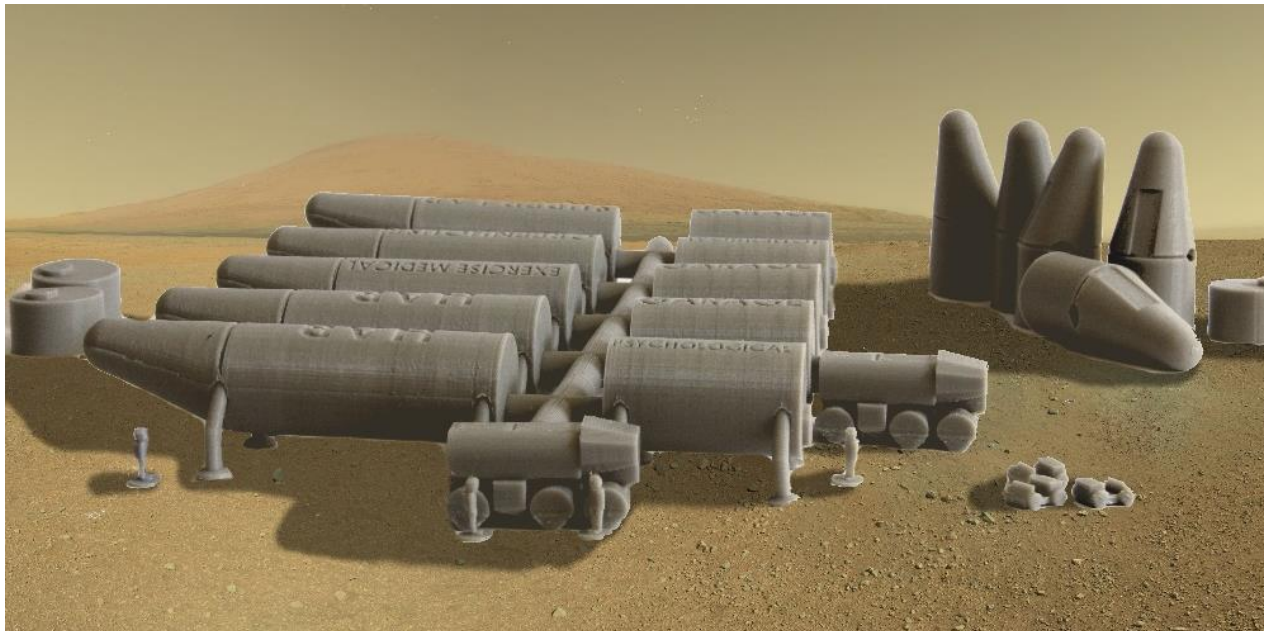


# Beyond the Mars-Oz Reference Mission

## Mars-Oz Mission Design



**Mars Station**  
**2016**

## Revision History

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## Executive Summary

The Mars Society of Australia (MSA) designed a “practical architecture for exploration-focused manned Mars missions...” in 2006. The MSA required that this architecture be built upon. This project, undertaken by a collaboration between the ANU and the MSA, aimed to verify the previous work of the MSA and build upon it by designing further modules, a mission sequence and a station structure.

The overarching scope of the project required the consideration of as many aspects as possible of personnel and equipment of the Martian surface only. This generally excludes the consideration of how payloads launch and reach Mars, certain functional systems included within the Mars station, and some aspects of equipment to be landed on Mars. Due to the high-level design of the missions’, estimates of mission parameters were made based on relevant sources, spaceflight related or otherwise, to provide verification and validation of design choices.

The first primary task of the project was to verify previous MSA designs, specifically of their designed Habitat and Cargo modules. This required the verification and validation of mission parameters such as total payload mass and power consumption by these modules. Items requiring verification included module structures, internals, crew and module consumables, and power consumption of module components.

The outcome of the verification for the 2006 MSA design showed that the Habitat and Cargo modules increased in mass from 52.68 to 58.10 tonnes and from 50.13 to 50.35 tonnes, respectively, a total increase of 5.64 tonnes (5.5% from initial estimate). The verification of solar panel and battery mass required a full analysis of power consumption, resulting in conservative estimations for the Habitat and Cargo of 151.4 and 69 kWh, respectively. This showed that overall power consumption increased over the initial estimates by the MSA, but due to technological advancements in solar power generation the total mass of solar panels required decreased.

The second primary task required the design of a number of specialised modules to build the size and technical capacity of the Mars station, and their integration into the station setup and mission sequence.

It was decided, based on the primary objectives of the MSA Mars Station (of safety and scientific value), that the following specialised modules be developed. These modules, of which there are 5 in total, provide added benefits to the Mars station that the standard Habitat and Cargo modules cannot provide, such as providing high-value scientific tools, added medical capabilities, the means to repair and build equipment, and grow and study crops on Mars. These modules are titled as follows: Laboratory, Workshop, Greenhouse, Leisure & Psychological, and Medical, Exercise & Quarantine. All specialised modules were designed based on a reference Habitat or Cargo module that had all possible equipment removed to allow for the addition of new items, and as a whole the new modules were both within the allocated mass budget of 62 tonnes, and provided enough

additional solar panels and batteries to maintain power generation and storage requirements.

Lastly the sequence in which these specialised modules should arrive and be positioned in the station was considered. To maintain modularity of the system it was decided that a number of smaller portions of the total capacity of each module would be sent in each subsequent mission, thereby allowing the station to diversify its capabilities, while building capacity over time. For example, the first module to arrive after the reference missions have been completed will include an amount of equipment and capabilities of each of the Greenhouse, Laboratory, and Medical, Exercise & Quarantine modules.

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## Acronyms and Abbreviations

ISRU	In-situ Resource Utilisation
MSA	Mars Society Australia
MORM	Mars Oz Reference Mission
HAB	Habitat
MAV	Mars Ascent Vehicle
MTV	Mars Transfer Vehicle
SHM	Specialised HAB Module
SCM	Specialised Cargo Module
MEQ	Medical, Exercise, & Quarantine Module
ISS	International Space Station
RED	Resistance Exercise Device

## 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
Power	$W$ or $kW$	Watts or Kilowatts (1000W)
Length	$m$	Meters
Mass	kg or $T$ or tonnes	1 tonne = 1000 kg
Energy Flux	$W/m^2$ or $kW/m^2$	Power per unit area
Power Density	$W/kg$ or $kW/kg$	Power per unit mass
Energy	kWh	1 Kilowatt hour = 3.6MJ
Power	kWp	Nominal power (photovoltaics)
Radiation Dose	$mSv$	Milli-sieverts
Efficiency	%	-

# 1 System Overview

## 1.1 Established System Overview

The Mars Society Australia (MSA) is an incorporated non-profit organisation that has proposed a “Mars-Oz” simulated Mars base to be set up on the Martian surface for between 4 – 8 inhabitants at one time for extended periods. It is described best in the Mars-Oz Reference Mission (MORM). This is the principal technical program of the organisation. The purpose of this project were to validate and improve the MORM. The due diligence and verification has been centred on the factors related to the engineering design for this program. Further development and re-design of the mission architecture and modules were based on these updates and are aimed to optimize mission success within these constraints.

The MORM outlined methods for creating a Mars station in 5 mission sequences, each involving a HAB (habitat) and Cargo module. The HAB module comprises of basics required for astronauts to survive on the Martian surface, as well as perform research tasks and live relatively comfortably. The Cargo comprises of 3 main components:

1. ISRU (In Situ Resource Utilisation) – Comes prior to each mission in the Cargo module and generates oxygen and water for the Mars station inhabitants, and fuel (hydrogen) for the rovers.
2. MAV (Mars Ascent Vehicle) – Allows the Mars station inhabitants re-enter the Mars atmosphere at the end of the mission such that they can come home.
3. Garage – Houses a pressurised rover which can be controlled by inhabitants for a variety of tasks, as well as unpressurised rovers which can assist in small automated tasks such as cleaning, moving components, and setting up items such as the PV solar generator carpets and the ISRU. It also contains many surface supplies for the inhabitants of the Mars station.

The MORM also outlined important parameters such as orbit techniques, transfer between Mars low orbit and Earth, and Delta V budgets. These were not touched on deeply in the following report, as the actual Mars base station was investigated. The Delta V budgets were assumed to be correct for each designed mission sequence, as the total mass of the specialised HAB and Cargo modules designed in this report were equal or under the specified mass values for the Delta V budgets.

The Mars-Oz document for “A Practical Architecture for Exploration” contains the numbers and calculations which required validation [1]. These included power, consumables and masses of various items within the modules used for the MORM.

As these numbers needed validation, part of this report outlines the due diligence process of checking the respective numbers in the "A Practical Architecture for Exploration" document with their sources, and a variety of other sources. The

verification consisted of deriving these numbers from external sources to check the calculations of the MORM. After the numbers were updated from the MORM, the mission requirements were re-established as a basis for further development.

From the new mission requirements, the mission architecture detailed in this report for the Mars base was completed. This involved re-designing modules based on these mission requirements that have been validated and extended upon. The mission architecture involved establishing a permanently crewed Mars station within 5 mission cycles. The Mars Base design was constrained by the minimum mass for ISRU, power, propellant, life support and consumables, and the maximum available mass detailed by the Delta V budgets. The introduction of specialised modules were built upon from the standard designs of the two basic modules outlined in the MORM. These were the HAB, and Cargo/garage modules.

The final documentation of the project provides MSA and other stakeholders with various benefits. The validation process is an additional peer-review of the MORM and either confirms the current progress or provides a notification of any updates that may be relevant. The methodology of the verification process is documented in Excel spreadsheets which include the formulas and the empirical data. These files can be reused and modified to achieve instant recalculations. A high-level design of specialised modules based on this material will act as a guide for future development.

The flow of this project and dependence on the MORM is summarized in the illustration below in Figure 1.

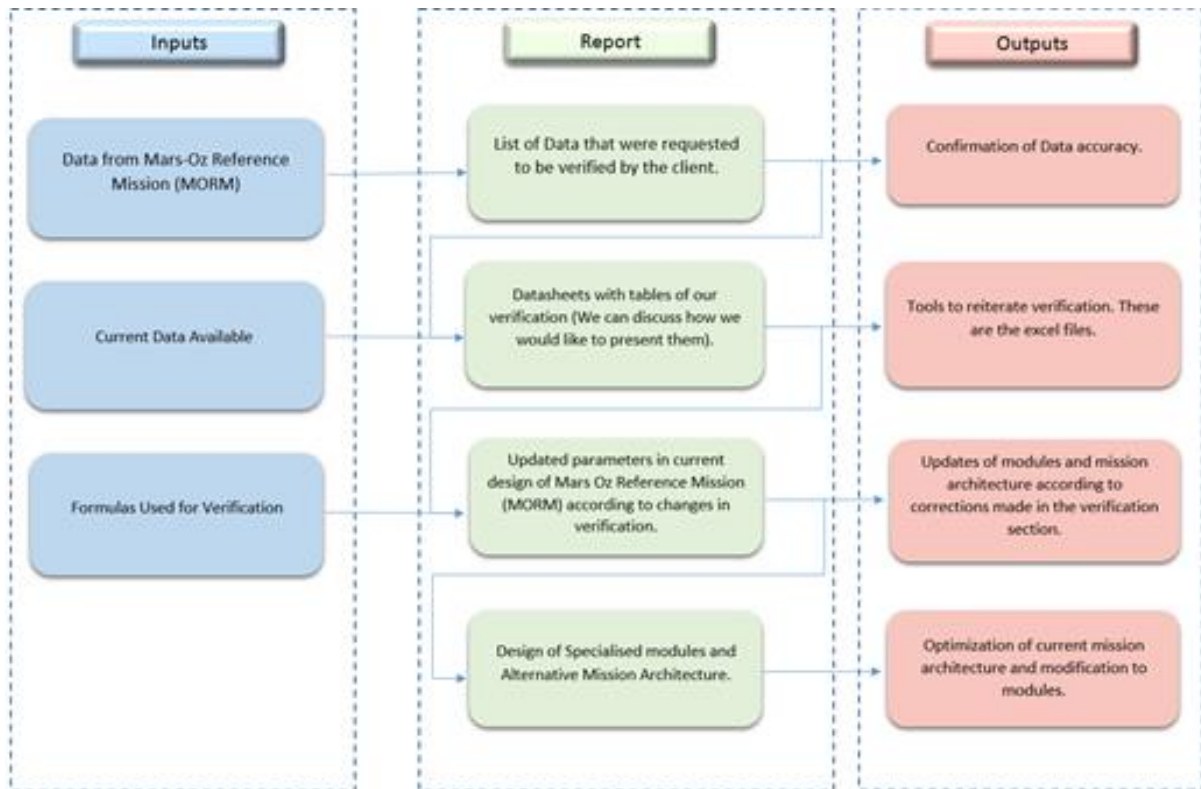


Figure 1. System overview functionality.

This process can be seen to follow a waterfall style approach to the verification, but with internal iterations constantly being done to provide the most informed outputs for the MSA.

## 1.2 Due Diligence and Verification Overview

The following report verifies calculations outlined in the "A Practical Architecture for Exploration" which was done in 2006 [2]. Values for mass and power for a variety of different technical components have changed drastically in the 10 years since this document was created. These were updated using parameters from the present that have likely changed since 2006 due to technological advancements.

The mass allocation was looked into with more depth. Different from what the NASA's Aries's expected maximum payload is, that is, 125tonnes, the MORM suggests that the maximum payload can be stretched to 130tonnes [1]. The individual modules on entry into the Martian atmosphere had to be below 62tonnes such that delta-v values did not become an issue. This was verified in the report, and the contents in each modules were also designed and calculated such that they did not exceed the limit. Any mass budget left over involved stacking the module with spare parts until the modules weighed closer to the 62 tonnes limit.

## 1.3 Designed System Overview

The mission sequence initially is set to have 1 unmanned mission and 5 manned mission where 1 HAB and Cargo would go and aid the astronauts in their time of

stay in Mars. However, the team looked into the advantages and disadvantages of the monotony of having a single functioning Cargo and HAB modules (i.e. the Greenhouse module fully coming in one mission, rather than split across multiple missions) landing in each mission, and looked into designing a Mars station which serves multiple functions at a time, as well as providing the inhabitants with a safe place to live for extended periods of time.

This report outlines the design of 5 specialised modules that will travel to Mars from 3<sup>rd</sup> Mission onwards (the first 2 missions were kept the same as the HAB modules have all the facilities required for astronauts to function safely and perform scientific tasks).

These modules are:

- Greenhouse Module – in a SHM
- Laboratory Module – in a SHM
- Exercise, Medical & Quarantine Module – in a SHM
- Workshop – in a SCM
- Leisure & Psychological – in a SCM

A subsequent modified mission sequence was then designed based off MSA's requirements such as enhancing crew safety, health, and scientific exploration. Details for the specialised modules and the mission sequence can be found later in the report.

## 2 Due Diligence

### 2.1 Consumables and Resources

The Mars-Oz Document for a practical architecture has previously calculated the mass of the consumables and resources (listed in Table 1 below) required for the mission. The verification of these values have resulted in either confirmation of the original data or changes. These changes have been shown in the tables as 'Discrepancy'. These tables were created using excel files. Within each excel file the number of people, number of days, and other parameters can be changed to give an instantaneous update of all the data tables. The formulas used to calculate these values can also be found by checking the cells. These verifications will be useful in ensuring the required payload is not exceeded. Additionally, the excel files also give the details of volume which will be useful for spatial designing.

The fixed resources and equipment have been verified for launch from Earth. The sustainability of 4 people have been considered for a period of 2.5 years. The Mars-Oz Document for a practical architecture has previously calculated these mass with the same parameters. The verification has confirmed the original document with little or no discrepancy other than two categories. The "test equipment" is 300kg less than originally determined. The "Fixtures, large machine tools, gloveboxes, etc." is 740kg



more than originally determined. This gives a net increase in the total value of “Fixed Resources and Equipment” of about 361kg. These values are based on the Human Spaceflight data on page 603 [3]. The Freezers weight is from page 582. In the Human Spaceflight document, the mass of each item needed per person per day is given. Using these standards, the values have been calculated as seen in Table 1.

**Table 1. Fixed Resources and Equipment (Verification of Consumables and Fixed Resources)**

Fix Resources and Equipment	Location	Mass (kg)	Subtotal	Discrepancy (kg)
Clothing	HAB and MTV		792	-8
Personal hygiene kit	Crew		7.2	-2.8
Personal stowage/closet space	HAB and MTV		400	0
Freezers	HAB and MTV		200	0
Conventional oven and microwave ovens	HAB and MTV		240	-20
Sink, spigot for food hydration and drinking water	HAB and MTV		30	-30
Dishwasher	HAB and MTV		80	0
Cooking utensils	HAB and MTV		40	0
Waste collection system (toilets)	HAB and MTV		180	0
Shower and wash basin	HAB and MTV		166	-4
Washing machine and dryer	HAB and MTV		320	0
Restraints and mobility aids	MTV		100	0
Vacuum (prine + 2 spares)**	HAB and MTV		26	-4
Trash compactor/trash lock	HAB and MTV		300	0
Hand tools and accessories	HAB and MTV		600	0
Test equipment (oscilloscopes, gauges etc)	HAB and MTV		1000	-300
Fixtures, large machine tools, gloveboxes, etc)	HAB and MTV		2000	740
Camera equipment (still & video cameras & lenses)	HAB and MTV		240	0
Exercise equipment	HAB and MTV		290	-10
Medical/surgical/dental suite and consumables	HAB and MTV		2500	0
<b>TOTAL mass</b>			<b>9511.2</b>	<b>361.2</b>

The General consumable resources are the items that are to be used on the trip from Earth to Mars. This should sustain 4 people over a duration of 2.5 years. There are only minor discrepancies between the original values and the verified values. However, the “operational supplies” were verified as half the original value while the “Contingency faecal & urine collection bags” were more than double. This resulted in an overall increase of approximately 294kg in the general consumables required. A summary of the breakdown is given in the Table 2 below. The data was verified using page 603 of the Human Spaceflight document. The ‘Disposable wipes’ weight is from page 597. The verified general consumables can be seen in Table 2.



**Table 2. General Consumables (Verification of Consumables and Fixed Resources)**

Consumable resources	Mass Subtotal (kg)	Discrepancy (kg)
Kitchen cleaning supplies	228.125	-21.875
Contingency faecal & urine collection bags	839.5	469.5
WCS supplies (toilet paper, cleaning, filters etc.)	182.5	-17.5
Hygiene supplies	273.75	-76.25
Disposable wipes	547.5	147.5
Trash bags	182.5	-17.5
Operational Supplies (diskettes, zip-locks, Velcro, tape)	80	-80
<b>TOTAL mass</b>	<b>2224.375</b>	<b>294.375</b>

The Minimum Design Consumables refers to the daily consumption of food, water and air by each individual. The verification of this data has shown the water recycled from air conditioning is more efficient than previously estimated. This resulted in the total fresh water being far greater than previously carried in the stores. As a result, the fresh water in stores have been completely removed but there is still more water available than previously calculated. However, the excel files contain the data to calculate the mass if compensation by recycling is not considered. Water recycled from wash water has been assumed to have an efficiency of 90% as per the original document. The daily product lost for each person has remained similar. Data verified with Human Spaceflight. The verified minimum design consumables can be seen in Table 3.

**Table 3. Minimum Design Consumables (Verification of Consumables and Fixed Resources)**

Product provided/person/day	Mass (kg)	Discrepancy	Product lost/person/day	Mass (kg)	Discrepancy (kg)
Oxygen from stores	0.84	0	CO2	1	0
Fresh drinking water from stores	0	-2.4	Urine	1.56	-0.44
Food (2/3 water) from stores	1.77	-0.03	Faeces	0.12	0
Fresh wash water from stores	0.7	0	Brine	2.3	-0.2
Water recycled from air conditioning	3.64	1.84	-	-	-
Water recycled from wash water	22.77	0.27	-	-	-
<b>Total</b>	<b>28.88</b>	<b>1.38</b>		<b>4.98</b>	<b>-0.64</b>

The Minimum Basic Consumables focus on the minimum required amount of food, water and air required by the astronauts over their entire mission. This consists of the 400 day return trip from Earth to Mars and the 600 day stay on Mars. The mass

lost due to leakage over the duration of travel to and from Mars is also considered. The amount of air lost is assumed to be 5kg each day as per the MORM. The composition of air for oxygen, nitrogen and water vapour has been assumed 18%, 78% and 4% respectively. These assumptions are the basis for calculating the additional mass required to compensate for the leakage. The overall total mass for Minimum Basic Consumables increased by 604kg. This is mainly due to an increase in the calculated water required during the trips. On each 200 day journey, an additional 328kg of water was required. These water needs are required for drinking water, food preparation and hydration of food. Data verified with Human Spaceflight and data calculated in the previous tables. The verified minimum basic consumables can be seen in Table 4.

**Table 4. Minimum Basic Consumables (Verification of Consumables and Fixed Resources)**

Product	Supply for 400 days travel to and from Mars in the MTV (kg)	Supply for leakage over 400 days (kg)	600 days on Mars	Total Mass (kg)	Total Discrepancy (kg)
Oxygen	1344	380	From ISRU	1724	-36
Water	5600	80	From ISRU	5680	700
Food (2/3 water)	2832	-	4248	7080	-120
Nitrogen	-	1560	From ISRU	1560	60
<b>Totals</b>	<b>9776</b>	<b>2000</b>	<b>4248</b>	<b>16044</b>	<b>604</b>

## 2.2 Solar Power Generation

The data for solar power generation is verified and updates are brought to solar cell performance and battery recharging efficiency as seen in Table 5. ISS arrays and Li-ion battery are used in this mission. Mars dust does not adhere to solar panels according to the MORM (Reference 1), hence we assume there is no efficiency drop of solar panels on Mars.

**Table 5. Verification of solar power generation assumptions and performance.**

Assumptions	Original Performance	Updated Performance	Source updated) (if
The solar energy flux in Earth orbit	1.37kW/m <sup>2</sup>	1.37kW/m <sup>2</sup>	Verified correct and
The solar energy flux in Mars orbit	0.603kW/m <sup>2</sup>	0.603kW/m <sup>2</sup>	Verified correct and
The solar energy flux on Mars on a clear day	0.301kW/m <sup>2</sup>	0.301kW/m <sup>2</sup>	Verified correct and
The solar energy flux on Mars during a dust storm	0.089kW/m <sup>2</sup>	0.089kW/m <sup>2</sup>	Verified correct and

Assumptions	Original Performance	Updated Performance	Source (if updated)
The solar cell performance and mass in Mars orbit	120W/m <sup>2</sup> and 25W/kg	120W/m <sup>2</sup> and 48W/kg	Cooper et al., 2010
The solar cell performance and mass on Mars	45W/m <sup>2</sup> and 10W/kg	60W/m <sup>2</sup> and 24W/kg	Cooper et al., 2010
The ISRU solar cell carpet performance and mass	45W/m <sup>2</sup> and 11.5W/kg	60W/m <sup>2</sup> and 24W/kg	Cooper et al., 2010
Assumed overall efficiency on Mars	15%	20%	Cooper et al., 2010
Battery recharging efficiency	60%	92%	Windandsun.co.uk, 2016

## 2.3 Power Budgets

As there is a limit on the mass that can be sent to Mars enforced by the efficiency of the launch rockets, it is required to find the correct amount of photovoltaic panels to offer power to the modules and Cargos. By verifying the power budgets of the HAB and Cargo modules the provided mass allowances for photovoltaic panels can be checked. This was done by first using a ground up approach to find the power consumption of both the HAB and Cargo modules. In the following sections it can be seen that the total power consumption for both the HAB and Cargo combined comes to a total of 220.42kWh. This value was then used to verify the mass of PV panels required by the MORM.

