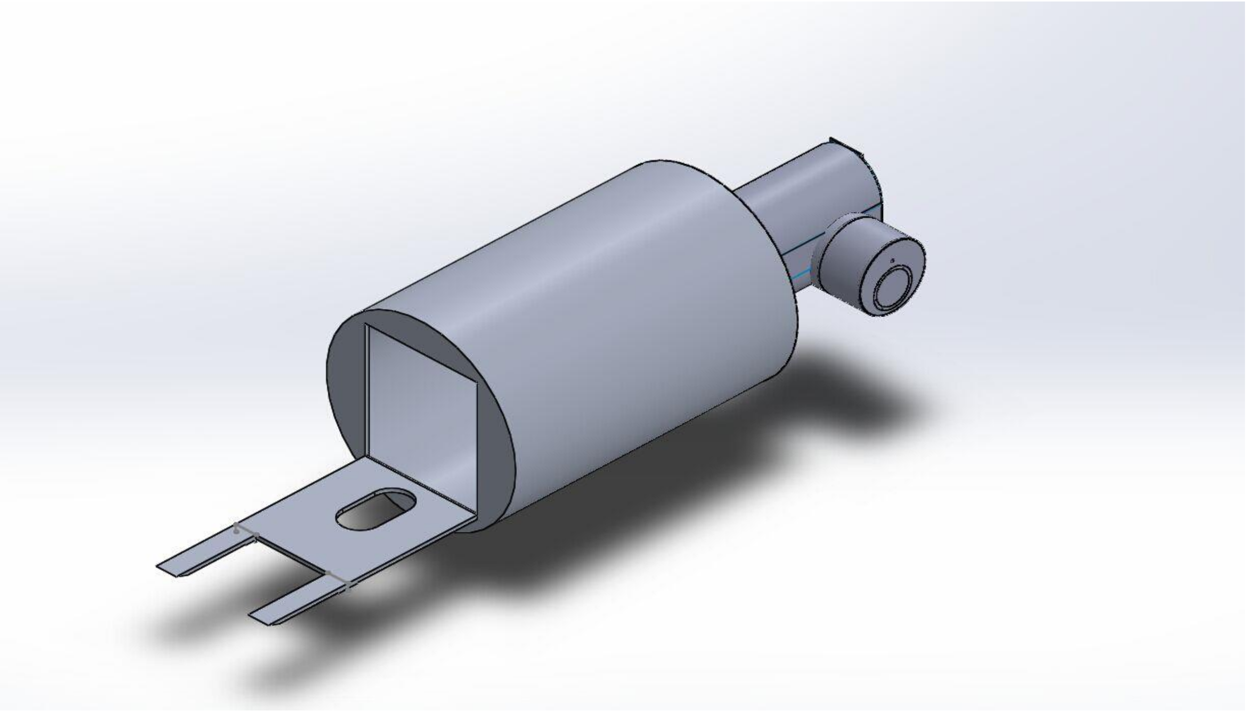
Final Design Report (FDR)

MarsOz Habitat Garage



MarsOz Garage Group

2015

Version 0.08

Revision History

Version	Comments	Author(s)	Date
D0.01	Document created. Formatting established.	XL	20-Oct-15
D0.02	Add design of Door Access, Bunkhouse and Storeroom, and HVAC	XL, RZ	3-Nov-15
D0.03	Improve grammar and content	ZX, TG, RZ, LW, XL, JZ	3-Nov-15
D0.04	Add design of docking module, improve door access part	IT, JW	3-Nov-15
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Executive Summary

The MarsOz garage project focuses on the design of multiple function garage in MARS. This also covers the docking module which serves as a connection and walkway between the habitat module and garage.

The final design report begins by introducing the context of the project. Before illustrating the final design of the team, the team restates the requirements and attributes from the SRS and SDS deliverables.

The description of the detailed design covers four subsystems, involving garage door access, bunkhouse/storeroom, HVAC, and docking module. There is a verification strategy for the components of every subsystem. There is a budget summary which lists the cost of every section. Finally the risks for the project and relative solutions are discussed in risk analysis.

The team goal was to achieve an easily implemented, cheap design with reliable quality and light weight.

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Acronyms and Abbreviations

SRS - System Requirement Specification

AS - Australian Standard

NZS – New Zealand Standard

IEC – International Electro technical Commission

ISO – International Organization of Standardization

MARS – Mars Analogue Research Station

MSA - Mars Society Australia

HAB – Habitat Module

FBD – Functional Block Diagram

FFBD – Function Flow Block Diagram

GAD – Garage door

GAR – Garage

BHS – Bunkhouse system

HVAC – Heating Ventilation Air-Conditioning system

AC – Air-conditioner

EER - energy efficiency ratio

DOS – Docking system

ROV – Rover

TOS – Towing system

ENV – Environment

USER – User

Units of Measurement

The International System of Units (SI) is used in this project unless otherwise specified.

Table A: Units of Measurement

Measurement	Symbol	Description
Area	m^2	Square metres
Volume	m^3	Cubic metres
Volume	gallon	Gallon
Pressure	Pa	Pascal
Power	W	Watts
Energy	kW h	Kilowatt hour
Energy	J	Joules
Time	s	Seconds
Currency	$	Australian dollar
Temperature	°C	Degrees Celsius
Luminous intensity	cd	Candela
Force	N	Newton
Air Flow Rate	L/sec	Litres per second

1 Introduction

1.1 Project Mission Statement

Mars Society Australia (MSA) proposes to build an analogue research station in Arkaroola, South Australia for the simulation of a Mars mission and environment. In this project, the main purpose is to design the interior layout of the garage so that it should provide accommodation for 12 people, or should be used as a storage room when the rover is out of the field. In the meantime, the design of the main garage door and the connection between the main habitat and the garage, named docking module are included in this project.

As for the requirements, the garage must be strong enough to hold the 4-ton rover and there shall be enough space for the accommodation of 12 people. The conversion time between garage, accommodation and storage room shall be no more than 8 hours, according to the client. For the main garage door, it should be able to hold the 4-ton rover, with an additional smaller door for human access available as well. For the docking module, it shall connect the main habitat with the garage design, and shall allow passage between modules, holding the weight of maximum 2 people. Considering the requirements from the client, the team has developed the following high-level customer needs.

- The garage shall be able to contain the 4-ton rover, both in space and load-bearing abilities
- The garage shall be able to convert into a bunkhouse or a storage room.
- When the rover is in the field, the garage shall be able to provide enough space for the accommodation of 12 people.
- The interior environment in the garage shall be comfortable for human living.
- The garage shall be connected to the main habitat.
- The garage shall have power access.

1.2 Document Purpose

The purpose of this document is to demonstrate the final design and prototype of the garage for MarsOz Habitat.

Final Design Report (FDR) is the finalized document that to be submitted to the client Dr. Jonathan Clarke from the MSA. The document includes the detailed design of the garage done by

the team, and verification of requirements outlined in the System Design Specification (SDS) document.

The team has divided the garage into independent subsystems. In this report, detailed design will be discussed in different subsystem sections. Each of the subsystem section will contain the following information:

- Overview of the design
- The strategic scheme of the design
- Requirements specifications and verifications
- Detailed design to meet the requirements
- Budget estimation

1.3 Current Progress.

The purpose of this document (FDR) is to provide a finalized detailed design of the garage in terms of all subsystems. Considering the milestone the team developed in the PMP-B, this is the sign that the Final Design Approval period ends. Submitting this report to the client will let the team approach to closure of the project. Based on the feedback from the client, the team could analyse the performance of all the team member as individual and as a team. After the analysis, this project will be officially closed.

2 Scope

As mentioned in previous sections, the aim of this project is to provide an appropriate design for the garage of MarsOz Habitat. This document includes the final design of a completed system design of the garage, and make convincible discussion and analysis about how the design shall meet all requirements and attributes in our System Design Specification document (SDS), provide justification of chosen design concepts and optimisation of performance and cost reduction.

The system design is divided into four sub-systems and this documents is divided to reflect the four major subsystems. This division was done at the beginning of the conceptual design process and is applied until now. The four groups take charge of the design of door access; bunkhouse & storeroom; heating, ventilation and air-conditioning (HVAC); and docking module. The division is according to the mutually independent subsystems of the system design, which are door access, internal design (bunkhouse, storeroom, and HVAC system), and docking module. The 3 subsystems have been well defined in previous document. In general, this FDR document will deliver the detailed design for these 4 parts, and make them integrated as a completed garage system.

The design process was based on official document, such as the document AAS 06-267 (Willson, Clarke & Murphy, 2005), which is a very useful document for the team to determine the specifications of requirements. We also quote the parameters from previous ENGN4221 works, such as the Final Design Report in 2012 MarsOz group (shown in reference). Each group of the team shall provide a cost estimation for its subsystem design. The costs accounting for products and materials in all groups are according to the price situation in current Australia or international market.

Be aware that because of the budget limit the team cannot provide any physical model or prototype to mimic the performance of the system design. However, the team applies useful tools such as ANSYS and Solidworks to produce a precise design sketch and simulate the performance, for example, force analysis, of the system design. With the simulation of the software the team shall show that the design for the garage should be able to finish the tasks justified in the document. However, the team should admit that the simulation cannot perfectly indicate the deployment of the design in reality. Therefore the document also gives risk analysis of the design and designing process.

Through the process of the project, the team conducted effective communication with the programme manager Dr. Liam Waldron and project client Dr. Jonathan Clarke. Their feedback had a great help for the team's progress, especially for the preliminary design review and final design report.

Hopefully the design from the ENGN4221 MarsOz Habitat project can make useful suggestion or even part of the design to the Australian Mars Analogue Research Station in Arkaroola.

3 System Requirements and Attributes

Before illustrating the final design, there is a review of system requirements and attributes. The final design is based on these system requirements which have already been accepted by the client.

The table below is the instruments of the system requirements and attributes table. Not all of the attributes have target values, for example, budget, the client claimed that the budget should be as low as possible. So there is no target value of the budget currently.

+	Maximize the target value for the corresponding technical attribute.
-	Minimize the target value for the corresponding technical attribute.
o	Optimize the target value for the corresponding technical attribute. Used when the suitable range of target value is not fully known, such that optimization process can be initiated to identify the suitable target value for the technical attribute.

R.I.D.	Engineering Requirement	Metric	D.O.I	Target Value	Dep. on	Req. by	V.I.D
R1.0	Garage						
R1.1	Volume	Volume (m3)	o	62.58m3		R2, R3, R4	V1.0
R1.2	Doorway access	Length (m) Power consumption (W)	o	3.181 x 3.181m 100W	R1.1	R8.1 R8.2	V1.0
R1.3	Weight	Load bearing(kg)	+	8000kg			V1.0
R2.0	Bunkhouse						
R2.1	Containing 12 people	Volume (m3)	+	m3	R1.1	R8.2	V2.0
R2.2	Living equipment	N/A	o	N/A	R1.1	R8.2	V2.0
R2.3	Bedding	Load bearing(kg)	o	150		R8.2	V2.0
R3.0	Storeroom	Volume (m3)	+	62.58m3	R1.1		V3.0
R4.0	Comfort (HVAC)						
R4.1	Air Conditioning	Temperature(C) Humidity (kg/m3)	o	26°C	R7.0	R4.2 R8.1 R8.2	V4.0
R4.2	Ventilation	Airflow rate(m3/h)	o	385 m3/h	R7.0	R4.1 R8.1 R8.2	V4.0
R4.2	Ventilation	Airflow rate(m3/h)	o	385 m3/h	R7.0	R4.1 R8.1 R8.2	V4.0
R5.0	Conversion						
R5.1	Conversion time	Time (hours)	-	Less than 8 hours	R1.1		V5.0
R6.0	Docking module						
R6.1	Passage	Length (m)	+	2.8m	R1.1		V6.0
R6.2	Passage	Weight capacity (kg)		200kg		R8.2	V6.0
R7.0	Power transmission	Energy (kWh)	+	64.5 kW h		R4.0 R5.0	V7.0
R8.0	Safety						
R8.1	Rover Protection						
R8.2	Liveable conditions	Temperature, ventilation, lighting, humidity	o	N/A	R2.0 R4.0		V8.0

R.I.D.	Engineering Requirement	Metric	D.O.I	Target Value	Dep. on	Req. by	V.I.D
R9.0	Lifespan	Years	+	5 years	R1.0 R4.0 R8.0		V9.0
R10.0	Budget	Cost ($AUD)	-	N/A	R1.0 R2.0 R4.0 R7.0		V10.0

Table 3.1: Requirements and attributes

4 Final Design

4.1 Bunkhouse and Storeroom

4.1.1 Bunkhouse

One of customer requirements for Mars garage is to convert from garage functioning to a bunkhouse that should be able to contain maximum of 12 people. The team plans to apply folding beds for 12 people living in the garage. The design process aims to provide the personnel a relatively comfortable environment with a low budget. The dimension of the garage is shown in Figure 4.1.1 below. The cylindrical garage is 3.385 m in height, 3.219 m in the floor width and 8.172 m in length. The radius of the cross section is 2.350 m, therefore the widest part of the garage will be around 4.700 m.

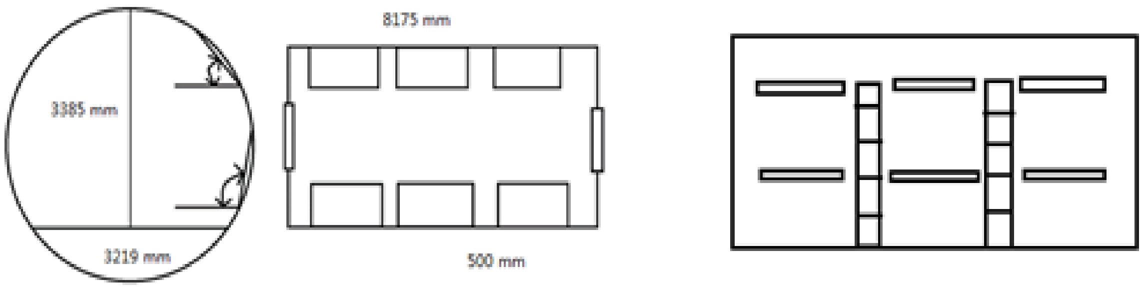


Figure 4.1.1 Dimension of the garage

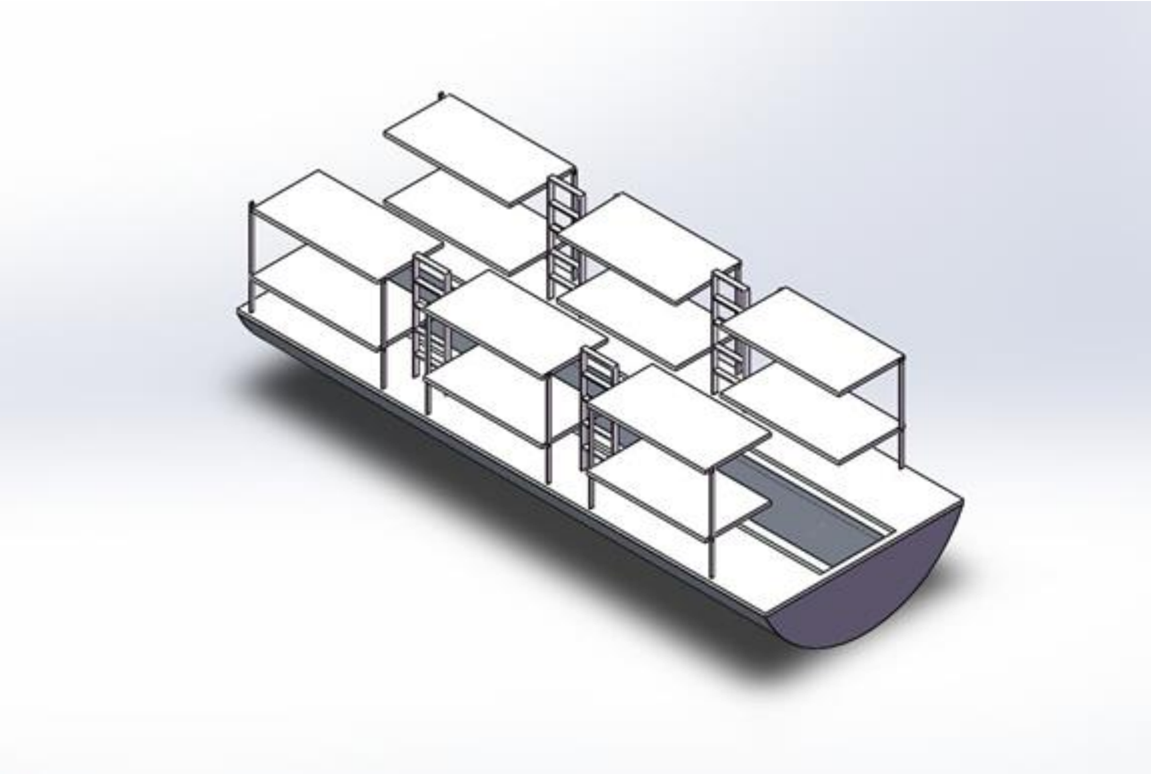


Figure 4.1.2 Overall internal design for bunkhouse

The bed is folded and installed on the wall of the garage, as shown above in Figure 4.1.2. Since the structure of the garage is cylindrical, the installation can be two beds in parallel with a thickness at around 0.1 m. The distance between two beds in parallel is 1.600 m. The lower levels of the beds are 0.500 m above the floor. The beds are around 2.100 m in length and 1.200 m in width. Four ladders need to be installed on the wall for people to climb up and down as it is shown in the figure. The team decides to use rope ladder instead of steel ladder, so that when the rover is coming in, the ladders can be rolled up to provide enough space to house it. When the rover is in the garage, the bed is folded on the wall. When it needs to convert garage to a bunkhouse, the beds are unfolded to let people sleep.

Considering the material for the bed, steel, which is commonly used for bedding, is a good choice for the design. Steel is strong enough to support a person sleeping on the bed, and the price is relatively low comparing to the wood and aluminium alloy. Since the bed is installed on the wall, the whole system must be stable when a person sleeping on the outer edge of the bed. The structural frame should be made of 0.025 m^2 hollow steel, and the surface should be painted with epoxy powder to resist corrosion. The whole bed base need to be made by multi-layer steel wire gauze with nylon fibres belts to secure the mattress on the bed when the whole bed is folded on the wall. We decide to add fence on the outer edge of the bed to ensure people would not fall down from the bed. The price of a bed frame on Alibaba is 80 AU dollars each (Alibaba bed frame, 2015).

For the rope ladder, the length is 2.100 m, and width is 0.800 m. The dimension of each footboard is 0.750m in length, 0.1m in width. The whole rope ladder can hold staff of maximum 160kg weight. Each footboard require anti-skid treatment. The price of ladder on Alibaba is around 14 AU dollars per metre. For 4 ladders, it is 112 AU dollars in total (Alibaba rope ladder, 2015).

As for the connection joint between the wall and the bed, shown in Figure 4.1.3, stainless steel could be the best choice due to the high stiffness and the relatively lower cost comparing with other materials. Again we need to consider a person sleeping on the outer edge of the bed, it is very important the system could balance the moment created by the person's weight. The weight of the stainless steel could be large enough to balance the system. The price of the connection joint is 15 AU dollars for each (need to be customized). Since we need two connection joints each bed, the total price is 360 AU dollars.

