	NAME	SIGNATURE	DATE
DRAWN	Pearce Brezmen		20/Jun/23
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

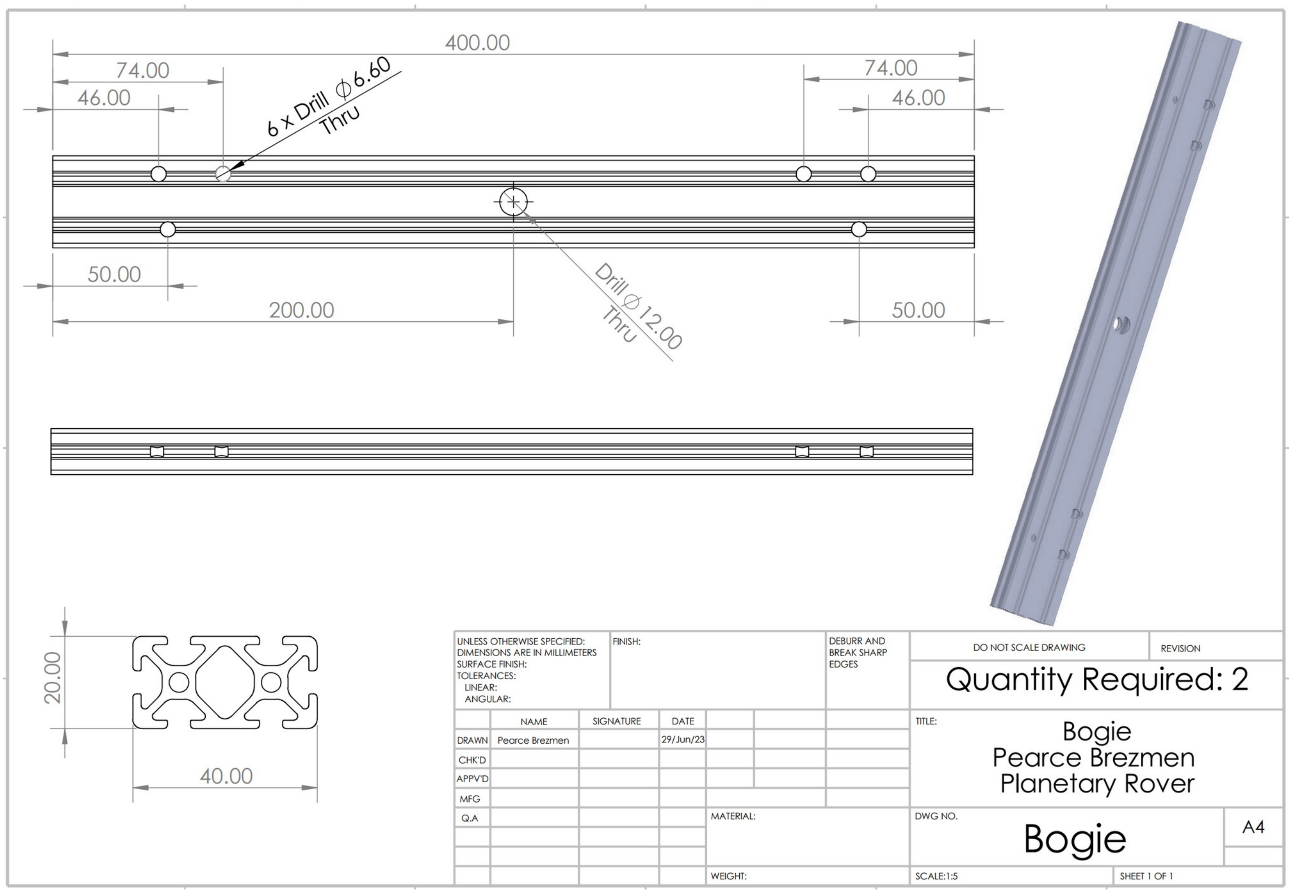
TITLE: Aluminium Extrusion Cutting List Pearce Brezmen Planetary Rover