### 2.3.1 HAB Power Budget

The HAB module involves many small electrical components and facilities of which the astronauts require to comfortably survive on the Martian surface. Many of these are different and unique to the HAB in the early missions, as a variety of different instruments are used such as food storage or preparation devices like refrigerators or stoves, safety systems such as life support for pressure and oxygen and medical operations or laboratory devices.

The largest use of power comes from the requirement to store food and prevent it from spoiling, as this requires 24 hour power usage to combat an environment not designed to sustain its components. Additionally, survival based systems such as life support and temperature control are consistently mandatory and constitute a large percentage of the power use for the HAB.

The main components of the HAB are outlined in the Table 6, with the number of units, nominal amount of time used per day at peak capacity, with some discrepancies and margins. Table 7 below summarises the components and their power consumption in kWh/day based on efficiency.

**Table 6. Detailed HAB power budget verification.**

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	All the lights in the rooms and throughout the HAB
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	External lighting
Avionics/Guidance/Reaction Control	85%	1	2	2	2	4	4.71	Altitude, translation, guidance, movement systems of module
Electric control systems	95%	1	0.5	0.5	6	3	3.16	Controller for all electronic systems (computer)
Life support system (Pressure)	80%	1	1	1	12	12	15.00	Pressure pump for air pressure in module
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	Pressure pump for oxygen
Water Pressure	80%	1	0.3	0.3	4	1.2	1.50	Pressure pump for water
Food Systems	60%	1	6.9	6.9	6.625	45.7125	76.19	Refrigeration, cooking, storage, cleaning of consumables
Interpersonal Communication Devices	85%	4	0.015	0.06	2	0.12	0.14	Communications between astronauts
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	Communications between modules
Interplanetary Communication Devices	70%	1	0.7	0.7	1.5	1.05	1.50	Communication between Mars, Earth, and Orbiter
Screens	80%	3	0.05	0.15	3	0.45	0.56	Computer screens for research/recreation/communication
Lab equipment	60%	1	2	2	3	6	10.00	Equipment and devices for lab work
Medical & Recreational equipment	90%	1	2.35	2.35	1.5	3.525	3.92	Medical, exercise, and other recreational equipment/devices
Clothes Washers & Dryer	60%	2	2	4	1	4	6.67	Washing and drying clothes
Waste Disposal (Toilets)	90%	1	0.09	0.09	0.55	0.0495	0.06	Removal and storage of human waste
Cleaning (Vacuuming/Mopping)	70%	1	0.125	0.125	0.24	0.03	0.04	Cleaning equipment to clean module
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	Module temperature control



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Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Hygiene System	90%	1	0.09	0.09	2.13	0.1917	0.21	Astronaut hygiene (showers, taps, dryers)
<b>Totals</b>				<b>23.01</b>		<b>102.55</b>	<b>151.40</b>	<b>Total including efficiency/24.62 (24 hours and 37 minutes per day)</b>
							<b>6.15</b>	<b>kW avg/hour</b>
							<b>49.61</b>	<b>kWh requirement for base specialised HAB</b>

**Table 7. HAB components and respective power consumption.**

Component	Power Consumption (kWh/day/eff)
Lighting Systems	10.25
Avionics/Guidance/Reaction Control	4.71
Electric Control Systems	3.16
Life Support Systems	22.5
Water Pressure Control	1.5
Food Systems	76.19
Communication Devices	1.78
Screens	0.56
Lab Equipment	10.00
Medical & Recreational Equipment	3.92
Clothes Washers & Dryers	6.67
Waste Disposal Units	0.06
Cleaning	0.04
Temperature Control	9.86
Hygiene Systems	0.21
<b>Total</b>	<b>49.61</b>

### 2.3.2 Cargo Power Budget

The Cargo module requires many of the same components as the HAB module seen in section 2.3.1, but also includes a few unique components; these will be discussed below.

The ISRU is the primary aspect that separates the power consumption of the HAB and Cargo modules. While the function of the ISRU was out of the scope of this project, its power consumption was checked to make sure the correct amount of PV mass had been allocated to it. After verification the ISRU was found to need, on average, 84kWh of energy - requiring an update of array size to around 50 kWp. This power consumption is not listed below as when the crew arrive the ISRU has already completed its job (producing H<sub>2</sub>O, O<sub>2</sub>, etc.) and has shut down.

While the pressurised rovers will run on carbon monoxide used in either a fuel cell or internal combustion engine, the unpressurised rovers are battery powered; and hence required charging. By assuming that 20kWh will be consumed daily by these rovers (per Cargo module), and a recharge efficiency of 95% [4] is used the total energy usage is about 21kWh.

**Table 8. Cargo components and respective power consumption.**

Component	Power consumption (kWh)
Lighting System	5.00
External Lighting System	5.25

Component	Power consumption (kWh)
Electric control systems	3.16
Life support system (Pressure)	15.00
Life support system (Oxygen)	7.50
Life support system (CO2 scrubbing)	1.50
Intermodule Communication Devices	0.14
Screens	0.56
Heating & Air Conditioning	9.86
ISRU	0.00*
Rover charging station (removable)	21.05
<b>Total</b>	<b>69.02 kWh</b>

The detailed power budget for the Cargo is seen below in Table 9.

**Table 9. Detailed Cargo power budget verification breakdown.**

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	All the lights in the rooms and throughout the HAB
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	External lighting
Avionics/Guidance/Reaction Control	85%	1	2	2	2	4	4.71	Altitude, translation, guidance, movement systems of module
Electric control systems	95%	1	0.5	0.5	6	3	3.16	Controller for all electronic systems (computer)
Life support system (Pressure)	80%	1	1	1	12	12	15.00	Pressure pump for air pressure in module
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	Pressure pump for oxygen, replenish O2
Life support system (CO2 scrubbing)	80%	1	0.3	0.3	4	1.2	1.50	CO2 removal for garage
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	Communications between modules
Screens	80%	3	0.05	0.15	3	0.45	0.56	Computer screens for research/recreation/communication
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	Module temperature control
ISRU	90%	1	0	0	0	0	0.00	Process plant - in-situ resource utilisation (not used when crew arrive)
Rover charging station (removable)	95%	1	10	10	2	20	21.05	Means to charge rover(unpressurised) batteries
<b>Totals</b>				<b>16.695</b>		<b>61.87</b>	<b>69.02</b>	<b>Total including efficiency/24.62 (24 hours and 37 minutes per day)</b>
							<b>2.80</b>	<b>kW avg/hour</b>
							<b>47.97</b>	<b>kWh requirement for base specialised Cargo</b>



### 2.3.3 Power Analysis Outcome

The outcome of completing the power consumption analysis allowed for the verification of the amount of photovoltaic panels required. By using ISS equivalent photovoltaic panels [5] and assuming 1.8 peak sunlight hours per Martian day (earth equivalent -  $1000\text{W/m}^2$ ), a PV panel requirement of 24.2kWp for the HAB and 98.5kWp (50kWp must be rollable for the ISRU plant) for the Cargo was found. This reduces the total mass of panels in the HAB by approximately 500 kg, and almost 1 tonne in the Cargo. The calculations for this can be seen in Appendix 1 to Appendix 5.

## 2.4 Module Mass Estimates

In order to estimate the mass of the HAB and Cargo modules the MORM was used as a starting point. This was taken to the client to confirm which elements of the initial breakdown required verification, resulting in items that were either in, or out, of scope. The items that were in scope were then verified by finding and applying relevant sources. This was through either a direct comparison, creating a formula based on data and information, or interpolation of available data. The verification of the HAB and Cargo modules are detailed below.

### 2.4.1 HAB Mass Estimates

The HAB verification consisted of verifying the mass of all the listed items of its composition. Most items remained the same as the original design mass. However there were a few items that had large discrepancies. The life support system was reduced from 3 tonnes to 0.5 tonnes as most of the life support system could be transferred to the garage. The weight of the batteries increased largely from 1.5 tonnes to 3.635 tonnes in order to allow minimum 4 days of power storage at full capacity. The weight of solar cells was reduced by a large margin due to advances in technology since the MORM was created. The consumables were recalculated using the excel sheets created as part of the verification process. The non-pressurized rover was removed from this module as requested by the client. The propulsion module has not been shown in the table because this section was not part of the verification process.

**Table 10. HAB mass estimates.**

Item	Mass estimate (kg)	Mass Subtotal (kg)	Discrepancy (kg)
<b>HAB</b>			
Main structure, (habitat volume $210\text{m}^3$ )	6800	6800	0
Aeroshell on HAB	5400	5400	0
Bulkheads, partitions, decks and furnishing.	4400	4400	0

Item	Mass estimate (kg)	Mass Subtotal (kg)	Discrepancy (kg)
Electrical control system	800	800	0
Life support system	3000	500	-2500
Power storage – Batteries	1500	3635	2135
Reaction control system	500	500	0
Landing engines in the HAB nose mass	500	500	0
Crew (4 off) and 4 off suits	800	800	0
Surface erected 15 kW solar power cells	1500	566	-934
Lab equipment	1000	995	-5
Consumables for 600 days (Water and O <sub>2</sub> is from the Cargo vehicle ISRU plant) + 200 days food air and water emergency supply	9970	10136	166
<b>Subtotal</b>	<b>36170</b>	35032	- 1138
<b>Margin 18%</b>	<b>6510.6</b>	6305.76	-204.84
<b>Total Mass at start of trans-Mars injection</b>	<b>42680.6</b>	41337.76	-1342.84

The total mass of the HAB excluding the propulsion module was estimated to be 35.032 tonnes (41.338 tonnes with the margin of 18%), which has been reduced from the original estimate of 36.170 tonnes (42.681 tonnes) by 1.138 tonnes (1.342 tonnes). The result shows that although there were some significant changes in the mass estimates of the subsystems, the total mass estimate of the HAB still remains valid.

### 2.4.2 Cargo Mass Estimates

The data in Table 11 shows both the initial MORM figures and the recalculated figures for the Cargo module. Due to a few discrepancies in the initial values and the new values, the vehicle mass at the start of trans-Mars injection is approximately 1.5 tonnes lighter.

One of the sections that increased in weight between the initial MORM figures and the new figures was the nose section. It increased by approximately 1400kg and this was due to the fact that the initial diagrams of the module did not include any angles or specific dimensions for the nose section. This resulted in the CAD modelled design dimensions done in this project being used to calculate surface areas for the total weight of the structure of the nose section.

The aeroshell also added some weight to the overall structure as it was assumed that it would be attached directly to the outer shell of the module. This addition in weight to the front of the Cargo module is preferable as the module will have greater stability in its descent to the Mars surface

The bogies and the Bobcat provided areas where weight could be significantly reduced. The bogies have been reduced to 0.07% of the weight of the original figure.

This value was found by researching readily available bogies and plotting their weights versus carrying capacity. Using interpolation on this data that was obtained, the weight for a bogie that could carry the required load was found. The reduction in weight for the Bobcat was due to the client informing the project team that there is a standard attachment for the rovers to convert them into the Bobcat that is required.

Since the floor and roof dimensions for the garage section were not supplied in the original MORM paper, it was assumed that the height and the width of the walls and the floors respectively were equal. If the wall or floor dimensions need to be changed, the client has been supplied with a spreadsheet that contains a formula that provides all of the weights for any change in wall height or floor width.

The adaptor module was assumed to be a maximum length of 10m. Using this length and the approximate diameter of 2.1m, the weight could be calculated assuming the material was to be the same as the shell of the modules. The material was chosen to be the same so that it could withstand the harsh conditions that it will face on Mars. A fabric based adaptor was considered however should the station need to be buried to avoid excessive radiation, the fabric would not be able to withstand the forces from the dirt.

**Table 11. Cargo mass estimates.**

Item	Mass estimate (kg)	Mass Subtotal (kg)	Discrepancy (kg)
<b>Nose section with ISRU plant and MAV</b>			
Nose section structure, landing engine mass and aeroshell	5000	6369.70	-1369.70
Mars Ascent Vehicle (dry mass)	3900	3900.00	0.00
Hydrogen stock in MAV tanks	700	700.00	0.00
ISRU Process plant. Manufactures liquid methane, oxygen and carbon monoxide.	500	500.00	0.00
Hydrogen Stock + tank in nose	1300	1300.00	0.00
Reaction control system	500	500.00	0.00
ISRU power storage – Batteries	500	3300.00	-2800.00
50 kWp solar cell power for process plant	2200	1950.00	250.00
Solar cell carpet laying rover	500	500.00	0.00
Subtotal	15100	19019.70	-3919.70
<b>Detachable Garage section</b>			
Garage structure, furnishing and aeroshell, (habitat volume 100m <sup>3</sup> )	8600	6020.18	2579.82
Garage power storage – Batteries	1000	1000.00	0.00
Life support system	500	500.00	0.00
Pressurised rover (unfuelled)	3000	3000.00	0.00
Bogies for moving garage and HAB	1200	80.00	1120.00
Adaptor module and flexible extension airlock	1500	1979.20	-479.20

Item	Mass estimate (kg)	Mass Subtotal (kg)	Discrepancy (kg)
48.5 kWp solar power generator for the mars station.	3000	2020.83	979.17
Medical Equipment	1000	1000.00	0.00
Small 'Bobcat' type front end loader	1000	500.00	500.00
Small Jack up roof to be filled with Mars soil	500	0.00	500.00
<b>Subtotal</b>	<b>21300</b>	<b>16100.21</b>	5199.79
<b>Entire Propulsion Module</b>	<b>15230</b>	<b>15230.00</b>	0.00
<b>Margin 20%</b>	<b>10326</b>	<b>10069.98</b>	256.02
<b>Vehicle Mass at start of trans-Mars injection</b>	<b>61956</b>	<b>60419.90</b>	1536.10

## 3 Designed System

### 3.1 Design Overview

Five specialised modules have been designed for the mission:

1. The Greenhouse module.
2. The Laboratory module.
3. The Medical/Exercise/Quarantine module.
4. The Leisure and Psychology module.
5. The Workshop module.

These modules are designed to satisfy our customer's two top requirements during the mission: keep crew safe and healthy and to implement a means to conduct valuable scientific research. The Greenhouse module is designed to support crew's basic living and to provide a scientific research opportunity as well. The MEQ module and the Leisure and Psychology module are helpful to guarantee physical and mental health for our astronauts. The Workshop module provides gear to maintain the Mars station and the Laboratory module supports high value scientific research on Mars.

The whole Mars-Oz project consists of 1 unmanned mission followed by 5 manned mission. The functionality of the Mars station is boosted by the Cargo module of each mission and the Mars base is expected to be a fully-functional station after the 5<sup>th</sup> manned mission.

### 3.2 Basic Design Approach

The basic design approach for the mission sequence and modules was to ensure that all requirements were satisfied, and that they were satisfied in order of their priority. The design approach that was taken was slightly complex, but ensured it covered all bases. Essentially the SHM were designed such that when they arrive they come partitioned into 4 parts, containing Greenhouse, Lab, Medical, and

Exercise components. These components will be designed in such way that they are easily moveable and transferrable between modules. Over the course of the last 3 missions, these sections will be moved around between the 3 SHMs to modules of only one or two facilities, as opposed to modules of 4 facilities. Additionally, the 2 SCMs will simply provide a workshop facility in one, and a Leisure and Psychological facilities, with no facilities or sections being moved. By the end of the 5<sup>th</sup> mission, the station will consist of 2 HAB modules, 1 Laboratory SHM, 1 Greenhouse SHM, 1 Medical + Exercise + Quarantine SHM, 1 Workshop SCM, 3 Garages (from the standard Cargo Modules), 5 ISRU's (from the 5 standard/specialised cargo modules), and 1 Leisure + Psychological SCM. A description of the purpose of each of these modules is given in Table 12.

**Table 12. Components of the finalised Mars station at the end of the 5<sup>th</sup> mission.**

Component	Description and Purpose	Quantity
HAB Module	Transports crew from orbit to the surface. Contains cabins, food, lab areas, and storage.	2
Garage	Stores the pressurised rovers and allows for maintenance. Comes with the 3 standard Cargo Modules.	3
ISRU	Develops rocket fuel using Martian atmosphere and imported hydrogen supplies. Also develops water for crew consumption.	5
Greenhouse SHM	Allows for maintenance and growth of plants for both possible crew consumption and research.	1
Laboratory SHM	Allows for determination and recovery of vital and significant scientific research and information relating to conditions and environment on Mars.	1
Medical + Exercise + Quarantine SHM	Quarantine zone ensures limited contamination of Earth microbes on Mars surface and vice versa. Medical area ensure proper medicines and equipment capabilities are provided to ensure health of crew. Exercise area allows crew to stay fit in the low gravity of Mars.	1
Workshop SCM	To allow for the crew to engineer, maintain, create, or repair any components of the station.	1
Leisure + Psychological SCM	To allow for the relaxation of the crew and to remove pressure of the harsh psychological situation due to the isolation.	1

These are the main structural components of the mars station, all of these modules will be mounted together to allow for easy access between every module without requiring the crew to be exposed to the Martian atmosphere.

In addition to these primary components there will also be solar panel 'carpet' and unpressurised rovers. The unpressurised rovers are used to lay the solar panels as

well as to keep them clean by removing dust. Additionally there will also be the MAVs which arrive with each Cargo and SCM, however, these MAVs come and go with the crew and are not part of the permanent mars station.

The station was designed with transferable sections of modules to focus on adaptability, to ensure that each crew has sufficient amounts of facilities to make reasonable scientific progress and stay safe and healthy, and as risk management. This type of system will ensure that if a section or module has issues or failure in an emergency, it will be possible to salvage large components of the facilities. It was decided that laboratory space, greenhouse, medical, and exercise facilities were all quite high priorities and difficult to rank, and so each mission will supply components of all of these. Finally, it was considered that in the case of a catastrophe resulting in entire module failure and un-useability of all components in the module, it is important that an entire facility is not destroyed, but instead the crew still has at least a small component of that facility available for use. Although this doesn't apply once the station is finalised, this is because convenience and simplicity of having all the one type of facility in one place outweighs this unlikely to occur risk.

### 3.3 System Environment

The system itself will be physically located in the Martian environment, more specifically, in the Meridiani Planum. This is a large plain on the surface of Mars and the site of the Opportunity rover mission. The surface gravity on Mars is 38% of that on Earth, an important consideration that impacts module design. The temperature in the Meridiani Planum is significantly colder than on Earth, and can vary anywhere from  $-100^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  [6]. The atmospheric pressure on Mars is much lower, being only  $1/100^{\text{th}}$  of the average atmospheric pressure on Earth, and has high winds with speeds of up to  $144\text{km/h}$  [7]. In addition to the harsh climate there are also many other dangers of the Martian environment such as dust, high radiation and harmful chemical compounds such as chlorates. The Meridiani Planum soil environment consists predominately of olivine basalt sands and concretion fragments eroded from rock which form a soil cover that thinly buries the bedrock in some areas. Sparse amounts of loose rocks are also present on the soil surface including both ejecta and meteorites [8].

### 3.4 Assumptions & Constraints

#### 3.4.1 Timing & Crew Assumptions

It is assumed for the purpose of the mission design that each vehicle arrives on Mars at the correct time. This is crucial as the travel times become restricted due to the Mars and Earth orbital position. The astronauts are assumed to have been provided with sufficient training on the operation of all the necessary facilities and systems.



### 3.4.2 Design Constraints

Due to safety and sustainability concerns with nuclear power generators, the mission is limited to solar power generation found in the ISRU, and developing methane and oxygen using oxygen in the atmosphere and stock hydrogen carried from Earth in the ISRU compartment.

As the mission equipment is required to operate for an extended period of time, only well-understood technology that has been tested for long term space operation will be used to mitigate the chance of mechanical or electrical failure in unknown conditions. This constrains the type of technology available for use in the mission and limits the mission architecture to old technology.

The initial document assumed that by the time the mission was put into action, the Nasa Ares rockets would be space-ready and capable of launching a maximum payload of 125 tonnes into low earth orbit and used this value for its mass constraint. Currently NASA uses the Space Launch System (SLS) (which combines aspects of the rockets Ares I – Ares V) to launch both manned and unmanned spacecraft into orbit. This system is capable of launching payloads of 130 tonnes into low earth orbit (NASA, 2016).

Due to the nature of the cycles of Earth and Mars around the sun, interplanetary travel is only feasible every 26 months. This imposes a time constraint on the mission and each stage must be designed so that its completion is possible within this time-frame.

#### Resource vs. Productivity

The mission sequence is constrained by the necessity of the different modules, both in terms of their facilities and the resources they produce.

#### Greenhouse Compartment

This compartment would allow the crew members to grow plants. Though this is a time consuming process, the benefit of having a greenhouse far outweighs the time needed. For the time that a crew member spends on each mission they are supplied with packaged food in sealed containers, and therefore the food produced in the Greenhouse module can be an excellent source of natural food. Some of the plants will be subjected to research on Mars surface, which will boost the productivity of this compartment.

#### Laboratory Compartment

A standard research laboratory that the crew member can use to research the conditions of the mars surface, use valuable information obtained from the land rovers and study them. The productivity of this compartment, again much like the Greenhouse, depends hugely upon descending on the Mars Surface and finding useful data.

### Medical, Exercise & Quarantine Compartment

This compartment would be used as a medical zone where proper medicines and treatment materials are setup, an exercise zone with treadmills for daily fitness for astronauts after a long day in the bulky suit, and a quarantine zone to contain any Earth microbes or any contamination from the Mars surface. This compartment measures more in necessity than productivity, as it is essential to living and even if it's never used, meaning no crew are injured and no contaminations were identified, the module will still be relevant.

### Workshop Compartment

The Mars surface is subjected to dangerous sand storms which may affect the structural integrity of the Mars station and components, and could block the solar panel with dust, or cause hardware to malfunction. The Workshop compartment allows a platform for necessary repairs of hardware for reusability purpose instead of the whole damaged component being useless.

### End-User Environment/Interoperability Requirements

The astronauts are the ones who will be the end-user in the whole mission, and having them trained with the equipment is mandatory.

### Availability or Volatility of Resources

The special modules will start landing from the 3<sup>rd</sup> mission onwards. These modules, once landed, will be available to use. As the scope of the design is to make a Mars Station to last for 30+ years, the system is predicted to be non-volatile.

### Standards Compliance

The design introduced in this project follows the standard specifications of the data presented by NASA that is the maximum mass of the HAB and Cargo modules and the size and shapes of them.

### Safety Requirements

Safety is definitely the highest priority given all design requirements, and apart from the medical knowledge each astronaut has, they will also be given special training to use the MEQ Compartment for further safety measures.

### Performance Requirements

These extra compartments do require power, and power is limited.

An astronaut is subjected to use 1000W of power per day while living on Mars Surface, which is plenty.

## **3.5 Modules**

This section will describe in detail the designed modules for the expansion of the Mars Station after the first 2 missions. This will include for each specialised module, a detailed discussion of the purpose of the module, what functions it performs, and



the reasons for including it in the mission sequence. Also included will be a summary of the mass and power breakdowns, and module specific schematics to provide a visual representation with approximate layouts and dimensions.

The following subsections will provide information for:

- The Greenhouse; a module designed to provide the means for the crew to grow their own food while studying plant growth on Mars,
- The Laboratory; a fully equipped lab designed to perform high value science on Mars,
- The Medical/Exercise/Quarantine module; to provide additional medical and exercise capabilities, while also providing a quarantine area to prevent the spread of infectious disease,
- The Workshop; which provides gear for the crew to fabricate and repair station equipment, such as rovers, and solar panels.
- The Leisure and Psychology module; to provide a relaxing environment for crew when the stresses of a working station become too much, and to provide a means for crew to look after their mental health.

Many of the specialised modules do not carry the total allowable mass available to them. This remaining mass capacity can be made up with spares, replacements or more equipment as deemed necessary and useful by detailed mission designers. This capacity will just be left 'as is' to provide a margin in launch mass before launch requirements become better understood after five HAB and Cargo launches by mission 3.