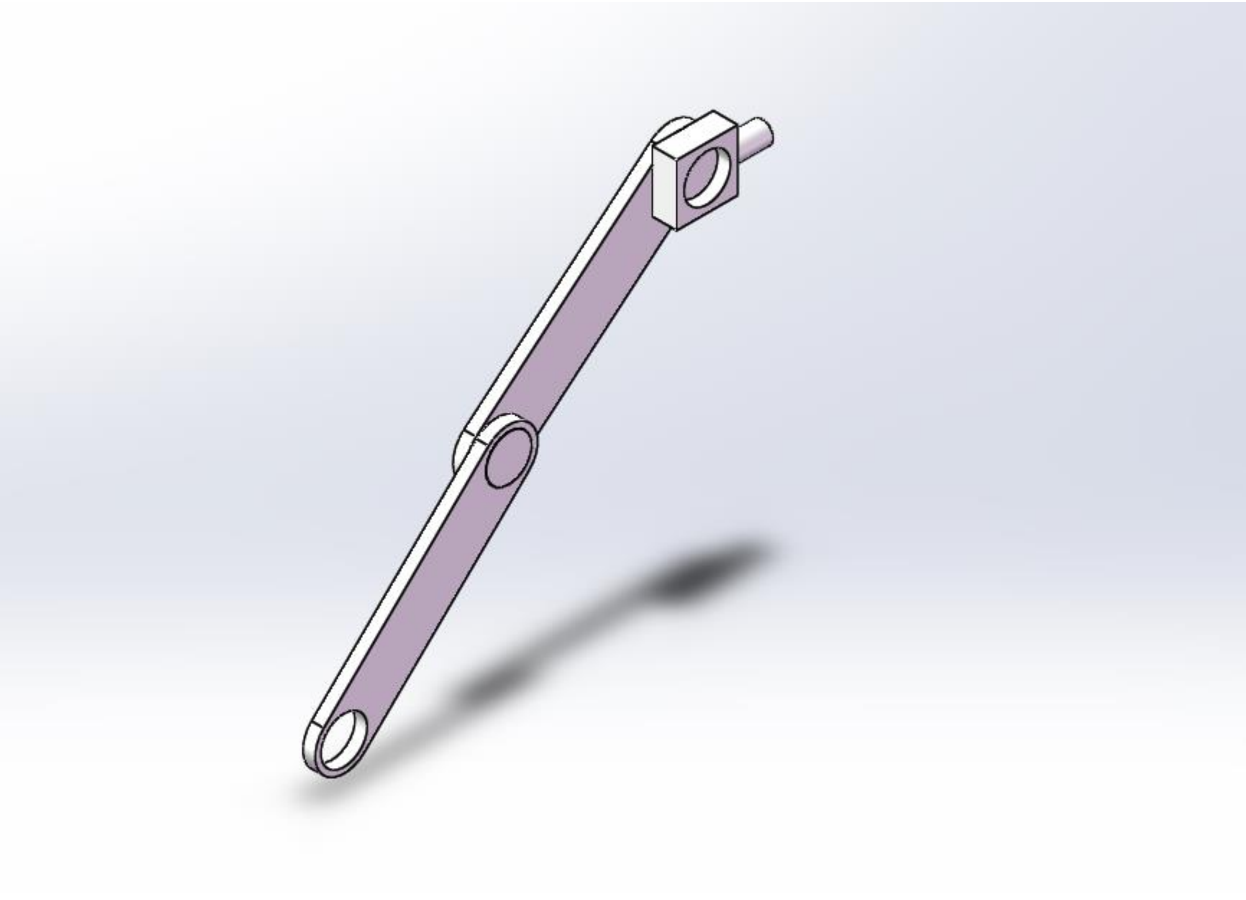


Figure 4.1.3 Joint connection overview

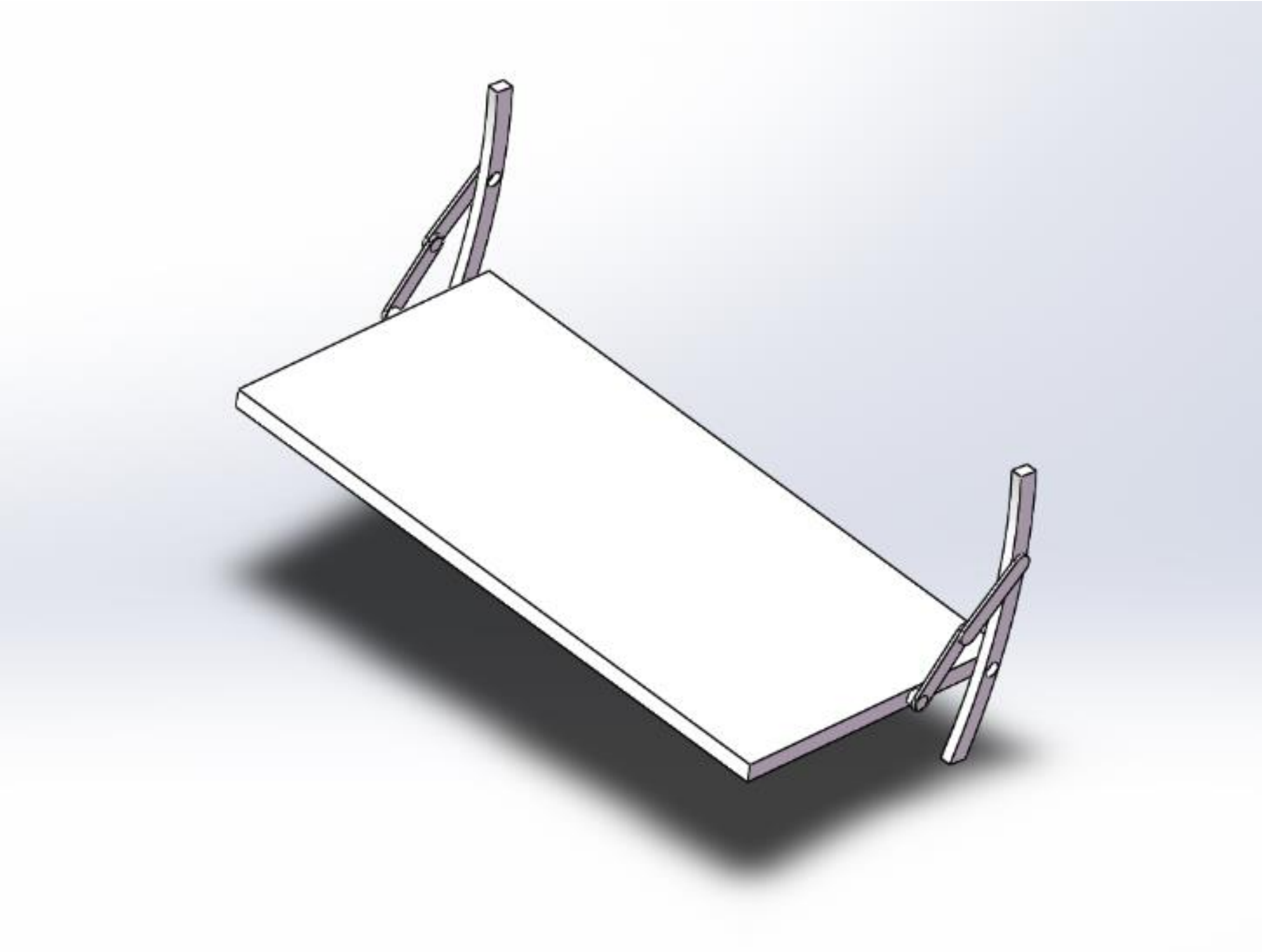


Figure 4.1.4 Joint connection and bed

The size of the mattress depends on the size of the bed. We decide the size of the mattress is 2 m in length, 1.1 m in width, and 0.180 m in height. The mattress can be found in local Australia, otherwise we can import them from China in a relatively low price (range from 40 to 70 AU dollars, total 840 AU dollars for our 12 beds) (Alibaba mattress, 2015). We can find custom size mattress manufacturer on Alibaba. Also a 0.018 m quilted fire retardant fabric is required to cover the surface of the mattress to meet the meets the Australian Standards for fire safety AS1530.3/1999 & AS2755.2/1995.

The maintenance of the whole system is simple. For the folding bed, corrosion resistant is the first priority. The epoxy powder may be recoated in a fixed time. Second is the weight support problem. Each bed can support 150kg. Any extra weight may cause system damage, also joint parts should be re-examined in a fixed time.

The design of the bunkhouse does not include any window, therefore lights are needed. The team decided that LED light tubes could be a solution, where be installed in the middle of the ceiling. The beam angle for a light tube is 120 degree. Considering the ceiling is around three metres and the total length of the room is eight metres, it would be reasonable to install the light tube in the middle of the room so that the light could cover the whole bunkhouse. The team considered that the light provided by a single light tube, which is approximately 1900 lumens, may not be enough for the bunkhouse. In this case two light tubes shall be installed in parallel in the middle of the ceiling. Meanwhile, the light is adjustable since the light tube is designed to be able to turn on and off separately to adjust the light intensity for different situations. The power consumption for a single LED light tube is approximately 18W and the total power required for the light shall be around 40W.

The price of the light tubes is $14 in total (Alibaba light tube, 2015).

4.1.1 Storage Layer

As it was indicated in the requirements from the client, the bunkhouse should be able to convert to storeroom when the rover is out in the field. The team decided to use the space under the floor be a storage layer as.

Main challenge for this task is that the floor shall hold the weight of the rover, which is approximately 4000kg. There should install strong spandrel girder under the floor. However, adding a storage layer would reduce the volume of spandrel girder and therefore reduce the weight-holding.

The team decided to use only the middle part of the space under floor as the storage space. The width of the floor was approximately 3 m so the team decided that the 1.5 m range in the middle for storage space could be reasonable, that is, no spandrel girder added underneath. The rest of the space would be supported by the girder, and be used for holding the weight of the rover and people.

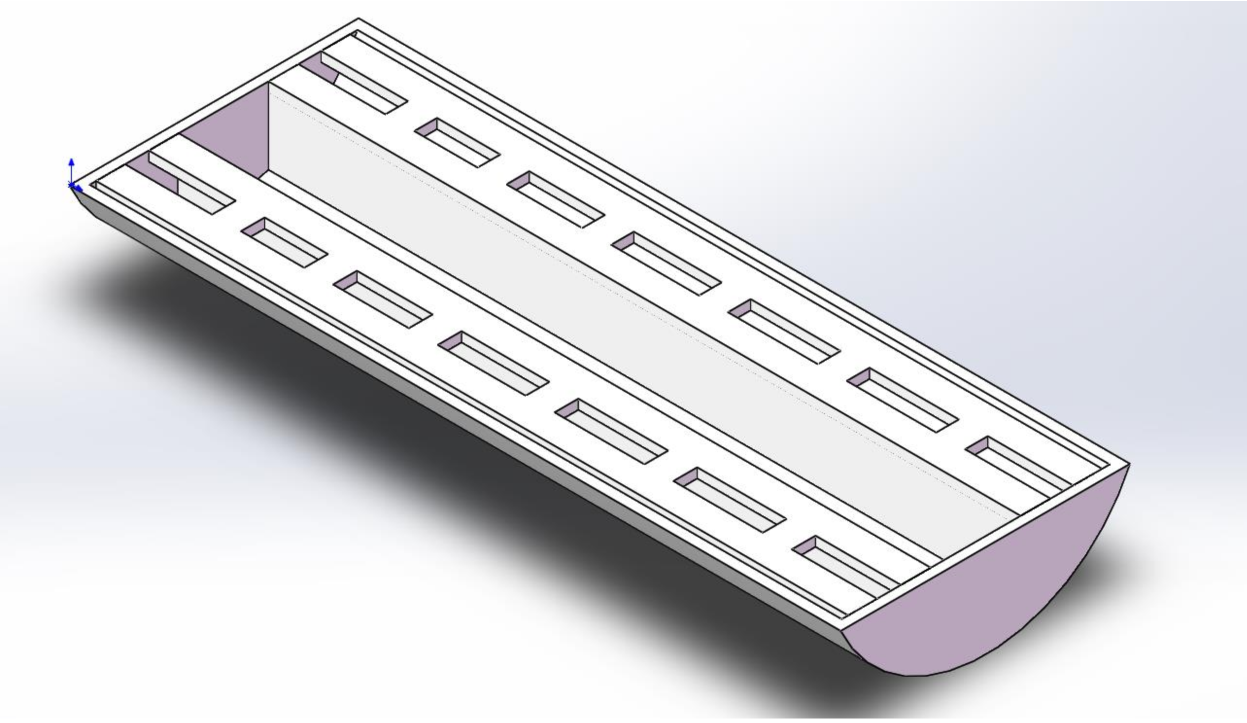
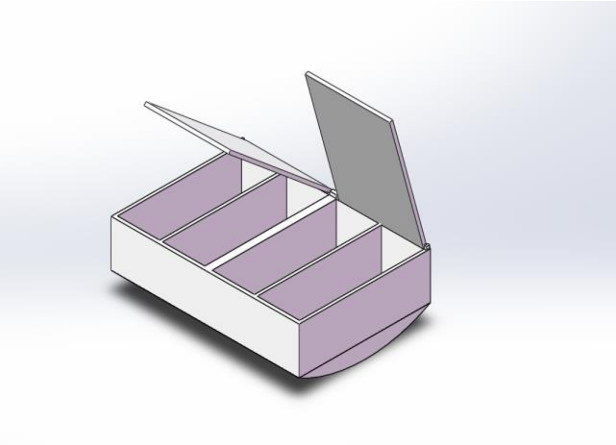


Figure 4.1.5 Design of the storage space under the floor

Figure 4.1.5 shows the position of the storeroom. When the rover is in the garage, the wheels would apply force to the ground. However, the force would be only applied on the two sides of the floor in the garage. In this case the stress capacity of the floor in the middle could be lower than the sides. In this way, the storage layer could be built under this area safely. As for the access to the storage layer, several lids (floor panels) should be installed on the floor. The lids are in level with other parts of the floor. The dimensions of the lid are 1 m long and 1.4 m wide and will cover two storage boxes so that people can step on it (Shown in Figure 4.1.6 and 4.1.7). The lids have a relatively big surface to reduce the pressure, and the weight is endured by multiple support points shown in Figure 4.1.7. The volume for each individual box is around 0.5 m^3, for a total volume of approximately $8m^3$.



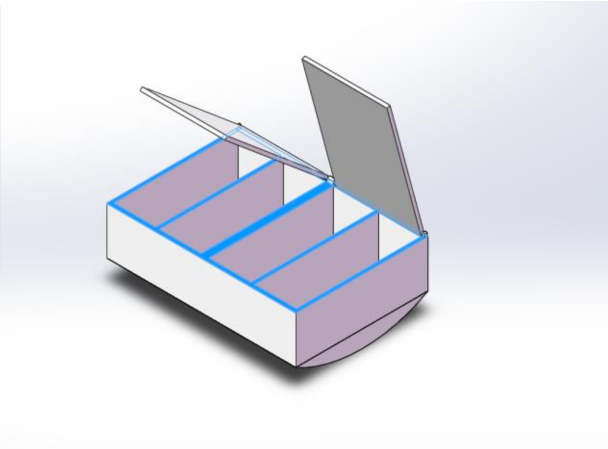


Figure 4.1.6 (left): Design of the storage area

Figure 4.1.7 (right): Blue area will be the supporting area that endure the weight of human.

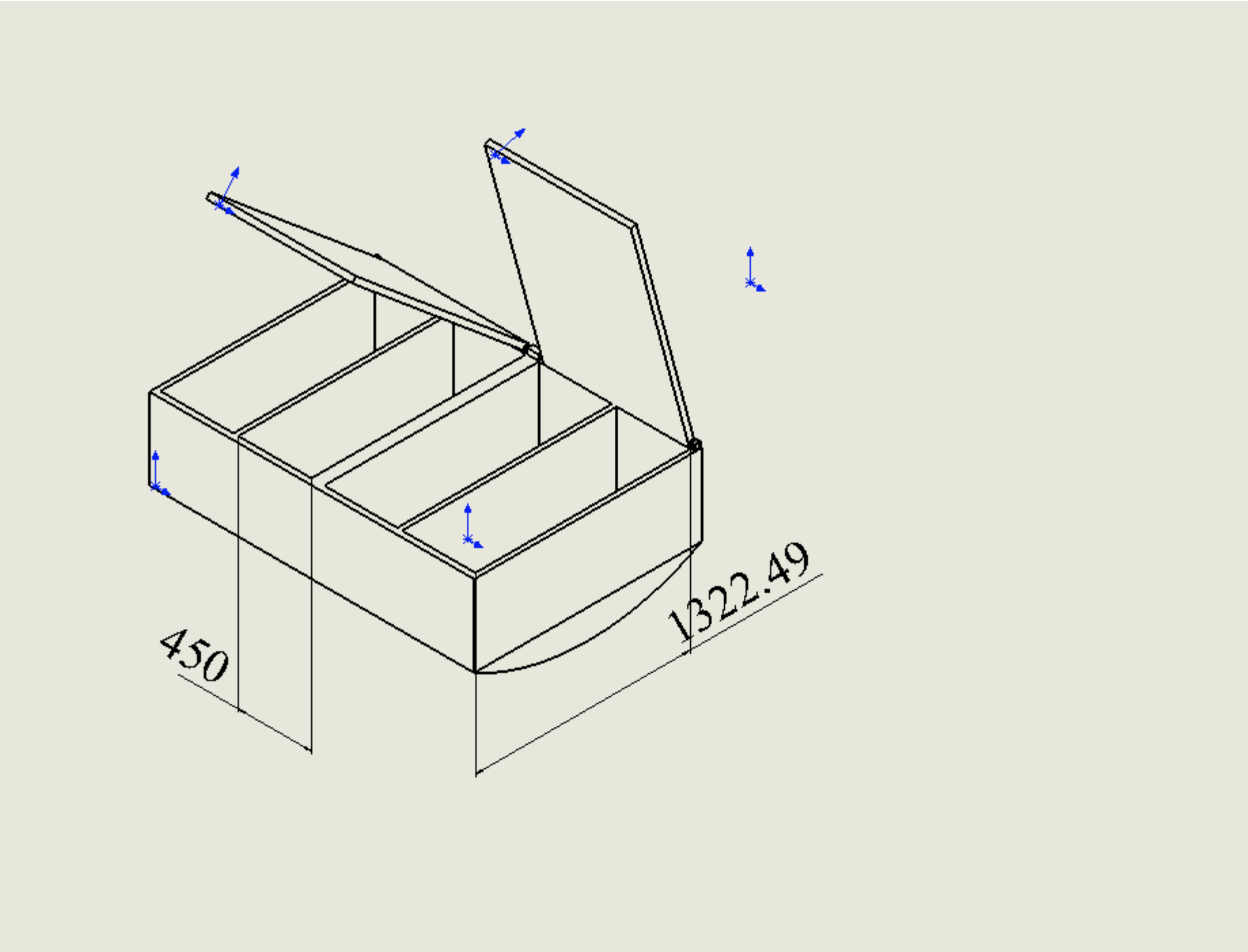


Figure 4.1.8 Dimension of each individual store box in mm

The design of the lids can provide access to the storage box for people. The AISI type 304 stainless steel grid will be chosen as the main material for the lid due to its high ultimate tensile strength (515 MPa) and high yield strength (205 MPa). This stainless steel grid should be aligned closely in order to provide a high durability when the rover is on it. When the research initially started, balsa wood was considered to be the choice due to its low density and decent ultimate tensile strength. However, after the ANSYS analysis, the result indicated that balsa wood cannot bear the force and pressure of the rover. Therefore after comparison stainless steel is the best choice, approved by the ANSYS analysis. The overview of the floor panels and lids is shown in the Figure below.

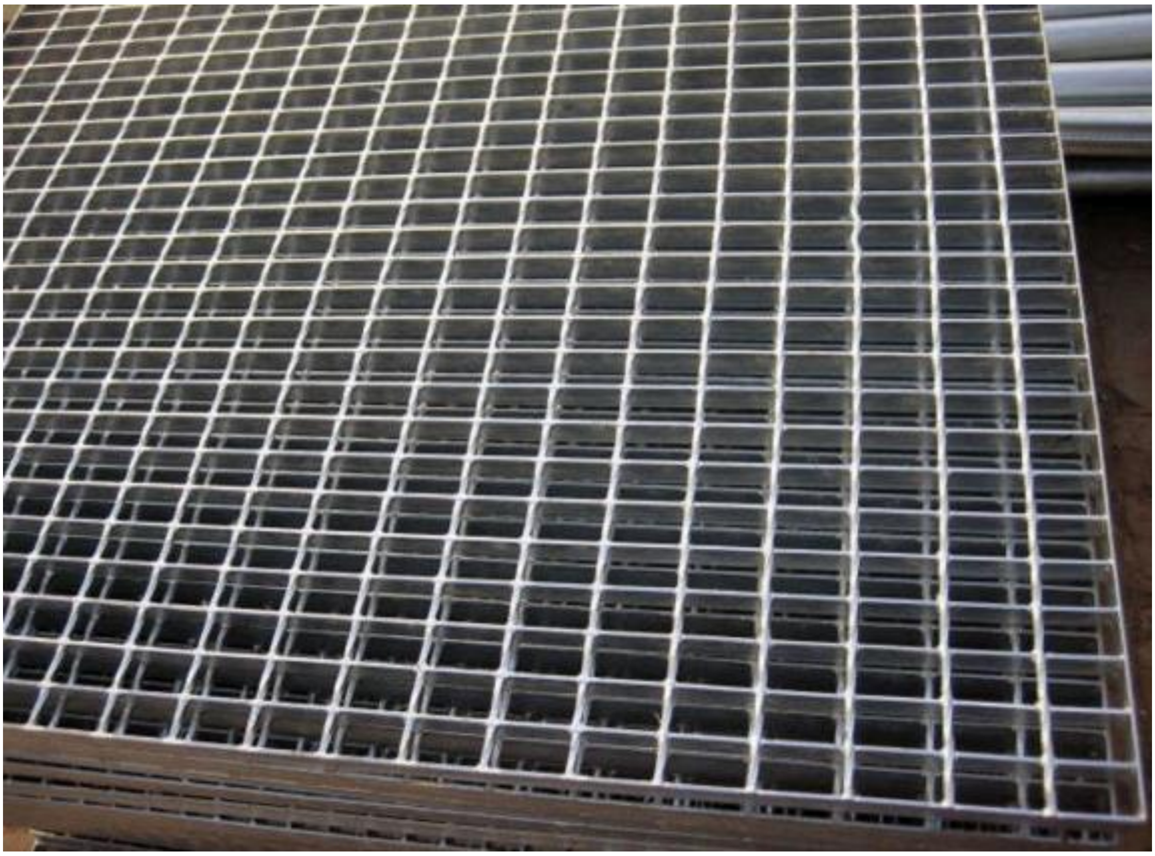


Figure 4.1.9 Metal grid flooring panels

The price of steel grid floor from Alibaba is $70 per metre. (Alibaba steel grid floor, 2015)

As for the material of spandrel girder that supports the stainless steel grid floor, pine wood is chosen due to the lower density compared with metal, and high ultimate tensile strength (40 MPa) among the wood. Specifically, pine wood pillars with a 90 mm× 45 mm cross section are used to support the stainless steel floor as the dominating girders, and there are totally three rows of pillars in one side underneath with a 500 mm distance between them. Shorter pine wood pillars with same cross section shape are fixed under the dominating girders to support them. Shown in Figure 4.1.10 below, the distance between the long pillars is 500 mm and the distance between each of the individual shorter pillars is the same as that of the longer one. The graph only shows three of the pillars and the distance is universal across the whole room. Three figures shown below are the three views drawing of the spandrel girder.