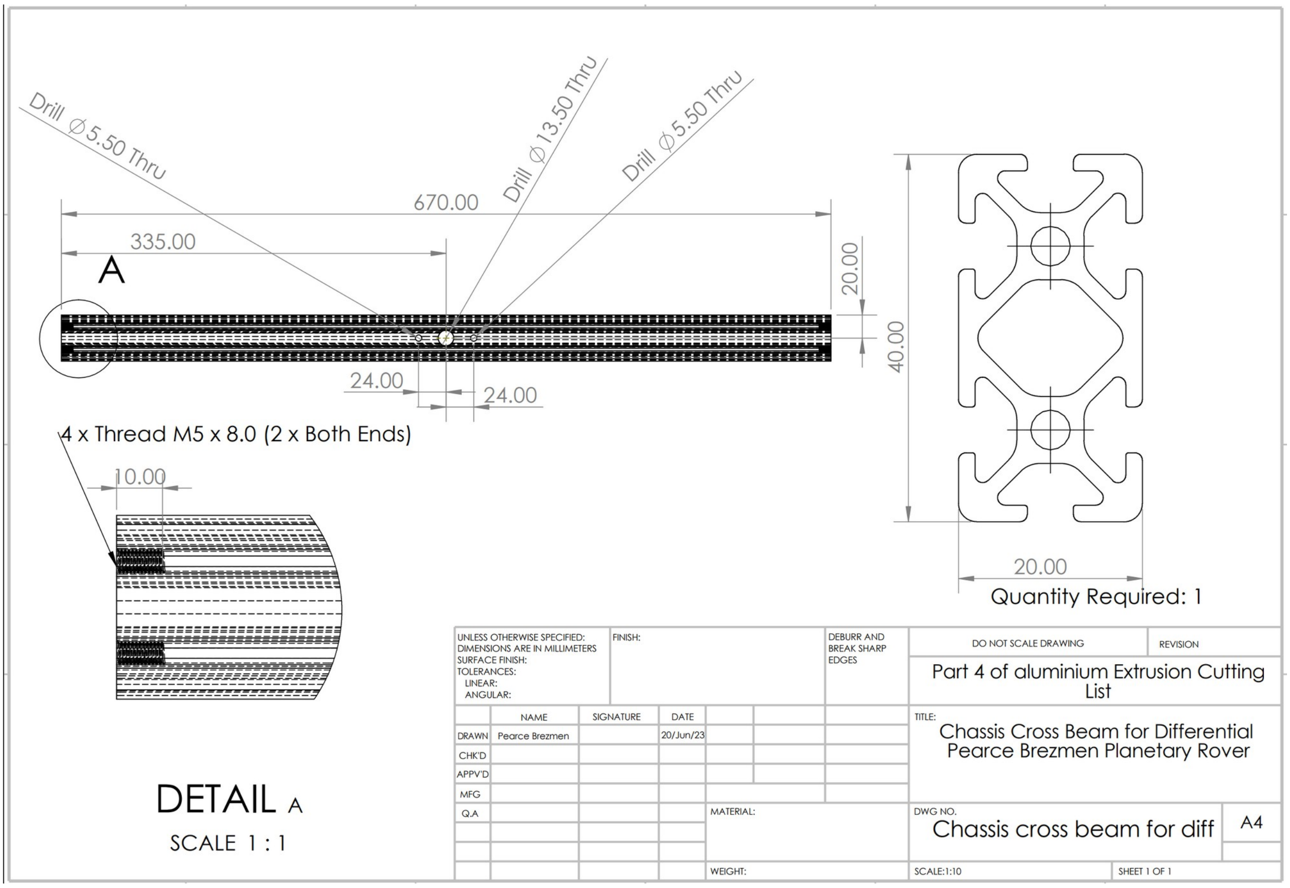
DWG NO. Aluminium Extrusion Cutting List