### 3.5.1 Overview of Mass and Power Estimates

Summaries for the modules are given in Table 13 and Table 14.

**Table 13. Summary of mass and power for standard modules.**

Standard Modules	Outcome
HAB Mass	58100 kg
HAB Power	151.40 kWh
Cargo Mass	50350 kg
Cargo Power	69.02 kWh

**Table 14. Summary of mass and power for specialised modules.**

Specialised Modules	Outcome
Lab Mass	51319 kg
Lab Power	87.11 kWh
Workshop Mass	58200 kg
Workshop Power	104.37 kWh

Specialised Modules	Outcome
Greenhouse Mass	54016 kg
Greenhouse Power	175.37 kWh
Leisure/Psychology Mass	42898 kg
Leisure/Psychology Power	62.95 kWh
Medical/Exercise/Quarantine Mass	46879 kg
Medical/Exercise/Quarantine Power	108.4 kWh

Note that all schematics in the following sections were based on those in the MORM [1].

### 3.5.2 Greenhouse

#### Description

The specialised Greenhouse module is designed to offset and supplement some of the food Cargo which is required to be brought from Earth, as well as provide scientific research opportunities by potentially utilising Martian soil to grow plants indoors. It can also provide a source to recycle CO<sub>2</sub> and create new O<sub>2</sub> for the astronauts to breathe.

The need and necessity of a Greenhouse module is to assist the astronauts who will be living within the Mars station in a variety of different ways. Long-term explorers on Mars will need food to continue living, therefore having plants grow in the confined indoor spaces of a module for food, for replenishing oxygen in the air, and creating motivation to recycle organic matter such as composting, is a logical reason to incorporate a greenhouse into the Mars station [6]. It would result in less supply mass that needs to be lifted from Earth and flown to Mars as less food will be required (or it can be used as a contingency), as well as air mass, as the air in the Mars station can be recycled through the greenhouse.

Also, as there are no greenhouses existing on the Martian surface, it will increase scientific output of the Mars station, allowing for a variety of testing into plant growing conditions, Martian soil utilisation, examining the effects of Martian sunlight for plants, and also examining the effects of observing and creating life on Mars has on the psychology of the astronauts.

The module will consist of two sections, one for the maintenance and growth of plants, the other for storage of water, seeds, fertilizer and other maintenance equipment necessary. The growing room will consist of two floors, each separated into three humidity and temperature zones via plastic sheeting. Within each zone there will be four levels of garden beds with included in-soil and misting watering system, artificial lighting and other necessary facilities. Included will be enough equipment to convert a number of these zones into a hydroponics system. Included in the hydroponic system will be an aquaculture tank such that aquaponics can be practiced to create fertilizer for the plants, and to purify the water for the fish, which

can then be eaten when they reach maturity. There will also be a small composting area for organic waste sustainability and reuse.

### Justification

#### Purpose & Considerations of the Greenhouse

From a scientific perspective, creating life on Mars will be an incredible research area. Therefore it is decided that treating the Martian soil to make it life bearable may be something to look into to see if plants can grow in these conditions. Seeing life grow through gardening is also considered emotionally uplifting. This Greenhouse module may positively affect the astronauts if life on Mars can actually be achieved, and fresh produce can be grown for them to eat. Considerations for the Greenhouse are shown below:

- The essential plant nutrients (oxygen, carbon, hydrogen, nitrogen, potassium, phosphorus, calcium, magnesium, sulphur, iron, manganese, zinc, copper, molybdenum, boron, and chlorine) are detected in Martian soil [9]. The primary nutrients required to grow plants are nitrogen, phosphorus, and potassium – and these are often monitored by the grower through the use of fertilizers, as they are required in larger quantities for the plants to grow healthy and strong [10].
- The plants which are to be grown have to grow vigorously, and produce a good yield – meaning the astronauts will see quick progress with the plants and reap the benefits soon afterwards.
- The daylight hours on Mars are very similar to Earth, however, the irradiance is approximately 42% that of Earth, meaning plants which enjoy low levels of sunlight on Earth may be ideal for Mars (equivalent to a cloudy day on Earth) [11]. However, depending on the radiation due to the thin atmosphere, the modules may have to be covered in sand – however some plants will still be considered for conditions like this.
- The volume of the Greenhouse module is not very large but the diameter is 4.78m – meaning having two floors within this module would be ideal. However, this means the plants which are grown cannot be too large as they will likely be planted in stacked rows to maximise planting space.
- To supplement lighting for plants which need more sun, the use of artificial sun lights on each row can be altered and tailored for the type of plants growing.
- Also it has been decided that the Greenhouse should be sectioned such that temperature and humidity can be altered, depending on what plants are growing and their optimal growing conditions.

#### Considered & Appropriate Plants

The plants which will be grown on the Mars station need to be adaptable to indoor/greenhouse style growing, hardy, and be able to supplement the astronaut's diets, not replace them completely. This is because the module itself does not have

a large enough volume to provide food without the need of regular cargo drops from Earth.

These plants below enjoy partial shade conditions on Earth [12], meaning they could be planted on the top floor of the Greenhouse, and be exposed to the Martian sun radiation through a clear ceiling within the module (if the module can be above ground), as solar irradiation is lower on Mars compared to Earth [13].

- Carrots (low plant, easy to grow a lot of them in cramped spaces, grow indoors well)
- Garlic (good supplement plant, low maintenance)
- Lettuce (good complementary food, grows well in hydroponic conditions)
- Potatoes (source of carbohydrates for hard working astronauts, low plant, low maintenance)
- Spinach (good complimentary food, very short plant, can grow hydroponically)
- Parsley (hardy plant which grows vigorously, probably would not be needed to eat)
- Peas (proven to grow on board the international Space Station)

Other considered plants are shown below and are chosen due to their suitability to growing in a confined space, vigorousness, yield production, and ease of growing.

- Raspberry (enjoys low sun, grows vigorously, produces large yield)
- Blackberry (needs full sun, grows incredibly vigorously, produces large yield)
- Onions (low maintenance plant)
- Chillies (grow quickly from seed, grows well indoors, good supplement plant)
- Capsicums (grows well indoors, large yield on small plants)
- Tomatoes (grows quickly, large yields on small plants, grows well indoors)
- Pumpkin (grows quickly, low vine, large fruits)
- Beetroot (can eat both the leaf and the root, low plant, low maintenance)

All plants have a variety of different nutrients which will be effective in supplementing the astronauts diet, including vitamins A (especially from carrots), B (especially from chillies), C (berries and chillies), D, (from berries and other vegetables) calcium, magnesium, iron (especially from spinach), and dietary fibre. Many vegetables have high levels of all of these essential nutrients the human body needs to function [14], making them perfect to maintain positive physical and psychological health while inhabiting the Mars space station.

The reason crop producing tree plants are not covered is due to the large space required and the time it takes from sapling to fruit production being many years.

For plants to grow effectively, the Greenhouse module needs to have high barometric pressure (air pressure) - similar to that on earth (approximately between 900 - 1100hPa), otherwise moisture is sucked out of the plants, stressing them, thinking that there is a drought, resulting in slower growing or plant death. However, scientists can alter these responses once they are understood completely,

increasing or decreasing the effects of the Martian environment and the effects it has on plant yield.

### Hydroponic & Aquaculture

Using the hydroponic system which will be on board the module, combining it with an aquaculture set up including fish can be used to make an aquaponics system. The fish in the aquaponics can break down and eat some plant matter, but will also require other food sources. The fish produce ammonia rich waste which can be pumped through the hydroponic part of the system to the plants which filter out the ammonia and return fresh water for the fish. This ammonia rich water is broken down to nitrides and nitrates by bacteria living in the hydroponic part of the system, which can be utilised by the plants as fertiliser [15] [16].

Types of fish which are suitable for such systems are freshwater, shallow stream or pond loving. Some examples include (sourced from [17]):

- Tilapia - most common in aquaponics due to their high protein, large size, rapid growth, taste, and because they have a mostly vegetarian diet. They can also handle a wide variety of tank conditions.
- Silver and Golden Perch – good eating, easy to look after, live mostly a vegetarian diet, meaning waste plant matter can be used as food, and they have wide environmental tolerance.
- Trout – very fast growing, suitable for cold regions, however they are carnivores and will require additional food for the fish.
- Barramundi – they are fast growing, suitable for cold regions, but can cannibalise each other and need a very large tank.

The benefit of having fish on board the Mars station compared to other sources of protein like chickens, pigs, or cows is that fish are in a confined tank area and are suspended in water. This means that in low gravity conditions, their muscle and bone density will not experience any ill effects, resulting in similar flesh growth for eating as here on earth. Whereas if chickens or pigs were used, large spaces would be required to house them in the Mars station, also creating smell issues through the cycled air system, as well as the animals experiencing a reduction in muscle and bone density in the low gravity environment on Mars. This would ultimately result in less meat for the astronauts.

### Utilising Waste Plant Matter

Plant waste from the hydroponic as well as organic waste from human consumption can be composted or used in two ways. The first is for food for the fish, especially if they are mostly vegetarian such as Tilapia or Perches [17]. The other is reusing organic waste as compost for the plant system. Composting will mean that proper storage of organic waste will have to be practiced within the Mars station, with the risk of rotting organics creating unpleasant smells if done incorrectly.

## Schematics

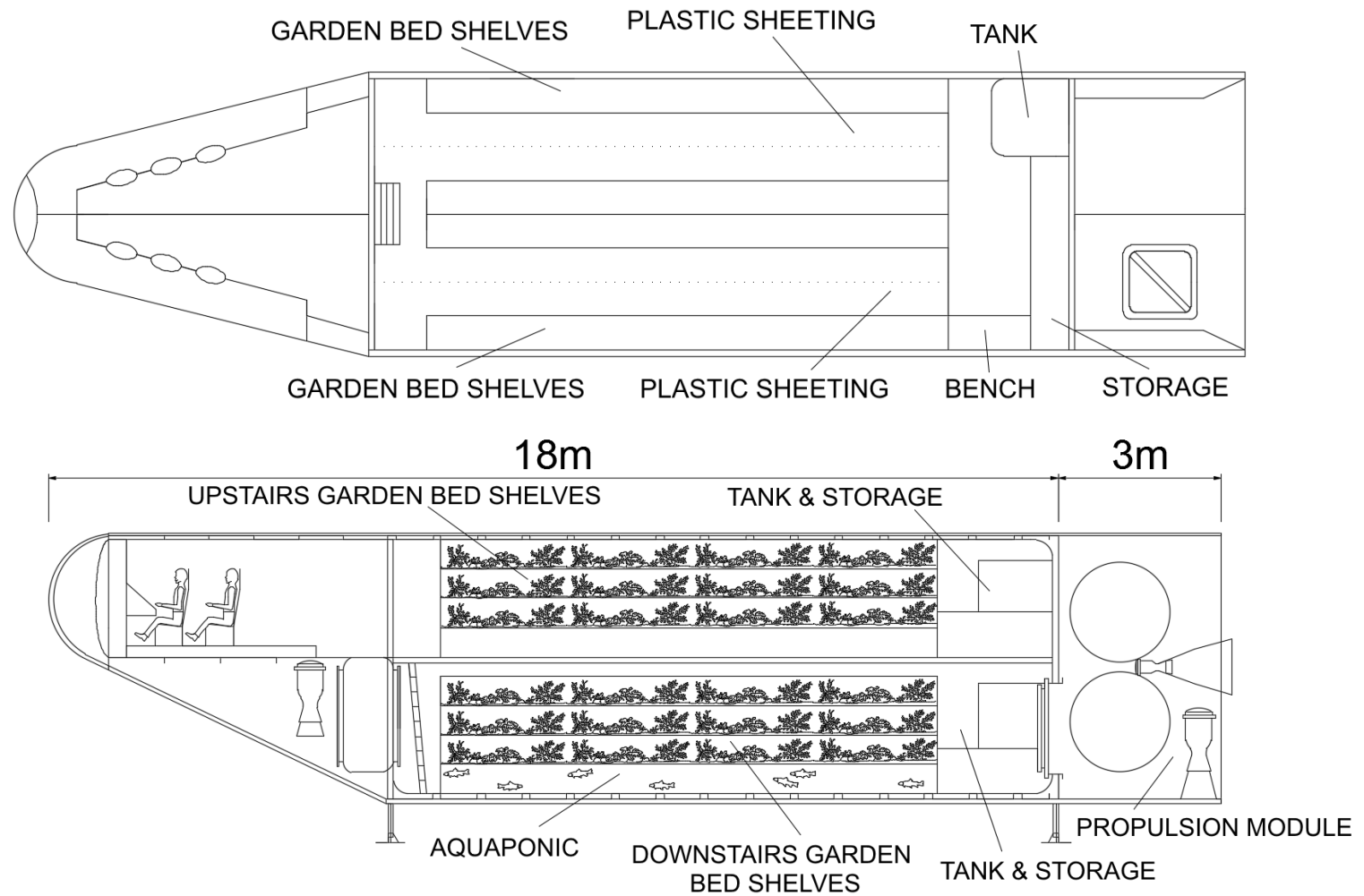


Figure 2. Schematics of top view (top) and side view (bottom) of the Greenhouse specialised module.

## Mass and Power Estimates

Table 15. Greenhouse mass estimates – SHM

Items	Mass (kg)
<b>HAB Module Components</b>	
Main structure	6800
Aeroshell on HAB	5400
Bulkheads, partitions, decks and furnishing.	4400
Electrical control system	800
Life support system	500
Power storage – Batteries	2000
Reaction control system	500
Landing engines in the HAB nose mass	500
Crew (4 off) and 4 off suits	800
Surface erected 24.2 kWp solar power cells	1008
Entire Propulsion Module	16110
Consumables for 600 days	4248
<b>Specialise Module Components</b>	
<b>Structural</b>	
Second Floor	1100
Plastic Sheeting (3m*15m*6mm *10)	2500
Garden Beds (15m *16)	1000
Shelving	400
Watering System	200
Humidity Control	200
Air Conditioning/Recondition System	200
Specialised Lighting	50
Storage Shelves	200
General Maintenance Supplies	100
<b>Aquaponics</b>	
Water Tanks and Piping	500
Aquaponic Garden Beds	200
Frozen Fish Embryos (Including Storage)	50
Fish Tanks (Empty)	2100
Fish Care Supplies	50
<b>Organic Matter</b>	
Dried Soil	2000
Dried Seeds and Sprouts	100
<b>TOTAL</b>	<b>54016</b>
<b>Total Payload Capacity</b>	<b>62000</b>
<b>Payload Capacity Remaining/Spares and Replacements</b>	<b>7984</b>



Table 16. Greenhouse power budget – SHM

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	All the lights in the rooms and throughout the HAB
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	External lighting
Electric control systems	95%	1	0.5	0.5	6	3	3.16	Controller for all electronic systems (computer)
Life support system (Pressure)	80%	1	1	1	12	12	15.00	Pressure pump for air pressure in module
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	Pressure pump for oxygen
Water Pressure	80%	1	0.3	0.3	4	1.2	1.50	Pressure pump for water
Interpersonal Communication Devices	85%	4	0.015	0.06	2	0.12	0.14	Communications between astronauts
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	Communications between modules
Interplanetary Communication Devices	70%	1	0.7	0.7	1.5	1.05	1.50	Communication between Mars, Earth, and Orbiter
Screens	80%	3	0.05	0.15	3	0.45	0.56	Computer screens for research/recreation/communication
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	Module temperature control
Watering System	90%	1	0.5	0.5	12	6	6.67	
Humidity Control	90%	1	2	2	18	36	40.00	From HAB Calc
Air Conditioning/Recondition System	90%	1	0.5	0.5	18	9	10.00	From HAB Calc
Specialised Lighting	90%	1	1	1	24	24	26.67	From HAB Calc
General Maintenance Supplies	90%	1	1	1	1	1	1.11	
Aquaponic Garden Beds	90%	1	2	2	18	36	40.00	
Frozen Fish Embryos (Including Storage)	90%	1	0.01	0.01	18	0.18	0.20	
Fish Care Supplies	90%	1	1	1	1	1	1.11	
<b>Totals</b>				<b>5.455</b>		<b>39.04</b>	<b>175.37</b>	<b>Total including efficiency/24.62</b>
							<b>7.12</b>	<b>kW avg/hour</b>



### 3.5.3 Laboratory

#### Description

The entire specialised Laboratory module is designed and implemented to help with scientific inquiry and exploration on Mars. It will serve as the primary tool and basis of the overall scientific strategy of the mission through its subparts and attributes as well as tools and equipment [18].

The need and necessity of such a module as a component of the mission sequence is to help fulfil and accomplish the mission's scientific goals. This corresponds to the long term goal of establishing long term human permanent settlement on Mars, thus determining the existing habitability of the planet is a vital first steps towards achieving the initial extensive goal. With regards to that, the Laboratory module will provide the scientific basis and means to obtain and explore the necessary scientific postulates.

As a whole, the dream of establishing a permanent settlement on Mars will hinge on the 'habitability' of the red planet itself. Thus the scientific goals of the mission will circulate and float around this predominantly which will include exploration of the relevant environmental attributes of Mars to determine suitability to human life. This will be precisely accomplished by the testing of knowledge or experimentation, the Laboratory module will help concisely unravel the traits of Mars suited to or otherwise with regards to human sustainability [19].

The previously employed term 'habitability' and the consequent need for exploration on Mars essentially is ambiguous and broad so far. Though in the spirit of approaching the complex problem by implementing a whole of systems approach, the broad requirement is broken down into smaller more concise pieces until suitably verifiable, unambiguous and traceable. In the context of the mission, the scientific goals can be best delivered and approached as seen below in no order of priority or importance in Table 17.

**Table 17. Scientific Goals**

Scientific Goals of Mars Mission
Characterizing and exploring the climate of Mars
Investigate and characterize the geology of Mars
Determining the presence or if life ever arose on Mars
Suitable preparation for human exploration or permanent settlement

The table above clearly summarizes the scientific goals that the presence of a Laboratory module will be utilized to address.

The Laboratory will be adequately equipped and capable in providing experimental foundation for the theoretical concepts that are grappled with, verify preconceived notion without bias instead being able to generate valid observations and

conclusions with regards to the conditions on Mars which will be extensively explored in the forthcoming sections [20].

### Characterizing and Exploring the Climate on Mars

One of the important factors that will influence human adaptability to life on Mars or the ability for humans to fit in to the conditions of Mars will depend on the climate on Mars. Considering that issues like climate change and global warming has driven along with other factors the pursuit of life on Mars, the mission adequately accommodates the hardware and software to ensure successful climate based data collection primarily through the specialised Laboratory module. In the context of research, accurate understanding of Mars current climate will help scientists model past climate as well as the climate in the future. Mission specifics will involve generating suitable weather maps and establishing the nature of dusts and water vapor in the atmosphere. The mission duration is suitable to observe all necessities over a full Martian year which in turn will allow understanding over a season and projections way into the future [21]. As a whole, the climate on Mars is extensively erratic and the mission will verify the forthcoming information that was previously attained as seen below.

The Mars weather can vary incredibly from day to day or worst still from hour to hour. Scientifically, this seems rather unusual and contradictory considering that Mars boasts an atmosphere that is comparatively only one hundredth that of Earth [22]. In terms of temperature, the conditions of Mars can reach or peak at 20 degrees Celsius at the equator as summer gears up or dip as low as -153 degrees Celsius at the poles during winter [23]. As a reasonable average the temperature on Mars is -50 degrees Celsius, this is derived from the Mars summer and winter temperature which are 20 degrees Celsius and -120 degrees Celsius respectively [24]. The humidity conditions on Mars is saturated at night and under saturated during the day. The air pressure on the planet of Mars though is significantly lower than that of Earth. More mission specific, this results in significant concerns with regards to the mechanical and electronic parts of the Laboratory devices and equipment as well as instrumentation during data collection and research. The mission and technology implementation will be designed and introduced with regards to this. Besides that, the module in itself should provide necessary temperature, humidity and pressure regulation to offset the temperature conditions on Mars.

In terms of air composition, Mars varies extensively with regards to Earth, most visibly in terms of oxygen and carbon dioxide levels. Unlike Earth, carbon dioxide is in abundance but oxygen is scarce whereby the remaining composition is made up of nitrogen and argon with traces of water and methane [25]. This is vital in the long term, the abundance of acidic carbon dioxide in excess is significantly corrosive such that long term research equipment need to be adequately designed to ensure effectiveness.

One of the major considerations climate wise is the presence of dust storms and the absence of rain which both have implications with regards to the technology aspects of the mission. The dust storms could be both small and large enough to be seen from telescopes on earth. As a whole, even the largest dust storms will not result in the destruction of major mechanical and technological equipment [26]. Though the major concern lies with efficiency, such dust storms will inhibit electrical and technological devices significantly, for instance plaguing solar efficiency or other electrical devices as the sand it transports and coats onto everything is electrostatic in nature as it grows to encapsulate the entire planet such that non-critical systems will be turned off [26]. In terms of scientific research, observations of the atmosphere during such dust storms are of increased significance and will be implemented [27]. There is no rain but scarce amounts of snow on Mars, the lack of rain rises from the presence of thin atmosphere and the absence of a magnetosphere which protects liquid water from solar radiation. This in addition to the presence of solar winds make rain impossible but snow is possible more interestingly comprising of carbon dioxide rather than water [22].

In addition to basic observation methods, the specialised Laboratory module will also look to measure and detect stable isotopes of elements such as carbon to research the composition of the atmosphere of Mars. As a whole, in this context it will study the weather patterns, distribution of elements such as water, carbon dioxide and hydrogen as well as measure the surface radiation present in various forms.

#### Investigate and Characterize the Geology on Mars

In general, the history of Mars in terms of its conditions and elements is intertwined in the layers of the Martian surface. As a consequence, it is extremely beneficial to explore the rock and soil records on Mars to understand how relevant geological processes have influenced the Martian crust and surface over time as this would be a significant step in deriving future conditions and possible human settlement systems on Mars. Of the highest significance will be isolating and identifying conditions that encourage human sustained life, for instance evidence of rocks that occurred in the presence of water or elements that have significance to human life [18].

As a whole, with regards to the initial theme, the degree of habitability will be accounted for in terms of the differences and similarities between Mars and Earth. Thus, the Laboratory module will be equipped in that context to study issues such as the roles of wind, water, volcanism, tectonics, cratering and other processes that have contributed to the development of the Mars surface over time as well as verify and update necessary data with regards to current conditions [21].

The mineral and elemental composition is vital to encourage extensive human exploration, elements such as silicon, oxygen, iron, magnesium, aluminium, calcium, potassium, titanium, chromium, manganese, sulfur, phosphorus, sodium and chlorine will be classified and recorded using in-situ analysis techniques in addition

to other complex minerals for example olivine and pyroxene. There are also sedimentary rocks like magnesium, iron and calcium carbonates in abundance on Mars [28]. As a whole, this will be compounded by the classification of the pH values and representation of the geology on Mars primarily depending on X-ray diffraction techniques and spectroscopy.

Proper comprehension of the nature and fundamentals of the volcanic systems present on Mars are also areas of extreme interest scientifically. Concepts such as volcanic intrusions and the fact that possible biosystems stem from volcanic systems makes its exploration vital. As such, high resolution imaging, Thermal Emission Spectrometer analysis and topographic mapping become important in accurate recording of the timing and patterns of volcanic activity [29].

On a more trivial note, the general outlook and non-homogeneous surface of Mars which seems rather eroded is evidence of interaction with factors such as wind and water. As previously mentioned, dust storms both global and local are regular occurrences. High velocity winds and solar heating of surface produces lots of surface erosion. Under current atmospheric conditions, water cannot exist on the surface as free liquids which gives rise to the possibility that the Mars atmosphere may have been denser in the past [30].