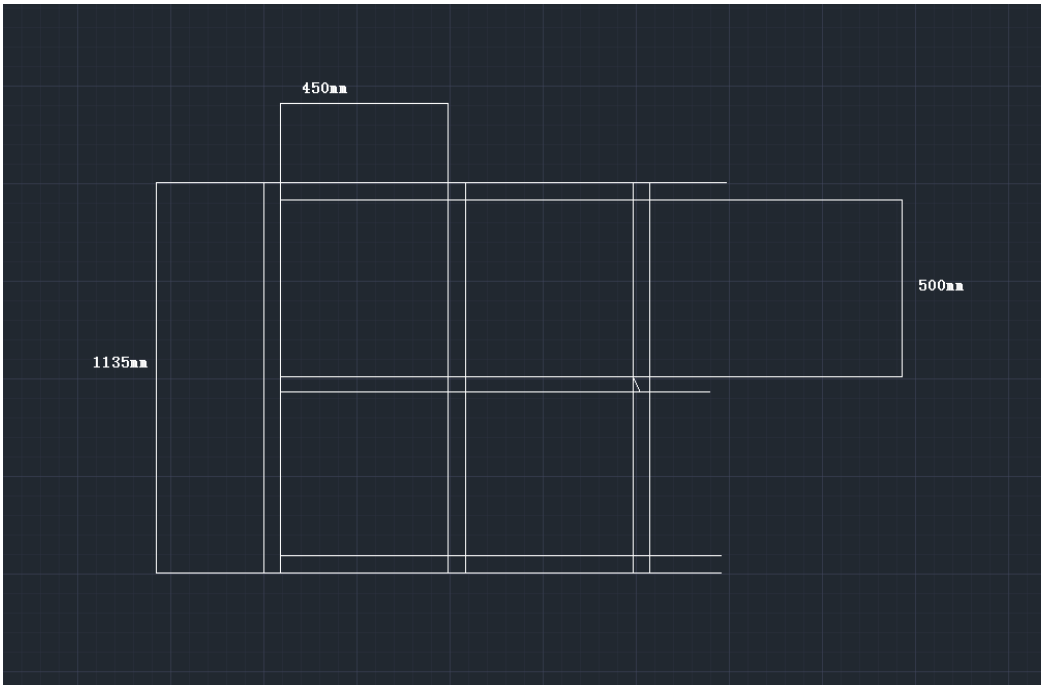


Figure 4.1.10 Plan view of the spandrel girder for one side of the room

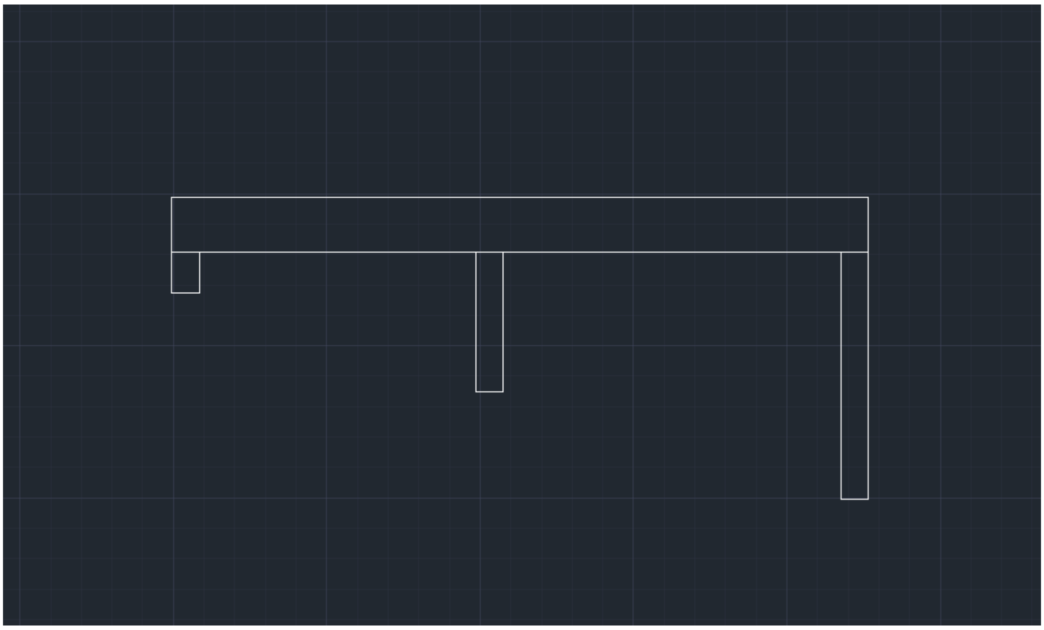


Figure 4.1.11 Side view of the spandrel girder

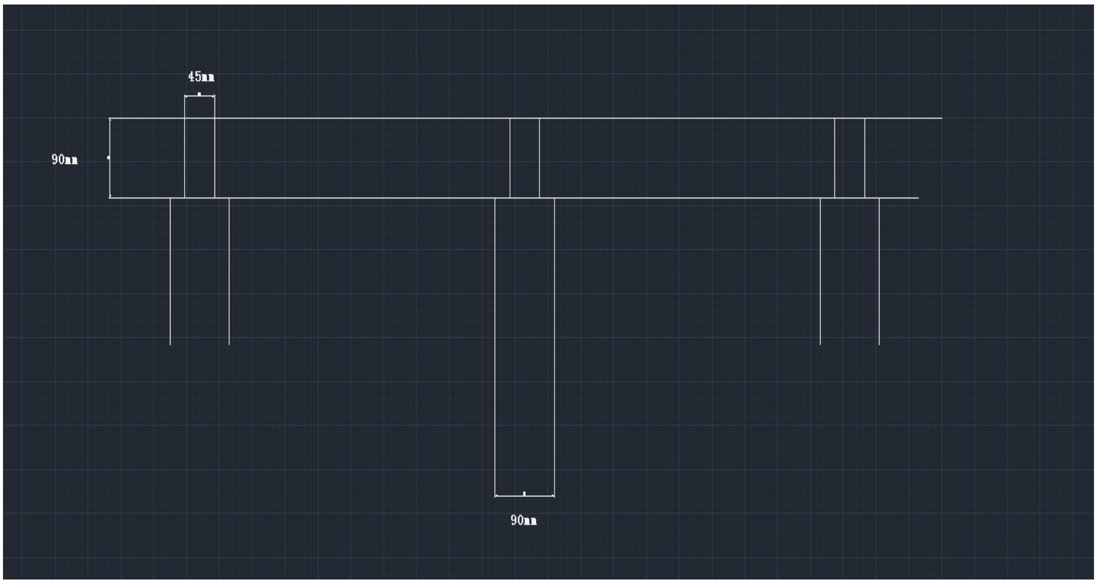


Figure 4.1.12 Front view of the spandrel girder

There were a few material choices available for the team when designing the spandrel girder, such as structure steel and aluminium alloy. Considering the ability of load-bearing, structure steel could be the best choice. However, the density of steel is much greater than the other two choices and if so the total weight of the garage will be significantly large. Regarding to aluminium alloy, the density would be an issue and the price could be another issue. The density of aluminium would be relatively lower than that of steel. However, it is also considered to be too large for the garage. As for the price, the price of aluminium beam is $25 per metre, which is much higher than that of pine wood. Pine wood is strong enough to hold the weight and the price is relatively reasonable compared with the other two choices. Moreover, the installation process could be less complicated if pine wood is chosen as the material since there is no need for custom made components.

Therefore the team decides that structural treated pine wood would be reasonably applied for the design due to the lighter density, enough beam stress and the relatively lower price. The floor will be covered with metal grid to enhance the strength of the floor and also reduce the weight of the total garage. The cross section of the structural treated pine is 0.09m * 0.045m, and we need 143m of them. The price of pine is $5.15 per metre. The total price is $736.45 (Bunnings warehouse, 2015).

There are disadvantages for this design. One of them would be the limited storing space, since two sides under the floor are filled with pine wood. The team have to make a trade-off between the storage and the space for bearing weight. Secondly, this design contains too many lids. It may not very convenient to take goods outside the storage layer. On the other hand, however, this is a reasonable design for safety concerns. The team needs to ensure floor can hold the weight of the rover and people for safety issues. The beam under the lids shall be strong enough to support the weight of human body. More lids can have better weight distribution. In this case, the priority requirement is met and the secondary requirement was also met but not in the perfect way.

4.1.3 Verification

The requirements of bunkhouse from client is shown below. Our design meet all requirements with relatively low price. The total price of our bunkhouse design is $3892.45, which is accepted by our client.

Verification ID	Reqd by	Description
V1.0	R1.1	Inspect volume of garage by measuring length, width, height. The irregular edge should be accurate. Use mathematical volume formula. Then sum several regular part together to get entire volume. Compare with target value 62.58 m^3
	R1.2	Inspect the power consumption by measuring the voltage and current between doorway access then using formula power=voltage × current to get power consumption. Compare to target value 100W.
	R1.3	Testing the load bearing by loading weight in garage. Put 0 kg to 8000 kg pressure to test it whether it can support. Compare to the target value 8000kg.
	R1.4	Test the force by applying load pressure on towing interface. Record the test value. No target value match required.
V2.0	R2.1	Inspect volume of bunkhouse by measuring length, width and height. The irregular edge should be accurate. Use mathematical volume formula. Then sum several regular part together to get entire volume.
	R2.2	Demonstrate living equipment by someone actually living in the bunkhouse, and record the feedback. The simulator will operate the system in the same living condition.
	R2.3	Test the bed load bearing by applying load pressure on bed vary 500 N (50 kg) to 2000 N (200 kg). The maximum value should larger than target value 150 kg.
V3.0	R3.0	Inspect volume of storeroom by measuring length, width, height. The irregular edge should be accurate. Use mathematical volume formula. Then sum several regular part together to get entire volume. Compare with target value.

Table 4.1 Verification of bunkhouse and Storeroom

4.2 HVAC

4.2.1 Heating & cooling (air conditioning)

According to the customer requirements for HVAC system listed in our previous part, the temperature in MarsOz habitat in Arkaroola, South Australia should be kept between 20°C to 26°C. The average environmental temperature and climate are recorded in appendix Figure 8.3. For the design consideration, the highest temperature can reach 50°C. Therefore the garage design needs a proper and effective heating & cooling system to control the temperature inside.

- **Design choice - heating**

For the heating system there are two methods: heater and air-conditioner.

(1) Heater

Most heaters are electric heaters, which transfer electrical energy to heat. On the one hand, the total volume of the garage is around 62.6 m^3 which is considerably large for relatively low efficiency of the heater; on the other hand, the highest temperature in Arkaroola can reach more than 50°C, cooling takes more important role compared with heating.

(2) Air-conditioner

The air-conditioner is mostly used for both heating and cooling. The major parts of an air conditioner are: evaporator, condenser, expansion valve, and compressor. There are several advantages of AC:

1) Efficiency. The experiment shows the efficiency of AC is better than heater. Heater need more time to response. Heaters need more time to warm up.

2) The safety factor of the air-conditioner is higher than heater since there is less risk of potential fire issue.

3) The AC can both provide cooling and heating function. For the design efficiency and budget consideration, AC is a better solution to control temperature in this design.

- **Design choice - cooling**

For the cooling system there are three potential methods: water-pipe, painting and air-conditioner.

(1)Water pipe

Water/coolant absorbs heat from garage to keep the temperature around 20-26°C. When water/coolant reaches saturation, it will transfer to underground to wait until the temperature drop. The new coolant/water will refill the pipe to keep temperature steady.

(2) Painting

Since most of heat comes from radiation of sun, painting gold or other material on the surface can reflect energy from the sun. This will keep garage at a comfortable temperature during the day. Cooling function can also achieve by AC.

From the choice above, we can find that air-conditioner is a better method to control garage temperature around 20°C to 26°C. Also the design needs some methods to improve performance like painting. Painting will help to increase efficiency of AC, and it will keep whole garage as a independent system. This will reduce the influence of radiation from the sun.

- **Specification:**

1. **Insulating paints:**

The list of price for painting is attached in appendix.

Due to empirical evidence, 1 litre of paint would cover about 8.6 m^2. According to the graph in appendix 8.5, the outer radius is 2.350 m, the length of garage is 8.2m. Therefore we can easily get the outer surface area according to the formula of cylinder

$$S = 2\pi rh + 2\pi r^2 = 155.776\ m^2$$

or equivalently, approximately 18.11 litres of painting. Considering the loss during painting or other reasons, the total amount of paint should be 19 litres.

Reason:

A. From the reviews and comments of painting materials, Insulating Primer #14 performs well in insulating radiation among the materials listed.
B. The price of Insulating Primer is $34.5 per gallon. The price is not as expensive as #18 Metal-Prime.

From these two main factors, choosing Insulating Primer #14 as the material to paint. The total price of 19 litres of painting is $172.50. The price of painting materials are listed in appendix.

4.2.2 Air conditioner

The air conditioner can operate for both cooling and heating purpose during day and night respectively. The basic operation process is shown below (The air conditioning company, 2011).

Considering the comparatively small volume of the garage, the team decide to choose a normal air conditioner instead of central air conditioner, which would be more expensive, hence there is no necessity for the design. There are several choices of air conditioner from famous brands among Australia.

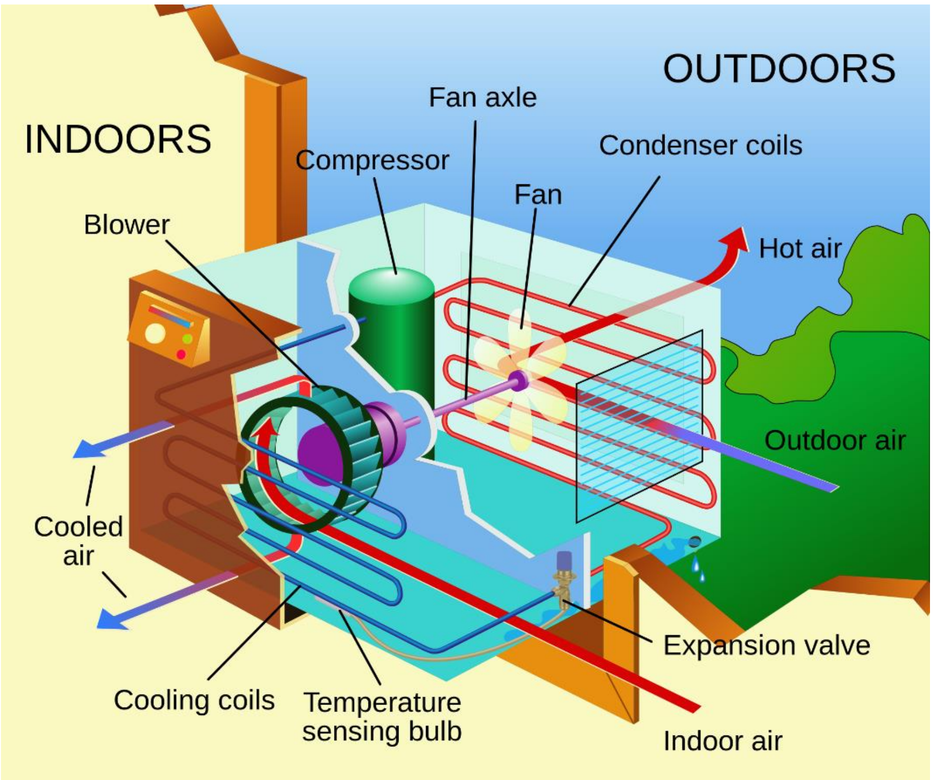


Figure 4.2.1 basic operation process of air conditioner

The most important issue needs to be concerned is the EER (energy efficiency ratio), which can be found in the guide book for every air conditioner. In addition, air conditioner capacity (W) and power output need also to be invested. According to the research, the comparison graph is shown below (JoshKirschner, 2014.)

ROOM SIZE	10m² - 20m²	20m² - 30m²	30m² - 45m²	45m² - 65m²
APPROXIMATE kW REQUIRED	2.6kW	3.5kW	5-6kW	7-8kW

Figure 4.2.2 Room size and power required

Note: this diagram is used for cubic shaped room. However in this project, the volume of cylinder is larger than square. Therefore the indicated power required would be smaller than practical value.

As for the radiation heat loss, it is prevented by painting method. This method will keep the habitat as an independent system, that is, not absorbing heat from the sun, and loss heat from inside. The area of the floor in garage is estimated to be 25 m^2, so that the required power for garage, according to the figure above, is 3.5 kW both for heating and cooling.

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Figure 4.2.3 Premium 3.5kW Reverse Cycle Split System: LG-P12AWN-14

Model number:	**LG-P12AWN-14**
Price	$1474
Cooling capacity	3.50kw
Heating capacity	4.00kw
Power input	Cooling: 862W Heating: 872W
Maximum Running Current	Cooling: 5.6A, Heating: 7.1A
Air Flow Rate (Indoor, Max)	240 L/sec
Outdoor Noise (dB(A) ± 3) (Sound Pressure Level[1]) (H/M/L/S)	45 (Actual installed noise levels are varying, which depends on the installed location)
Indoor Noise (dB(A) ± 3) (Sound Pressure Level[1]) (H/M/L/S)	39 / 33 / 23 / 19 (Actual installed noise levels vary depending on the installed location)
Dimensions	Indoor Product (W × H × D) 885 × 295 × 235 mm Outdoor Product (W × H × D) 770 × 545 × 28 8mm Weight (Indoor / Outdoor) 11 kg / 36 kg
Operation range:	Cooling -10 ~ 48 degrees Heating -15 ~ 24 degrees

Table 4.2.1 AC technical specification

Also the air conditioner system for garage is a split unit. Air conditioners are made up of two parts, with one attached to the internal wall of the room, while the other installed on the outside to exhaust heat out.

From the explanations above, the team choose Premium 3.5 kW Reverse Cycle Split System to be applied for the heating and cooling system. The technical system is shown in the Table 3.3 below. It is easily justified that this product has a desired performance to achieve all performance explained above. There are also some specification parameters for installation and deployment

Item	**Price**
Air conditioner brand:lg-P12AWN-14.	$1474
Painting material Insulating Primer #14	$172.5
Two exhaust fans	$132

Table 4.2.2 Cost estimate

4.2.2 Ventilation

The team offers several potential designs, the specific data are list in the table below.

It is clear to find that the third option, the 'Exhaust Fan Inline Hot or Cold Air Transfer' is the most powerful device as well as the most expensive one. For the first and the second option, the airflow rates of both of them do not satisfy the airflow rate requirements at 626m3/h if single unit is installed. By taking the factor of efficiency and cost into consideration, the price-quality ratio of the three options are utilized to determine which one has better performance based on the cost and the airflow rate, which are 4.8, 5.3 and 4.2 respectively. It is apparent to see that the second option performs best.

Type	**Model**	**Power (W)**	**Diameter (mm)**	**Hole Size (mm)**	**Airflow(m^3/h)**	**Price ($)**

Vortice Vario Exhaust Fan – Wall / Window		38	230	262–267	480	100
Whisper Round Exhaust Fan with Draft Stop Brilliant		27	300	330	350	66
Exhaust Fan Inline Hot or Cold Air Transfer or Extraction 20cm Mixflow Ventair		130	200	230	700~820	195

Table 4.2.3 Choices of exhaust fan for ventilation

Therefore, it is recommended to install two of the Whisper Round Exhaust Fan with Draft Stop Brilliant so as to achieve the total airflow rate of 700 m^3/h (beyond the desired airflow rate of 626m^3/h) and the total cost of the device is $132, which is greatly smaller than the third option for only single unit, $195. The feature of the device is the lower noise (under 30dB while working).

In addition, considering the outside environment of desert, two separate sand filters should be applied to the outer parts of the exhaust fans to prevent sand particles from entering the room, as shown in the figure # below.

Figure 4.2.4 Sand filter

4.2.3 Verification

In order to achieve the basic requirement of comfort of the garage, it is necessary to ensure the room has appropriate air flow rate. It requires the function of a proper ventilation system which is capable of circulating air in the room. To be more specific, the ventilation system is used to control the interior environment by venting out unwanted odours, particulates, smoke, moisture, and other contaminants which may be present in the air. The system is of extreme importance to the design of the garage especially in the case of the droughty desert in South Australia.