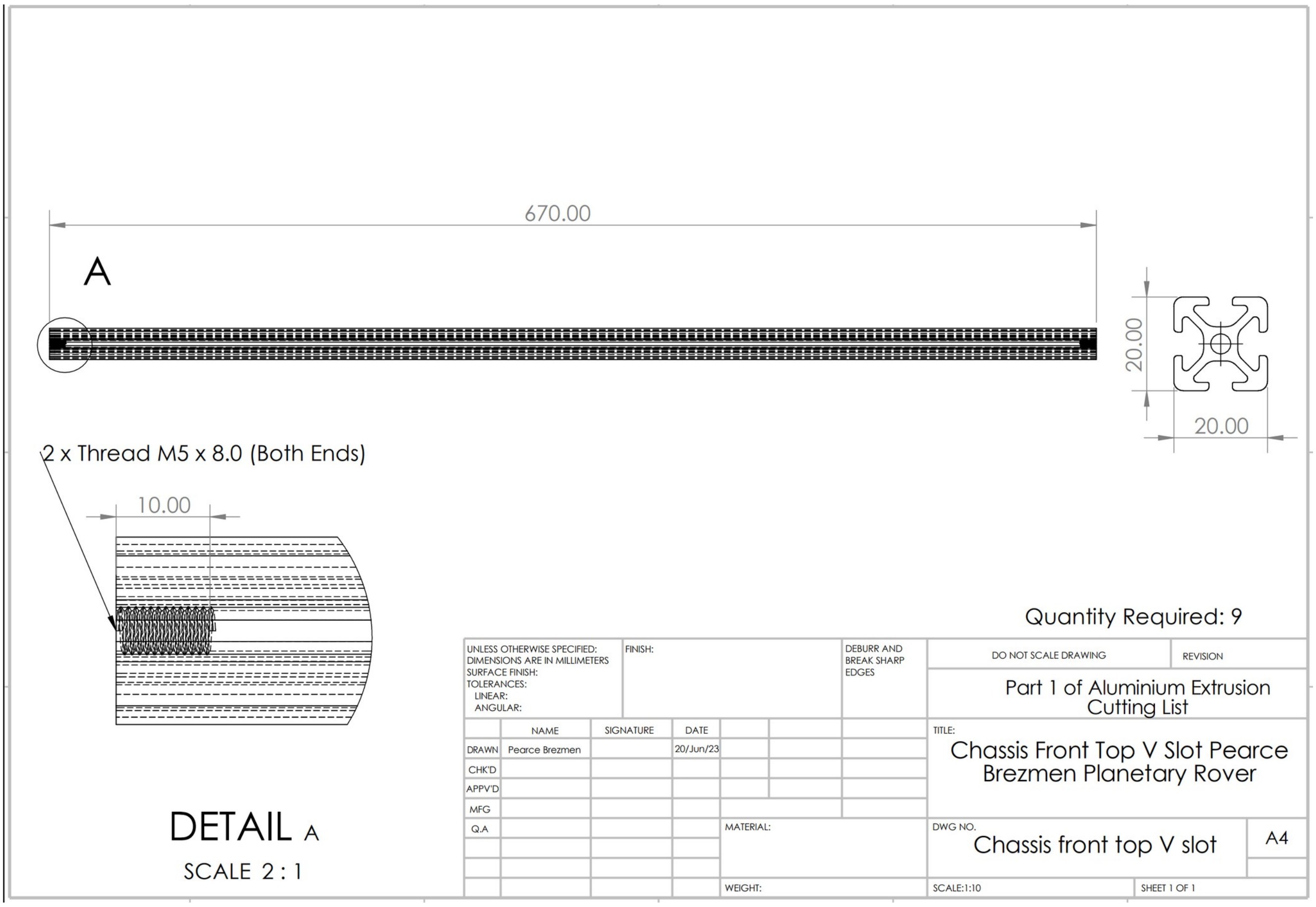
A4

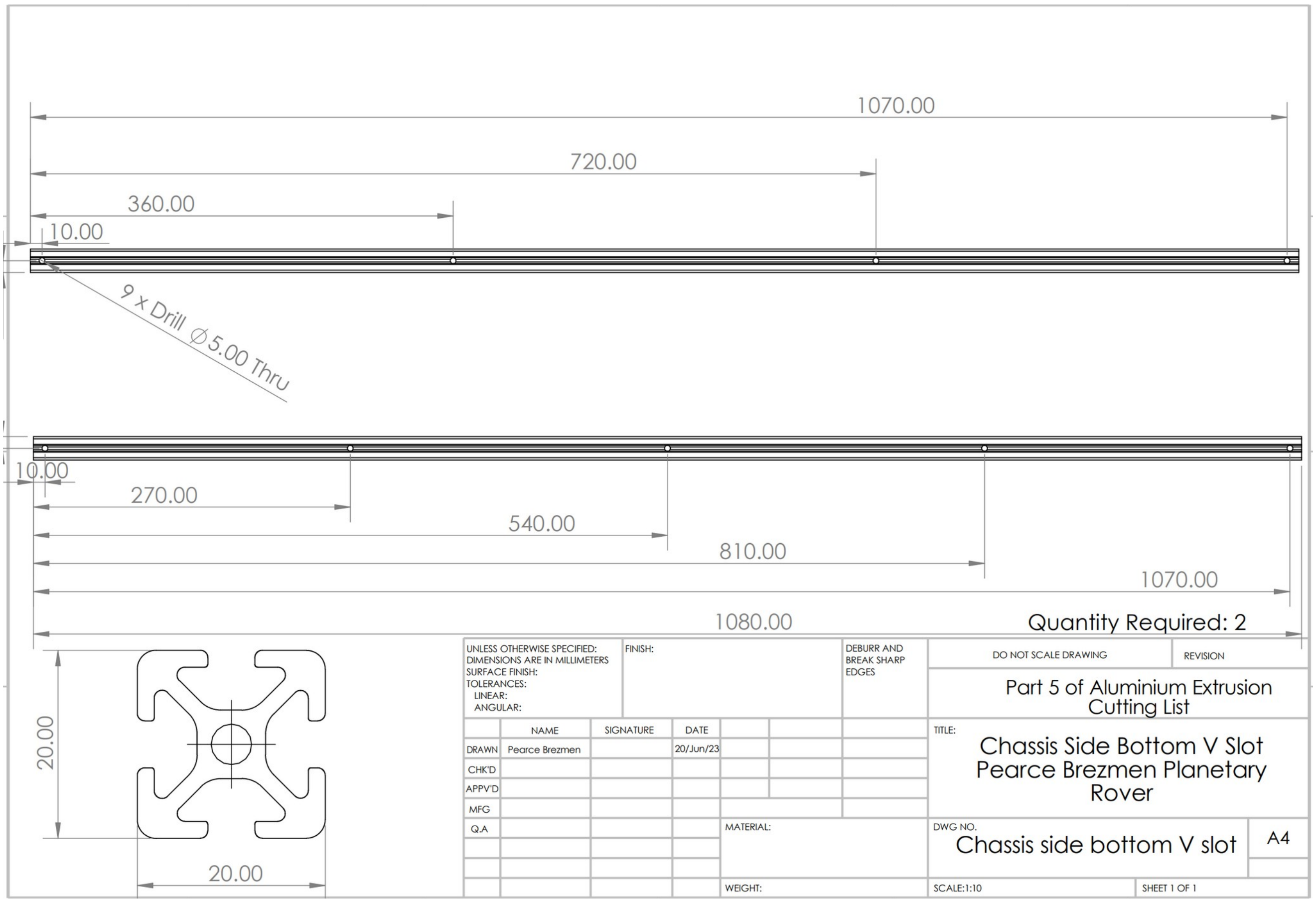
SCALE:1:20

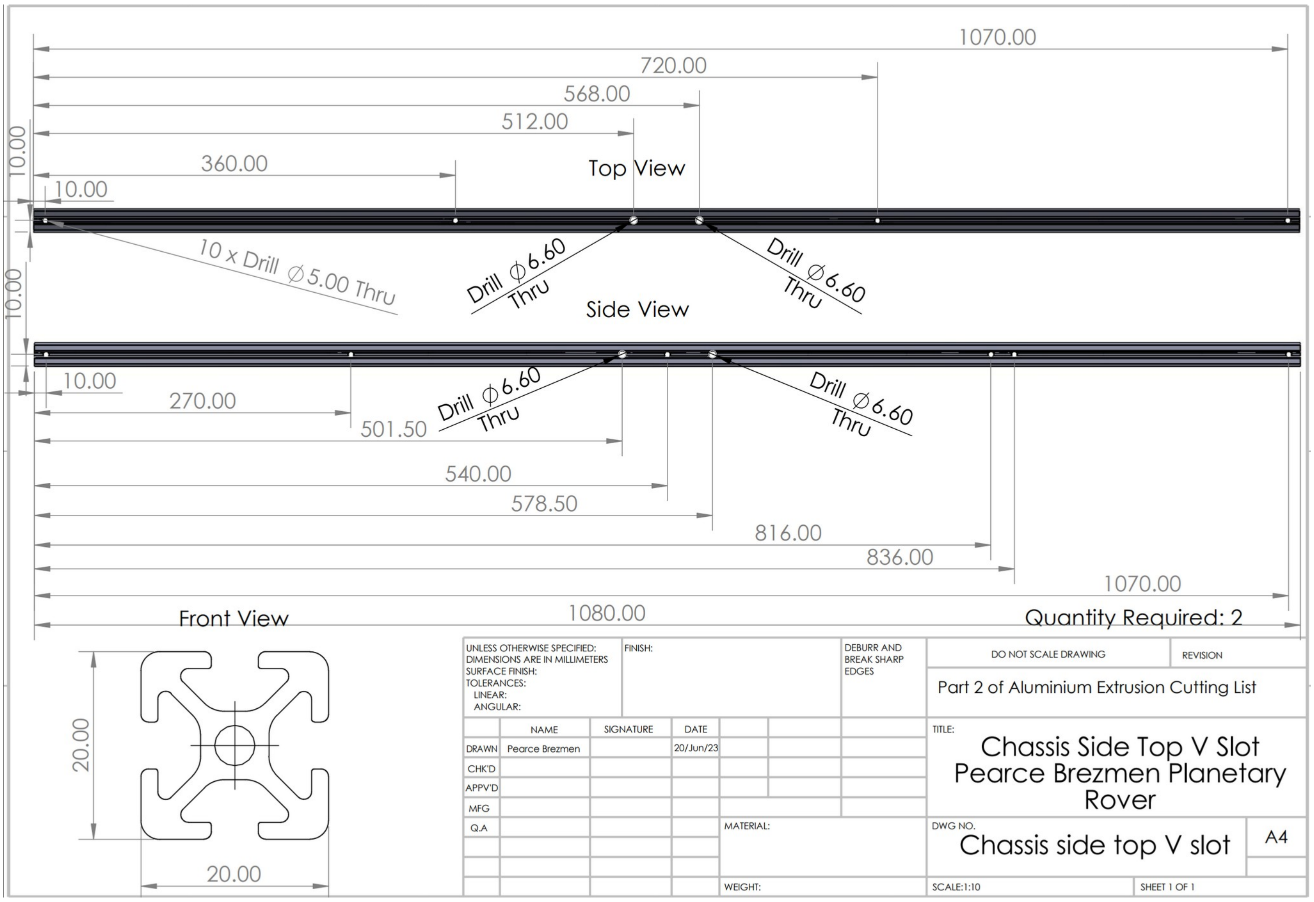
SHEET 1 OF 1

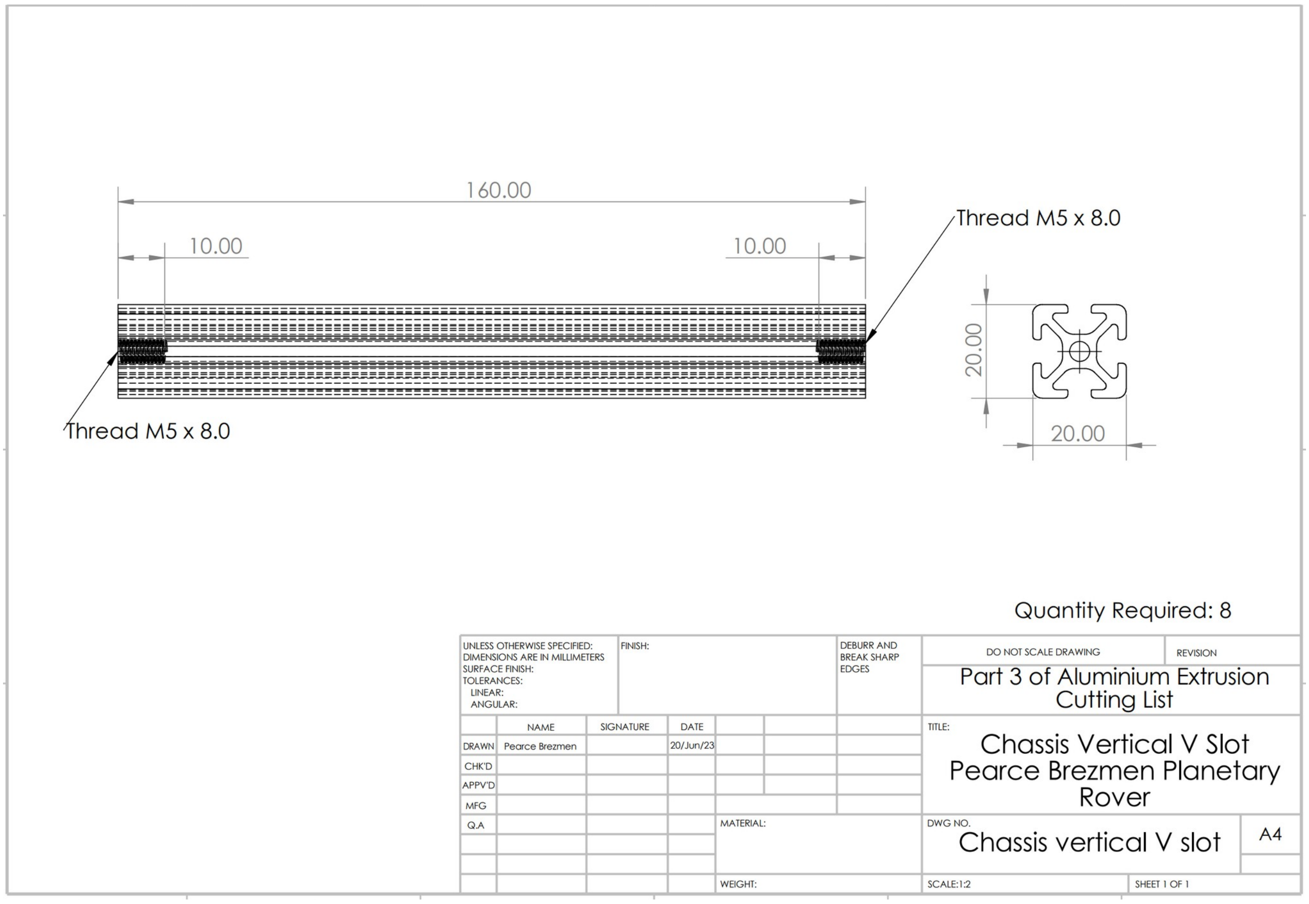

400.00
74.00
46.00
74.00
46.00
6 x Drill ⌀6.60 Thru
Drill ⌀12.00 Thru
50.00
200.00
50.00
20.00
40.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