Exploring the magnetic behaviour of Mars is also of extreme significance as it will adversely affect the behavioural antics of technologies and devices on Mars. The presence of magnetic materials on Mars also determines the degree of cosmic radiation protection that Mars is to experience [21]. The magnetosphere on Mars is expected to be less intensive than that on Mars and helps protect Mars against solar winds and charged particles [31].

Identifying and determining the presence of polar caps and ice caps on Mars will also have significant scientific benefits to the mission and possible future human settlement. Usage of high resolution imagery will help determine positions of such spots on the surfaces of Mars, thus allowing it to be studied and developed effectively as possible source of life.

In short, the responsibility of characterizing and studying the geology will be employed by conducting global high resolution topography and images, thermal mapping of rocks and relevant soil types. Utilizing enhanced spectral range and resolution, mapping of surface and near-surface water and ice as well as the research of shallow crustal structure on the Martian surface. It will also involve mapping of gravity and magnetic anomalies, the roving determination of surface geology, physical properties, geochemistry, mineralogy and astrobiological investigations and sounding of the subsurfaces.

### Determining the Presence or if Life Ever Arose on Mars

One of the longest lasting questions in the context of Mars has also been the possibility if life could have ever existed on the planet through the search of relevant signs, clues and indicators that can substantiate such claims instead of mere

conjuncture [21]. Ideally, the fact that sedimentary rocks and substances on the surface of Mars resemble that of the structures shaped by microbes on Earth, this in turn fuels the claims extensively. The scientifically accepted term for this on Earth being microbially-induced sedimentary structures [32].

In terms of the mission precisely, this will be accomplished through the Laboratory module by searching and detecting telltale markers and bio-signatures. Carbon is the most prominent element used as fundamental indicator of life in distinct forms. Organic molecules or materials in the form of mineralogical and textural indicators are tested through sample electron microscopy analysis and by bringing back samples for further analysis [33]. Through this necessary and conclusive evidence could probably be established to corroborate existence of life in addition to imagery evidence that can withstand scrutiny.

Besides sedimentary geology, naturally occurring elements such as lakes and streams are also explored to identify similar bio-prints developed by microbes. Concerted efforts are also implemented to ensure it is not false positives brought from Earth that is detected by life detection technologies. For instance, methane is an indicator of life generated from microorganisms through their metabolism but also a fixture on technologies that are to be utilized by the mission, differentiation is vital [34].

In addition, this is also to be accomplished by pursuing locations of alternative energies other than solar energy. The basis being that organisms, perhaps subsurface organisms may thrive with such conditions thus resembling their behaviour on Earth. Thus chemical and geothermal energy sources if present on Mars represent locations of possible presence of life, locating them is the first step in that search [21].

#### Suitable Preparation for Human Exploration or Permanent Settlement

There has always been and will continually be consistent efforts to journey to Mars by humans, the essential issues will be ensuring their safety throughout the process up to the point of return back to Earth. Therefore, successful accomplishment of the aforementioned goals will depend critically on complete understanding of the Martian environment and conditions such that it coexists with human presence. Accordingly, a sequence of properly thought out tests and experimentation will be implemented to comprehensively establish such conditions within the mission by utilizing the Laboratory module.

Safety and wellbeing is of paramount importance such that everyone and anyone should only be exposed to Mars surroundings if it is seen feasible. With regards to that and the climate factors previously covered, the research done will look to ensure streamlined adaptation of a proper life conditions in the boundaries of Mars.

For instance, fluid dynamics in lower gravity and corresponding research suited to establishing and optimizing the usage of fluids in Mars. Currently, basic and simple pipe and water transfer systems are implemented for short term stays on Mars. This

will involve developing models of fluid flow to study both laminar and turbulent flows such that a reliable water and fluid transport systems to sustain human life and accommodate water based devices effectively [35]. This will be conducted in addition to study of gas flows as well.

There is also a need to study combustion behaviour in Mars with regards to adequate comparisons to Earth. Combustion is an essential source of energy on Earth, thus it poses similar potential to be harvested on Mars for similar purposes with maximized efficiency. This will involve control experiments to test combustion basics in gas chambers and simple laboratory experiments in the specialised Laboratory module.

On a similar note, the fact that the environmental and basic conditions on Mars is distinct to that of Earth makes it necessary to establish the laws of physics and chemistry to encapsulate optimized life on Mars. This will include tests of general chemical behaviour on Mars, testing of factors such as gravity and air pressure as well as other relevant concepts. This way appliances and devices can be designed to perform at its best.

It is also important to explore corrosion in the context of Mars, to better protect and safeguard appliances in the surroundings of Mars. It will be enlightening to inspect the dynamics of corrosion in Mars and how it differs to Earth with actual credible data. This will involve developing simple corrosion test sets like galvanic cells.



## Schematics

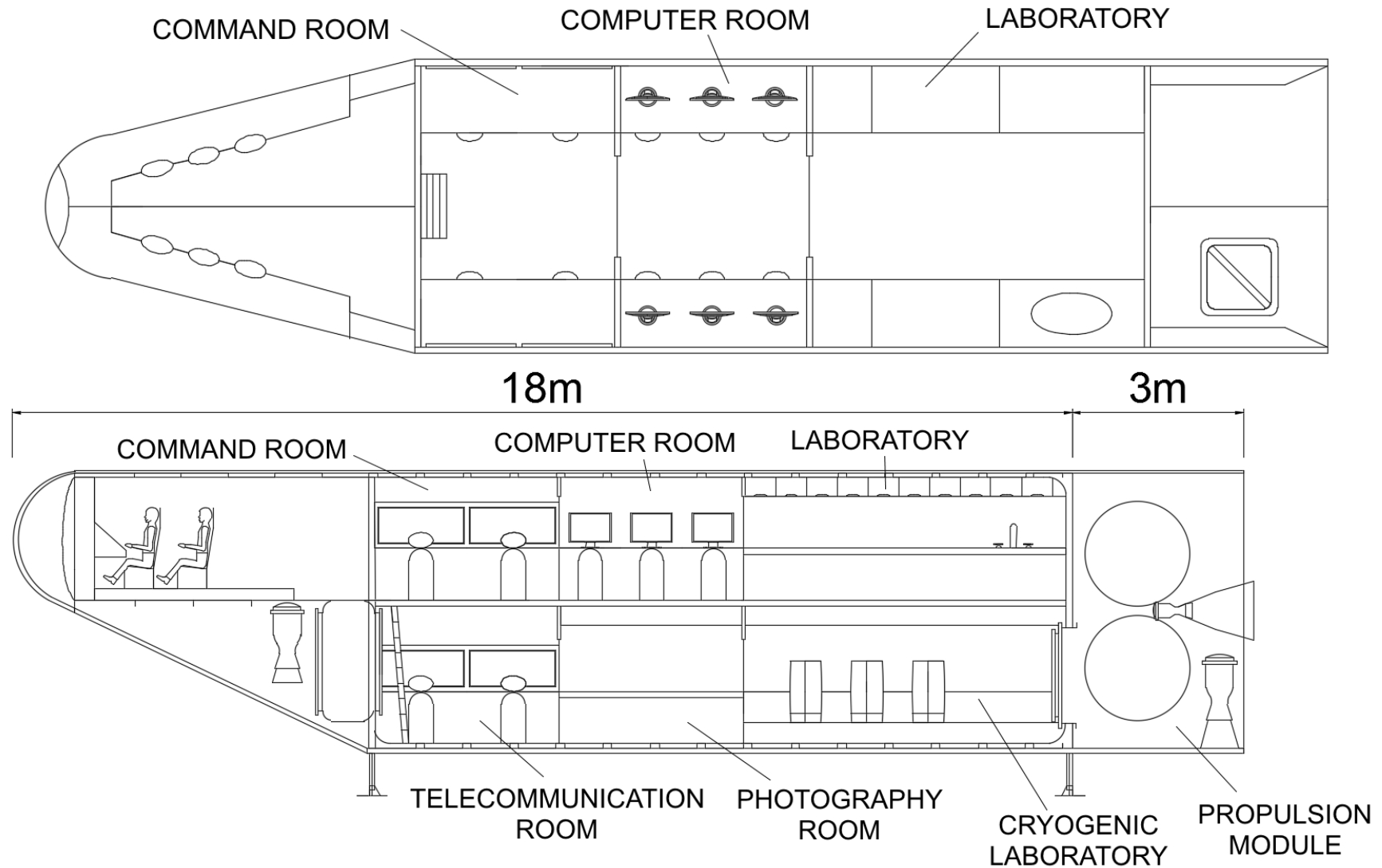


Figure 3. Schematics of top view (top) and side view (bottom) of the Laboratory specialised module

The values of mass and power utilized in this section represent figures corroborated by commercial sources for device such as X-ray diffractometer and other high level technological device. Though these estimations do represent rather accurate values, devices and technologies actually deployed in space are specifically designed and crafted to fit actual mission design, thus relative discrepancies are expected. In addition, devices and corresponding power estimations are generally overestimations based on the fact that there are relatively non-regular usage patterns. The total mass estimated based on the aggregates of devices and appliances present was approximately 51.319 tonnes which also amounted to an approximate power consumption of 87kWh per day. The concise mass and power tables can be found below.

**Table 18. Laboratory mass estimates – SHM**

Items	Mass (kg)
<b>HAB Module Components</b>	
Main structure	6800
Aeroshell on HAB	5400
Bulkheads, partitions, decks and furnishing.	4400
Electrical control system	800
Life support system	500
Power storage – Batteries	2000
Reaction control system	500
Landing engines in the HAB nose mass	500
Crew (4 off) and 4 off suits	800
Surface erected 24.2 kWp solar power cells	1008
Entire Propulsion Module	16110
Consumables for 600 days	4248
<b>Specialise Module Components</b>	
<b>Furniture</b>	
Additional Laboratory Furniture - storage cupboards, biological safety cabinets, workbenches, mobile sinks, fume cupboards etc	1257
<b>Electronics</b>	
Photography Equipment - lenses, still cameras, video cameras, satellite camera, telescope, panoramic camera, military grade camera etc	3131.5
Computer Equipment - computers, keyboards, desktops, projectors, printers etc	362
Communication Equipment - monitors, LED screens, communication dock and assembly, geophones etc	270
Command Equipment - command assembly and facilities	100
<b>Lab Equipment</b>	





Items	Mass (kg)
Basic Lab Equipment - sample disinfectant, preservation and preparation kits, chemicals, safety equipment etc	688
Exobiological Equipment - freezer, chemical mediums, centrifuges, incubators, PC hoods etc	250
Discretionary Science Equipment - isotope mass spectrometer, microscope, x-ray diffractometer etc	300
Geoscience Equipment - neutron spectrometer, magnometer, drilling appliances, thermal emission spectrometer etc	794
Astronomy and Atmospheric Equipment - gas indicators, magnetometer, moisture meter, meteorological balloons, air sampler etc	600
Particle and Field Science Equipment - reflection seismometer, EM soundmeter, field microscope, UV-Vis spectrometers, dosimeters, biological dipsticks, shovels etc	500
<b>TOTAL</b>	<b>51318.5</b>
<b>Total Payload Capacity</b>	<b>62000</b>
<b>Payload Capacity Remaining/Spares and Replacements</b>	<b>10681.5</b>

**Table 19. Laboratory power budget – SHM**

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	
Avionics/Guidance/Reaction Control	85%	1	2	2	2	4	4.71	
Electric control systems	95%	1	0.5	0.5	6	3	3.16	
Life support system (Pressure)	80%	1	1	1	12	12	15.00	
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	
Water Pressure	80%	1	0.3	0.3	4	1.2	1.50	
Interpersonal Communication Devices	85%	4	0.015	0.06	2	0.12	0.14	
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	
Interplanetary Communication Devices	70%	1	0.7	0.7	1.5	1.05	1.50	
Screens	80%	3	0.05	0.15	3	0.45	0.56	
Waste Disposal (Toilets)	90%	1	0.09	0.09	0.55	0.0495	0.06	
Cleaning (Vacuuming/Mopping)	70%	1	0.125	0.125	0.24	0.03	0.04	
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	
Hygiene System	90%	1	0.09	0.09	2.13	0.1917	0.21	
Laboratory								
Freezer	90%	1	0.54	0.54	4	2.16	2.40	
Desktop	90%	2	0.1	0.2	5	1	1.11	
Projector	90%	1	0.31	0.31	2	0.62	0.69	
Satellite Camera	90%	1	0.024	0.024	8	0.192	0.21	
Communication System	90%	1	0.4	0.4	4	1.6	1.78	
LCD Screen	90%	2	0.1	0.2	7	1.4	1.56	
High Speed Computer	90%	1	0.5	0.5	5	2.5	2.78	
Assorted lab equipment	90%	1	1.5	2	12	24	26.67	



## Mars-Oz Mission Design

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
<b>Totals</b>				<b>11.934</b>		<b>76.78</b>	<b>87.11</b>	<b>Total including efficiency/24.62</b>
							<b>3.54</b>	<b>kW avg/hour</b>

### 3.5.4 Medical, Exercise & Quarantine

#### Description

The purpose of the MEQ module is to allow the crew to maintain their cardiovascular fitness, muscle mass and bone density while subjected to Mars gravity, to perform medical procedures and emergency surgeries in the case of injury, and to isolate any crew member who becomes sick.

The MEQ module contains both essential and specialised exercise, medical and quarantine equipment to maintain the health of the crew and perform emergency surgeries for almost every type of injury. The exercise section of the module will consist of two treadmills, one cycle ergometer and one resistance exercise device. The exercise equipment will be used daily by the crew to prevent the decline of their cardiovascular fitness, muscle mass and bone density. The medical section of the module will consist of generic medical supplies, life support systems, operating tables, and other specialised machines. It is the assumption that all crew members will be trained prior to the mission on how to operate each medical machine. The medical, exercise and quarantine sections will be contained separately on two different levels of the module, with the medical taking up the top level and the exercise and quarantine on the bottom (see Figure 5 below). The medical area will contain a bed, an intravenous pole and fluids, patient monitoring equipment and also a television. Plastic sheeting has been included to isolate the quarantine section from the exercise section.

The MEQ module will be assembled during the beginning of mission 4 however sufficient quantities of the exercise and medical components will be present throughout every stage of the mission sequence. Small quantities of generic exercise and medical equipment are equipped with every HAB module to ensure the crew are able to maintain their health in the zero gravity environment during the journey from Earth to Mars. The MORM does not specify the exact equipment and consumables for medical and exercise needs but does allow a mass reserve of 300kg for exercise equipment and 2500kg for medical for one HAB [1]. Specialised exercise and quarantine equipment will arrive for mission 3 and it is proposed that it will take up half the space of the HAB for that mission. Specialised medical equipment will be transported in time for mission 4. It is envisaged that by mission 4, the generic exercise and medical equipment from the initial HAB's will be moved and integrated with the specialised equipment sent in mission 3 and 4 to form the MEQ specialised module.

#### Justification

The specialised MEQ module is an essential module that must be integrated into the Mars station with a higher priority given to timing than the other specialised modules due to the high risk nature of the Mars mission. The dangers associated with

interplanetary travel and exploration of the Mars environment means that all essential and specialised medical equipment must be on hand in the case of injury or sickness. The necessity for this module is emphasised through the Mars station design priority of maximising safety. The medical component of the MEQ module will contain all equipment necessary to perform anything from treating small abrasions and cuts to highly complicated surgeries to account for any type of injury that might occur. Equipment such as surgical lights, patient monitors, defibrillator, X-ray machines, and anaesthesia devices are examples of the specialised equipment that will be available in the MEQ module (see Table 20 below for the full list of medical equipment).

Aside from illness and injury, crew must also partake in regular exercise to maintain health. Crew on the Mars Oz mission will be subjected to Martian gravity one-third the strength of Earth's gravity, making it essential to perform daily exercise routines to retain fitness and strength. Astronauts living on the ISS (International Space Station) must partake in two and a half hours of exercise each day to maintain cardiovascular fitness, muscle mass and bone density. Aside from eating and sleeping, this daily exercise holds the highest priority and must be performed so that astronauts can function properly once they return to Earth (NASA n.d.). This exercise is also important for ensuring the crew are capable of coping with the physical demands of walking on the red planet, especially in the case of emergencies such as getting caught in storms, as conditions can become harsh and dangerous.

Bone density has been found to decrease by 0.4-1% per month in space while muscle and cardiovascular fitness also decrease significantly [36]. The Mars gravity will not negatively impact their strength to the extent the microgravity on the ISS would, however daily exercise must be performed if they are to retain strength and bone density to maintain their health and perform strenuous tasks during the mission. Ensuring strength and bone density are retained will also assist their transition to Earth's gravity after completing the mission.

Astronauts on the ISS currently use three pieces of exercise equipment including a treadmill, cycle ergometer, and a resistance exercise device (RED) for strength exercises [37]. A harness fixes the astronaut to the treadmill and applies a variable load to simulate a gravity force acting on them. The load is set to approximately model Earth's gravity such that the astronauts can maintain an appropriate strength to function normally once returned to Earth.

It is proposed that a similar treadmill, cycle ergometer and RED be incorporated into the exercise module to allow the Mars crew to effectively maintain their health and strength. The treadmill and cycle ergometer will allow them to keep up cardiovascular fitness and the RED will help avoid muscle deterioration. This will allow them to effectively perform strenuous tasks aligned with their mission goals and also allow them to physically cope in an emergency.

### Schematics

Figure 4 and Figure 5 on the following pages show the basic layout of the medical and exercise equipment. The main structure of the module will be split into two levels with the medical section on top and the exercise and quarantine sections below. The HAB height is 4.78m and therefore the bottom level will have a height of 2.28m and the top level 2.5m. The medical area was given a greater height to accommodate for the dimensions of some of the large pieces of medical equipment such as the x-ray machine and the surgery microscope.

## Mars-Oz Mission Design

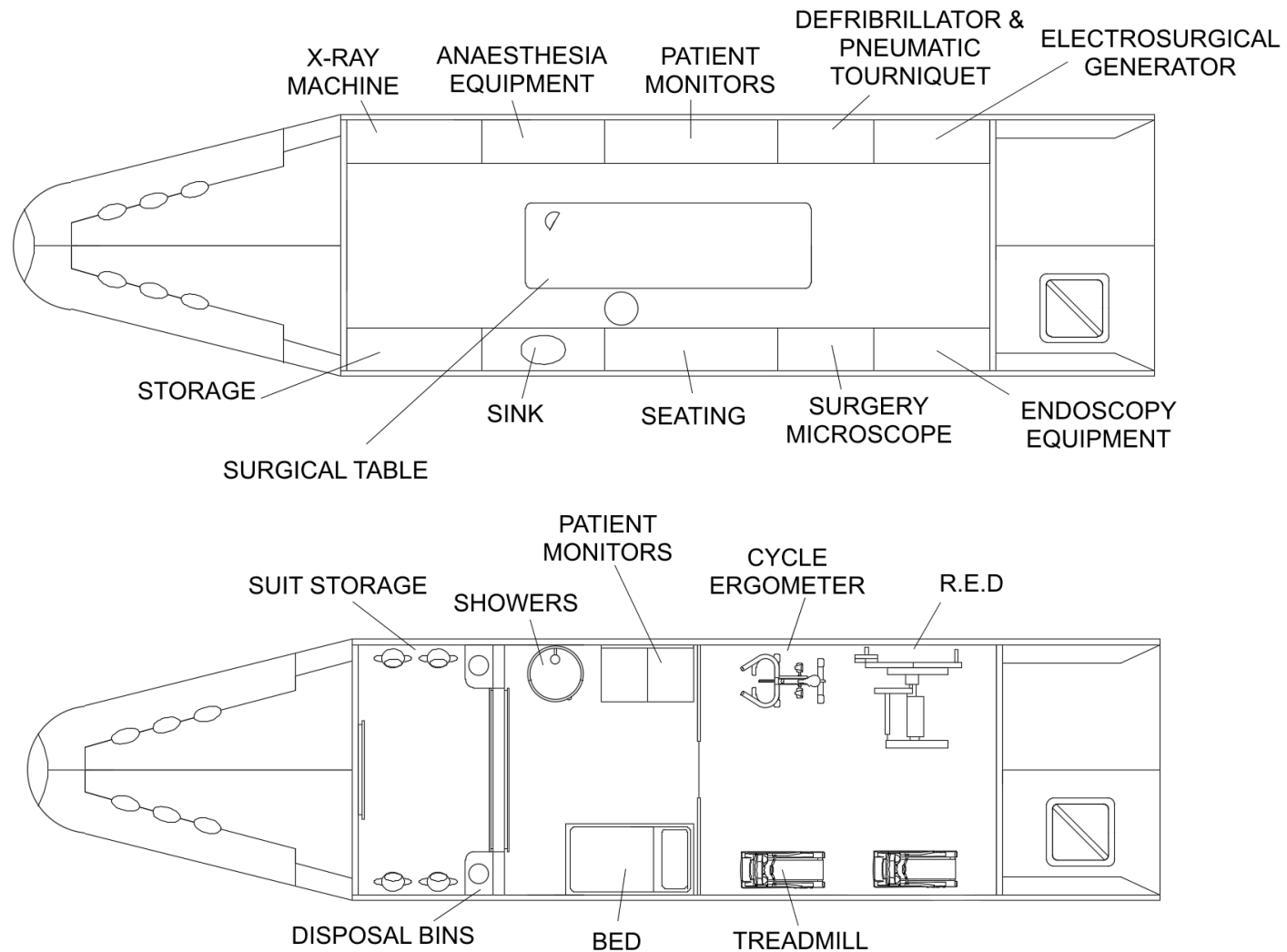


Figure 4. Schematics of top view of top floor (top) and top view of bottom floor (bottom) of the MEQ specialised module.

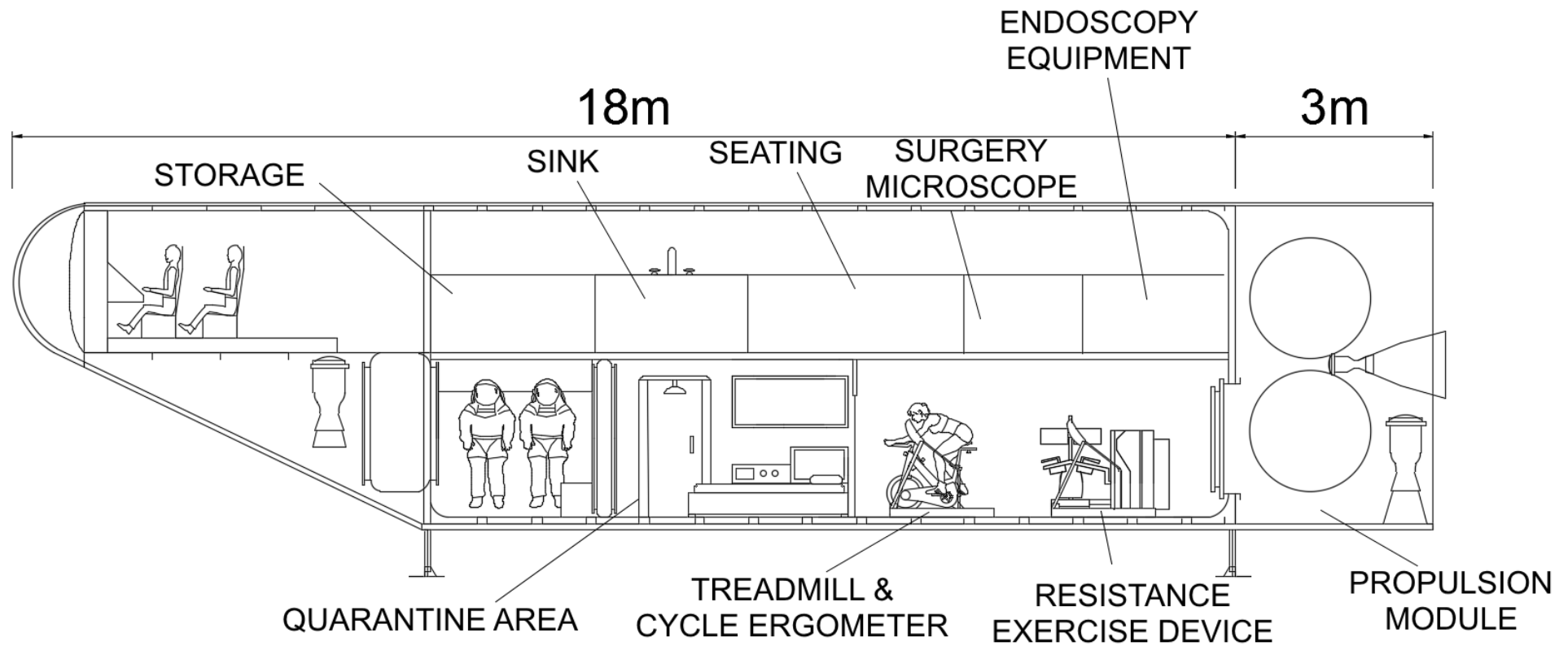


Figure 5. Schematics of side view of the MEQ specialised module.