To achieve the function of ventilation, the common strategy is to make use of an exhaust fan, which is usually installed on the ceiling or the wall of the room. The fan is able to exchange indoor air and outdoor air. It is designed to eliminate indoor air pollution, and to regulate temperature and humidity. Using an exhaust fan is a supplement to an air conditioning system. The next step should be choosing a proper exhaust fan that satisfies the airflow requirement of the garage room. According to the information provided by Engineering Toolbox, it is recommended to achieve a minimum of 10 air changes per hour in the room combining the functions of garage, storage and bunkhouse, to remove excess moisture. To work out the recommended capacity needed for the room, calculate the volume of air in the room (length × width × height, all in metres) and multiply this by the number of air changes to get the required air volume of the fan. (This will be adequate in most normal situations.)

Verification ID	**Reqd by**	**Description**
V4.1	R4.1	Test the temperature by measuring the temperature during the power supply test which the air-conditioner will control the 138m3 space temperature at about 26 degrees.
V4.2	R4.2	Analyse ventilation by simulating ventilation procedure. The simulation graph about air flow show the orientation. There should be both flow in and out air to achieve the ventilation goal.

Table 4.2.4 Verification of HVAC

The requirements of HVAC is providing a comfortable environment to the staff. Basically, there are two main factors: temperature and airflow rate. As displayed in the table # above (from SDS), the volume of the room is approximately 62.6 m^3. Hence, the exhaust fan is recommended to achieve a minimum airflow rate of 626 m^3/h.

Initially, when considering the basic requirements of ventilation, three potential options of the exhaust fan were provided which vary in their shape, mounted position, diameter, power, airflow rate and price. The details of the three options are listed in table # below. All of them are available online which could be delivered within Australia. As for air-conditioning, testing the temperature in a similar volume room, to see the AC can achieve the temperature.

Note: because it is impossible to test in a real situation. Therefore, it can be estimated by comparing to a similar size room. Placing a thermometer in a similar size room to test whether it can reach the goal.

The functionality of the ventilation system is tested by using an air flow metre to see whether the inside environment meets the target value, 626 m^3/hr after using the two proposed exhaust fans.

4.3 Door Access

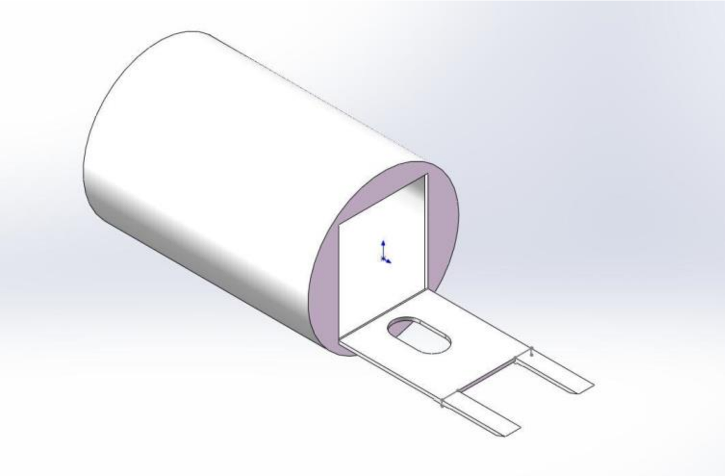

Figure 4.3.0 Main garage door (CAD drawing)

4.3.1 Operation and dimension description

- **Main garage door**

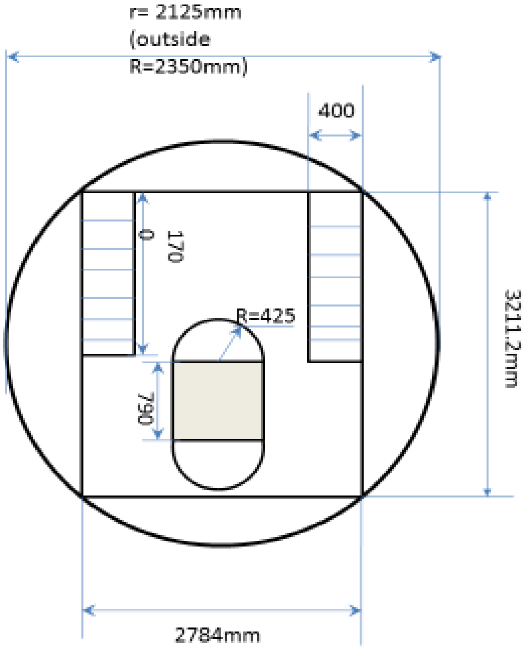

Figure 4.3.1 Main garage door

To ensure the rover to enter the garage easily, the size of the main door should be large enough. Given the size of the rover is approximately 6 m in length, 3 m high and 2.2 m wide, the design dimension of main garage door is approximately 3.21 m in high and 2.78 m wide (Figure 4.3.1). The main garage door also performs as a part of the Figure 8.5 from the past design.

However, since the client requests the climb slopes of the rover to be around 20 degree, and 3.21 m height of the main garage door provides approximately 30 degrees ramp. In order to achieve 20 degrees' ramp, the group presents another pair of extendable ramps with 1.7m in length. Thus, the total length of the ramp is main garage door's height plus length of the extendable ramp, which is approximately 4.91 m, and this provides a ramp angle around 20 degrees (As shown in Figure 4.3.2 below). When the main garage door and ramp fully open, consider safety issue, the group designs a safety lock on human access door to ensure it close tightly when rover driving on the ramp.

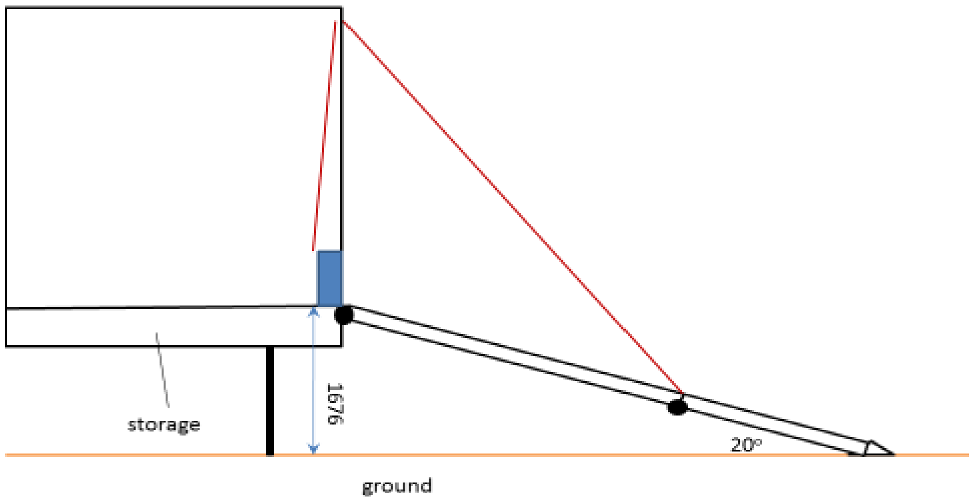

Figure 4.3.2 Main door fully open

The ramps are installed outside the door and using axle to make it able to unfold. When the door is closed, the ramps will naturally hang on the door due to the gravity, and a lock on them to make the ramps stay cling to the main garage door. The opening mechanism of the main garage door is presented by a cable and a motor. The motor provides power enable the cable to lay down and lift up the door, and the door opens outward. There are two electric capstan have power approximately 1kw for each. (As shown in Figure 4.3.3 below). When the main garage door closed, and the people requires go out the garage, there is a separate 1.8m length single lift ladder prepared in the storage room for people to climb up and down.

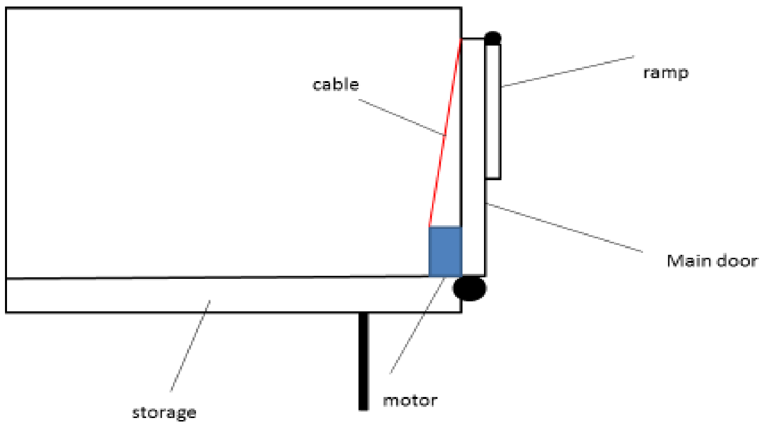

Figure 4.3.3 Main door close

Both the inner side of the door, which is the surface of the ramp will be made rough or added some grooving to increase friction. (As shown in Figure 4.3.4)

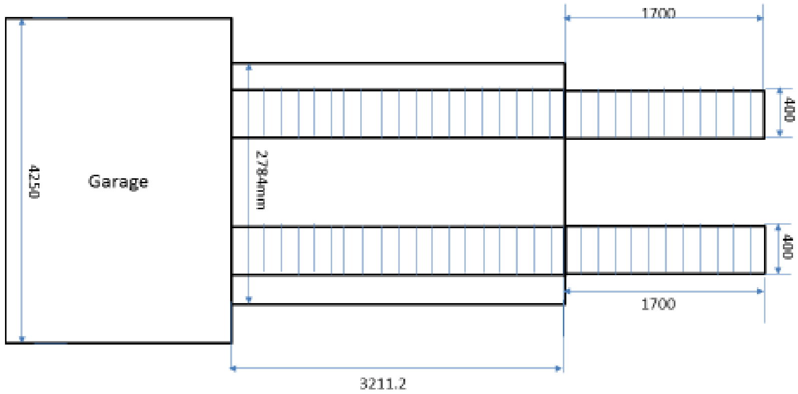

Figure 4.3.4 Ramp

- **Human access door**

Moreover, the design also include a human access door in main garage door, it develops on client's original drawing. The human access door provides access to habitats and other visitors when there is no require to open the main garage door, and the human access door can save heat and air of the garage. It opens toward outside, and the top and bottom of the human access door has semicircle shape, and there is a rectangle between two semicircles. The radius of both semicircle is 0.43m, and rectangle in the middle has 0.79 in wide and 0.85 length. Thus, the total height of the human access is approximately is 1.64m (As shown in Figure 4.3.1). The human access door is consistency with other human access door of the habitat. The group design a handle outside the human access door, which the people and hold on it when they climb up and down by the 1.8m single lift ladder.

- **Air tightness**

Furthermore, the client requests air tightness for both main garage door and human access door. Based on budget and practicability, the group presents the synthetic rubber seals that contains several types of synthetic materials and also to achieve it, the length for the synthetic rubber seals is approximately 13.46m.

4.3.2 Features of our design

The overall structure of our design is simple, and easy to operate. Since each section is independently, the maintenances are easier and would not interrupt with other components or systems; and the main garage door functions as a part of the ramp, it is more cost-effective. Moreover, the existence of human access door provides another does not require to open the main garage door frequently if it is not necessary, it extended main garage door's life time directly, and also save air and heat inside the garage. Based on the simulated results, our 2410 kg aluminium alloy door will be able to support 4000 kg rover. And the grooving surface increases frictions and level of safety, and also avoids slippery occurs.

The synthetic rubber seals are widely used for sealing in the market, relatively low cost and has the desired characteristics as design requests such as, high/low temperature resistance, excellent aging resistance and air tightness. Moreover, it also has ozone and oil resistance.

The synthetic rubber seals are widely used for sealing in the market, relatively low cost and has the desired characteristics as design requests such as, high/low temperature resistance, excellent aging resistance and air tightness. Moreover, it also has ozone and oil resistance.

4.3.3 Materials and models

After simulated several materials by the ANSYS, the group decides the material of the cable is stainless steel, 6061 aluminium alloy for the main garage door, and the weight of main garage door is approximately 2410 kg.

6061 aluminium alloy (As shown in Figure 4.3.5 below) will be chosen as the main material of the door and the ramp. This aluminium alloy has 45,000 psi ultimate tensile strength and the yield strength of it is 40,000 psi. These two main properties ensure that it has a large strength and easy machinability. Since the dimension of the door for the garage is 3.1m × 2.7m, this aluminium alloy can ensure its safety when the rover is on the door. ANSYS are used to verify the safety issue of the aluminium alloy door. From the module created in ANSYS and the analysis, it illustrates that the door undergoes a low equivalent stress and there is no fracture in each part when using the 6061 aluminium alloy. Ramp are also analyzed through ANSYS to ensure the safety and strength of it when rover is on it. Moreover, the density of the 6061 aluminium alloy is 2.7g/cm^3, which is much lower than steel. Although steel could be used on the garage door and ramp, its high density will lead to overweight to the door, which does not match the customer requirements. Balsa wood is first considered to be the choice of the door. However, after the analysis in ANSYS, it is found that the door can't force the rover when using the balsa wood since its low ultimate tensile strength (13.8 MPa). Hence, the best choice of the door and the ramp for this garage is 6061 aluminium alloy.

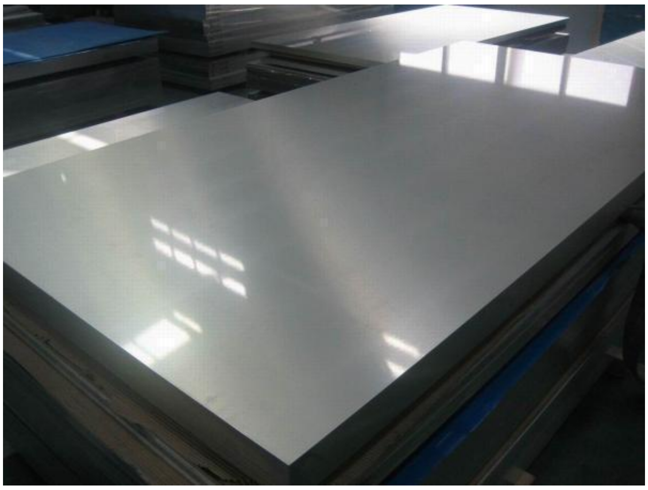

Figure 4.3.5 6061 Aluminium Alloy

The group has chosen PowerTools K5000-P (As shown in Figure 4.3.6 below) model of electric capstan in our system, and we require two of it. The maximum required pulling forces to lift up/down the main garage door and ramp is 8500 N. This type of electric capstan has 22680 N load capacity, which will provide sufficient forces to achieve operating mechanism of the door. Its dimension is 41.5 × 34.5 × 28.5 cm, which is small enough for the group to put it on the roof.

Figure 4.3.6 PowerTools K5000-P electric capstan

The 7x19 Stainless cable with diameter 5 mm (As shown in Figure 4.3.7) will use in the system to assist the door opening process. This type of stainless cable suitable for running rigging, control cables, cranes and winches, and it is widely used in the industry. As demonstrated before, the required pulling forces are 8500 N, and the 7x19 stainless cable's breaking strain is 1276 kg (12760 N), which will satisfied our requirements.

Figure 4.3.7: 7x19 Stainless cable with diameter 5mm

For air tightness, the group chooses TH-QC301 synthetic rubber sealing strips (As shown in Figure 4.3.8 below). This synthetic rubber sealing strips can operate in wide temperature range -30 ~ 120°C, its dimension is 0.45 × 0.22 × 0.15mm. It contains different types of rubber to achieve our requirements. The NBR provides an excellent oil resistance; EPDM has excellent resistance to weather and ozone, good resistance to heat, low temperature and chemical; NR has high elasticity with good chemical strength; CR is generally good resistance to ozone, aging and chemical as well; and Silicone provides stably in high and low temperature.

Figure 4.3.8: YH-QC301 Synthetic rubber sealing strips

4.3.4 Ramp Design

When the main opening, the angle between door and ground is too large to let rover drive in, so the ramp is used to extend the length of the main door, so the rover will easily get in. The lamp will be hang outside of the main door which is the blue part in Figure 4.3.9, ramp is showed as the orange colour part in Figure 4.3.9.

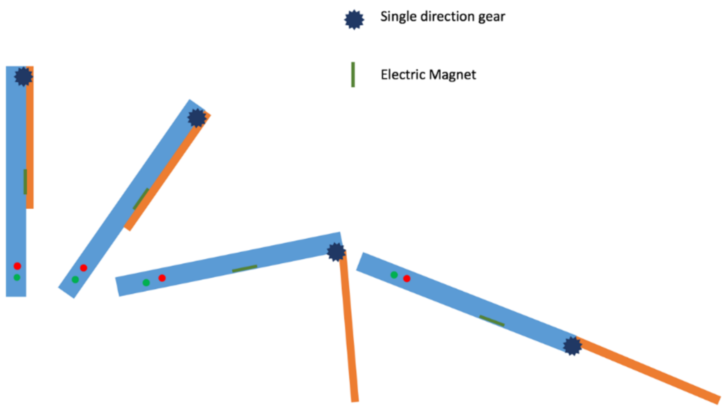

Figure 4.3.9 Operating process of the main garage door

For safety reason, there are two key points in the ramp design, to make it easy to use and safe. First design was the single direction gear (As shown in Figure 4.3.10 below). Single direction gear is different with normal gear, it can only turn in one direction without any further operation, and there are few blockers inside the gear, to block it turning to another direction. The material to make the gear will be steel, because it is cheap and strong to support the force. For strong single direction gear, it is able to support 1000 kg, our lamp made by aluminium alloy, it is not heavy for the gear to support. And also we will also design a switch for the single direction gear, which can control it to turn in another direction. For example, it only turn in clockwise, after press the switch, the blocker inside the gear will shrink, so the gear will be able to turn in anti-clockwise.

Figure 4.3.10 Single direction gear

The second design is the electromagnet, which act as the magnet with power support. It will be located at the end of the ramp, to make sure the ramp is bonded with the main door. So the ramp will not drops down in case any accident happens. The electromagnet need to support by 24 V power supply, we plan to have two magnets at the end of the ramp, each of its can support 100 kg weight, so with these will make sure the ramp will boned with the main door.

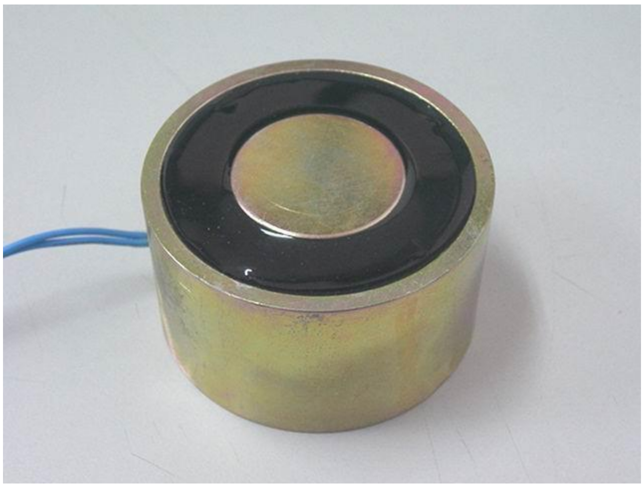

Figure 4.3.11 Electromagnet

According to Figure 4.3.9 above, at the beginning ramp is hang out side of the main door, with the main door opens, the ramp will still be bonded with the door, when the main door opens more than 45 degrees, the operator may press the magnet switch, so the ramp will open automatically under the effect of weight, because of the single direction gear, the ramp will open in one direction slowly, it won't shake or turn to another direction, that will make sure it will be safe to operate it. With the main door opening, the ramp will fully extend until it become one unit.

When the door closing, the ramp won't turn back, because the single direction gear, so the operator may press the button of the gear, in that case, the ramp may turn back in short time period, the operator will control the gear to make sure the ramp close slowly, and finally the magnet will seal the ramp again to finish the whole process.

Price

Components	**Prices ($)**
DC motor	860
Stainless steel cable (7x19, most flexible wire, widely used for running rigging, control cables, cranes and winches) total length: 15m diameter: 5mm	75
Main garage door	5,000 - 5,500
Synthetic rubber	270
Single direction gear	160

Table 4.3.1 Total price of the door design

From the table above, the total costs for the design is between $6,365 - 6,865. The price for main garage door and synthetic rubber is based on Chinese market price.

4.3.5 Interact with other systems

The overall design of the main garage door system is independent from other subsystems. However, there is a motor in the design which requires electricity from the front section of the cargo.

4.3.6 Future Consideration

After communicated with the client during the preliminary design review presentation (PDR), the client concerned the weight of the main garage door is too heavy. In order to reduce the weight of the door, the group design to only make the door solid for the wheel trail section, and the rest part is hollow with cellular structure supported. Thus, a force body diagram is applied to calculate the feasibility of this design.