29/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Bogie
Pearce Brezmen
Planetary Rover
MATERIAL:
DWG NO.
Bogie
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

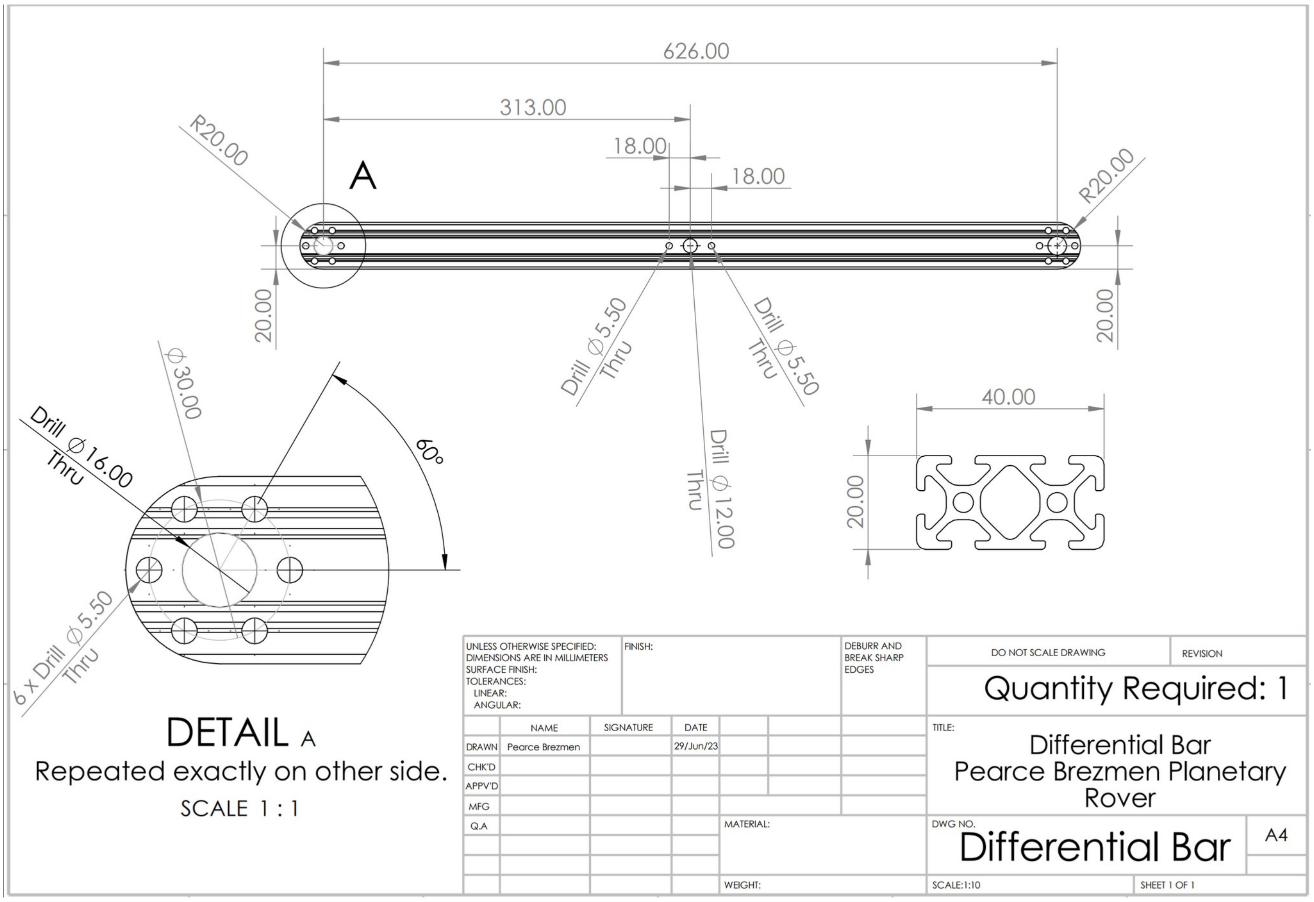

Drill ⌀5.50 Thru
Drill ⌀13.50 Thru
Drill ⌀5.50 Thru
670.00
335.00
A
20.00
40.00
24.00
24.00
4 x Thread M5 x 8.0 (2 x Both Ends)
10.00
20.00
Quantity Required: 1
DETAIL A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Part 4 of aluminium Extrusion Cutting List
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
20/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Chassis Cross Beam for Differential
Pearce Brezmen Planetary Rover
MATERIAL:
DWG NO.
Chassis cross beam for diff
A4
WEIGHT:
SCALE:1:10
SHEET 1 OF 1