### Mass and Power Estimates

The final mass and power estimates are given in Table 20 and Table 21 below. The total mass of the MEQ, accounting for a 20% margin, came to 54.55 tonnes, which leaves room for an extra 7.45 tonnes of free weight before the maximum limit of 62 tonnes is reached. The maximum power, once again including a 20% margin, was 129.77 kW/Unit/Day which also accounts for losses in efficiency. This power estimate takes the assumption that all medical, exercise and quarantine components will be used to their maximum capacity in a single day. In reality, this is unlikely to occur and therefore the power calculated more gives an estimate on the limit for the maximum power that could ever need to be generated in a day.

**Table 20. MEQ mass estimates – SHM**

Items	Mass (kg)
<b>HAB Module Components</b>	
Main structure	6800
Aeroshell on HAB	5400
Bulkheads, partitions, decks and furnishing.	4400
Electrical control system	800
Life support system	500
Power storage – Batteries	2000
Reaction control system	500
Landing engines in the HAB nose mass	500
Crew (4 off) and 4 off suits	800
Surface erected 24.2 kWp solar power cells	1008
Entire Propulsion Module	16110
Consumables for 600 days	4248
<b>Specialise Module Components</b>	
<b>Medical room</b>	
Anaesthesia equipment (Count: 1)	110
Operating table (Count: 1)	170
Surgical light (Count: 2)	40
Seating (Count: 2)	20
Cabinet (Count: 1)	100
Table (Count: 1)	20
Patient monitors (Count: 7)	30
Defibrillator (Count: 1)	10
Electrosurgical generator (Count: 1)	10
Endoscopy equipment (Count: 1)	50
Surgery microscope (Count: 1)	30
X-ray machine (Count: 1)	500
Infusion pump (Count: 1)	5
Pneumatic tourniquet (Count: 1)	20

Items	Mass (kg)
Hospital stretcher (Count: 1)	320
Surgical tools (Count: 1)	20
Sink (Count: 1)	30
<b>Exercise room</b>	
Treadmill (Count: 2)	200
Cycle ergometer (Count: 1)	100
Resistance exercise device (Count: 1)	315
TV (Count: 1)	20
<b>Quarantine area</b>	
IV Pole (Count: 1)	8.6
Patient monitors (Count: 7)	30
Bed (Count: 1)	90
TV (Count: 1)	20
Plastic Sheeting (Count: 1)	1.2
Shower (Count: 1)	120
<b>TOTAL</b>	<b>45455.8</b>
<b>Total Payload Capacity</b>	<b>62000</b>
<b>Payload Capacity Remaining/Spares and Replacements</b>	<b>16544.2</b>

Table 21. MEQ power budget – SHM

Component	Stored power to use efficiency	Unit	No. of Units	Peak Per Unit Basis kW	Total Peak kW	Time/Day (hours)	kWh/Unit /Day	Total Including Efficiency
Lighting System	80%	W/globe	20	0.025	0.5	8	4	5.00
External Lighting System	80%	W/globe	6	0.175	1.05	4	4.2	5.25
Avionics/Guidance/Reaction Control	85%	W	1	2	2	2	4	4.71
Electric control systems	95%	W	1	0.5	0.5	6	3	3.16
Life support system (Pressure)	80%	W	1	1	1	12	12	15.00
Life support system (Oxygen)	80%	W	1	0.5	0.5	12	6	7.50
Water Pressure	80%	W	1	0.3	0.3	4	1.2	1.50
Interpersonal Communication Devices	85%	W/unit	4	0.015	0.06	2	0.12	0.14
Intermodule Communication Devices	85%	W/unit	4	0.03	0.12	1	0.12	0.14
Interplanetary Communication Devices	70%	W	1	0.7	0.7	1.5	1.05	1.50
Screens	80%	W/unit	3	0.05	0.15	3	0.45	0.56
Medical & Recreational equipment	90%	W	1	2.35	2.35	1.5	3.525	3.92
Waste Disposal (Toilets)	90%	W	1	0.09	0.09	0.55	0.0495	0.06
Cleaning (Vacuuming/Mopping)	70%	W	1	0.125	0.125	0.24	0.03	0.04
Heating & Air Conditioning	70%	W	1	0.575	0.575	12	6.9	9.86
Hygiene System	90%	W	1	0.09	0.09	2.13	0.1917	0.21
<b>Specialise Module Components:</b>								
<b>Medical room</b>								
Anaesthesia equipment	90%	W	1	0.15	0.15	2	0.3	0.33
Operating table	90%	W	1	0	0	2		
Surgical light	90%	W	2	0.055	0.11	2	0.22	0.24
Seating	90%	W	2	0	0			
Cabinet	90%	W	1	0	0			
Table	90%	W	1	0	0			

## Mars-Oz Mission Design

Component	Stored power to use efficiency	Unit	No. of Units	Peak Per Unit Basis kW	Total Peak kW	Time/Day (hours)	kWh/Unit /Day	Total Including Efficiency
Patient monitors	90%	W	7	0.065	0.455	24	10.92	12.13
Defibrillator	90%	W	1	0.13	0.13	0.1	0.013	0.01
Electrosurgical generator	90%	W	1	0.2	0.2	2	0.4	0.44
Endoscopy equipment	90%	W	1	0.16	0.16	2	0.32	0.36
Surgery microscope	90%	W	1	0.02	0.02	2	0.04	0.04
X-ray machine	90%	W	1	0.15	0.15	0.5	0.075	0.08
Infusion pump	90%	W	1	0.03	0.03	2	0.06	0.07
Pneumatic tourniquet	90%	W	1	0.05	0.05	2	0.1	0.11
Hospital stretcher	90%	W	1	0	0			0.00
Surgical tools	90%	W	1	0	0			0.00
Sink	90%	W	1	0.09	0.09	0.5	0.045	0.05
<b>Exercise room</b>								
Treadmill	90%	W	2	0.13	0.26	2.5	0.65	0.72
Cycle ergometer	90%	W	1	0.13	0.13	2.5	0.325	0.36
Resistance exercise device	90%	W	1	0.1	0.1	2.5	0.25	0.28
TV	90%	W	1	0.15	0.15	2.5	0.375	0.42
<b>Quarantine area</b>								
IV Pole	90%	W	1	0.065	0.065	24	1.56	1.73
Patient monitors	90%	W	7	0.065	0.455	24	10.92	12.13
Bed	90%	W	1	0	0			
TV	90%	W	1	0.15	0.15	12	1.8	2.00
Plastic Sheeting	90%	W	1	0	0			
Shower	90%	W	1	0.09	0.09	0.5	0.045	0.05
<b>Totals</b>					<b>13.055</b>		<b>75.25</b>	<b>90.12</b>
<b>Totals (+20% margin)</b>					<b>15.666</b>		<b>90.31</b>	<b>108.14</b>

### 3.5.5 Workshop

#### Description

The Workshop module provides the tools for the Mars station crew to engineer, create and repair, allowing greater self-sufficiency, and greater reusability of shipped mission apparatus.

The Workshop is intended to provide the Mars station crew with the means to create and repair items for use in the station and abroad, including parts for the repairing of rovers. Having a workshop will allow the crew to increase the usable life of equipment, and allow niche items to be created on an ad-hoc basis. This will be made possible by equipping the workshop with items such as 3D printers [38, 39], a CNC machine [40], welding apparatus [41], rover maintenance tools, equipment and spares. There will also be a small amount of electronics [42], so the crew can build new electronic control systems, or RC rovers, for example. Finally there will be various tools (powered and unpowered), including a lift [43] for the rovers, and workshop consumables for the fabrication of many different, more basic items.

The specialised Workshop module arrives prior to mission 4 as part of the Cargo module, carrying the fully furnished and outfitted Workshop, and the required extra cargo and consumables for mission 4. Once the mission 4 crew arrive they can attach the Workshop to the station in a similar fashion to a Garage.

#### Justification

The purpose of the Workshop module is two-fold. It serves as a means to produce or repair specific items on site thereby reducing the need to send as many specific spares as might be required, replacing it with more generic 'feedstock'. This reduces the burden of both redundancy and total payload required. The Workshop will also provide a certain amount of redundancy and safety in and of itself, by letting the crew fix and scavenge more effectively providing potential resolutions to non-catastrophic failures. Ultimately the inclusion of a Workshop in the mission provides increased cost efficiencies and allows for greater safety and more science research per investment dollar.

The Workshop should be positioned in a relatively central position in the station. As a significant part of the Workshops capabilities revolve around rover maintenance placing the Workshop as close to as many garages as possible would be beneficial, and as time progresses the need to use the Workshop may increase, and timely and easy access could be useful.

## Schematics

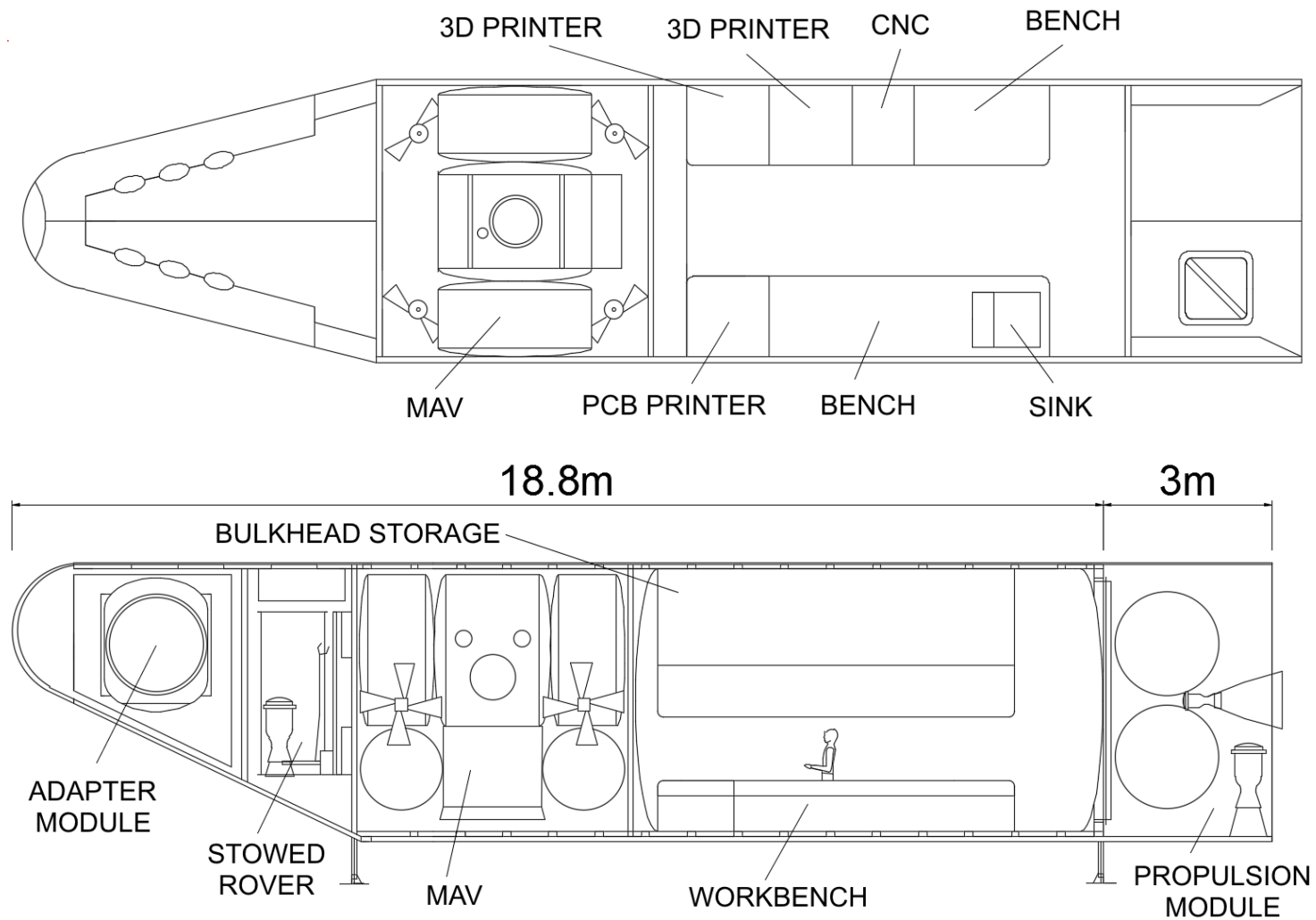


Figure 6. Schematics of top view (top) and side view (bottom) of the Workshop specialised module.

### Mass and Power Estimates

As the values for mass are high level estimations sources were used for some unusual and specific items, such as the 3D printers and CNC machine, while an ‘educated guess’ was made for the remaining general items. Exactly what is chosen to taken to Mars will be the decision of the mission engineers. Included in the mass estimate was the addition of 70kWp of solar panels to offset the power consumption of the Workshop while also to help build the power generating capacity of the station. The total mass calculated for the Workshop module is 58.2 tonnes.

To calculate the average power consumption a tool ‘on-time’ of 15% (30% of working day) has been assumed. Usage of the Workshop will depend heavily on need, and power requirements will fluctuate heavily as a result. As an indication the nominal energy consumption of the Workshop module will be around 104kWh per day.

A full breakdown of both mass and power for the Workshop module can be Table 22 and Table 23.

**Table 22. Workshop mass estimate – SCM**

Items	Mass (kg)
<b>Nose section with ISRU plant and MAV</b>	
Nose section structure, landing engine mass and aeroshell	6370
Mars Ascent Vehicle (dry mass)	3900
Reaction control system	500
Batteries – ISRU power storage and station power storage	3300
<b>Detachable Garage section</b>	
Garage structure, furnishing and aeroshell, (habitat volume 100m <sup>3</sup> )	6020
Garage power storage – Batteries	1000
Life support system	500
Bogies for moving garage and HAB	80
Adaptor module and flexible extension airlock	1980
48.5 kWp solar power generator for the Mars station	2020
Medical Equipment	1000
Entire Propulsion Module	15230
<b>Specialised Module Components</b>	
<b>Fabrication and tools</b>	
2x multi-material 3D printer,	1000
inc. 2000kg of various feedstock	2000
Small CNC machine,	400
inc. 1500kg of various feedstock	1500
Welder and rods	500
Tools – spanners/wrenches, ratchet spanner sets, torque wrench, screwdrivers, blowtorch, heat gun, vacuum, table saw, hacksaws, jigsaw, drills, angle grinder, hammers, rulers, vernier callipers, etc.	2000





Items	Mass (kg)
<b>Electronics</b>	
Electronics tools – PCB printer, soldering irons, breadboards, FPGA boards, oscilloscopes, multimeters, computer	400
Consumables – wide variety of various IC chips, resistors, capacitors, inductors, diodes, wires, proto-board, solder, cameras, microphones, motors, actuators, LEDs, plugs, connectors, etc.	400
<b>Rover maintenance</b>	
Jacks, lifts, ramps, pulleys, chains, ropes , creeper	1500
Rover spare parts - tires, fuel cells, batteries, running gear (shock absorbers, springs, steering/control arms, etc.)	2000
<b>Various</b>	
Various workshop consumables (small) - screws, lubricants, bulbs, wiring, tubing, paints, brushes, tubs, containers, glues, etc.	1000
Various workshop consumables (large) - sheet metal, sheet plastic (hard and soft), sheet rubber, etc.	2000
70 kWp of solar panels (to power Workshop activities)	1600
<b>TOTAL</b>	<b>58200</b>
<b>Total Payload Capacity</b>	<b>62000</b>
<b>Payload Capacity Remaining/Spares and Replacements</b>	<b>3800</b>

Table 23. Workshop power budget – SCM

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	
Avionics/Guidance/Reaction Control	85%	1	2	2	2	4	4.71	
Electric control systems	95%	1	0.5	0.5	6	3	3.16	
Life support system (Pressure)	80%	1	1	1	12	12	15.00	
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	
Life support system (CO2 scrubbing)	80%	1	0.3	0.3	4	1.2	1.50	
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	
Screens	80%	3	0.05	0.15	3	0.45	0.56	
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	
ISRU	90%	1	0	0	0	0	0.00	
multi material 3D printers	90%	2	1.5	3	3.6	10.8	12.00	3d printers for fabrication
CNC machine	90%	1	1.5	1.5	3.6	5.4	6.00	CNC machine for fabrication
Welder	90%	1	2.4	2.4	3.6	8.64	9.60	For metal repair
Power tools	90%	1	4.8	4.8	3.6	17.28	19.20	General power tool usage
Electronics tools	90%	1	0.2	0.2	3.6	0.72	0.80	General electronics tools
Lift	90%	1	2.2	2.2	3.6	7.92	8.80	Rover lift - to work underneath
<b>Totals</b>				<b>20.795</b>		<b>92.63</b>	<b>104.37</b>	<b>Total including efficiency/24.62</b>
							<b>4.24</b>	<b>kW avg/hour</b>

### 3.5.6 Leisure + Psychological

#### Description

The Leisure and Psychological module acts as a relaxation and restoration zone for the crew of the Mars station, intending to remove pressure due to the isolation created from their working environment, and add a social aspect to an otherwise work dominated atmosphere within the station.

This SCM is simplistic in design and purpose compared to the intricacies the other HAB and Cargo based modules exhibit. By utilizing this simple nature to make a relaxing and low pressure environment, this module seeks to restore crew members both physically and psychologically, as well as reduce pressure and professionalism of the station.

The size and variety of the module is designed to accommodate the needs of the entire crew, ensuring that any member can remain in the module for extended periods of time if required. This is especially relevant for the psychological aspect of the module, as crew members suffering from any form of psychological issue due to their residence or occupation may find it optimal to recover here.

Considering leisurely activities, small non-electronic physical belongings designed for entertainment purposes such as books or board or card games would require the least amount of implementation, and as such can be stored at request within the module. The requirements for digital systems that involve a computer would be simple to implement, allowing access to movies, games, music, and other forms of digital media.

The module will only arrive at the beginning of mission 5, towards the end of the mission sequence, and come as a fully devoted module without any mixed parts. None of the other modules will exhibit this specialization throughout the mission sequence. The module will be a customized Cargo as there will be no need for additional rovers by this point in the mission.

#### Justification

Most other specialised modules that arrive throughout the mission sequence fulfil a distinct purpose towards furthering the primary goals of the station. The Greenhouse allows for self-sustainability, the Workshop allows for stability and development, and the lab allows progress. The Leisure and Psychological module differs in that it does not support the ongoing mission objectives, but rather seeks to improve the quality at which those objectives will be achieved. The Leisure and Psychological module is in no way mandatory for the ongoing procedures at the station, but it exists to assist in its longevity. 'Fun' is an essential ingredient to the quality of life.

The International Space Station is an observable case study; the crew members on board have often used books, games, and other common entertainment devices to entertain themselves and others, even recording their activities to be viewed from earth

[44]. This doubles as entertainment and research, as it is prominent to investigate if some devices operate as intended in differing gravity environments [45].

From a broad perspective, the operation of this component of the station is a long term goal in the colonization of Mars. Being able to develop society within the atmosphere presented by the mission structure should be an objective of its own, but still be low priority compared to scientific endeavours. This specialised module along with the greenhouse do the most to further this secondary goal, and their success should only be judged further in the future of the Mars stations development.

As the Mars station structure begins to reach the tail end of the mission sequence, the Leisure & Psychological module will likely be the most effective, hence its late position in the mission sequence. It is also highly irrelevant to have it in a partitioned form at any point in the mission, as personal cabins or currently unused modules can perform the leisure function to a small degree already. Bringing in an entire module devoted to this once life at the station has become more routine would be most ideal. Breaking up a monotonous schedule and ensuring that the crew receives some sort of down time prevents any stress build up from the nature of their occupation.

Setting up the module as planned is viable under the mission restrictions, doubly so due to the module being fully devoted. Static resources for the module can easily be installed before launch. Any fragile materials can be added after landing. Additional shipments of content can be requested and sent by cargo. These requests would need to be made well in advance to the particular crew members arriving at the station, as the cargo drops only arrive when the new crew members change. For the purposes of the planned mission structure, this is only relevant for the final crew to arrive at the station, but should be observed as good practice for any future missions to the station.

Entertainment material that does not become stale easily would be the most efficient due to this; however it is mostly up to the discretion of the crew. The additional communication systems would allow an extra safety net for the existing system structure and subsequently allow signals from earth of entertainment variety to be broadcast to the module, as well as add to the relaxing atmosphere in case the crew needs to contact one another.

### Schematics

Figure 7 gives an educated example of how the Leisure & Psychological module could be set up. Note that the placement of furniture and other entertainment items can be moved around at the discretion of the crew, to keep things fresh and interesting. Alternatively, the entire second floor could be removed to create a single roomed module that utilizes the full height of the enclosure (4.78m) to create a spacey and relaxed area.