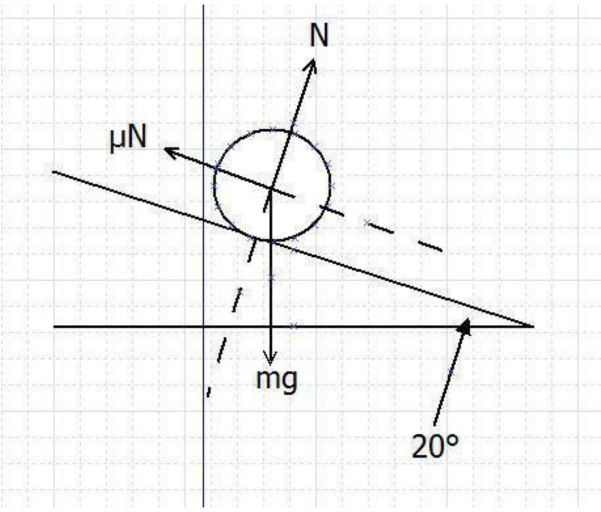

Figure 4.3.12 The Force Body Diagram (FBD) for the rover

As shown in Figure 4.3.12 above, the equilibrium equations can be calculated:

$$mgsin20° = \mu N$$

$$mgcos20° = N$$

Since the FBD is on one side of the rover wheel, the weight mg should be one fourth for the whole rover which equals to 1000kg × 9.8N/kg = 9800N. Therefore, the normal force should be 9800 N × cos20° = 9209 N. According to P = FS, F equals to the normal force 9209 N and the area between the wheel and ground is measured to be 0.03 m^2 for each wheels. Hence, the pressure equals to 307 kPa.

This figure is far less than the ultimate tensile strength and therefore using 6061 aluminium alloy is quite safe for the whole garage.

Based on the calculation, the design is feasible, nevertheless, the structure is too complicated to test by ANSYS. Therefore, the group is lacking the test results.

4.3.7 Verification

The requirements of doorway access from client is shown below. The designed dimension of the is 3.21×2.78m, the height is longer than the target value and the width is narrower than the target value (V1.2 in Table 4.3.2 below). The purpose of design is to reduce the surface area of the main garage door in order to lower the weight, and with designed dimension, the rover still can be able get access. The dimension of the human access door is 1.64×0.85m, its dimension is consistent with other human access doors on the habitat (V1.2 in Table 4.3.2 below). According to the Force Body Diagram (FBD) analysis above, it is feasible in theory. (V1.3 in Table 4.3.2 below). The budget of doorway access is accepted by the client.

Verification ID	**Reqd by**	**Description**
V1.2	R1.2	Inspect length of doorway access by measuring the length. Compare to the target value 3.181×3.181 m. Inspect the power consumption by measuring the voltage and current between doorways. Compare to target value 100 W. Inspect the length of door for man pass by measuring the length and height. Compare to the target value 2×1.5 m.
V1.3	R1.3	Testing the load bearing by loading weight in garage. Place 8000 kg load as a stress test. Compare to the target value 8000 kg.
V10.0	R10.0	Analyse the budget of system by carrying out costing analysis on subsystems and components. Costs include labour loss and material. Compare to the budget.

Table 4.3.2 Verification of the doorway access design

4.4 Docking Module

4.4.1 Main Compartment

The main compartment of the adapter module is the body that connects the Habitat and Garage modules. It houses all the components within adapter module and is the main body through which people and goods are moved between the Garage and Habitat modules. The dimensions of the main structure have been constrained by the client.

4.4.1.1 Design Description

The docking module is a simple aluminium structure. There is an aluminium floor plate that is supported by beams positioned under the plate as well as four legs welded to the support beams. There are beams bolted to the floor that extend to the roof of the docking module. A weatherproof tarpaulin canopy is used as a roof and wall material where possible. The structure is stored in the garage and can be assembled on site. The structure is assembled using M10 hex bolts. The length of the system, between garage and habitat module, is 2.8 m. The diagram below shows a CAD model of the docking module excluding the tarpaulin canopy and wheel attachment.

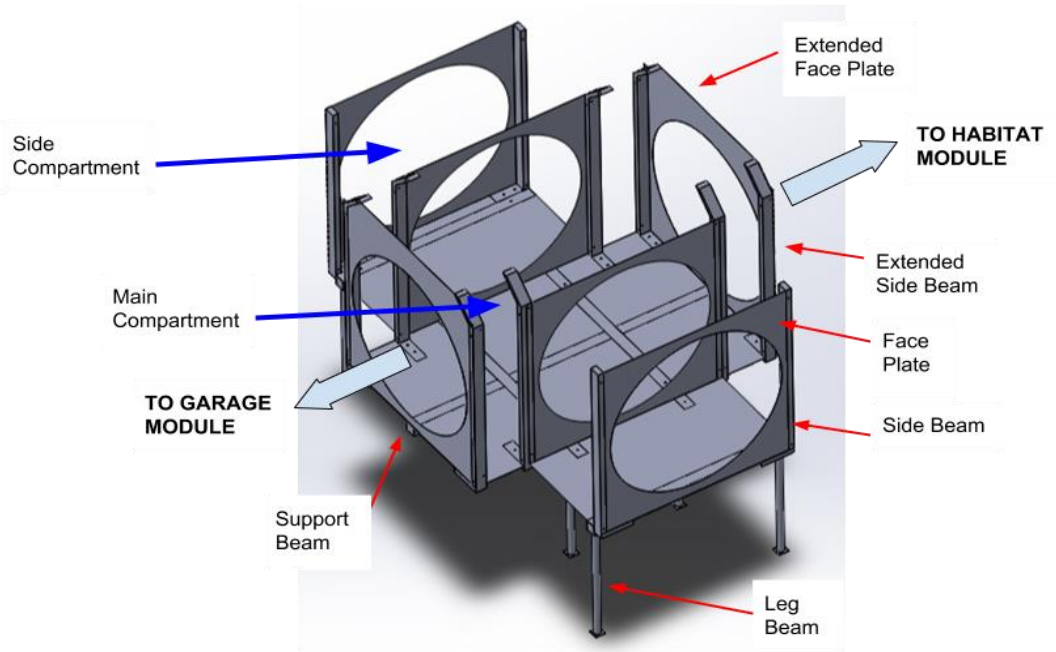

Figure 4.4.1 CAD model of docking module frame and floor

The major components of the docking module are the floor plate, support beams and legs, side beams, face plates and the canopy. These components and their analysis are discussed in detail in the subsequent sub-sections.

Adapter Module Specifications Summary

Weight: 119 kg
Load Capacity: 200 kg
Securing Mechanism: M10 × 100 Structural Grade 8.8 Zinc Plated Hex Bolt Fastener Assembly
Number of legs: 4
Factor of Safety (Weight): 6
Mobility System: Integrated Wheel and Pad Castor
Number of wheels: 4
Size: 2.8m× 1.8m× 2.0m (Main Compartment)
Roof: 240GSM Tarpaulin

4.4.1.2 Cost Summary

The table below details the approximate component costs of the main compartment.

Name	Description	Unit Cost ($AUD)	Quantity	Total Cost ($AUD)
Fastening Assemblies	Total cost of all fastening assemblies used	N/A	N/A	124.72
Aluminium Floor Plate	2800x1800x5mm Aluminium Treadplate	~690.50	1	~690.50
Support Beam	850x100x100x6 Aluminium 6061 Rectangular Tube	~100.58	2	~201.16
Support Beam	1830x100x100x6 Aluminium 6061 Rectangular Tube	~216.55	2	~433.10
Support Beam	900x100x100x6 Aluminium 6061 Rectangular Tube	~106.50	1	~106.50
Leg Beam	1048x60x5 6060-T5 Aluminium Hollow Tube	~95	4	~380
Castor Wheel	Adjustable levelling castor with wheel and pad	$71.50	6	~429
Side beam Standard (ROM)	1830x100x5 Side Beam Aluminium 6060-T5	~96.60	4	~386.40
Side beam Extended (ROM)	1830+x100x5 Side Beam Aluminium 6060-T5	~96.60	8	~772.80
Face End Plate	2000x1800x2 Aluminium 6061 Plate	~220	2	~440
Face Side Plate	1800x1800x2 Aluminium 6061 Plate	~220	4	~880
			Total:	~$4844.22

Table 4.4.1 Docking module main compartment approximate component cost

4.4.1.3 Fastening Assemblies Used in the Docking Module

Below shows all the fastening assemblies used for different component interfaces in the docking module. Subsequent sections will refer back to this section in regards to the fastener used for that component. The fastening assembly used to secure the docking module to main modules (ID no. 1) is discussed in high detail in section 6.5, as it is an important interface in the system.

ID no.	Used in (Component/ Assembly)	Diameter	Bolt Length	Thread Length	Grade	Comments	Quantity Required	Total Cost ($)	Supplier
1	Docking to Main Modules Fastening Assembly	M10	100	26	8.8 Structural	Hex. High Tensile, Zinc Plated, Pack of 10	4	10.97	Scrooz.com.au
2	Floor Plate/ Support Beams	M10	120	26	8.8 Structural	Hex, High Tensile, Zinc Plated, 2× Pack of 50	12	98.02	Scrooz.com.au
3	Floor Plate/ Side Beams						24		
4	Face Plate/Side Beams						28		
5	Leg Beam/ Castor Wheel	M8	25	25	304 Standard	Stainless Steel, Pack of 20	16	15.73	Scrooz.com.au

Table 4.4.2 Fastening assemblies used between different components of the main docking module compartment

4.4.1.4 Docking to Main Modules Interface

The adapter module needs to be securely attached between the Garage and Habitat sections. A secure connective interface at each end of the adapter module is required to achieve this. This is done using fastening assemblies (bolt, nut & washer). Fastener assemblies are widely used in construction for their relative low price and lifespan for the structural strength they provide.

A suitable fastener assembly is supplied by "scrooz.com.au". It has a diameter of 10 mm, a length of 100mm for a length of engagement of 77 mm. The length of the thread is 26 mm. Out of the total length of engagement (77 mm), 3mm will be threaded and the remaining is smooth. The diameter of the hole is 12mm, considered a loose fit, for easier fitting.

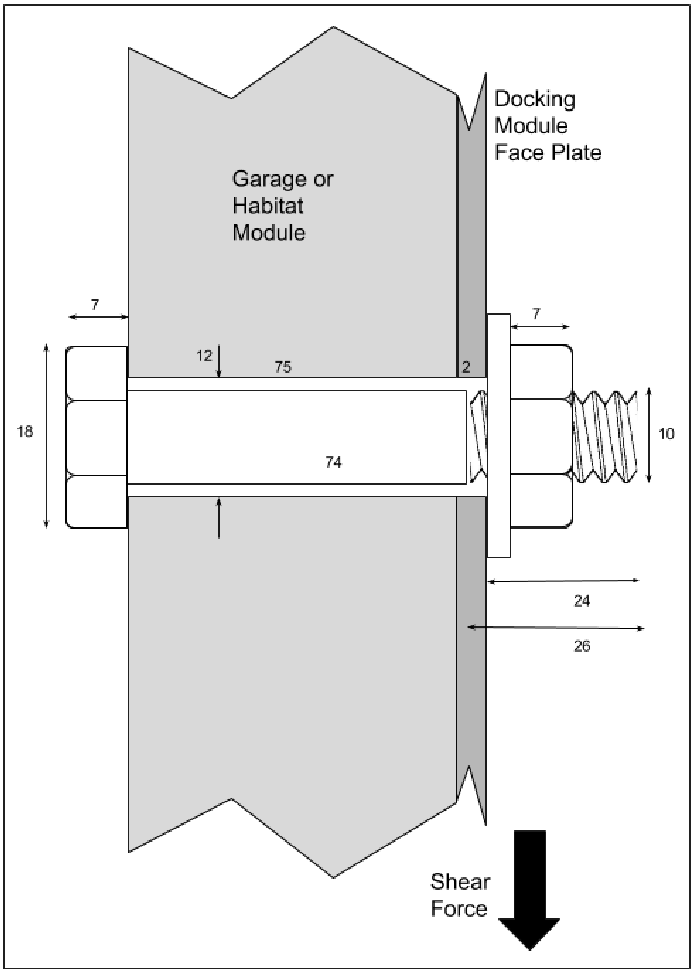

Figure 4.4.2 fastening assembly diagram

- **Fastener Bolt Benchmarking Process**

The fastening assemblies are not exclusively responsible of supporting the gross weight of the docking module; as it has legs designed to support the weight. The bolt must be able to withstand 3924 N of shearing force. The stress on the fastener bolt will be primarily due to shearing forces. It is assumed that shear forces to the bolt are attributed solely to the weight of the docking module and its carrying contents. The weight of the docking module is a maximum of 200 kg; which can internally support a payload of 200 kg; for a total of 400 kg (3924 N). (Sidenote: Originally, the docking module was 200kg, however in the new design, the docking module is 100kg;this section assumes a 200kg docking module).

The fastener bolt must have a minimum shear strength of 3924 N. Shear strength is approximately 0.60 of ultimate tensile strength in a bolt. The ultimate tensile strength of a specific grade and diameter of a bolt is given by (Portland Bolt, 2015):

$$s_{tensile} = t_{min} \times a$$
$$s_{shear} \approx s_{tensile}$$

$Where:$
$s_{tensile} \ = \ Ultimate\ tensile\ strength$
$s_{tshear} \ = \ Shear\ strength$

$t_{min} \ = \ Minimum\ tensile\ strength\ of\ bolt\ grade$
$a \ = \ Stress\ area\ of\ diameter$

Fastener Bolt Benchmarking

The ultimate tensile strength of bolt grades 4.6 and 8.8 are shown below. The tensile stress area of various diameter bolts are also shown below. These are used in benchmarking.

Bolt grades and Ultimate Tensile Strength	
Grade	**MPa (N/mm2)**
4.6	400
8.8	830
Area under tensile stress	
Diameter (mm)	**Area (mm)**
M6	20.1
M8	36.6
M10	58
M12	84.3
M16	157

Table 4.4.3 fastener information used for benchmarking

Different types of bolts from various suppliers are benchmarked against their cost and shear strength. A minimum factor of safety of six is required

Name	Diameter	Grade	Min Tensile Strength	Stress Area	Ultimate Tensile Strength (N)	Maximum Shear Force (N)	Factor of Safety	Total Cost
M16x130 HDG 8.8 Struct	16	8.8	830	157	130310	78186	19.9	28.53
M12x140 HDG 8.8 Struct	12	8.8	830	84.3	69969	41981.4	10.7	23.00
M8x130 BLK 8.8 HT BN	8	8.8	830	36.6	30378	18226.8	4.6	22.22
M6x130 HDG 4.6 HEX BN	6	4.6	400	20.1	8040	4824	1.2	7.17
M8x130 ZP 4.6 HEX BN	8	4.6	400	36.6	14640	8784	2.2	8.44
M8x130 HDG 4.6 HEX BN	8	4.6	400	36.6	14640	8784	2.2	12.80
M10x130 BLK 4.6 HEX BN	10	4.6	400	58	23200	13920	3.5	11.50
M10x130 HDG 4.6 HEX BN	10	4.6	400	58	23200	13920	3.5	12.94
M10x130 ZP 4.6 HEX BN	10	4.6	400	58	23200	13920	3.5	11.50
M12x130 High Tensile Grade 8.8 ZP Box of 50	12	8.8	830	84.3	69969	41981.4	10.7	65.53
M10x130 High Tensile Grade 8.8 ZP pack of 50	10	8.8	830	58	48140	28884	7.4	53.46
M10x130 Grade 4.6 Galvanised Box of 50	10	4.6	400	58	23200	13920	3.5	42.17

Table 4.4.4 benchmarking of different types of fasteners

4.4.1.5 Main Compartment Floor

An aluminium tread plate spans the length of the docking module. It is 2.8m long and 1.8m wide, with an area of 5.04 square metres. The floorplate has a thickness of 5mm. The cost of the plate alone is $ 690.50

Floor Material and Thickness Selection Process

The main compartment of the adapter module must be able to hold 200kg.The adapter module has support beams under it. However, there will be areas of the floor that is unsupported by the legs. The unsupported areas of the compartment floor must be able to support a 200kg load.

Consistent with other components and subsystems, the floor’s most prioritised qualitative attributes are: 1. as cheap as possible; and 2. as light as possible. The best floor according to these attributes must be chosen. The independent variables that affect these attributes are shown below. These variables affect the plate thickness.

- Material (Steel vs. Aluminium): Different materials have different Young’s modulus and Poisson’s ratio.
- Unsupported Area: The unsupported area affects how thick the material needs to be to support the required load. The number of supports will determine the unsupported floor area.

Two possible configurations for floor support beams are shown below. For the first configuration, the maximum unsupported floor area is 900 × 1000 mm; for the second, the maximum unsupported area is 900 × 700 mm.

The stress for varying materials and unsupported areas are calculated; the minimum thickness is determined such that the stress is below the material's yield stress. The cost and weight are then derived from material and thickness. Naturally, more support for the floor plate results in a thinner plate; however it is a trade-off with the cost of the support beams. Assumptions and points regarding the benchmarking process:

- The floor plate loading will have a factor of safety of six, standard in structural design in buildings (Engineering Toolbox FOS, 2015). Therefore, a 1200kg (11772N) load will be used in calculations.
- The floor is simply supported under a uniformly distributed load of 1200kg (11772N).
- The minimum thickness will be to a whole mm value.

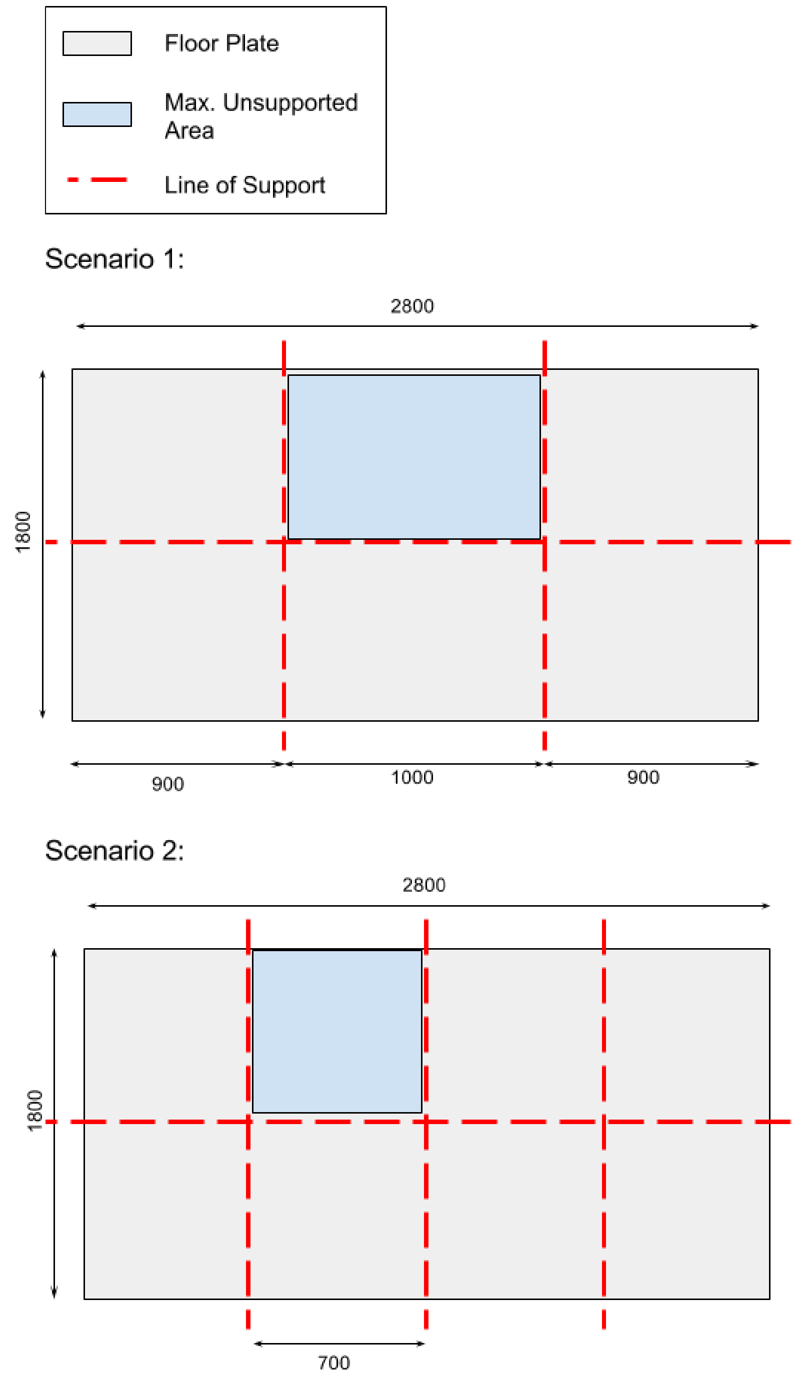

Figure 4.4.3 possible configurations for floor support beams

Floor Benchmarking

An online tool by 'efunda' to calculate stress and displacement in simply-supported rectangular plate under a uniformly distributed load is used for the benchmarking (efunda, 2015).