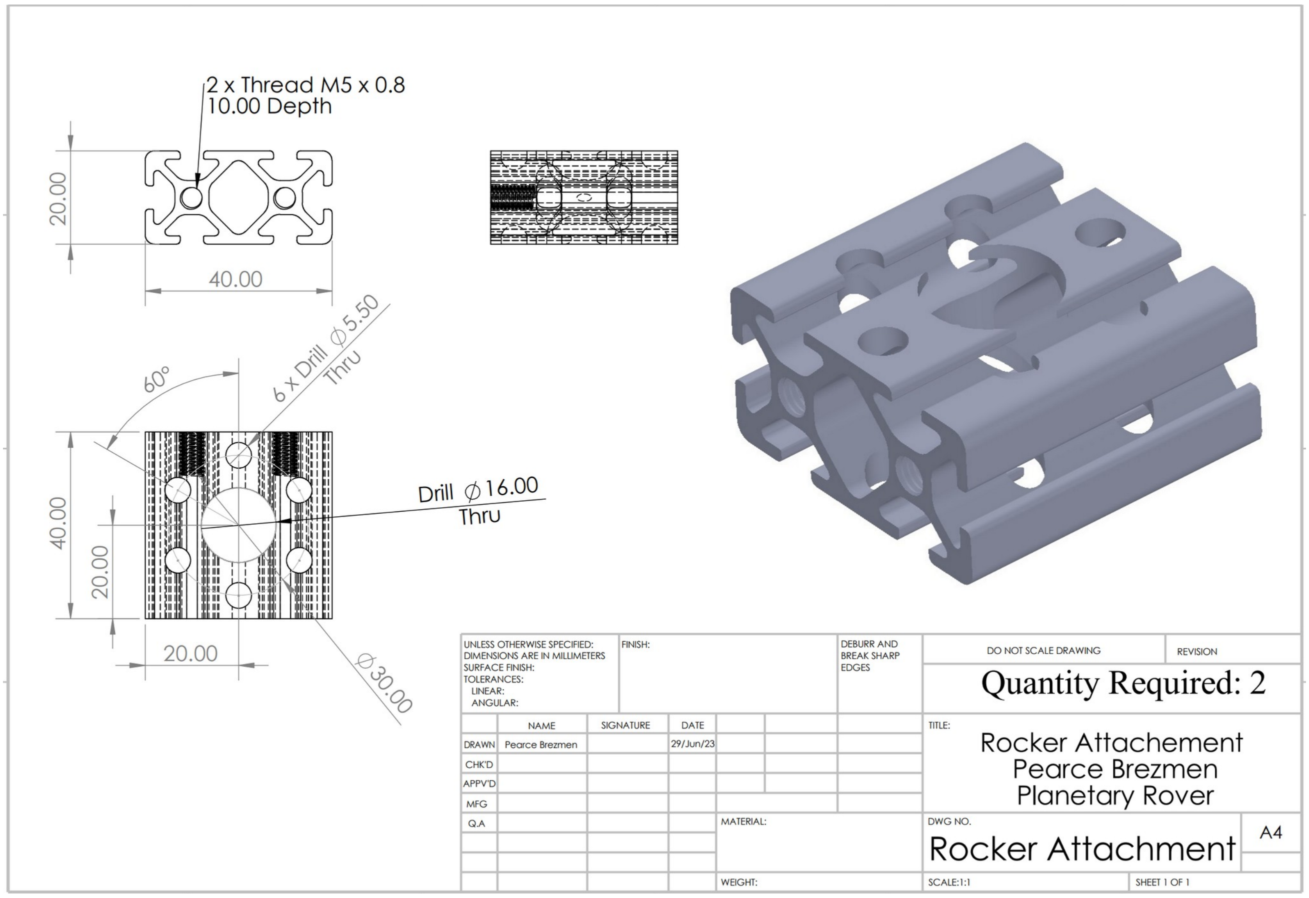

670.00
A
20.00
20.00
2 x Thread M5 x 8.0 (Both Ends)
10.00
Quantity Required: 9
DETAIL A
SCALE 2 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Part 1 of Aluminium Extrusion Cutting List
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
20/Jun/23
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Chassis Front Top V Slot Pearce Brezmen Planetary Rover
DWG NO.
Chassis front top V slot
A4
SCALE:1:10
SHEET 1 OF 1