## Mars-Oz Mission Design

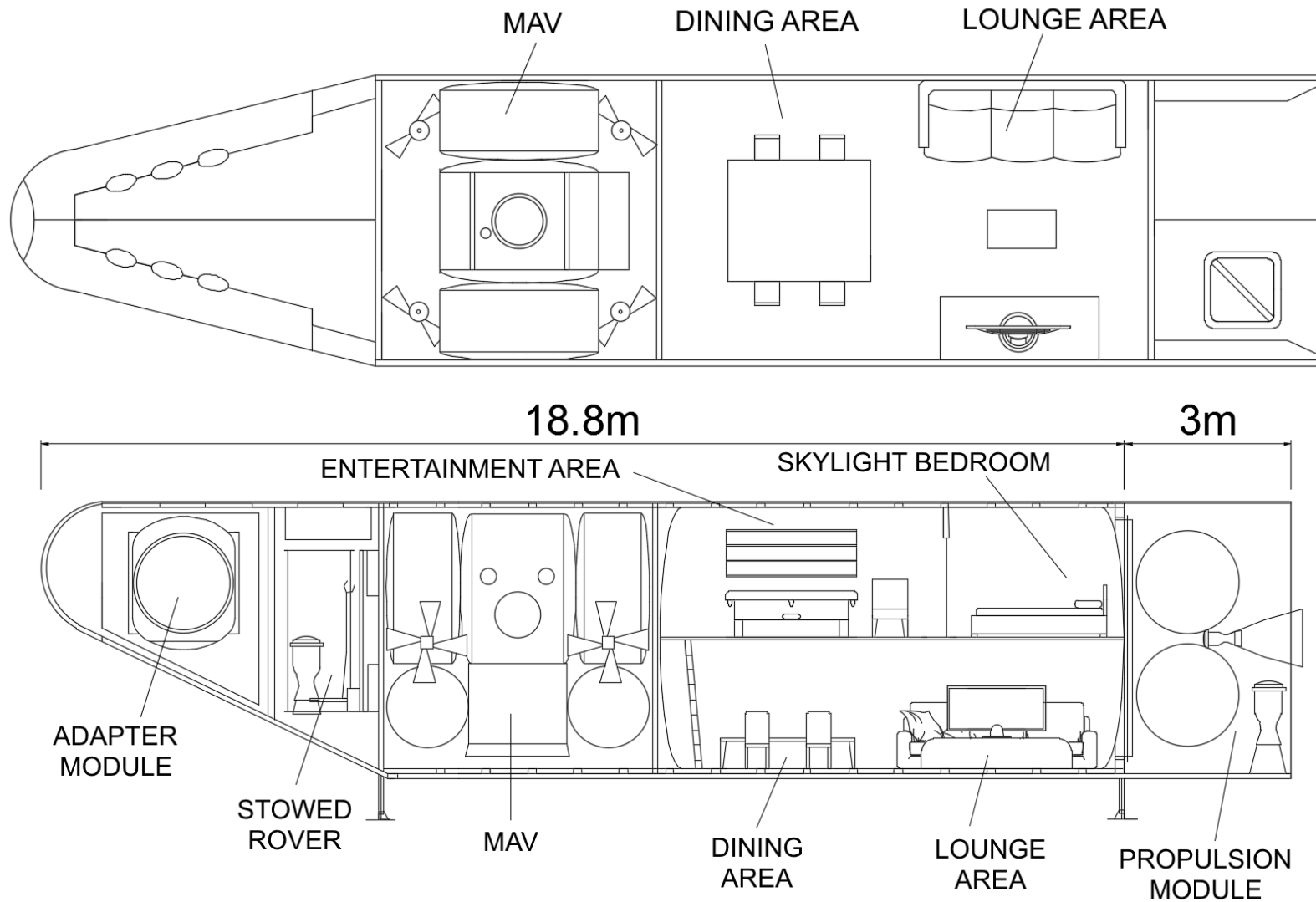


Figure 7. Schematics of top view (top) and side view (bottom) of the Leisure & Psychological specialised module.

### Mass and Power Estimates

Table 24 and Table 25 detail the components unique to the specialised module and records their respective mass and power consumption. The components listed are assumed to originate from a fully dedicated module.

Due to the nature of the module, additional components are constrained to high variability as per the crew's requests. This is listed under Variable Components on the table, and can include objects such as board games, card games, books, puzzles, stationary, video games, digital media, and other low weight objects that come with varying content. Note that this is only a guideline for what can be obtained and housed by the module; to meet the crew's suggestions is paramount.

**Table 24. Leisure & Psychological mass estimate – SCM**

Items	Mass (kg)
<b>Nose section with ISRU plant and MAV</b>	
Nose section structure, landing engine mass and aeroshell	6370
Mars Ascent Vehicle (dry mass)	3900
Reaction control system	500
Batteries – ISRU power storage and station power storage	3300
<b>Detachable Garage section</b>	
Garage structure, furnishing and aeroshell, (habitat volume 100m <sup>3</sup> )	6020
Garage power storage – Batteries	1000
Life support system	500
Bogies for moving garage and HAB	80
Adaptor module and flexible extension airlock	1980
48.5 kWp solar power generator for the Mars station	2020
Medical Equipment	1000
Entire Propulsion Module	15230
<b>Specialised Module Components</b>	
Large Tables (Dining, Conference) (Count: 2)	60
Small Tables (Coffee, Bench) (Count: 4)	60
Chairs (Count: 8)	48
Couch (3 Piece) (Count: 1)	90
Wall Units (Cabinets, Shelves) (Count: 4)	80
Beds (Count: 2)	104



Items	Mass (kg)
Pinball Machine (Count: 3)	405
Pool Table (Count: 1)	55
Table-Tennis Table (Count: 1)	30
Mini-bar (Count: 1)	12
Laptops (Count: 8)	20
Television (Count: 1)	26
Stereo (Count: 1)	8
Miscellaneous Decorative Objects (Plants, Pictures, etc.) (Variable)	N/A
Additional Crew Items (Books, belongings, board games, etc.) (Variable)	N/A
<b>TOTAL</b>	<b>42898</b>
<b>Total Payload Capacity</b>	<b>62000</b>
<b>Payload Capacity Remaining/Spares and Replacements</b>	<b>19102</b>



**Table 25. Leisure & Psychological power budget – SCM**

Component	Efficiency	#	kWp/unit	kWp	hrs/day	kWh/day	kWh/day/eff	Description
Lighting System	80%	20	0.025	0.5	8	4	5.00	
External Lighting System	80%	6	0.175	1.05	4	4.2	5.25	
Electric control systems	95%	1	0.5	0.5	6	3	3.16	
Life support system (Pressure)	80%	1	1	1	12	12	15.00	
Life support system (Oxygen)	80%	1	0.5	0.5	12	6	7.50	
Life support system (CO2 scrubbing)	80%	1	0.3	0.3	4	1.2	1.50	
Intermodule Communication Devices	85%	4	0.03	0.12	1	0.12	0.14	
Screens	80%	3	0.05	0.15	3	0.45	0.56	
Heating & Air Conditioning	70%	1	0.575	0.575	12	6.9	9.86	
Television	90%	1	0.3	0.3	8	2.4	2.67	
Stereo	90%	1	0.06	0.06	8	0.48	0.53	
Pinball Machine	90%	1	0.4	0.4	16	6.4	7.11	
Mini-bar	90%	1	0.15	0.15	12	1.8	2.00	
Laptop	90%	4	0.1	0.4	6	2.4	2.67	
<b>Totals</b>				<b>6.005</b>		<b>51.35</b>	<b>62.95</b>	<b>Total efficiency/24.62 including</b>
							<b>2.56</b>	<b>kW avg/hour</b>

### 3.5.7 Specialised HAB Module

#### Description

The SHM features a modular interior design combining three of the different modules into one, using a quarter each of the normal space allocated for the Greenhouse and Laboratory, and half of a module for the MEQ. This allows for these areas to begin work towards completing their respective goals early in the mission structure.

The Greenhouse will include the capability to begin growing plant life using a small segment of garden beds, including the required hydroponics systems to vitalise the plants. Dedicated storage of objects related to greenhouse activity such as seeds or gardening tools shall be excluded until the module is expanded. The Laboratory only has capability to do basic research on the purely scientific endeavours at this point of the sequence, and instead focuses on supporting the mission until it is expanded in later missions. It will primarily include the ability to characterise and explore the climate on Mars, and continue to do so throughout the mission, assisting the crew in survivability by giving forewarning to dust storms and other natural phenomena that occurs within the Mars atmosphere. The MEQ will include specialised exercise equipment along with a dedicated quarantine zone that will not move throughout the mission sequence.

#### Justification

The purpose for each of the segments within the SHM are covered by each of their respective sections (3.4.2 for the Greenhouse, 3.4.3 for the Laboratory, 3.4.4 for the MEQ). The primary differences discussed here are the modulatory, size, and positioning of the module during the mission structure.

By sending this module with the four specialised aspects early in the mission, the crew can have access to certain tools and begin necessary work that may take years to fully accomplish. Things such as growing plants in the Greenhouse requires a great length of time to complete, while certain capabilities of the MEQ may be needed to keep the crew healthy. Alternatively, the early arrival of these modules will give the crew involved with the mission a clear indication of the capabilities they have access to, and whether or not the modules will actually meet their requirements. For example, if the Greenhouse fails to grow plants due to unforeseen circumstances, it can be scraped early to allow an alternative solution to be found or mission abortion can commence early to minimise losses. The primary idea behind sending part of each module towards the start is to ensure time is not squandered and that all mission objectives can be achieved simultaneously. Note the only specialised modules that are not included is the Leisure & Psychological module and Workshop module for reasons outlined in section 3.4.5).

The four separate aspects of the module are designed to be modular sections; the objects contained within can be moved from one place to another within the Mars

station. During future missions, this allows the crew to slowly repurpose each SHM until they become more fully devoted to a singular role rather than being divergent. The only segment to not move within the SHM is the Quarantine sector, as it is a sealed airtight room that allows no substances to permeate through its enclosure to ensure no risk of infection should it be in use by a crew member who is contaminated. Removing this air tight room from the SHM is not possible.

### 3.6 Mission Sequence

There are 5 crewed missions, and one no crew preliminary mission, to set up the Mars station. There are two main types of modules, described briefly again below.

#### **HAB:**

This module will serve as the Crew's living quarters. In the initial two missions these HABs will be optimised to have medical and exercise equipment. As the specialised modules starts arriving from mission 3 onwards this equipment will be moved to the specialised medical and exercise modules.

#### **Garage:**

The garages will come with every module. This part will be designed to be flexible and reusable, allowing the garage to be repurposed based on the requirements of the station at any given point in time. However, the primary purpose of the garage will be to provide storage space for rovers and consumables.

#### 3.6.1 Outline and Justification

The mission sequence for the whole Mars station project consists of 5 landing missions on the Martian surface. The first mission 0 will consist of a HAB and Cargo module to land on the Martian surface. Mission zero is named such, as it is an unmanned mission which takes place prior to the first manned mission.

This design suggests the modification of Mission sequence 3, 4 and 5 by adding one Specialised Cargo Module each time. Specialised Cargo module is a combination of different parts from proposed MEQ, Laboratory, Exercise and Greenhouse modules. All the extra Cargo will travel in the same time line as originally scheduled. Missions 0 through to 2 will follow the landing sequence from the MORM, with the Cargo landing on Mars and the HAB module sent into Martian orbit before manned MTV travel. The table below outlines some of the modifications introduced to the mission sequence due to the addition of extra modules for the Mars Station.

**Table 26. Summary of what activities happens in the 5 missions.**

Timeline (Months)	Mission Sequence	Inclusion of new modules	Explanation and Operation
0	0	N/A	Cargo and HAB leave earth. Cargo lands on Mars.

Timeline (Months)	Mission Sequence	Inclusion of new modules	Explanation and Operation
26	1 (Start)	N/A	MTV links with the HAB in Mars orbit. HAB lands on Mars surface.
44	1 (End)	N/A	Rovers detach Garage from the Cargo and docks it on the HAB. Crew from 1st Mission leaves.
52	2 (Start)	N/A	2nd HAB and Cargo lands.
70	2 (End)	N/A	Both HAB's are docked to their respective garage. 2nd Crew leaves.
78	3 (Start)	Specialised Cargo Module.	The proposed addition is a specialised Cargo with a garage. The crew arrives in specialised HAB module.
96	3 (End)	N/A	3rd Crew leaves in MAV
104	4 (Start)	Specialised Cargo Module	4th crew arrives in a specialised HAB module. Specialised Cargo module arrives with additional workshop module components. Crew will attach the SHM and workshop component of the SCM to the station and transfer Medical and Exercise facilities from the 2nd SHM to the 1st SHM, and transfer Greenhouse and Laboratory facilities from the 1st SHM to the 2nd SHM.
		Workshop Module	
122	4 (End)	N/A	All HABs are docked. The first three Cargo had garages that are docked to the first three HAB's.
130	5	Specialised Cargo Module	5th crew arrives in a specialised HAB module. Specialised Cargo module arrives with an additional Leisure & Psychological module components. Crew will attach the SHM and Leisure & Psychological component of the SCM to the station and transfer facilities such that only 3 modules of singular or dual facilities exist. 5th crew will leave at end of the mission in MAV.

A quick summary of what is in the modules at a given time is shown in the table below.

**Table 27. Summary of what is in the modules during the mission's at a given time.**

MODULES	Mission 0	Mission 1	Mission 2	Mission 3 Start	Mission 3 End	Mission 4 Start	Mission 4 End	Mission 5 Start	Mission 5 End	FINAL
Mission 0 CARGO 1	Does Stuff	Garage	-	-	-	-	-	-	Garage	Garage
Mission 1 HAB 1		HAB	-	-	-	-	-	-	HAB	HAB
CARGO 2		Does Stuff	Garage	-	-	-	-	-	Garage	Garage
Mission 2 HAB 2			HAB	-	-	-	-	-	HAB	HAB
CARGO 3			Does Stuff	Garage	-	-	-	-	Garage	Garage
Mission 3 S.HAB 1				GR, LA, MQ, EX	-	-	EX, ME, MQ	EX, ME, MQ	EX, ME, MQ	EX, ME, MQ
S.CARGO 1						CARGO, W, GR, LA, ME, EX,	WO GR, LA	- GR, LA	WO GR	W GR
Mission 4 S.HAB 2								CARGO, LP GR, LA, ME, EX	LP LA	LP LA
S.CARGO 2										
Mission 5 S.HAB 3										

### 3.6.2 Detailed Mission Sequence Structure

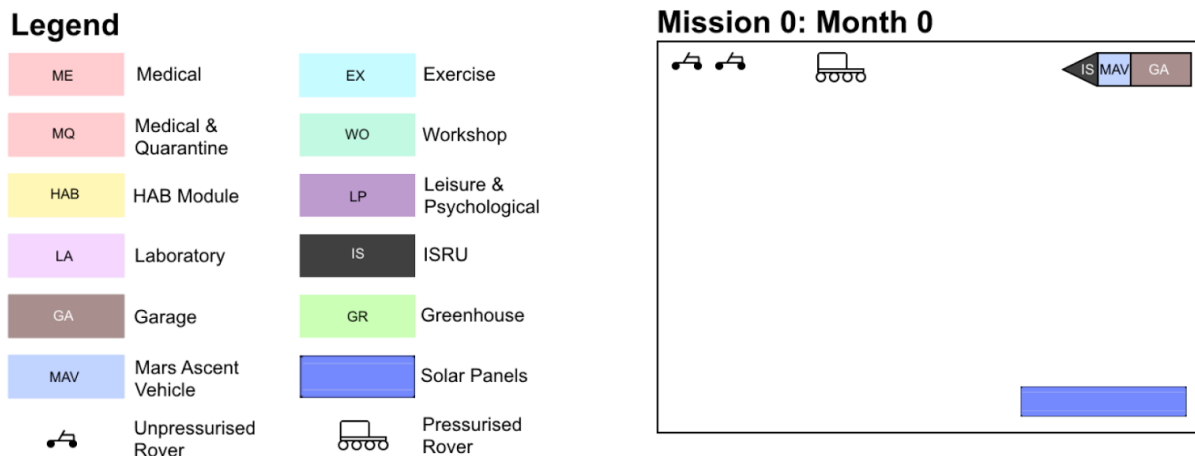
The progression of the mission sequence is illustrated below in Figure 8 to Figure 13. However, the schematics are not to scale and some special designed modules are split into four different facilities to showcase what is in there.

The modules are not illustrated to be representative of respective space occupied by the different facilities. Hence, it is just a representation of what kind of facilities each module is containing. Therefore, it doesn't necessarily mean  $\frac{1}{4}$  of the module is Greenhouse,  $\frac{1}{4}$  is Medical,  $\frac{1}{4}$  is Exercise, and  $\frac{1}{4}$  is Laboratory, but it does mean that there will be a large mass budget dedicated to that particular facility in that module.

The reason why the SHM were designed to contain 4 different facilities, is due to the requirements of the Mars mission. There are some slight priorities in terms of what facilities should be on Mars first, but also there are many benefits of having multiple facilities delivered at once.

It is expected that having Medical, Exercise, Laboratory, and Greenhouse facilities delivered at once, will allow for physical health of the astronauts to be kept, more research can be done with better lab facilities, and food and oxygen can be offset using the Greenhouse. This gives a more advantages in many disciplines over a single facility module.

It also allows a variety of different astronauts with knowledge backgrounds come to Mars in a single mission, who can collaborate collectively, as well as be the expert on board in a particular area.



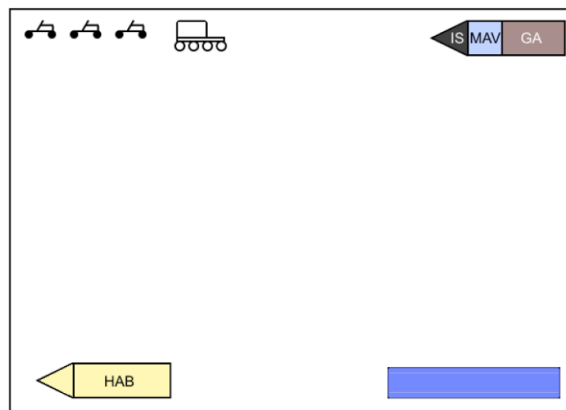
**Figure 8: Mission 0 - Preliminary mission to provide water and fuel for the first mission (no crew)**

The initial mission has no crew, but only the cargo module which includes a pressurised rover, as well as 2 unpressurised rovers. These unpressurised rovers can be controlled externally and automated to perform tasks, such as positioning the module, the PV solar generator carpet, and the ISRU plant.

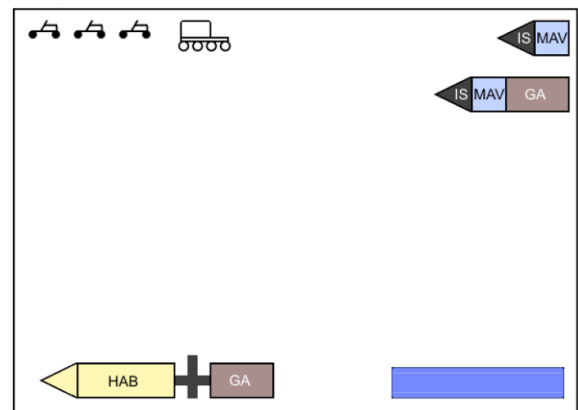
In this mission Cargo and HAB leave earth and the Cargo module lands on Mars. The Cargo module consists of an ISRU unit, MAV and Garage. The first garage will have space for a small workshop for the initial missions until the specialised workshop arrives. It will also facilitate the need of primary exercise and medical needs. A solar panel carpet will be constructed to provide power for future manned missions.

The reason there is a preliminary mission is to provide oxygen, water, and fuel for the astronauts when they touch down for the first crewed mission.

### Mission 1 Start: Month 26



### Mission 1 End: Month 44



**Figure 9: Mission 1 – First crewed mission (4 astronauts), comprising of a HAB and garage**

Mission 1 involves the arrival of the first crew. The crew will deploy and attach the garage with docking station. The HAB module used in this mission will be equipped with generic exercise and medical equipment to ensure the crew are able to maintain their health in the zero gravity environment. Hence, the exercise and medical facilities from the first garage can be moved into HAB module leaving more space for Workshop.

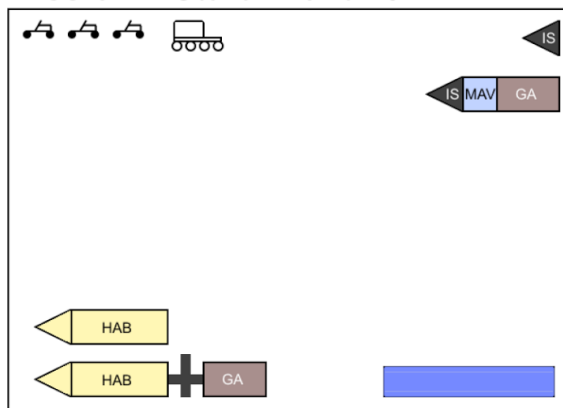
The first crew establish the first part of the station. In this part of the mission the positioning does not play a big role. However, the crew will find a suitable position to establish the station in a straight line. A straight line design is implemented because of its convenience and simplicity.

The first crew of 4 astronauts make it to the surface in the HAB module and are supported by the water, oxygen and fuel generated by the ISRU which has been working prior to the start of this mission for 26 months.

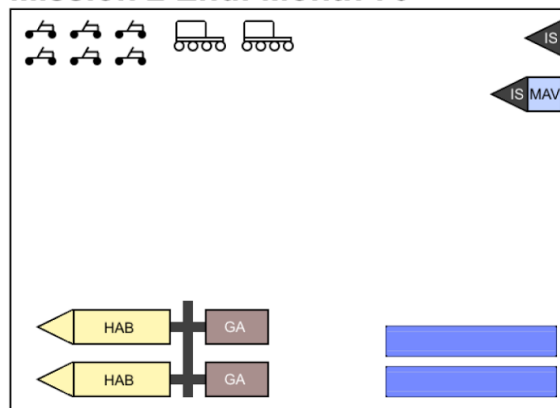
The Garage and HAB module can be connected via extendable tunnel connectors and air locked, such that the astronauts can walk between the modules without life-support gear. As of now, the HAB module holds all the appropriate medical, exercise, and laboratory equipment to start doing research on the Martian surface. However, the facilities are limited due to the lack of space. A third unpressurised rover is also delivered.

At the end of the 1st mission, another cargo module arrives which provides another garage, and ISRU plant which will, like the preliminary mission, provide water, oxygen and fuel for the 2nd mission's Mars station crew.

### Mission 2 Start: Month 52



### Mission 2 End: Month 70

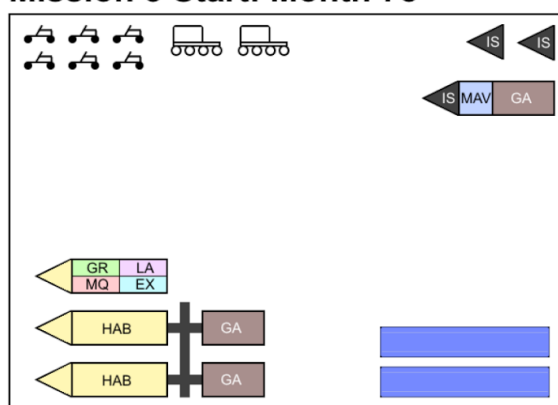


**Figure 10: Mission 2 - Comprising of a HAB and garage module, and more supporting equipment**

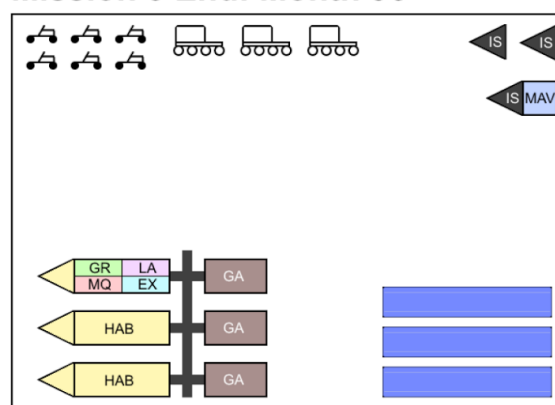
Second crew arrives in a HAB module and attaches the HAB and garage to the station beside the first HAB. The second garage with the second HAB will be used as a makeshift laboratory so that the crew can start their scientific works and bring samples back to earth with them.

The second HAB and Garage will be docked right beside the first one so that crew from both the HABs can easily access the Workshop and Laboratory facilities in the garages. The second mission sees a 2nd HAB come down, which can be connected with the other HAB and Garage. More solar PV carpet generators are laid down to power the extra modules. Another 3 unpressurised rovers (2 in the Garage, and 1 in the HAB) and 1 pressurised rover are also delivered.

### Mission 3 Start: Month 78



### Mission 3 End: Month 96



**Figure 11: Mission 3 - Comprising of the first SHM and another garage module**

Mission 3 introduces the first specialised module. The module is designed and optimised to have Greenhouse, Laboratory, Medical and Exercise equipment. Greenhouse, Health and Quarantine modules will consume most of the space of this



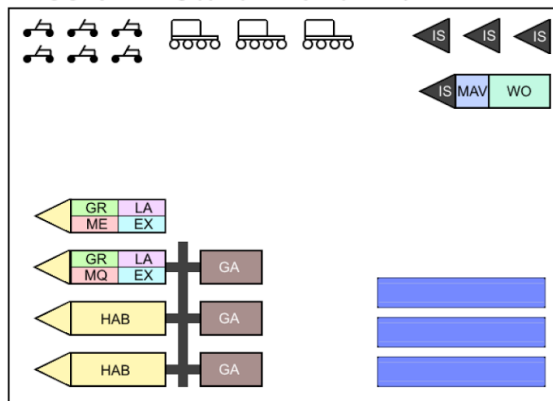
specialised module as the garages and HABs will be already catering the need for Workshop, exercise and Laboratory. The garage will be used as additional storage for rovers and others necessary commodities.