The two materials considered are aluminium and steel. Table 4.4.5 below outlines their relevant physical strength properties. Material thickness is determined such that the stress on the plate is less than the yield strength.

Material Properties			
Material	**Young's Modulus (GPa)**	**Poisson's Ratio**	**Yield Strength (MPa)**
Aluminium 6061 Alloy	70	0.33	27
Stainless Steel	210	0.3	81

Table 4.4.5 material properties (Alumatter, 2010)

Maximum Unsupported Area Configurations 1 and 2			
Leg Configuration	**Unsupported Length (mm)**	**Unsupported Width (mm)**	**Area (m^2)**
Config. 1	900	1000	
Config. 2	900	700	

Table 4.4.6 maximum unsupported area for each floor support configuration

Support Configuration	**Young's Modulus**	**Poisson's Ratio**	**Area**	**Distributed Loading (MPa)**	**Required Thickness (mm)**
Aluminium 2-Pair Support	70	0.33	0.9	13080.0	5
Aluminium 3-Pair Support	70	0.33	0.63	18685.7	5
Steel 2-Pair Support	210	0.3	0.9	13080.0	3
Steel 3-Pair Support	210	0.3	0.63	18685.7	3

Table 4.4.7 required thickness calculation for different materials in different configurations

Material	**Density (kg/m^3)**	**Thickness (mm)**	**Volume (m3)**	**Weight (kg)**	**Cost (ROM)**
Aluminium 6061	2720	5	0.0252	69	$690.48
Steel	7850	3	0.01512	119	$650

Table 4.4.8 Quantity and cost for each material. (Engineering Toolbox MAD, 2015)

The configuration of supports do not affect the minimum thickness of the plate. The material is the sole variable responsible for thickness. The company, “Specialist Metal Fabricators”, supply 5mm aluminium tread plate for \$137/m^2 (Rapid Fab, 2015); a total cost of \$690.48 for the floor. “Scott Metal’s” fabricates 3 mm steel tread plates for \$130/m^2 (Scott Metals, 2015); for a total cost of \$650. The Aluminium tread-plate is the most suitable choice, costing \$40.48 more in exchange for a 50 kg weight saving.

4.4.1.6 Support Beams and Legs

The main compartment is propped up with support legs and cross beams. Two support beams, each having two having support legs, span the width of the adapter module. One support beam spans the length of the module. Aluminium alloy round hollow tubes is used as opposed to steel to reduce weight of the system.

Support Beams

Five aluminium horizontal beams support the adapter module floor plate to reduce its thickness. The floor plate is bolted down against the beams using fastener assembly 2 from section 4.4.1.3. The configuration is shown below in figure 4.4.4. They are 100×100 mm aluminium rectangular hollow tubes with 6mm thickness. The total length of the beams are 6.26m for an approximate cost of \$740.77 (\$118.33/m). This value is extrapolated from the supplier “Williamstown Metal Merchants Pty. Ltd.” that supplies 300 mm lengths for \$25.50.

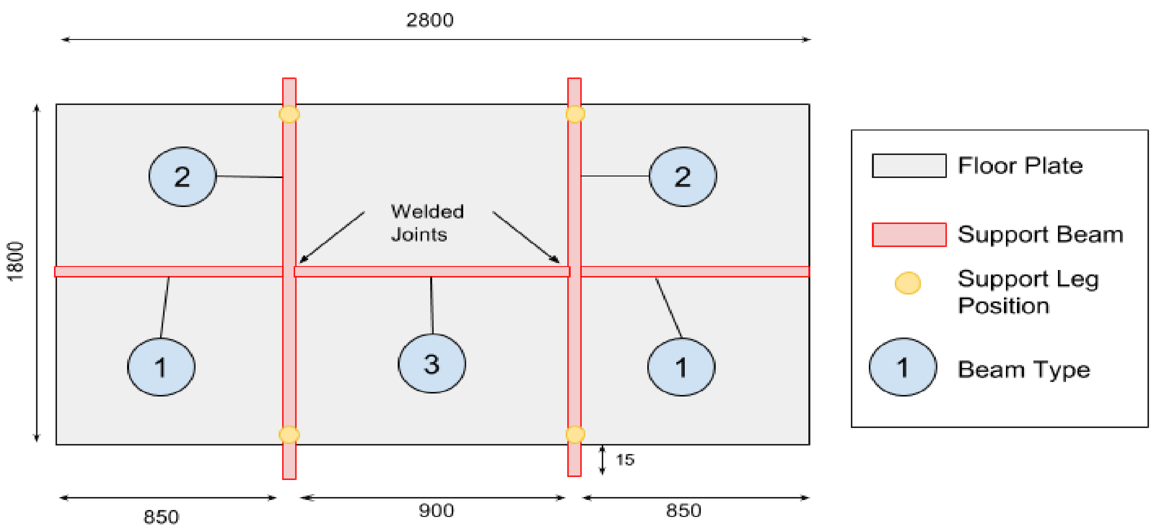

Figure 4.4.4 floor support diagram

Stress in Support Beams

For analysis, we deduce the beam types are:

- Beam 1: Cantilever beam under concentrated point load at free end
- Beam 2: Fixed beam under concentrated point load at centre
- Beam 3: Fixed beam under concentrated point load at centre

A tool to design beam members under compression and column buckling by 'Advanced Mechanical Engineering Solutions' aids in calculating resulting stress (Advanced Mechanical Engineering Solutions SBD, 2015). We require the maximum bending stress to be less than 27MPa (Yield strength of aluminium).

Beam Specifications		
Metric	**Unit**	**Value**
Width	mm	100
Height	mm	100
Thickness	mm	6
Modulus of Elasticity	GPa	70
Second Moment of Area	cm^4	492
Cost	$/m	118.33

Table 4.4.9 floor support beam specifications

Analysis	Length	Weight	Load	Target	Maximum Bending Stress
Beam Type 1	895	8.764	1962N	< 27MPa	17.6

Analysis	Length	Weight	Load	Target	Maximum Bending Stress
Beam Type 2	1800	17.626	1962N	<27MPa	4.5
Beam Type 3	990	9.694	1962N	<27MPa	2.7

Table 4.4.10 Analysis of different beams for use as floor support

The stress in all three beams are low the yield strength of aluminium. The selected beam is suitable for use.

Support Legs

There are four support legs welded to two of the support beams. They are 60mm diameter, 5mm, 1048mm long thick hollow tube beams made from 6060-T5 aluminium alloy. Each leg can withstand gross weight (300kg) of the docking module under compression with a factor of safety 7.81. The cost of each leg is approximately $95, for a total cost of $380 (four legs). The specified tube at a shorter 300mm length can be supplied for $24.50 (Williamstown metal merchants, 2014), the approximate value of the leg beam is extrapolated from the shorter length tube.

The bottom end of the tube leg has a 90× 90mm welded plate with four bolt hole centres 70mm apart in a square constellation. The plates allow the castor wheels to be attached to the leg.

A tool to design beam members under compression and column buckling by ‘Advanced Mechanical Engineering Solutions’ aids in determining a suitable leg beam (Advanced Mechanical Engineering Solutions CBCM, 2015). The tool calculates allowable compressive load on the cross section of a beam. The leg loading have a factor of safety of six, standard in structural design in buildings (Engineering Toolbox FOS, 2015). The weight of the adapter module is 100kg. The gross mass at full load capacity is 300 kg (2943N); therefore, each leg must withstand a load of 2943 N compressive force.

Diameter	Thickness	Cross Sectional Area (cm^2)	Second Moment of Area (cm^4)	Mass (kg)	Allowable Load (N)	FoS	Cost/m	Cost/Leg ($)
50	2	3.016	8.701	0.86	7989.64	2.71	28.33	32.52
50	3	4.43	12.281	1.263	11726.28	3.98	32.67	37.51
50	4	5.781	15.405	1.805	15290.04	5.2	30.4	34.90
60	3	5.372	21.878	1.531	14310.65	4.86	49.33	56.63
60	5	8.639	32.938	2.698	22992.48	7.81	81.67	93.76

4.4.11 benchmarking of circular tubes for legs

Wheel System

Each of the four legs has a levelling castor bolted to it. The castor has wheels and a friction pad that can be used interchangeably to allow manoeuvrability or stability of the docking module. When the docking module is in place using the wheel system, the polyurethane pad can be wound down to the ground to make the docking module stable. The castor is bolted to the leg plates using fastener 5 which is detailed in Section 4.4.1.3.

Castor Specifications (Castors Galore, 2014):
Wheel Diameter: 60mm
Plate: 90× 90mm
Hole Centres: 70mm× 70mm
Height: 102mm
Retractable Height: 113mm
Load Capacity: 500kg
Cost: $71.50

Figure 4.4.5 castors for the bottom of each leg

4.4.1.7 Side Beams and Face Plates

The docking module features face plates to interface with the hatches. That is, a face plate is attached to the docking module where a hatch is required. The face plates are a 1.8x1.8m 2mm thick aluminium plate with a 1.6m diameter hole at the centre. The face plates are bolted to the side beams using fastener assembly 4 in Section 4.4.1.3.

The side beams have two main functions. The face plates are bolted to the side beams for support and positioning. They also serve to hold up the canopy for weather protection. The side beams are a rectangular hollow tube with dimensions 100x50mm, 3mm thick aluminium. The side beams placed under the floor plate to extend upwards and bolted down using fastener assembly 3 in section 4.4.1.3.

4.4.1.8 Canopy

The docking module will be closed using a heavy duty tarpaulin. A tarpaulin is a lightweight weatherproof solution that provides UV protection. “Discount Tarpaulins” supplies an industrial grade heavy-duty 240GSM tarpaulin which is considered very high grade can withstand exposure to the sun over extended periods of time. The length of unsupported tarp should be no more than 2.5m.

4.4.2 Flexible Extension Section

The flexible extension section is used to connect to the rover when people need to move directly to the rover in docking module. When the flexible section is used, it can be expanded to 2.2 metres and connect the rover. When it is not used, this section will be compressed to save the space. It is mainly made up by three parts: Outer layer, tunnel and prop shaft, which will be discussed below.

4.4.2.1 Outer layer

The outer layer of the flexible extension section protect the airtightness of the flexible section when it is expanded or compressed. The shape of outer layer is a circular column without top and bottom parts. The maximum length of the outer layer is 2.2 metres and the diameter is 1.7 metres, which is a little bit larger than the size of the door.

The material of the outer layer is similar to the material of boarding bridge canopy in airport (See in Figure 4.4.6). This material consists of antibacterial property, fire resistance and radio resistance. The price of this type of material is also cheap enough for the whole design, 7.64 AUD per square metre.

Figure 4.4.6 The picture of Boarding bridge awning

4.4.2.2 Tunnel

The tunnel inside the docking module is the passageway for people to move from docking module to the rover. The diameter of the tunnel is 0.8 metre and the length of it is also 2.2 metres, which is the same size of the outer layer.

The material of the tunnel includes two types of material: aluminium alloy and polyethylene. The lower part of the tunnel uses aluminium alloy, which can support the weight of people moving through.

The upper part of the tunnel uses polyethylene material (See in Figure 4.4.7) to achieve the heat isolation from outside.

Source: 

Figure 4.4.7 Product of tarpaulin used in the tunnel (Bunnings warehouse, 2015)

4.4.2.3 Prop Shaft

The function of prop shaft is to support the whole flexible section. While the prop shaft on both ends of the flexible section are used to fix the whole section to the docking module and the rover, the prop shaft on the side of the flexible section are used to expand or compress the flexible section, which can be seen in Figure 4.4.8.

The material of the prop shaft is AISI 4140 Alloy Steel, which is widely used as support. Moreover, this type of material has high fatigue strength, abrasion and toughness, which can satisfy the requirement of long lifespan.

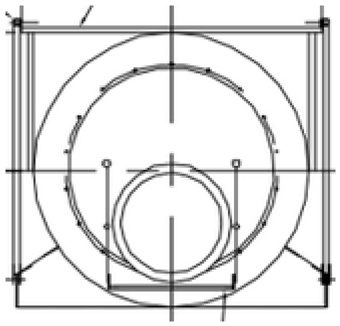
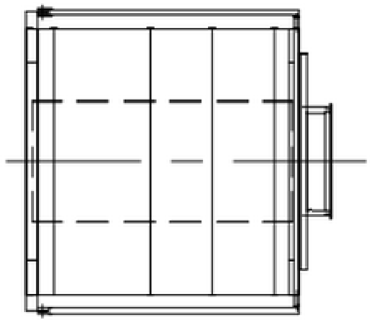
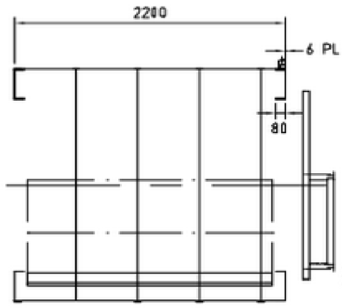

Figure 4.4.8 The front elevation. Figure 4.4.9 The vertical elevatio Figure 4.4.10 The side elevation

4.4.2.4 The material used in flexible section:

Outer layer

The area of the outer layer is 5.35×2.2 square metres, where 2.2 is the length of outer layer and 5.35 is the round of outer layer.

Materials	Area (m^2)	Density (kg/m^2)	Mass (kg)	Cost per kg ($/$m^2$)	Total Cost
Boarding bridge canopy (70% Polyvinyl chloride)	5.35×2.2	0.9	56.46	7.64	89.75 dollars (AU)

Table 4.4.12 Material specification for outer layer of flexible section

Tunnel

The area of Polyethylene material is 2π×0.42×2.2÷2=2.903 m2, where the external of the tunnel is 0.84 metre.

Materials	Area (m^2)	Density (kg/m^2)	Mass (kg)	Cost per product (AU$)	Total Cost
Polyethylene	2.903	0.1	0.290	16.45	16.45 dollars (AU)

Table 4.4.13 polyethylene specification for tunnel of flexible section

The volume of aluminium alloy is 2π×(0.422-0.42)×0.02×2.2÷2=0.0567 m^3 , where the external of the tunnel is 0.84 metre and the thickness of the tunnel is 0.02 metre.

Materials	Volume (m^3)	Density ($10^3 kg/m^3$)	Mass (kg)	Cost per kg ($/kg)	Total Cost
Aluminium alloy	0.0567	2.75	155.925	$2.103/kg	327.91 dollars (AU)

Table 4.4.14 aluminium specification for tunnel of flexible section (Online Metals, 2015)

Prop shaft

The prop shaft on both ends of the outer layer:

8 prop shafts, the diameter of each prop shaft is 0.0142875 metre and the length of them is 1.72 metres.

The prop shaft on sides of the outer layer:

12 prop shafts, the radius of each prop shaft is 0.0142875 metre and the length of them is 1.86 metres.

Materials	Length (m)	Density (kg/m)	Mass (kg)	Total Cost($)
Alloy Steel 4140	36.08	1.265	45.64	619.70

Table 4.4.15 Material specification for outer prop shaft of flexible section (AZO Materials, 2015)

4.4.3 Docking Module Hatch

There are two kinds of hatches in docking module:

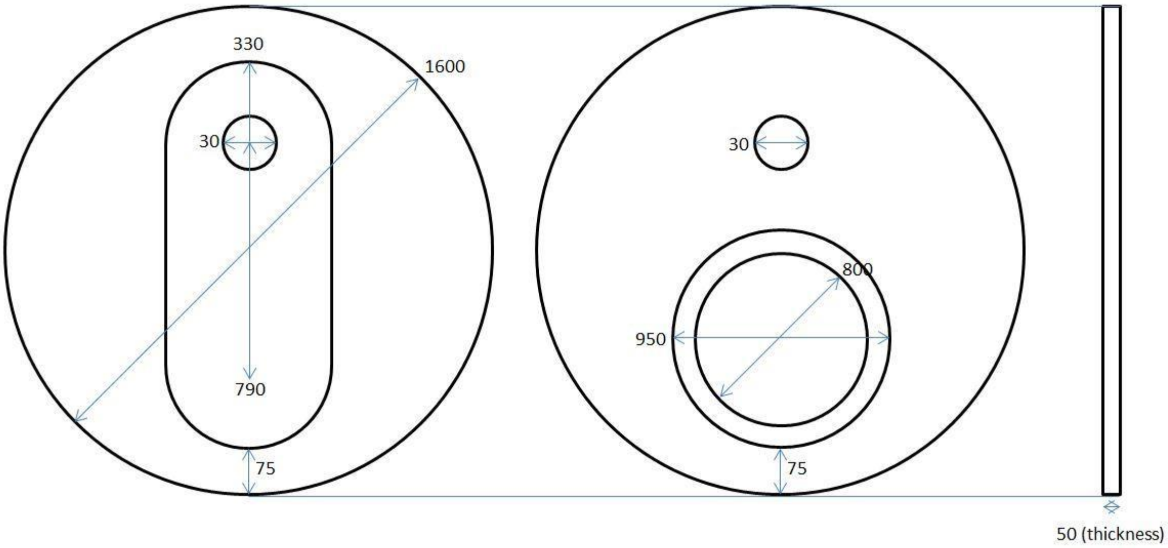

Figure 4.4.11 diagram of two door systems used in docking module

The first kind of door is used to connect the HAB module and the garage module to the docking module. It is also used in connection of different docking passages. The second kind of door is directly connected to the flexible extension part.

The door connected to the garage is designed to be in the garage side and open outward to the garage. In this way, docking passage's small space will not cause problems to the use of the door and people can use the door conveniently and safely. This design idea satisfies the requirement A8.2.2 Safety living equipment. In addition, design of the door connected to the Habitat module is similar to the discussed one.

The door which connects the main passage and the side passage should be designed in the side passage side and open inward to the side passage side, so that when opening, the door will not hinder the use of the main passage especially when there is an emergency condition. Based on same consideration, the door connected to the extension section is designed to open inward to the passage.

4.4.3.1 Detailed Door Design

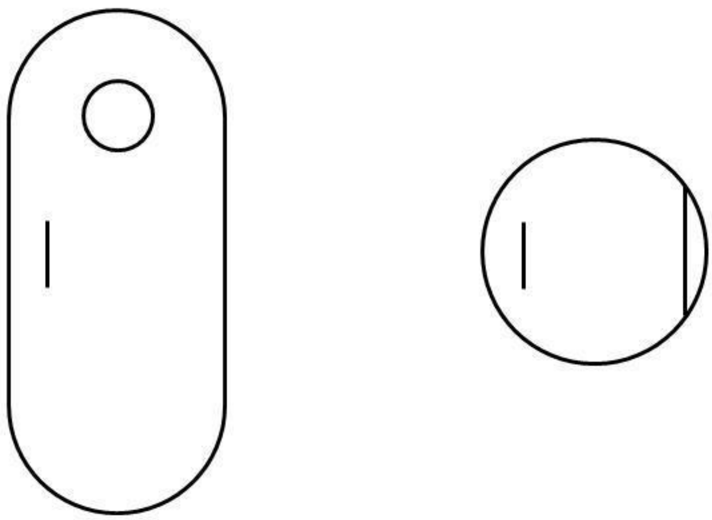

Figure 4.4.12 diagram of the two doors

As required, there is a small window on each door except the one connected to the extension section (for that door, window is on the wall). Each door also has a doorknob so that people can open it. The mechanism of seal section is the same with the design of our door subsystem group. Thus for a big door, the length of rubber seal should be 3.66 metres, while for the small door, the length should be 2.52 metres.

4.4.3.2 Material & Budget

In general, materials analysis is consistent with the design of door subsystem.

Parts	Chosen Material	Density (g/cm^3)	Mass (kg)	Price
Window	PMMA	1.18	0.21	~AUD 10
Rubber seal	Synthetic rubber	\	\	~AUD 100
Door	Aluminium alloy	2.75	665	~AUD1500

Table 4.4.16 material specification for door system

4.4.4 Verification

The requirements of the docking module and a description of how verification that the design detailed above meets these requirements is outlined in the table below.

Verification ID	**Reqd by**	**Description**
V6.1	R6.1	The length of the passage must be 2.2m length. To verify this, the length of the passage can be measure using a tape measure
V6.2	R6.2	The docking module must be able to hold a weight of 200kg. To verify this ANSYS modelling of the system can be done. Once the design has been built it can be verified by loading the system with an increasing weight until deformation starts to occur and comparing it to the required 200kg load
V7.0	R7.0	Test the power source from the garage by measurement using electronic measuring tools. Compare with the target value.

Table 4.4.17 Verification

5 Budget Summary

The following section summarizes the cost analyses of all design solutions within the current project scope. It is noticeable that this is not a quote, but instead provides a preliminary cost estimation based on the information available to the design teams. The cost of different sections are summarized in the table, which shows a positive result, considering that several important subsystems such as bunkhouse and docking modules have been covered.