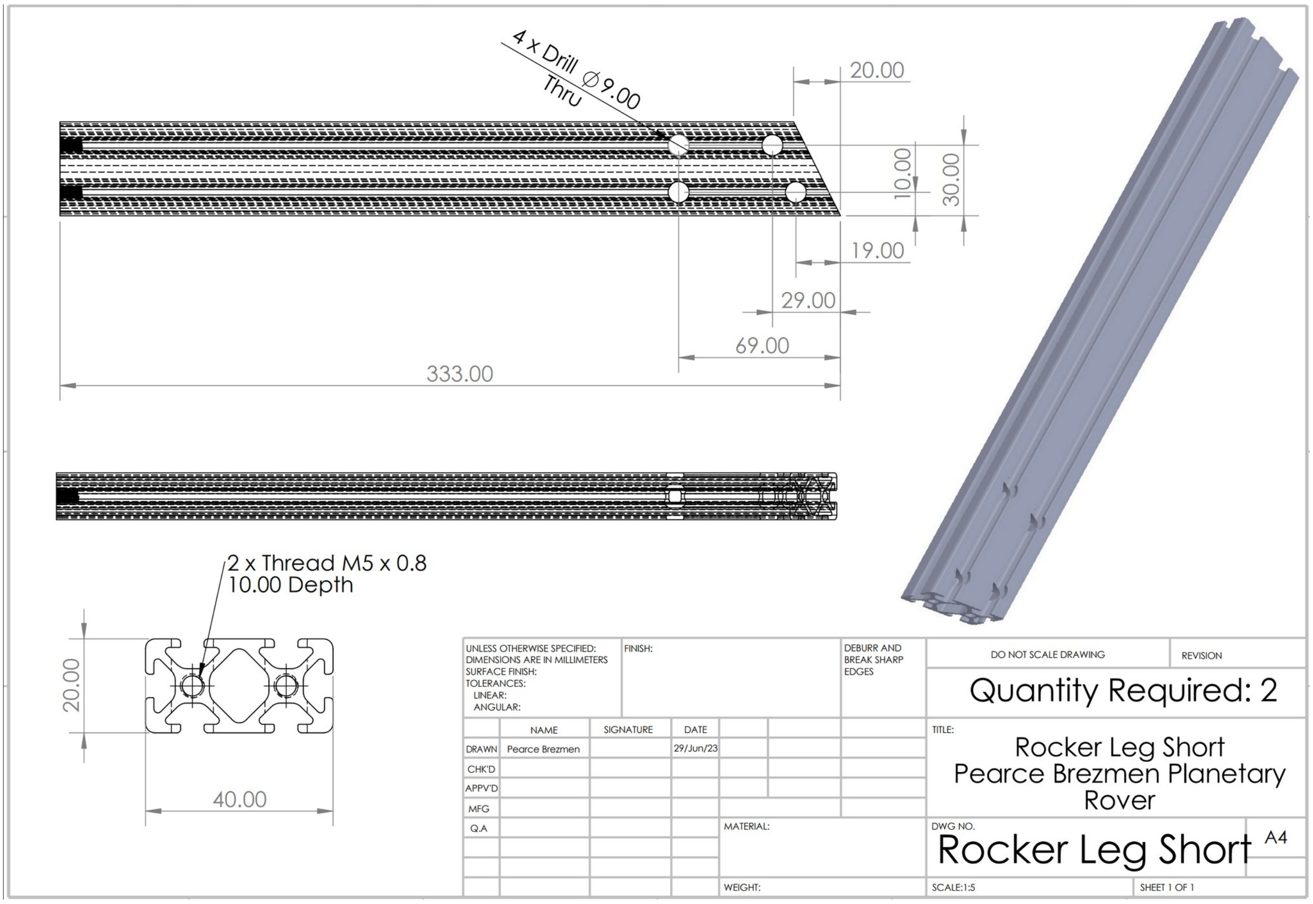

1070.00
720.00
360.00
10.00
9 x Drill ∅5.00 Thru
10.00
270.00
540.00
810.00
1070.00
1080.00
Quantity Required: 2
20.00
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Part 5 of Aluminium Extrusion Cutting List
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
20/Jun/23
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Chassis Side Bottom V Slot Pearce Brezmen Planetary Rover
DWG NO.
Chassis side bottom V slot
A4
SCALE:1:10
SHEET 1 OF 1