The SHM will be placed such that Medical and Exercise modules are closest to the HAB module. Crew will do this to ensure they are as close as possible to all medical and emergency facilities. This will also enable the crew to access the medical facilities in any kind of emergency situation easily.

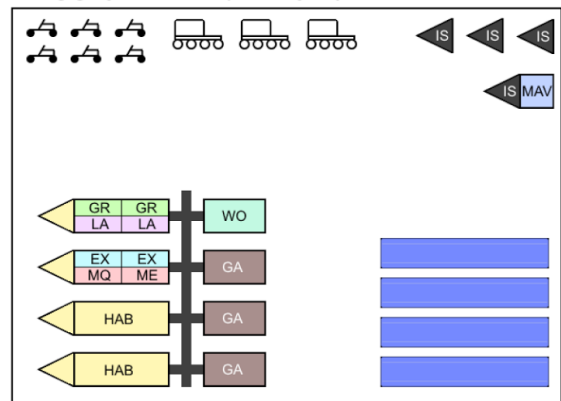
Mission 3 shows the start of the specialised module deliveries. This one contains Greenhouse, Laboratory, medical quarantine, and exercise facilities, which will extend the capabilities of the two HABs, as well as starting to offset food and oxygen dependence on the Cargo modules and ISRU plants through the Greenhouse.

Again, more PV carpets are laid out to accommodate the increase on power load.

#### Mission 4 Start: Month 104



#### Mission 4 End: Month 122



**Figure 12: Mission 4 – Comprising of the second SHM, and the first SCM**

A SHM similar to the one described in the previous mission will arrive at the beginning of the 4th mission. This module will have Greenhouse, Medical and Quarantine, Exercise and Laboratory supplies. The garage will be exclusively used for Workshop activities. Hence, the crew will bring all the Workshop equipment from other garages and assemble it together in the 4th garage. The crew will also transfer Medical and exercise facilities from the 2nd SHM to the 1st SHM and transfer Greenhouse and Laboratory facilities from the 1st SHM to 2nd SHM.

The crew will ensure that the Medical and Exercise module will be as close as possible to the HABs. Consequently, Laboratory and Greenhouse will share the furthest SHM from the living quarters. Workshop and Laboratory can be a source of noise, this another reason to keep these modules away from the HABs. Lastly the Workshop component from the SCM will be docked with the furthest SHM from the HABs.

This SHM comprises of more Greenhouse, Laboratory, medical, and exercise equipment which further extends the facilities of the Mars station. By the end of the 4th mission, the equipment can be moved such that all similar facilities are collated

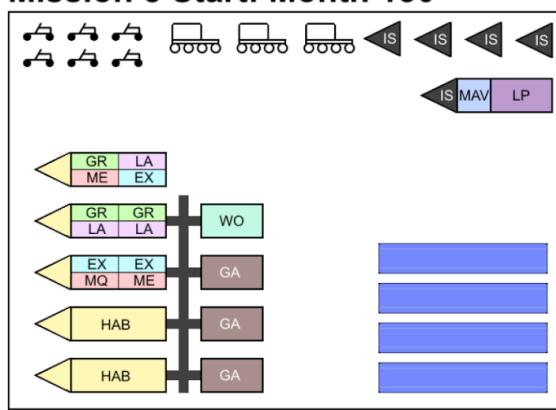


in the one module, such as the Greenhouse and lab equipment all in the one module, rather than split across 2.

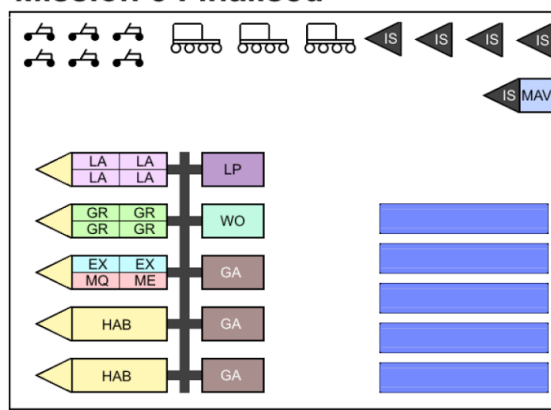
The medical quarantine area is a static item however, as the room is designed in a specific way such that if someone is very sick and contagious, they can be kept in this room with all the facilities required to rest comfortably. The air system and waste disposal of this medical quarantine area will be separated from the main station supply to stop and avoid contamination of clean air space.

The Workshop comes in a SCM such that if there are problems with rovers or components in the Mars station, they can be fixed with better tools than what are stored in the HAB modules.

### Mission 5 Start: Month 130



### Mission 5 Finalised



**Figure 13: Mission 5 – Comprising of the third and final SHM and the second and final SCM**

The 5th crew will arrive in a SHM like the previous missions. Crew will attach the SHM as well as the leisure and psychological components of the SCM to the station. Crew will transfer the facilities and will come up with a combination 3 modules with 1 or 2 facilities. The proposed combination is one module for Laboratory components exclusively and a separate module to contain Greenhouse facilities. The other module will be shared by Medical and Exercise equipment. This will enable the crew to free up space from the initial garages, which can then be dedicated for storage.

The crew will attach Leisure and Psychological module with the Laboratory modules. Crew will be working intensely in the labs and the leisure module will provide entertainment for the crew. Both these modules complement each other and ensure better performance of the crew.

The final SHM consists of the 3rd round of Greenhouse, Laboratory, medical, and exercise facilities. By the end of the 5th mission, having a whole module dedicated to a Laboratory, Greenhouse, and one with medical, exercise and quarantine (all health related) will ensure that all appropriate equipment can be found in that one module.

The Leisure and Psychological module comes in a SCM and is seen as a relaxation zone outside of the HAB modules for the astronauts. This was decided to come last

as it does not further the requirements of the Mars mission, but rather just adds comfort to the astronauts during their time on the Martian surface.

This does come with risks, such that if one module caught on fire, or exploded in a catastrophic event, all facilities in that module would be lost. However, the HAB modules will still have facilities which will ensure human life can be supported on Mars in case this does happen, and hopefully through the use of the Workshop, the module can be repaired with spare parts and scraps from Cargo modules, ISRU plants, propulsion modules, and MAV storage spaces.

### 3.6.3 Final Mars Station Structure

The team followed a systems approach while designing the final Mars station structure. This helps explore possible problems and identify opportunities to make crew experience in the Mars station better. Consequently, issues like accessibility, noise reduction, enhanced pastoral care, efficient working environment etc. were considered in the design process. This section will analyse and justify module arrangement decisions based on the affairs mentioned above.

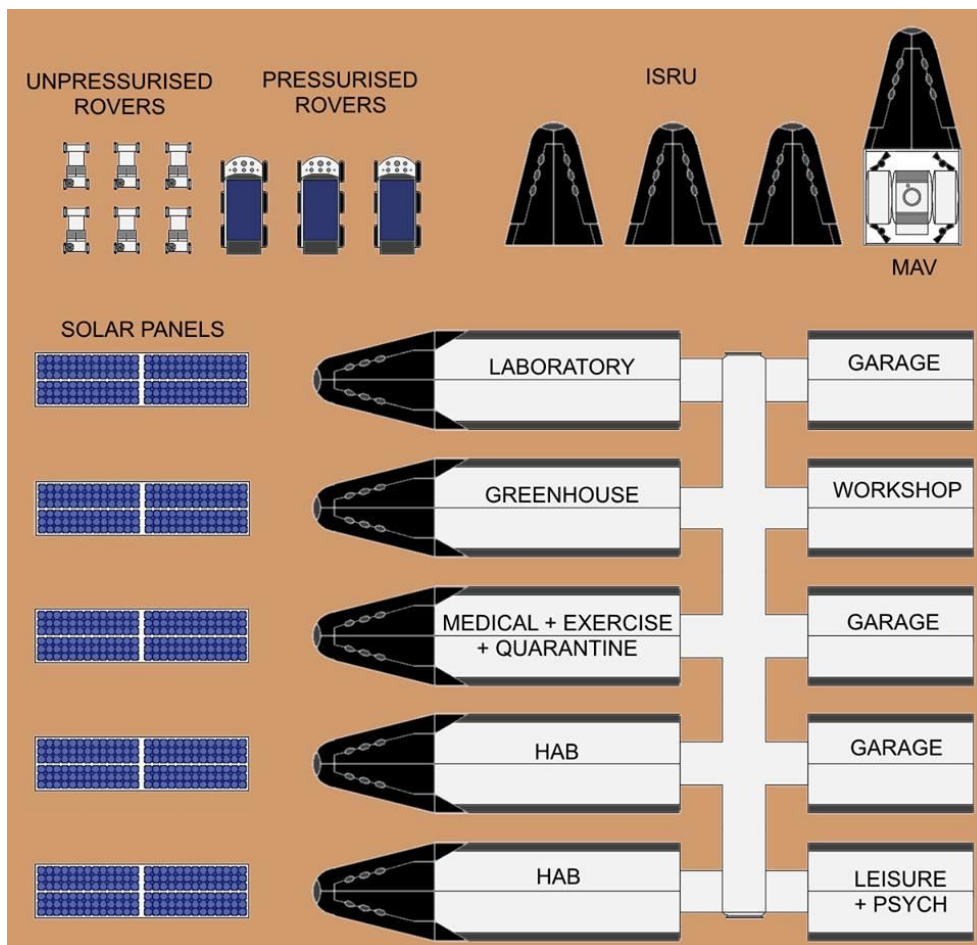


Figure 14: Final Mars Station Structure after the 5th Mission

In the end, the leisure and psychological module and one of the garages will be

moved around if possible. This ensures that both the 'HAB's and 'Leisure & Psychological' modules will be close to each other for easy movement throughout the Mars Station. This will ensure close proximity between the crew members as well as enhanced emotional health.

The MEQ module is right beside the HAB, thus ensuring more accessibility to the healthcare facilities in case of any emergency. The team realised the importance of ensuring no noise in the MEQ module. According to World Health Organisation standards the background noise level of a medicare zone should be within 35 dB in the patient rooms [46]. Hence, the working zones such as Laboratory and Workshop will be kept as far as possible from the MEQ, HAB and Leisure & Psychological modules for inhabitant comfort.

The optimisation criteria of a Greenhouse design is based on rock bed, wet soil, phase change materials, solar radiation, thermal performance, crop yields etc. [47]. The crew will be gathering these as samples and perform experiments to improve and optimise the Greenhouse. Hence, Greenhouse and Laboratory modules will be installed close to each other to carry out these experiments competently.

The Workshop and garages will be used frequently while doing maintenance work, especially on rovers. Accordingly, moving the garage with the Leisure & Psychological module ensures that the Workshop is in between two garages will ensure efficient and optimised working environment. The Workshop will also be in close proximity to research intensive modules such as the Laboratory and Greenhouse.

Lastly, the team decided to go with straight-line connections for the station because it would make it more accessible compared to other alternatives such as X shape or T shapes. It also allows for everything to be in closer proximity, as well as allows for coverage of certain modules with land to protect it from the radiation on the Martian surface. The ends can also be used as airlocks for items such as further modules or pressurised rovers.

#### **3.6.4 Final Mars Station Power Considerations**

As the station grows over the 5 mission sequence it is important to consider, as the station builds capacity and performs new and different tasks, whether the building of power generation and storage capacity is keeping pace.

The below graph, although based on full modules arriving at each mission, is indicative of how the generation capacity grows while the consumption also grows (note that the x-axis is mission number).

Furthermore the consideration of whether the amount of batteries brought to Mars will be enough to satisfy the station requirement of being able to run at full capacity for four days without power generation (in the case of total blackout of the sun by dust storm or technical fault).

The graph shows that as the station increases in size and capacity the generation rate of power keeps pace with the consumption of the station. Furthermore, the 4 days without generation requirement is constantly fulfilled.

It is important to note that all estimates for this analysis are conservative and power consumption is flexible in both the long and short term. Further analysis could be completed to more accurately represent the growth of the station but due to the changing nature of the way power is consumed and generated, even on a day to day basis, this may not provide further value.

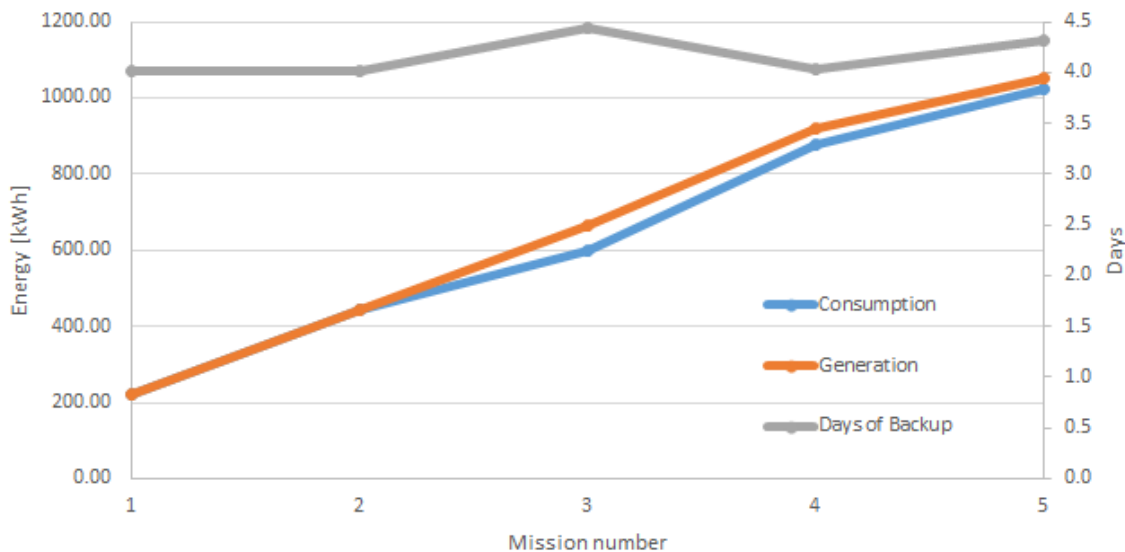


Figure 15: Mars OZ Station power generation and consumption vs. growth of station.

## 4 System Partitioning and Interfaces

### 4.1 Partitioning

The systems boundary chart lists considerations which are internal – can be directly controlled by the crew members, external – somewhat controllable but are affected by various parameters which are outside of the crew's control, and outside – which are considerations which cannot be controlled at all by the crew.

Table 28. System Boundary Chart for the completed Mars Base Station and activities.

Internal	External	Outside
Structural/base layout	Power generation	Sunlight received
Insulation of base	Oxygen generation	Dust storms
Water movement	Water supply	Weather
Electronic controls	Module maintenance	Temperature
Rearrangement of module internals	Rover maintenance	Radiation
Number of Occupants	Type of land/area the station is	Terrain/ground

Internal	External	Outside
	on	
Water usage	Crew capabilities	Availability of local resources
Power usage	Crew knowledge	Abrasiveness of environment
Fuel usage	Component lifetimes	Length of Mars occupancy
Communications	Modularity of base components	
Cleanliness of base	Dust coming into the base	
Movement flow throughout base	Peak power generation installed	
Crew social system	Maintenance	
	Storage	
	Cargo module supplies	
	Research of Mars	
	Exploration of Mars	
	Crew member illness/injury	
	Crew member psychological health	
	Crew member	
	Available materials/tools to use	
	Crew motivation	
	Mission objectives	
	ISRU Capabilities	

As it can be seen, there are a lot of considerations which fall within the external category. This suggests that many of the considerations can be controlled, but are dependent on various other considerations which may be in the internal or outside system. This leaves a lot up to chance, resulting in many requirements that have to be fulfilled before a task can be completed. For example, the weather has to be good before exploration of Mars can be done. However, some of the more controllable considerations such as crew member illness and health can be accounted for and make up the logical reasoning to include various facilities in the base, such as the leisure and psychological module for mental health and relaxation of the crew, and medical facilities in case of injury or illness.

These system boundary considerations are used to help develop the system partitioning into various systems and sub-systems which are shown in Table 29.

**Table 29. Mars station partitioning into systems and respective sub-systems.**

Systems	Sub Systems	Description
Rovers	Power and Life Support	Electrical power, oxygen (pressurized rover)
	Control	Driving systems

Systems	Sub Systems	Description
	Maintenance	Modularity of components, ability to repair
	Communication	Between all astronauts, station, MTV and Earth, CCTV
Power	Generation (solar cells)	Solar cell carpet
	Supply (cabling etc.)	Transferring electricity from array to station
	Maintenance	Cleaning and repair of modules, cabling
MTV	Fuel	Rocket fuel for propulsion between Earth and Mars
	Communications	Between all astronauts, station, MTV and Earth, CCTV
	Power and Life Support	Electrical power, oxygen and atmospheric controls
	Storage	For small cargo, astronaut's personal belongings
MAV	Fuel	Rocket fuel for propulsion to MTV
	Power	Electrical power
	Communications	Between all astronauts, station, MTV and Earth, CCTV
Consumables	Storage	Space for other cargo as required, or for other sub systems
	Food	Dried and fresh, storage and preparation
	Spare parts	For rovers, modules, astronaut suits
	Cargo	Other general cargo
Habitation	Power and Life Support	Electrical power, oxygen and atmospheric control
	Communication	Between all astronauts, station, MTV and Earth, CCTV
	Crew Quarters	Sleeping, private space and storage, hygiene facilities
Garage	Storage	For rover, spare parts and equipment
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Communications	Between all astronauts, station, MTV and Earth, CCTV
	Rover Repair	Facility to perform small to medium scale repair on rovers
Laboratory	Communications	Between all astronauts, station, MTV and Earth, CCTV
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Containment	Controlled sealed environments for research or emergency containment
	Research	Equipment and apparatus to perform required scientific research
	Storage	For equipment and samples
Workshop	Repair	Ability to repair components of modules, rovers or any other part of the station
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Communication	Between all astronauts, station, MTV and Earth, CCTV
	Storage	For spare parts, fabrication equipment, PPE
	Fabrication	Using basalt or other materials to produce necessary parts for repairs, or to create add-ons for modules or rovers for additional capabilities.
Greenhouse	Communications	Between all astronauts, station, MTV and Earth, CCTV



Systems	Sub Systems	Description
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Plant Growth	Facilities for growth of plant life and harvesting.
	Plant Maintenance	Care and harvesting of grown plant life
Leisure	Psychological	Assessment and care of astronaut's psychological well-being.
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Communications	Between all astronauts, station, MTV and Earth, CCTV
	Recreation	Tailored facilities for astronaut enjoyment
Health	Quarantine	Separation of crew member or station components/sample for quarantine and study
	Exercise	Equipment necessary for crew to maintain peak fitness and health
	Power and Life Support	Electrical power, oxygen and atmospheric control
	Communication	Between all astronauts, station, MTV and Earth, CCTV
	Crew Health	Diagnostic and rehabilitation
	Storage	Records, equipment etc.
Outside	Terrain	The type of terrain the Mars station is built on. May affect the layout of the station.
	Weather	Hinders or enables the crew from going out of the base.
	Sunlight/Radiation	May allow growth in greenhouse, or cause dangerous radiation resulting in the base to be buried.
	Local resources	Affects the generation of water, oxygen, and fuel, as well as research objectives.
Crew	Health/Motivation	Affects how the crew members work and act.
	Social	Affects how crew members interact with each other
	Communication	They will be the ones communication to each other, to other modules, and to the machines.
ISRU	Propellant Production	Production of propellant for various sources such as the MAV.
	Oxygen production	Production of oxygen for crew to breathe
	Water production	Production of water for crew to drink

From Table 29 it can be seen that there are a variety of different systems within the larger Mars base station system, each with their own respective sub-systems which could also be broken up further to explain the tasks which will be complete in each sub-system.

## 4.2 Mars Station Interfaces

There are a variety of interfaces between the different partitioned sub-systems. The table below shows the major interfaces between the sub-systems, with other more general interfaces described after Table 30.

**Table 30. Types of interfaces between two different sub-systems.**

Subsystem	Interface type	Passing through interface	Subsystems it Interfaces with
Rovers	Physically	Through use and maintenance of rovers	Crew, garage workshop, outside,
	Physically	Through use outside	Outside
Power	Electronically	Through providing power	All Subsystems
	Externally	Through power generation from PV systems	Outside (sun)
MTV	Physically	Through displacement of Crew	Crew
MAV	Physically	Through displacement of Crew	Crew
Consumables	Physically	Through providing consumables	Crew
Habitation	Physically	Through providing areas to live, work, and rest	Crew
Garage	Physically	Through storage of tools and rovers	Rovers, Crew
Laboratory	Physically	Through testing various items	Crew, outside, Greenhouse, ISRU
Workshop	Physically	Through maintenance of parts	All module externals, rovers
Greenhouse	Emotionally	Through the growth of plants	Crew
	Technically	Through research on life on Mars	Crew, laboratory
	Physically	Through the products of the Greenhouse (such as food)	Crew, laboratory, consumables
Leisure	Physically, emotionally	Through providing a quiet space to relax and reflect	Crew
Health	Physically	Through providing medication, health, and exercise	Crew
Outside	Physically	Through doors, airlocks, windows	All modules, and the Mars space station
	Physically	Through surface conditions, local resources, sun resources	Mars station, MTV, ISRU, MAV, rovers, power, Greenhouse
	Emotionally	Through isolation of Mars Base	Crew
Crew	Physically	Through physical interaction/working	All subsystems
	Emotionally	Through emotional and social interaction	Crew, outside
ISRU	Physically	Through resource gathering and processing.	Outside



Subsystem	Interface type	Passing through interface	Subsystems it Interfaces with
	Physically	Through the products of the ISRU (water, oxygen, propellant)	Crew, MAV, MTV, consumables

For clarity reasons many of the major interfaces which interface with a variety of sub-systems were only outlined once, such as power interfacing with all subsystems, rather than writing the power sub-system in every other sub-system.

Other general interface types are listed below which were excluded from the table as they are much more general.

- Physical interfaces between the outside environment and the entirety of the Mars base station.
- Physical interface between dust from the outside environment and possible internals within the Mars base station.
- Physical interface between crew inside the Mars base station and the outside environment through the use of doors, airlocks, pressurised and unpressurised rovers.
- Electric interfaces between power and every sub-system by supplying power for electricity.
- Physical interface between the Workshop and every external and internal of the modules which require it to function properly, especially for maintenance issues. This is completed by interfacing with the crew as well.
- Communication interfaces between the crew and other crew, other modules, other subsystems such as the ISRU for status reports and interactions. This is completed through a variety of different physical interfaces such as radios, visual devices, touch devices, and electronic devices both wirelessly and wired.
- Physical interface between crew and controllable sub-systems such as the MTV, MAV, and rovers is done through electronics responding to crew movements and commands.

This partitioning and interface analysis makes the basis for the system interface/flow block diagram of the Mars base station which is in Figure 16. The colour of the arrows do not represent anything but rather are there to assist in distinguishing which arrow connects with what subsystem.