Subsystem	Items	Costs/AUD	Total cost/AUD
Bunkhouse	Frame×12	840	3892.45
	Mattress×12	840	
	Ladder×4	112	
	Joint×24	360	
	Floor×25m^2	1750	
	Spandrel girder	736.45	
	Light Tubes	14	
Doorway access	Stainless steel cable	75	6865
	DC Motor	860	
	Synthetic rubber sealing strips YH-QC301×100m	270	
	Aluminium alloy door and ramp	5500	
	Single direction gear	160	
Docking module	Boarding bridge canopy (70% Polyvinyl chloride) ×11.77m^2	90	7475
	Polyethylene material×3m^2	17	
	Aluminium alloy×156kg	328	
	Alloy steel4140×46kg	620	
	Main Compartment	4720	
	Hatch	1700	
HVAC	LG-P09AWN-NM14 Air-conditioner	1474	1779
	Painting material×18.9L	173	
	Exhaust fan×2	132	
Total			20011.45

Table 5.1 Budget summary

The current total estimated cost will be $20011.45. There are a number of factors that has large influence on the cost estimation including:

- Quotes from different suppliers
- Labour and installation costs
- Location based costs
- Occupants' ability to follow equipment protocols

Possible suppliers have been found for each of the materials given above. Additional costs include the manufacturing cost of the panels. It is important to note that the total cost is a rough estimate and not a quote. It is recommended that the client seek a full quote from a supplier should they decide to use this system.

Labour costs may increase or decrease costs depending on the nature of the final design solution. Currently, the total cost of each subsystem only covers the cost of materials required. The additional shipping, transportation and installation fees of these materials haven't been taken into account yet but they do have an impact on the total cost because of the location of the habitat.

The ability of the residents to follow the equipment protocols can directly affect the cost of the habitat. Where the crewmembers are improperly or incompletely trained, oversights and accidents can occur which leads to damage to the systems at considerable expense. For example, improper use of bunkhouse facilities can lead to damage which would result in costly repair or replacement.

6 Risk analysis

Risk assessment helps to minimise the occurrence and impacts of risks inherent to the project, through the identification of preventative measures and mitigation strategies. In this part, risks will be identified first, following with scaled strategy with the help of risk matrix which is shown below. After that, possible solutions will be provided. In addition, risks in this project are mainly divided into two parts: management risks and design risks.

Risk matrix used in the assessment:

Likelihood	**Consequence**				
	Negligible	**Minor**	**Moderate**	**Major**	**Catastrophic**
Rare	L	L	L	M	M
Unlikely	L	L	M	M	H
Possible	L	M	M	H	H
Likely	M	M	H	E	E
Almost certain	M	H	H	E	E

Ps: L = low impact; M = medium impact; H = high impact; E = extreme impact

As can be seen from the matrix, the likelihood for each risk is divided into five ranks: rare, unlikely, possible, likely, and almost certain. Besides, the consequences are also scaled into five levels: negligible, minor, moderate, and major. The impact of a risk will be assessed combining these two aspects and the expected potential damage will be indicated.

Here is the project management risk:

Risks	Issues at Risk	Consequence	Likelihood	Consequence*Likelihood	Mitigation Plan
Failure of manager to lead the team	The project team cannot operate normally	Minor	Unlikely	L	Set up a substitute manager to help the project manager
Failure of Team members on some tasks	The project will be behind schedule	Moderate	Possible	M	All members have to give ideas to others' work
Insufficient time to meet deadline	The influence of thesis report and poster will reduce the available time for those members	Moderate	Possible	M	Set sub-deadlines for each small task. Make sure all small task can be completed within time limit
Conflict among group members	Team cannot accomplish the project efficiently, and provide a perfect work	Moderate	Likely	H	Different opinions should be discussed by all members, and vote should be taken when situation getting worse
Misunderstanding client needs	Waste much time, and go into the wrong direction	Major	Likely	E	Record every contact with clients in formal way, and contact to clients regularly

Table 6.1 team management risk

As for design risk

Risks	Issues at Risk	Consequence	Likelihood	Consequence* Likelihood	Mitigation Plan
Lack of knowledge about outer space or desert environment	Cannot provide a safe enough design	Moderate	Rare	M	Read more outer space materials
Client not satisfied with the design	The project will be considered as a failure	Moderate	Possible	M	Response to clients the team's achievement timely
The connection joint failing to hold the folding bed in bunkhouse	The bed is not safe for people to sleep	Minor	Possible	M	Increase the number of connection joints for each bed
Outer layer broken when flexible section is expanded or compressed	The airtightness will be unreliable	Moderate	Possible	M	Do regular maintenance and examination. Be careful when expanding or compressing this section
Tunnel in docking module faiingl to support people	People may get hurt	Minor	Possible	M	Do regular maintenance and examination.

Risks	Issues at Risk	Consequence	Likelihood	Consequence* Likelihood	Mitigation Plan
The noise of air conditioner	People may not be comfortable, disturbing the rest or works of staff	Moderate	Possible	M	Choose low noise air conditioner type
The stainless cables and electric capstans failing to provide enough force to lift up or down the main garage door and the ramp due to durability problems	Safety problem, damage to the metal shell of the garage, and also have a bad influence on seal system	Moderate	Possible	M	Do regular maintenance and examination.
Lack of experience in both hardware and software for this project	Cannot produce a satisfied prototype	Major	Possible	H	Record every contact with clients in formal way, and contact to clients regularly
The upper part of the docking tunnel broken when flexible section is expanded or compressed	The airtightness will be unreliable	Moderate	Likely	H	Do regular maintenance and examination. Be careful when expanding or compressing this section

Risks	Issues at Risk	Consequence	Likelihood	Consequence* Likelihood	Mitigation Plan
Deformation of the floor due to the expansion with heat and contract with cold	Result in safety problem and damage to the seal system	Moderate	Likely	H	The installation process should be careful. Besides, good HAVC system is required
Assumptions and ideas are diverged from reality	Badly influence the quality of the design	Catastrophic	Likely	E	Contact to clients and tutor regularly
Low efficacy of quilted fire retardant fabric covered on mattress after long time	Result in safety problem and damage to the metal shell of the garage, and also have a bad influence on HVAC system	Major	Almost certain	E	Change mattress every 5 years
Durability of the joint between the main garage door and the garage	The joint may easy to be abraded when using due to the heavy weight of the door and other external forces	Major	Likely	E	Do regular maintenance and examination.

Risks	Issues at Risk	Consequence	Likelihood	Consequence* Likelihood	Mitigation Plan
Few in the team majoring in the Material field	This will be a challenge in building the habitat, because the team does not have a good idea about which materials are suitable for Mars environment	Catastrophic	Almost certain	E	Do the searching about materials from the very beginning, and make several members be responsible for this problem

Table 6.2 Design Risk

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8 Appendix

8.1 Project Team and Team Structure

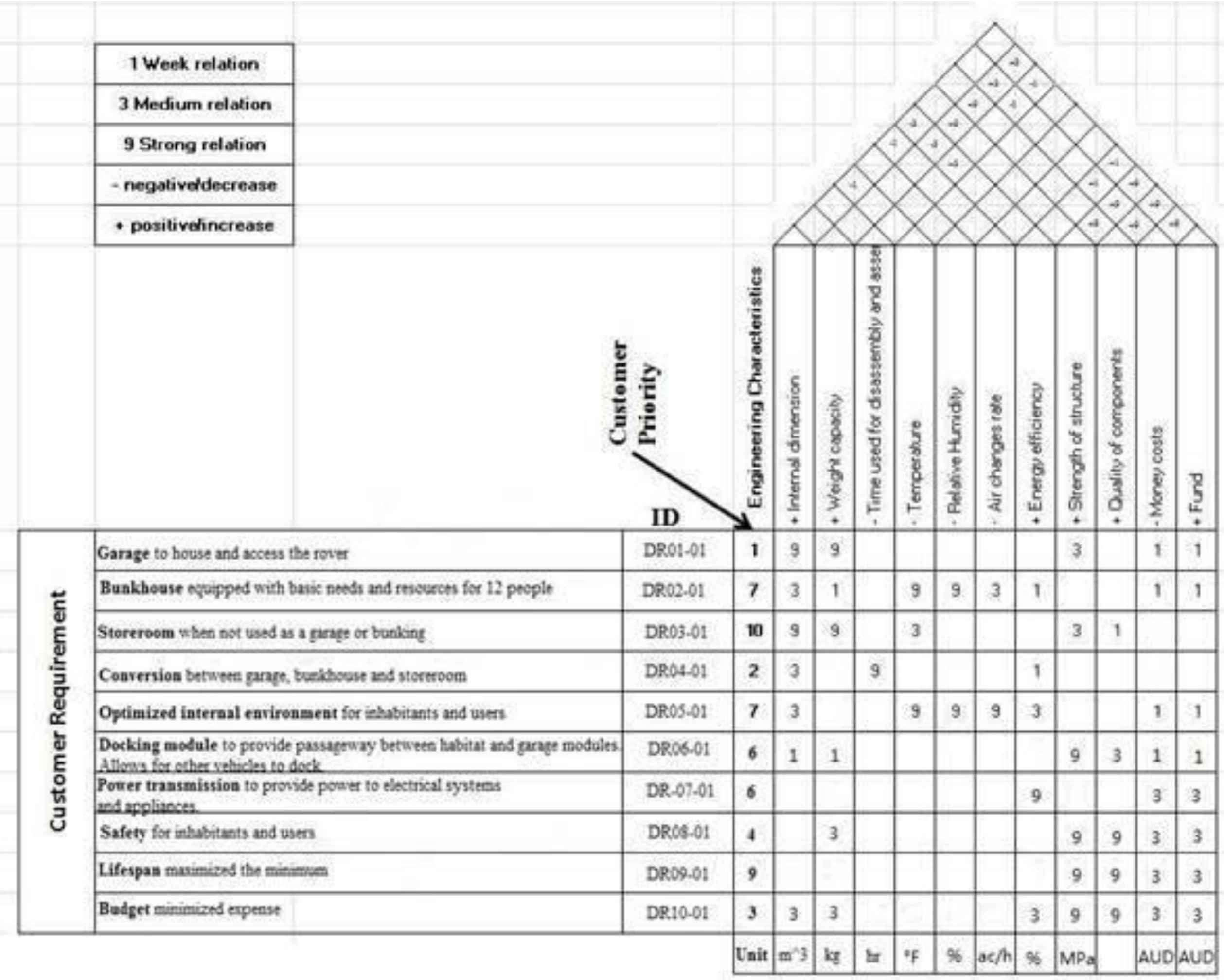
The team of this project consisting of 15 students from ANU ENGN4221. As the four subsystem, the team is divided into 4 subgroups according to personnel technique matrix.

Figure 8.1 Team structure

Except the groups of subsystems, there is also some temporary sub-team, such as presentation team and brochure team. Among these subgroup. SDS is a sub-team which exists for over 2 weeks and draw solid work for both the presentation and report. The names of members in this team are in black.

8.2 Trade off Analysis (House of Quality)

A House of Quality is shown in Figure 5.1. Technical performance measures are given a relative rating of their correlation to the design requirements. The roof of the HoQ shows the trade-offs between TPMs. TPMs need to be optimised bearing in mind their trade-offs and the priority of the design requirements attached to certain metrics.



Customer Requirement	ID	Customer Priority / Engineering Characteristics	+ Internal dimension	+ Weight capacity	- Time used for disassembly and asse	- Temperature	- Relative Humidity	- Air changes rate	+ Energy efficiency	+ Strength of structure	+ Quality of components	- Money costs	+ Fund
Garage to house and access the rover	DR01-01	1	9	9						3		1	1
Bunkhouse equipped with basic needs and resources for 12 people	DR02-01	7	3	1		9	9	3	1			1	1
Storeroom when not used as a garage or bunking	DR03-01	10	9	9		3				3	1		
Conversion between garage, bunkhouse and storeroom	DR04-01	2	3		9				1				
Optimized internal environment for inhabitants and users	DR05-01	7	3			9	9	9	3			1	1
Docking module to provide passageway between habitat and garage modules. Allows for other vehicles to dock	DR06-01	6	1	1						9	3	1	1
Power transmission to provide power to electrical systems and appliances.	DR-07-01	6							9			3	3
Safety for inhabitants and users	DR08-01	4		3						9	9	3	3
Lifespan maximized the minimum	DR09-01	9								9	9	3	3
Budget minimized expense	DR10-01	3	3	3					3	9	9	3	3
		Unit	m^3	kg	hr	°F	%	ac/h	%	MPa		AUD	AUD

Figure 8.2: House of Quality

In order to provide sufficient room to contain rover and allow for storage, the internal dimension of garage and garage's weight capacity has high correlation and requires high attention. Air temperature, relative humidity and air changes rate has strong relationship with human comfort living in bunkhouse and HVAC requirement. And as optimized power transmission method, the design requires consider relative energy efficiency heavily. Safety for users, operating life both has strong relationship with strength of structure and quality of components. The design should concentrate on the trade-offs between internal dimension, weight capacity and energy efficiency. Since increase internal dimension or weight capacity will decrease the energy efficiency performance.

8.3 System Cascade

The table of system cascade displaying two levels of derived attributes are shown below

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
A1.0 Use as a garage	A1.1 Rover housing	A1.1.1 Space efficient bunkhouse system	BHS/ROV/GAR
		A1.1.2 Space efficient docking module system	DOC/ROV/GAR
		A1.1.3 Space efficient garage door system	GAD/ROV/GAR
		A1.1.4 Weight capacity (4000kg)	GAR/ROV
		A1.1.5 Garage internal structural design	GAR/ROV
	A1.2 Convertible to garage	A1.2.1 Collapsible bunk beds	BHS
		A1.2.2 Stow-able bunkhouse facilities	BHS

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
		A1.2.3 Manually convertible by station personnel	BHS/USER
	A1.3 Drivable in and out	A.1.3.1 Sufficient ramp weight capacity	GAD/ROV/GAR
		A1.3.2 Ramp incline angle	GAD
		A1.3.3 Ramp positioning in-line with housed rover	GAD/ROV/GAR
		A.1.3.4 Efficient ramp deployment mechanism	GAR/GAD
		A1.3.5 Space for maintenance and repairs	GAR/BHS/ROV
		A1.3.6 Space for vehicle entry and exit	GAD/GAR/BHS
A2.0 Use as a bunkhouse	A2.1 Basic living conditions	A2.1.1 Accommodate 12 people	BHS/GAR

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
		A2.1.2 Air ventilation and climate control	HVAC/GAR
		A2.1.3 Foldable bunk beds	BHS/GAR
	A2.2 Convertible to storeroom	A2.2.1 Eight hours maximum conversion time	BHS/GAD/USER/HAB/DOC
		A2.2.2 Manually convertible by station personnel	BHS/GAD/USER/HAB/DOC
		A2.2.3 The frame of bunk bed could be used as a shelf	BHS
	A2.3 Convertible to garage	A2.3.1 Eight hours maximum conversion time	BHS/GAD/USER/HAB/DOC
		A2.3.2 Manually convertible by station personnel	BHS/GAD/USER/HAB/DOC
		A2.3.3 Foldable bunk bed frame	BHS

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
	A2.4 Living equipment	A2.4.1 150kg bunkbed maximum load	BHS
		A2.4.2 Mattress removable for conversion	BHS
		A2.4.3 Appropriate mattress size	BHS/DOC/HAB
A3.0 Use as storeroom	A3.1 Convertible to bunkhouse	A3.1.1 Eight hours maximum conversion time	BHS/GAD/USER/HAB/DOC
		A3.1.2 Manually convertible by station personnel	BHS/GAD/USER/HAB/DOC
	A3.2 Convertible to garage	A3.2.1 Eight hours maximum conversion time	BHS/GAD/USER/HAB/DOC
		A3.2.2 Manually convertible by station personnel	BHS/GAD/USER/HAB/DOC
	A3.3 Storage condition	A3.3.1 Around 180kg frame maximum load	BHS
		A3.3.2 Good ventilation to prevent the goods from decay	BHS/GAD/HVAC/DOC

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
		A3.3.3 Door should be airtight to prevent the sands from going in	BHS/GAD/HVAC/DOC
		A3.3.4 Keep the room dry to protect from mould	BHS/GAD/HVAC/DOC
A4.0 Comfort	A4.1 Proper temperature	A4.1.1 Keep the temperature around 26°C	HVAC/POW/GAD/ENV
	A4.2 Proper air pressure	A4.2.1 The pressure in the room shall be at around 101 kPa	HVAC/POW/GAD/ENV
	A4.3 Proper airflow rate	A4.3.1 Keep the airflow rate around 385 m^3/h	HVAC/POW/GAD
	A4.4 Proper humidity	A4.4.1 Keep the humidity in the room at around 50%	HVAC/GAD/POW/ENV
A5.0 Convertible	A5.1 Ease of conversion	A5.1.1 Reduce required resources	BHS/GAD/ROV/USER/HVAC
		A5.1.2 Reduce required manpower	BHS/GAD/ROV/USER/HVAC
		A5.1.3 Reduce man-hours	USER/BHS

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
		A5.1.4 Reduce complexity	USER/BHS
	A5.2 Cost of conversion	A5.2.1 Manual conversion (Cost over time)	BHS/USER
		A5.2.2 Conversion infrastructure (Initial cost)	BHS/USER
A6.0 Docking module	A6.1 Capacity to accommodate staff/facility	A6.1.1 Accommodate up to 8 people	DOC/ENV/USER
		A6.1.2 Accommodate up to 800kg weight	DOC/ENV
		A6.1.3 Strong metal legs to support	DOS/ENV
	A6.2 Sufficient power supply	A6.2.1 Equipped with 2 LED lights	POW/DOC/HAB
		A6.2.2 Set consuming power to 20W	POW/DOC/HAB

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
	A6.3 Effective connection with other parts	A6.3.1 Safety airlock connected to the garage and the outside	DOS/ENV
		A6.3.2 Flexible section connected to rover	DOS/ROV
A7.0 Power transmission	A7.1 Reliable transmission rate	A7.1.1 Cable length	HAB/USER
		A7.1.2 Clear wiring of cables	HAB/USER
	A7.2 Easy to transmit and receive	A7.2.1 Compatible with various appliances	HAB/USER/GAD
		A7.2.2 Reliable connection ports	HAB/USER/GAD
	A7.3 Safety limit	A7.3.1 Automatic outage when overloading	ENV/GAD/POW
		A7.3.2 Connection points covered with insulated rubber	POW

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
A8.0 Safety	A8.1 Safety for the rover	A8.1.1 garage door	GAD/ROV
		A8.1.2 Internal structural design	ENV/ROV
		A8.1.3 Extinguishing System	ROV/HVAC/DOS/GAD
	A8.2 Safety for human	A8.2.1 Effective airlock	DOS/GAD/USER/ENV
		A8.2.2 Safety living equipment	BHS/USER/HVAC
		A8.2.3 Power safety issue	GAD/BHS/DOS/HVAC
		A8.2.4 Emergency exit	GAD/DOS/USER
A9.0 Lifespan	A9.1 Docking system	A9.1.1 Backup Lights available (LED lights)	DOS/HAB
		A9.1.2 Durable passageway lasting for at least 5 years	DOS/HAB

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
	A9.2 Garage door	A9.2.1 Strong ramp lasting for at least 5 years	GAD/ROV
		A9.2.2 Sturdy main door lasting for at least 5 years	GAD/ROV
	A9.3 HVAC system	A9.3.1 Heating and cooling system lasting for at least 5 years	HVAC/USER/ENV/HAB
		A9.3.2 Ventilation system lasting for at least 5 years	HVAC/USER/ENV/HAB
	A9.4 Bunkhouse system	A9.4.1 Safety bed lasting for at least 5 years	BHS/USER
		A9.4.2 Major equipment lasting for at least 5 years	BHS/USER/HAB
		A9.4.3 Backup minor equipment available	BHS/HAB/DOC/GAD
A10.0 Budget	A10.1 Cost of modelling the design	A10.1.1 Simple modelling on computer	GAD/BHS/HVAC/DOS
		A10.1.2 Actual prototype (low cost)	GAD/BHS/HVAC/DOS

Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems and Interfaces
	A10.2 Cost of building actual garage	A10.2.1 Low building cost	GAD/BHS/HVAC/DOS
		A10.2.2 Low maintenance and repair cost	GAD/BHS/HVAC/DOS/ENV/TOS
		A10.2.3 Cost for instruments	----