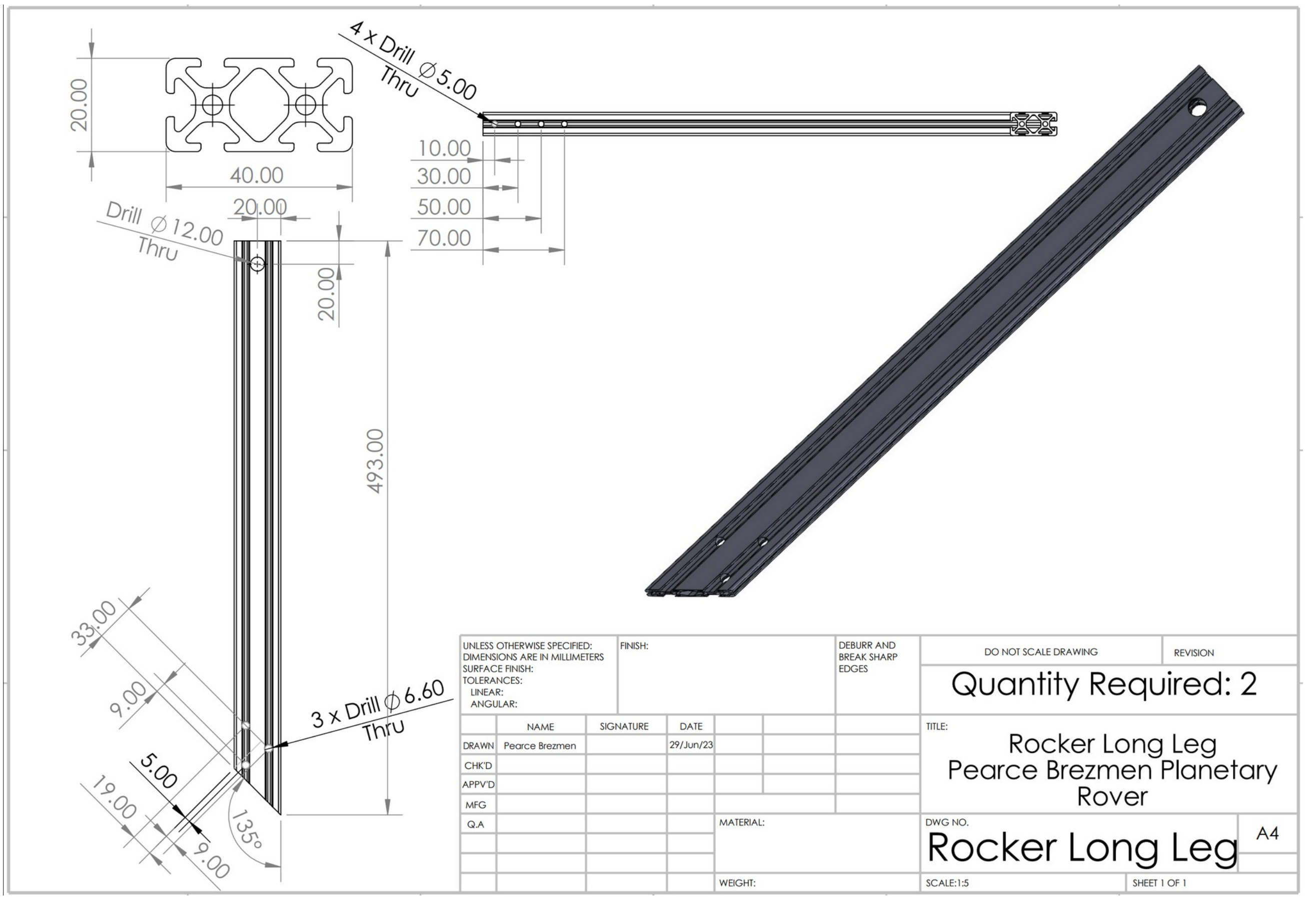

1070.00
720.00
568.00
512.00
360.00
10.00
10.00
Top View
10 x Drill ∅5.00 Thru
Drill ∅6.60 Thru
Drill ∅6.60 Thru
10.00
Side View
10.00
270.00
501.50
Drill ∅6.60 Thru
Drill ∅6.60 Thru
540.00
578.50
816.00
836.00
1070.00
1080.00
Front View
Quantity Required: 2
20.00
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Part 2 of Aluminium Extrusion Cutting List
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
20/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Chassis Side Top V Slot Pearce Brezmen Planetary Rover
MATERIAL:
DWG NO.
Chassis side top V slot
A4
WEIGHT:
SCALE:1:10
SHEET 1 OF 1


160.00
10.00
10.00
Thread M5 x 8.0
Thread M5 x 8.0
20.00
20.00
Quantity Required: 8
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Part 3 of Aluminium Extrusion Cutting List
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
20/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Chassis Vertical V Slot Pearce Brezmen Planetary Rover
MATERIAL:
DWG NO.
Chassis vertical V slot
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1


626.00
313.00
18.00
18.00
R20.00
A
R20.00
20.00
20.00
Drill ∅5.50 Thru
Drill ∅5.50 Thru
Drill ∅12.00 Thru
40.00
20.00
∅30.00
Drill ∅16.00 Thru
60°
6 x Drill ∅5.50 Thru
DETAIL A
Repeated exactly on other side.
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 1
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
29/Jun/23
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Differential Bar
Pearce Brezmen Planetary Rover
DWG NO.
Differential Bar
A4
SCALE:1:10
SHEET 1 OF 1


2 x Thread M5 x 0.8
10.00 Depth
20.00
40.00
60°
6 x Drill ∅5.50 Thru
Drill ∅16.00 Thru
40.00
20.00
20.00
∅30.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2
NAME
SIGNATURE
DATE
DRAWN
Pearce Brezmen
29/Jun/23
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Rocker Attachement
Pearce Brezmen
Planetary Rover
DWG NO.
Rocker Attachment
A4
SCALE:1:1
SHEET 1 OF 1


4 x Drill ⌀9.00
Thru
20.00
10.00
30.00
19.00
29.00
69.00
333.00
2 x Thread M5 x 0.8
10.00 Depth
20.00
40.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2
NAME
SIGNATURE
DATE
DRAWN Pearce Brezmen 29/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Rocker Leg Short
Pearce Brezmen Planetary Rover
MATERIAL:
DWG NO.
Rocker Leg Short
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1


4 x Drill ⌀5.00
Thru
20.00
40.00
10.00
30.00
50.00
70.00
Drill ⌀12.00
Thru
20.00
20.00
493.00
33.00
9.00
5.00
19.00
9.00
135°
3 x Drill ⌀6.60
Thru
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
Quantity Required: 2
NAME
SIGNATURE
DATE
DRAWN Pearce Brezmen 29/Jun/23
CHK'D
APPV'D
MFG
Q.A
TITLE:
Rocker Long Leg
Pearce Brezmen Planetary Rover
MATERIAL:
DWG NO.
Rocker Long Leg
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1