Table 8.3: System cascade showing two levels of qualitative attributes

8.4 Arkaroola information

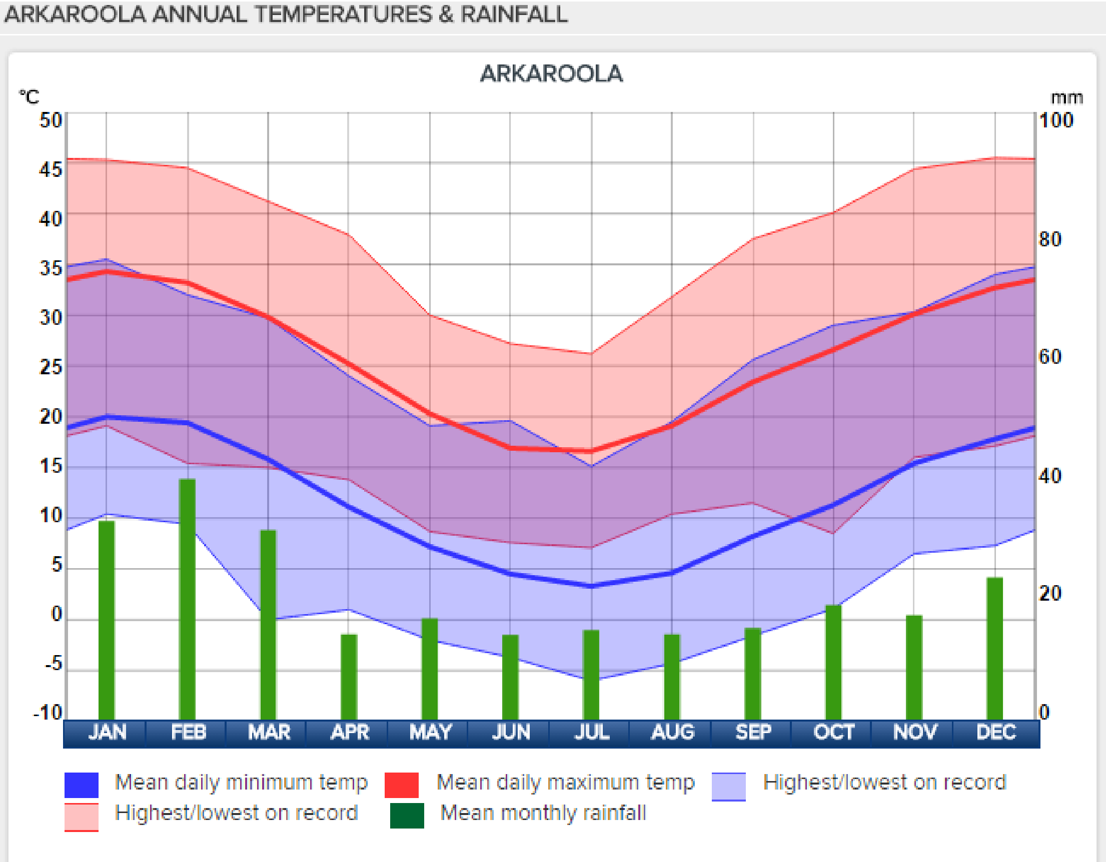


Figure 8.3 Arkaroola annual temperatures & rainfall

ARKAROOLA LONG-TERM AVERAGES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mean Max (°C)	34.3	33.2	29.8	25.2	20.3	16.9	16.6	19.1	23.4	26.6	30.1	32.7	*25.7*
Mean Min (°C)	20.0	19.4	15.8	11.1	7.2	4.5	3.3	4.6	8.2	11.3	15.4	17.8	*11.5*
Mean Rain (mm)	32.9	39.8	31.4	14.3	16.9	14.2	15.0	14.3	15.3	19.1	17.4	23.6	*255.1*
Median Rain (mm)	13.8	12.6	4.1	3.6	5.7	5.6	9.2	8.4	5.6	12.0	8.1	11.0	*209.2*
Mean Rain Days	3.0	2.9	2.3	2.3	2.7	3.0	3.5	3.2	2.8	3.1	2.9	2.9	*33.6*

ARKAROOLA DAILY RECORDS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
High Max (°C)	45.3	44.5	41.2	37.9	30.0	27.2	26.2	31.8	37.5	40.1	44.4	45.5	*45.5*
Low Max (°C)	19.1	15.4	15.0	13.8	8.7	7.6	7.1	10.4	11.5	8.5	16.0	17.1	*7.1*
High Min (°C)	35.5	32.0	29.7	24.0	19.1	19.6	15.1	19.5	25.6	29.0	30.3	34.0	*35.5*
Low Min (°C)	10.4	9.4	0.0	1.0	-2.0	-3.7	-6.0	-4.3	-1.6	1.1	6.5	7.3	*-6.0*
High Rain (mm)	182.4	113.2	189.7	67.0	65.3	51.3	42.0	53.6	97.8	52.6	89.0	61.2	*189.7*

ARKAROOLA MONTHLY RECORDS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
High Mn. Max (°C)	37.9	36.7	33.8	29.3	22.8	19.5	19.8	22.8	29.2	30.9	33.3	35.5	*27.1*
Low Mn. Max (°C)	30.2	29.8	25.7	21.7	16.8	14.2	13.9	16.0	19.1	23.6	27.1	29.7	*24.1*
High Mn. Min (°C)	24.2	22.8	19.7	13.7	10.1	8.1	5.5	6.7	10.4	13.7	19.2	20.2	*12.8*
Low Mn. Min (°C)	17.5	16.2	12.2	8.9	4.3	0.7	-0.2	1.5	5.2	8.8	12.7	14.9	*10.2*
High Rain (mm)	363.0	340.8	403.8	223.0	134.4	138.0	80.0	72.3	99.6	108.1	138.5	125.4	*949.4*
Low Rain (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*55.9*

Figure 8.4 Arkaroola temperature record

8.5 Past work diagram

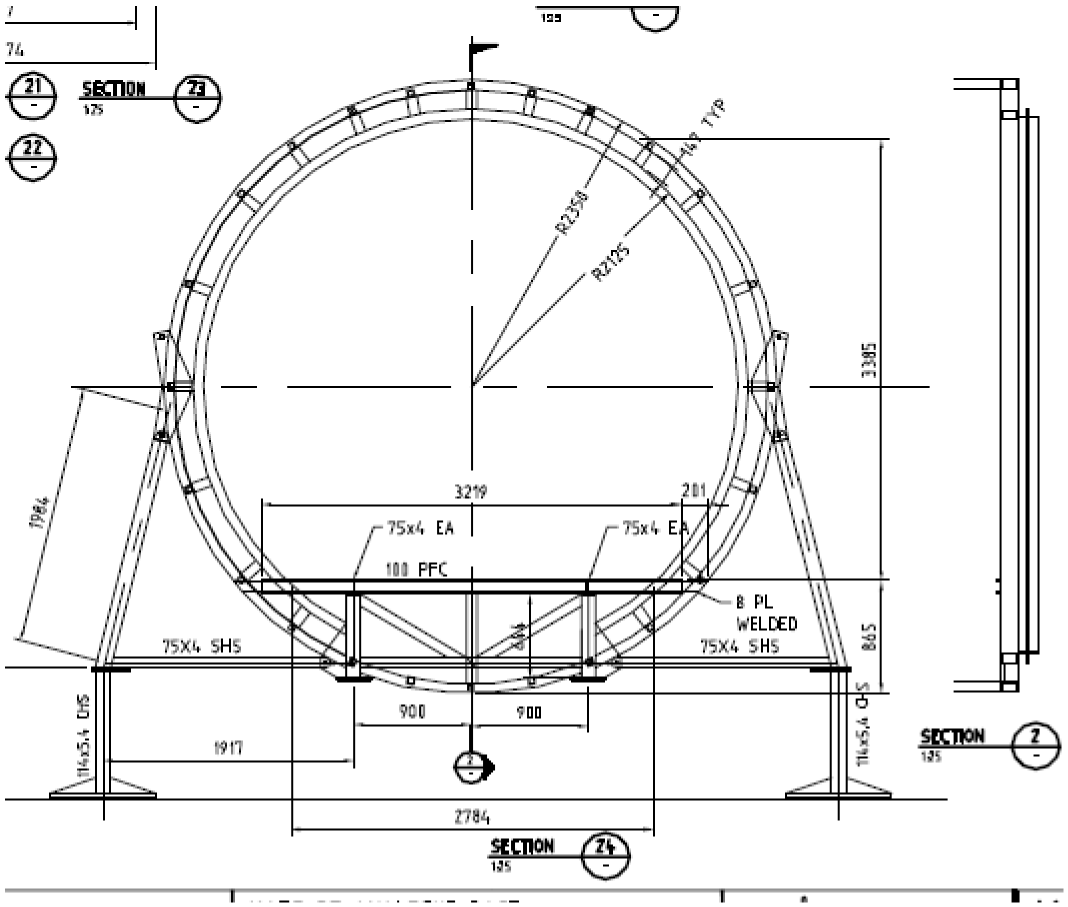


Figure 8.5 Past design diagram

8.5 Price of paint

List of price and sealers:

Material name	Price
#10 Chalk Locker	1 Gallon: $21.95 ...5 Gallon: $109.75
#14 Insulating Primer	1 Gallon: $34.50...5 Gallon: $172.50
#15 Aqua-Prime	1 Gallon: $39.50...5 Gallon: $197.50
#16 Stain-Blocker	1 Gallon: $32.95...5 Gallon: $164.75

#17 Rust Reform	1 Pint $ 12.95...1 Quart $25.95...1 Gal $84.50...5 Gal $422.95
#18 Metal-Prime	1 Gallon: $36.95...5 Gallon: $184.75
#SR1220 Bondit	1 Gallon: $28.50... 5 Gallon: $142.50

Table 8.5 Price of paint

8.6 Docking Module

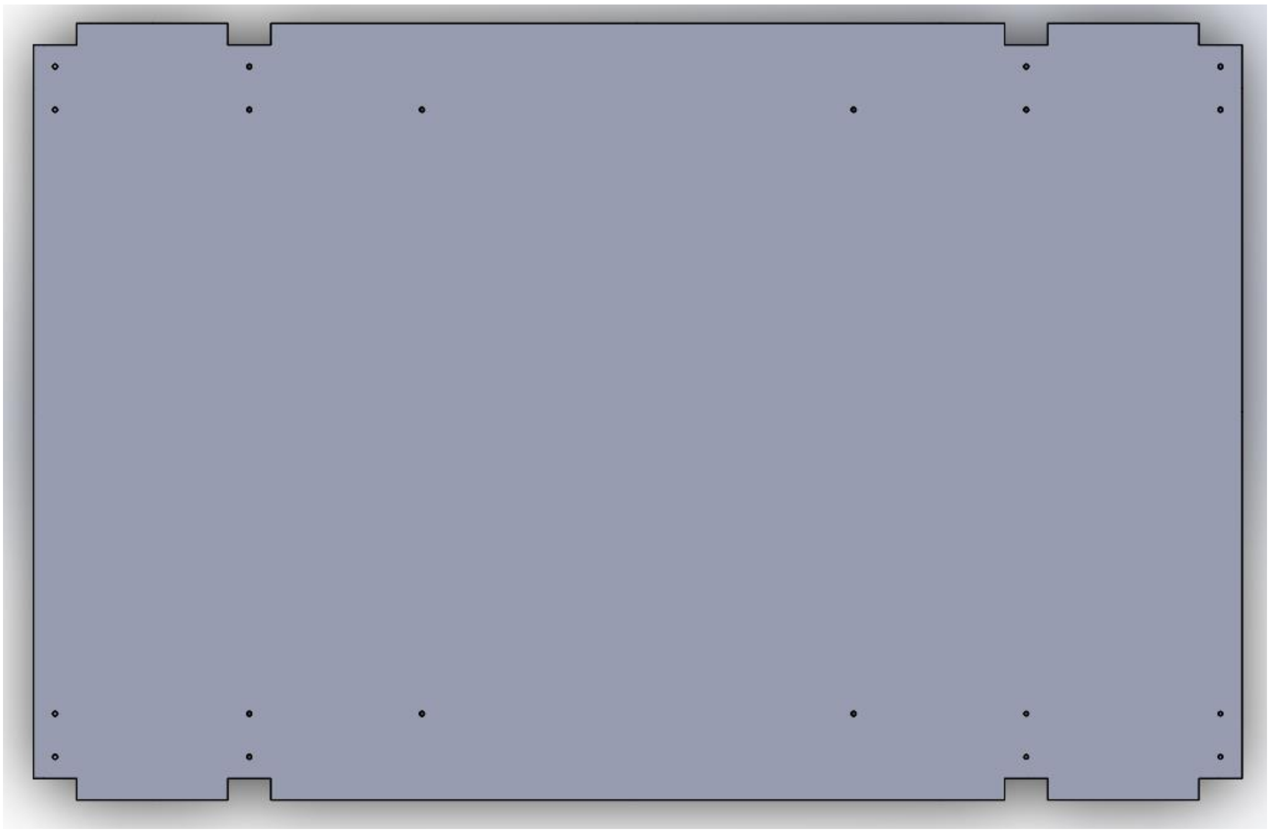


Figure 8.6.1 docking module material 1

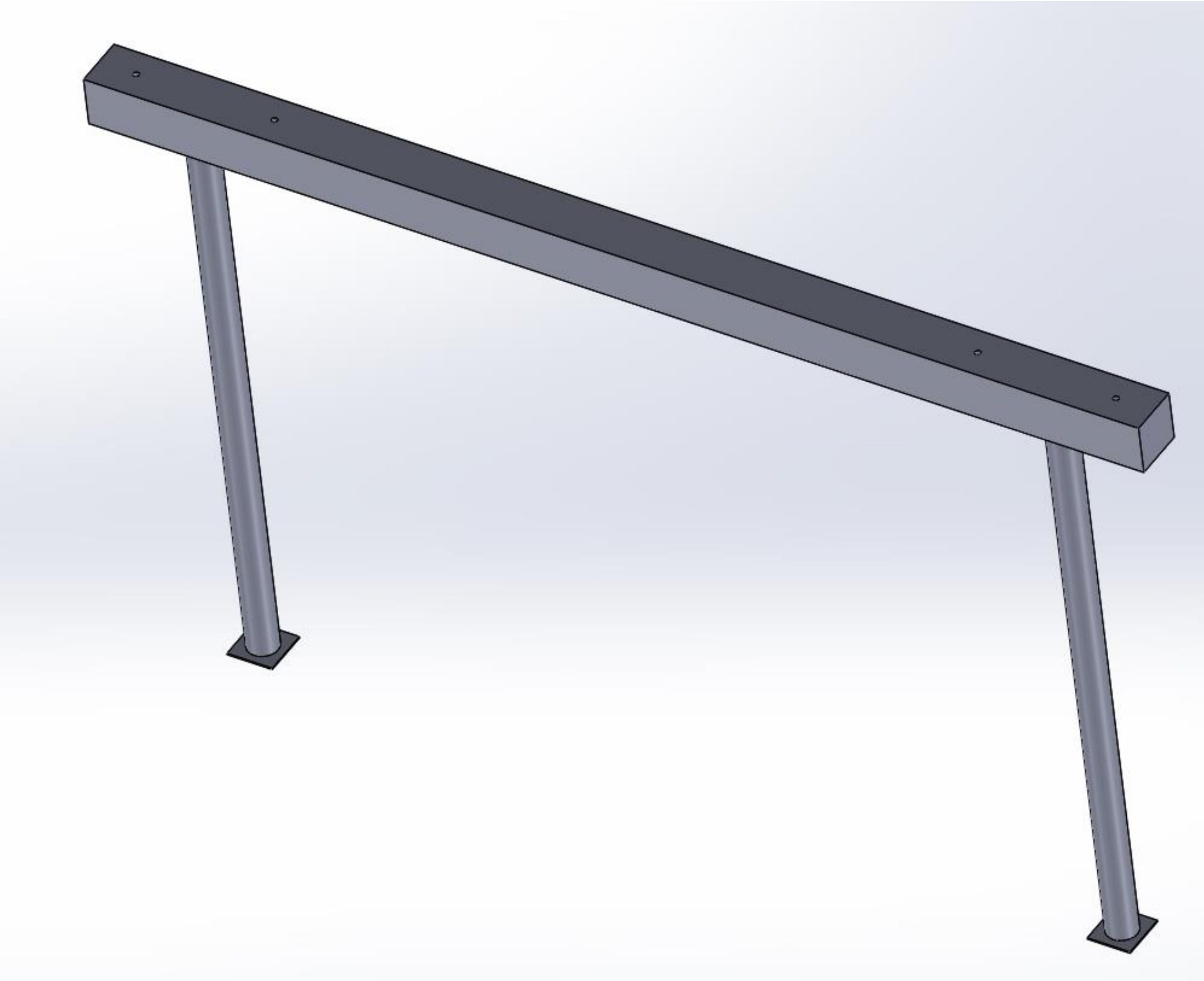


Figure 8.6.2 docking module material 2

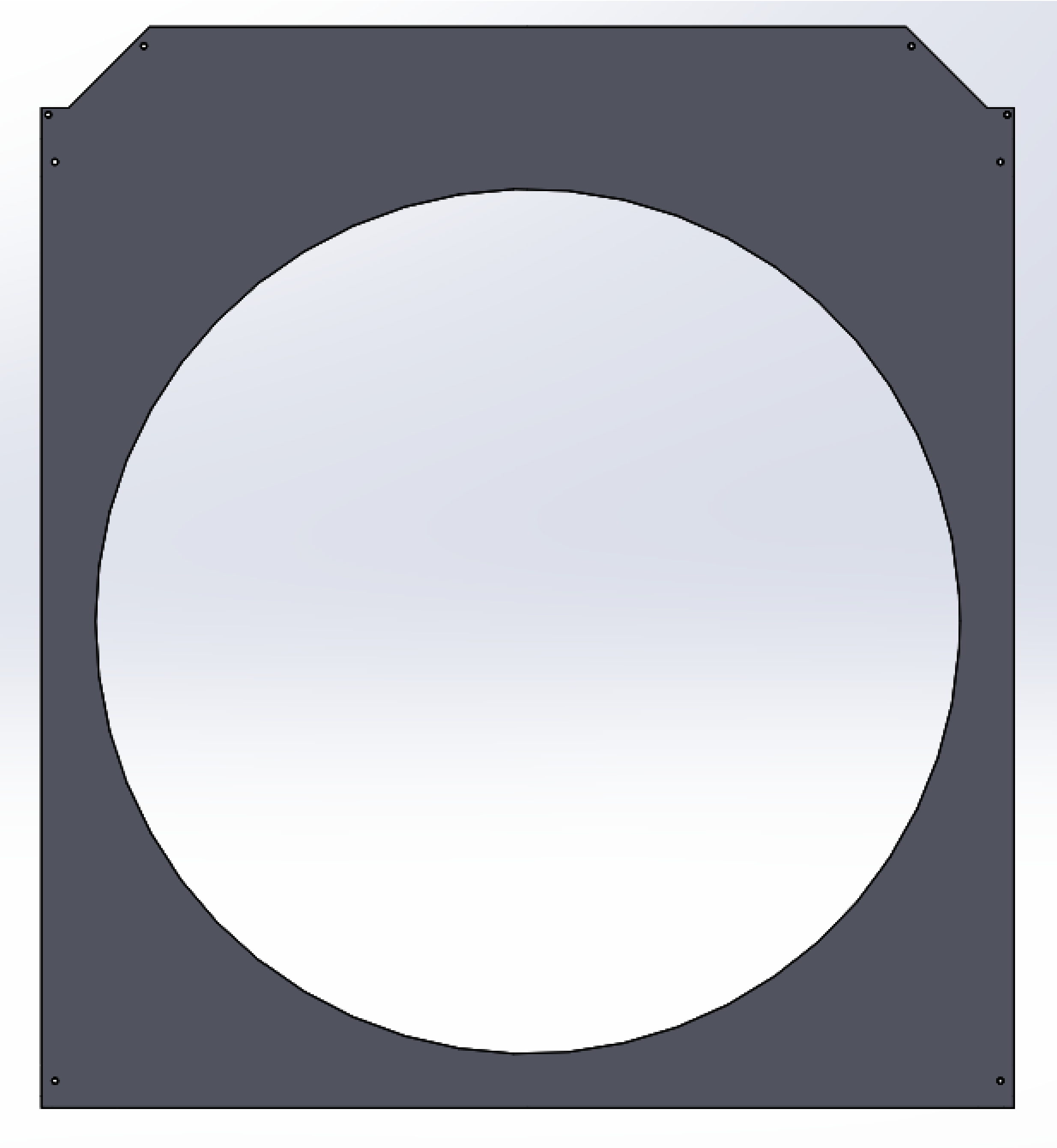


Figure 8.6.3 docking module material 3

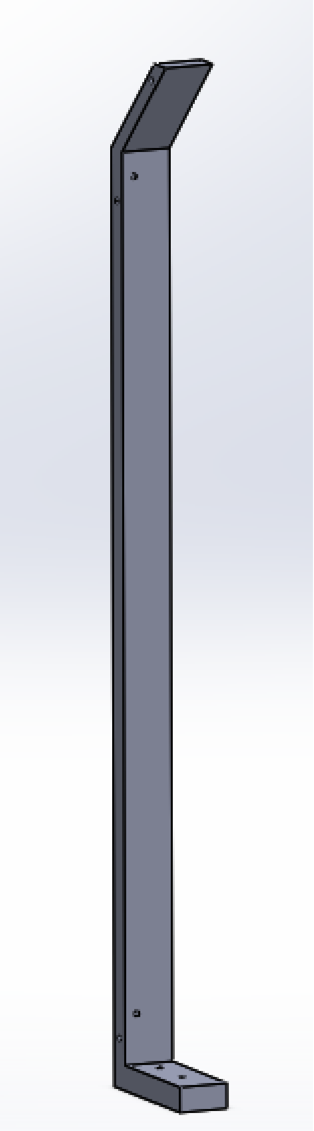


Figure 8.6.4 docking module material 4