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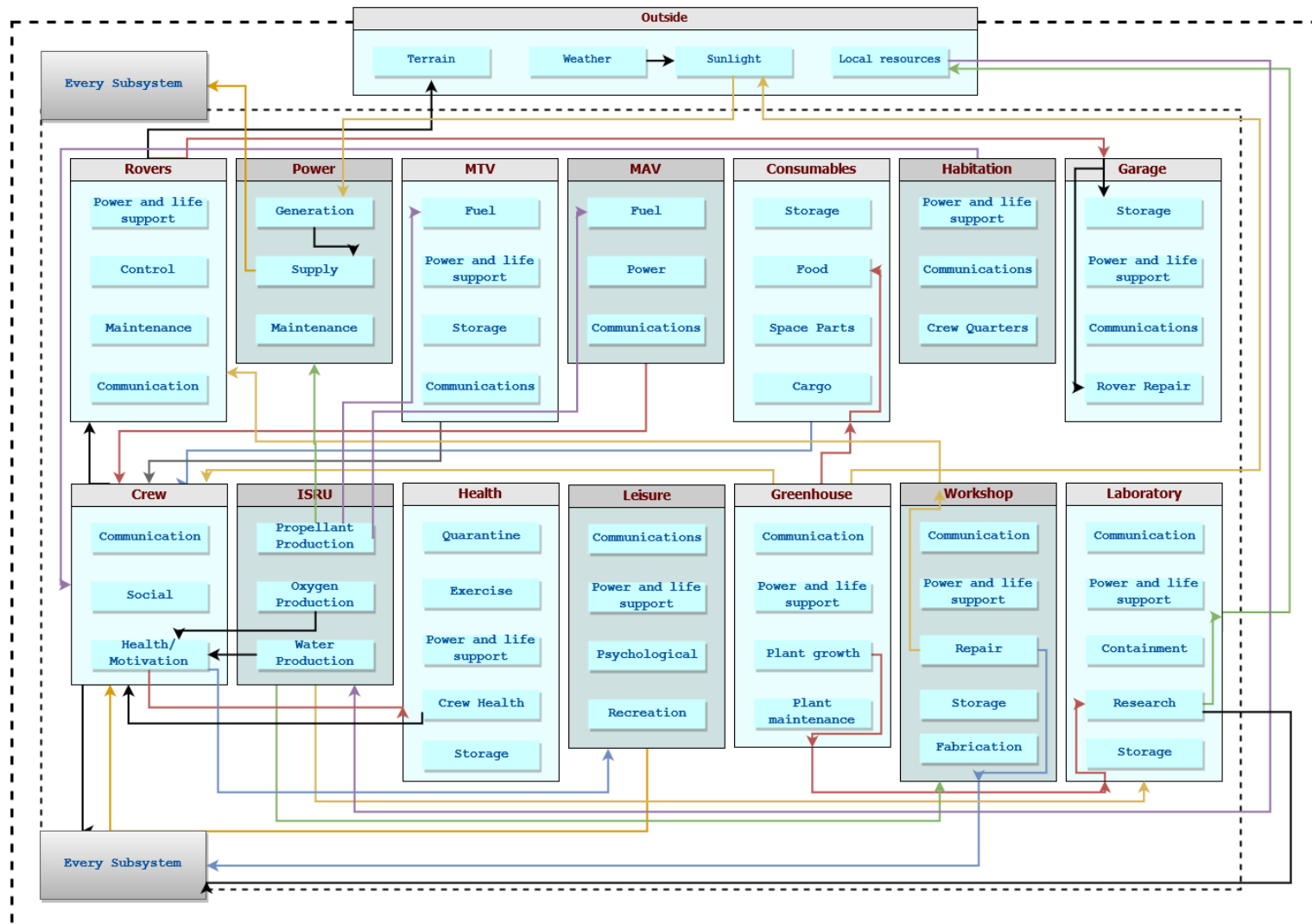


Figure 16: A functional block diagram showing the Mars station interfaces.

## 5 Risks and Concerns

### 5.1 Design Risks

Although safety of the crew is paramount for the mission and this is taken into consideration at all stages of consideration, it is still a possibility that a crew member could get sick, become injured or even pass away during the mission. The risk of this is mitigated through the inclusion and effective design of medical facilities on the SHM that is proposed in this design.

There are numerous risks inherent to the Martian environment. The temperature on Mars is considerably colder than on Earth. Based off the “Mars Exploration Rover Landing Press Kit” it is known that the temperature of the Meridiani Planum ranges from  $-100^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  [6]. The temperature for the rest of Mars depends on the time of day and the season, varying from  $-140^{\circ}\text{C}$  to  $30^{\circ}\text{C}$  [7].

The atmospheric pressure on Mars is very low, being only 1/100th of the average atmospheric pressure on Earth. Mars has high winds with speeds up to 40 m/s [7]. There is a large amount of dust in the Martian atmosphere at all times; this dust has an average diameter of 3.4 microns. The combination of the winds and the dust result in frequent dust storms on both the global and the local scale, known as dust devils. [48]

The average daily radiation on Mars is 0.67 mSv. This is fairly high considering that the radiation generated from having an x-ray is 0.02 mSv. NASA states that exposure to doses of 1000 mSv can increase the risk of fatal cancer by 5%. [49]

There are numerous activities in the HAB and Cargo Vehicles areas which could result in a fire damaging or destroying areas of the station. Additionally, unforeseen circumstances could also cause the loss of one of these areas and their resources. As a contingency to this possibility, the mission sequence and vehicles have been designed in a way such that vital functions (storage, habitation, etc.) can be transferred to another module.

### 5.2 Internal Risks

A table which details and outlines the internal risks of the system is seen in Table 31.

**Table 31. Risks involving the proposed design.**

Risk Identification	Cause	Impact	Level of Risk	Mitigation Strategy
Insufficient solar power generation	Solar generation efficiency on Mars lower than expectation Dust storm (short term) Higher power requirement	Insufficient solar power generation depending on severity could have serious impact on the research productivity and safety of the crews	HIGH	Safety margin for power generation Backup Generator Plan according to weather forecast High capacity power storage
Malfunction/loss of module	Possible mechanical/chemical damage from martial soil and dust Fire Gale Seismic event Human factor – insufficient training, overly complicated design, mistakes Other unexpected events	Possible loss of essential equipment and scientific data Reduced productivity Risk on the safety of the crews	HIGH	Equipments for maintenance and repair (Workshop Compartment) Spares Redundancy in modules Developing protective systems for likely events such as fire, gale and seismic events
Delay in arrival of modules	Unexpected events	Insufficient consumables Reduced productivity	MODERATE	Safety Margin for consumables Greenhouse compartment can be good extra source of consumables Modules with combined compartments enable the crews to access essential equipments for mission at early stage, which greatly reduce the impact of possible delay in module arrival
Crew Injury/Illness/Death	Injury during mission Reduced immune function Long term exposure to cosmic rays	Reduced productivity Earth return depending on severity	HIGH	Medical equipments and exercise equipments to maintain healthy lifestyle Ensuring shielding from cosmic rays Detailed medical examination of the crews before boarding mission

## 6 Further Considerations

Essentially, the project from its germination up to its closure has projected significant progress whilst corresponding to the needs, necessities and requirements of the client. The documents and results both generated and verified provide a concrete platform and basis going forward though establishing a broad spectrum of further considerations that need to be meticulously and diligently explored. This will consequently fine tune and enhance the feasibility and sustainability of the project.

In terms of further considerations of this project, the following key areas provide possibilities for potential analysis and devoted research, these include:

- general verification and corroboration
- environmental considerations
- long term station considerations

The first stage in continuing this project would be the analysis and verification of the design considerations and assumptions that this document has delivered, as well as the numerical verification of the numbers computed and displayed. This noting that the aerospace and space exploration field experiences extensive development, values and postulates may vary based on technological advancements or mission specific devices.

Following this up, there are several environmental aspects of the Mars Station that should have dedicated research and planned contingencies. These areas include a general consideration of the impacts to the Martian environment from the presence of the station and its' inhabitants, the potential utilization of old Mars mission inventories, the formulation and implementation of a long-term plan for a sustainable future for the planet, and designing contingencies to counteract the possible presence of microbes from the Martian environment which may be particularly harmful to human health. Additionally, any potential biological impacts of the station and inhabitants will need to be considered adequately.

Finally, extensive effort has to be also dedicated to establish mechanisms to extend the longevity and future of the Mars Station. This may include though is not confined to, establishing a feasible framework of supplementary supply missions, base infrastructure expansion and population growth plans or implementations. The corresponding research and analysis pertaining to all of the aforementioned will ensure the production of the highest quality recommendations that will be made on behalf of the MSA.

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## 8 Appendices

### 8.1 PV Calculations

#### Appendix 1. ISRU Power Verification

Power for reactions (kW)	Operational time required (hrs)	Energy
8.3	610	5063 kWh
9.1	4440	40404 kWh
8.9	370	3293 kWh
	<b>total</b>	<b>48760 kWh</b>
	ISRU mission length	580 days
	energy per day	84.07 kWh
	peak solar hours (earth equiv.) on mars	1.80 kWh/kW
	PV capacity needed @ ~STC (earth equivalent)	46.70 kW
	panels required (from ISS)	1946.04 kg
	panels required (thin film)	65.39 kg

#### Appendix 2. HAB and Cargo PV Verification

Operation	Energy
HAB energy requirement	151.4 kWh
Cargo energy requirement	69.02 kWh
<b>total</b>	<b>220.42 kWh</b>
energy per day	220.42 kWh
peak solar hours (earth equiv.) on mars	1.80 kWh/kW
PV capacity needed @ ~STC (earth equivalent)	122.46 kW
panels required (from ISS)	5102.31 kg
panels required (thin film)	171.44 kg
PV for ISRU	50.0 kWp
PV for HAB+Cargo	72.5 kWp
PV for HAB	24.2 kWp
PV for Cargo	48.3 kWp

#### Appendix 3. Updated PV Parameters

ISS Equivalent PV	Value	Thin Film PV	Value
per 1 m <sup>2</sup>		per 1 m <sup>2</sup>	
efficiency	0.2	efficiency	0.15
Mars irradiance	300 W/m <sup>2</sup>	Mars irradiance	300 W/m <sup>2</sup>

ISS Equivalent PV	Value	Thin Film PV	Value
panel (power/area)	60 W/m <sup>2</sup>	panel (power/area)	45 W/m <sup>2</sup>
panel (mass/area)	2.5 kg/m <sup>2</sup>	panel (mass/area)	0.063 kg/m <sup>2</sup>
Specific power	24 W/kg	Specific power	714.2 W/kg
Specific power	0.024 kW/kg	Specific power	0.714 kW/kg

#### Appendix 4. New HAB and Cargo PV Masses (ISS Equivalent Panels)

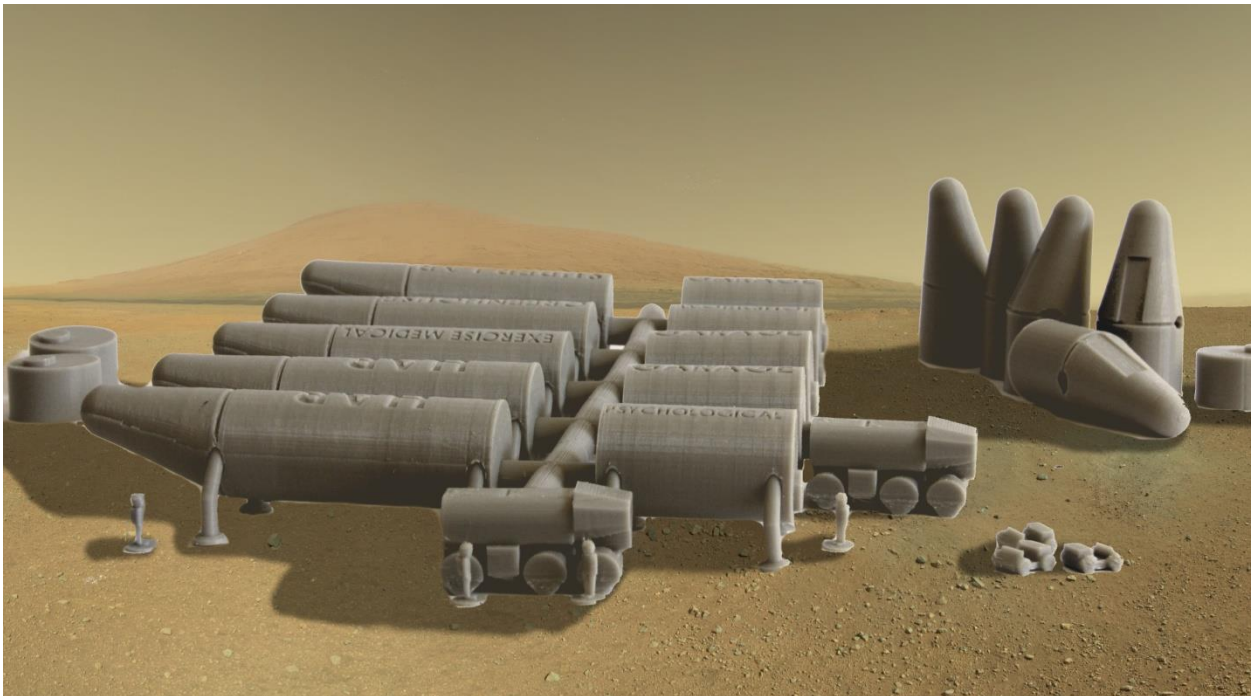
	Initial allowance (kW)	Initial allowance (kg)	New Mass (kg)	New power rating (kWp)	Mass Change (kg)
HAB	15	1500	1006	24.2	-494
Cargo	30	3000	2013	48.3	-987
ISRU (in Cargo)	25	2200	2083	50.0	-117
<b>totals</b>	<b>60</b>	<b>6700</b>	<b>5102</b>	<b>122.5</b>	<b>-1598</b>

#### Appendix 5. New HAB and Cargo PV Masses (thin film panels)

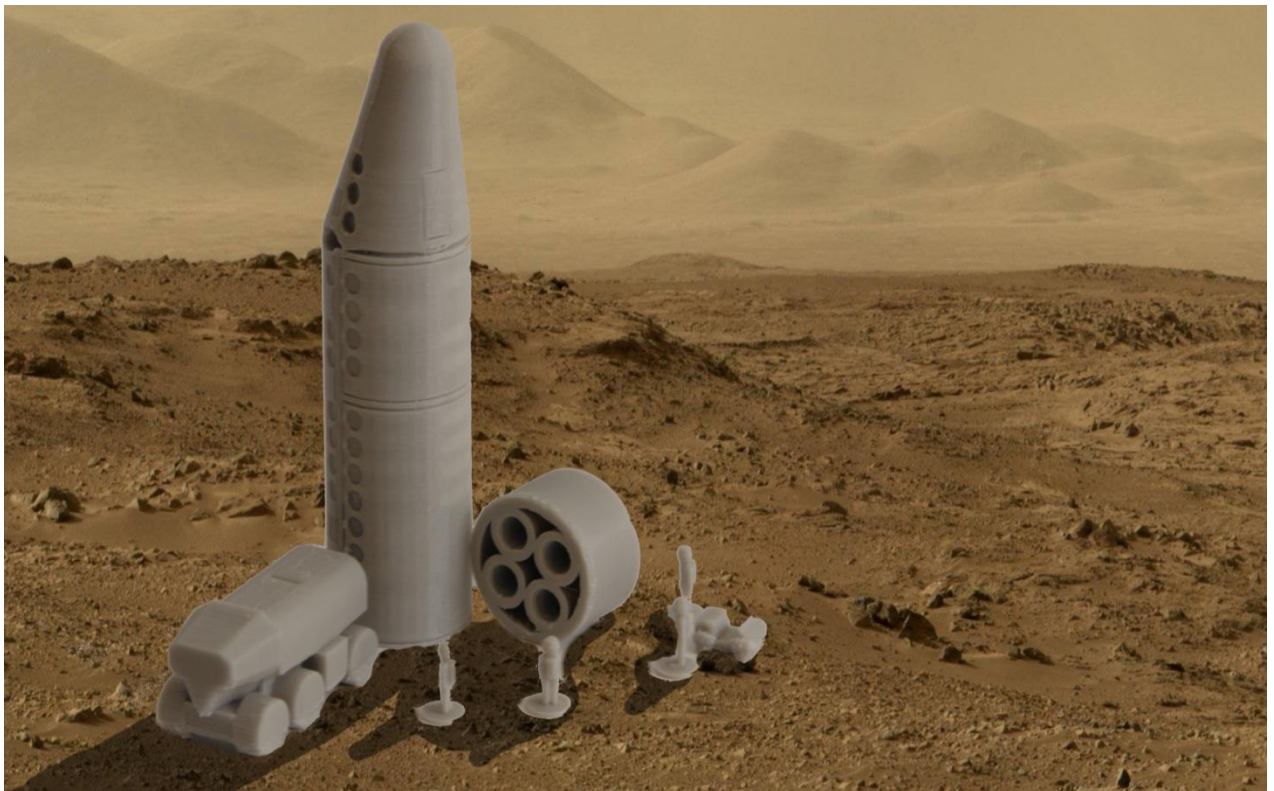
	Initial allowance (kW)	Initial allowance (kg)	New Mass (kg)	New power rating (kWp)	Mass Change (kg)
HAB	15	1500	34	24.2	-1466
Cargo	30	3000	68	48.3	-2932
ISRU (in Cargo)	25	2200	70	50.0	-2130
<b>totals</b>	<b>60</b>	<b>6700</b>	<b>171</b>	<b>122.5</b>	<b>-6529</b>



## 8.2 Artist Impression of Mars Station

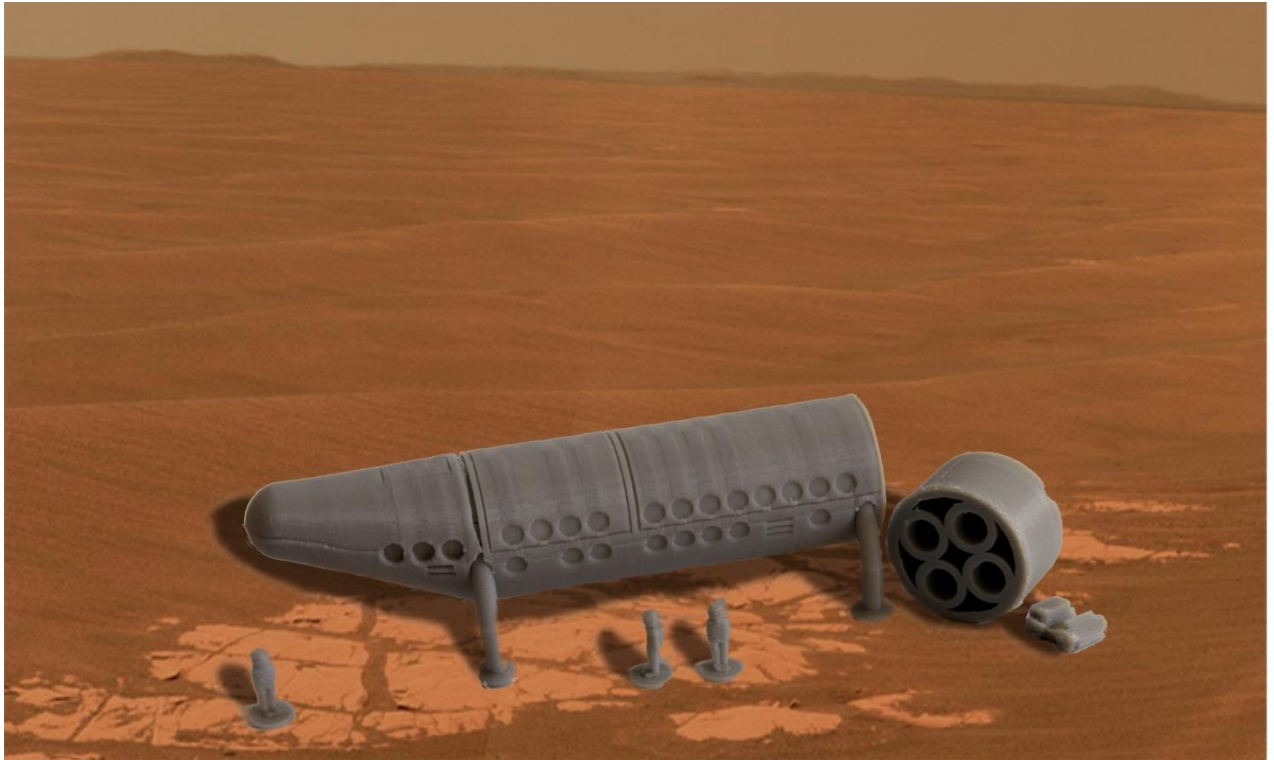


Appendix 6. Artist Impression 1 of the entire Mars Station with most components

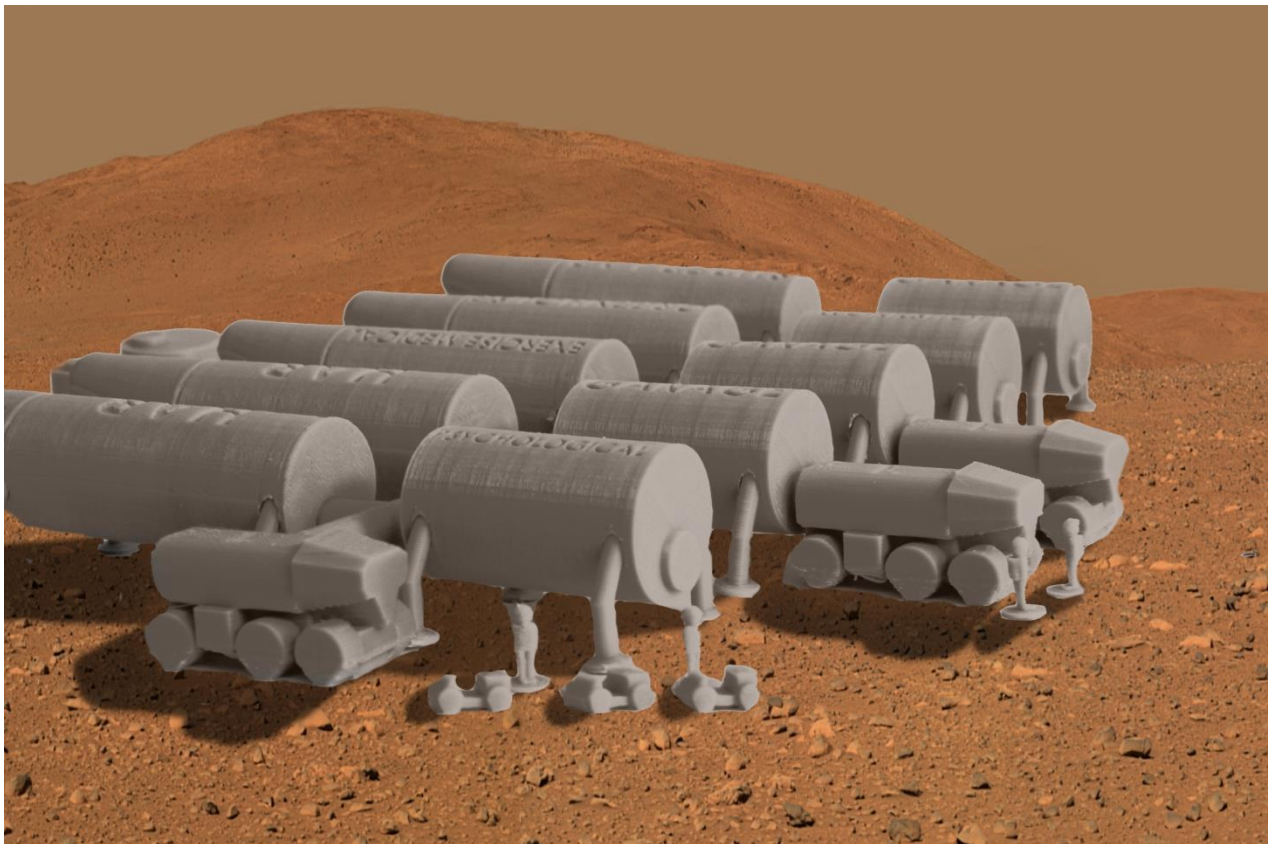


Appendix 7. Artist Impression 2 of setting up the HAB module on Mars



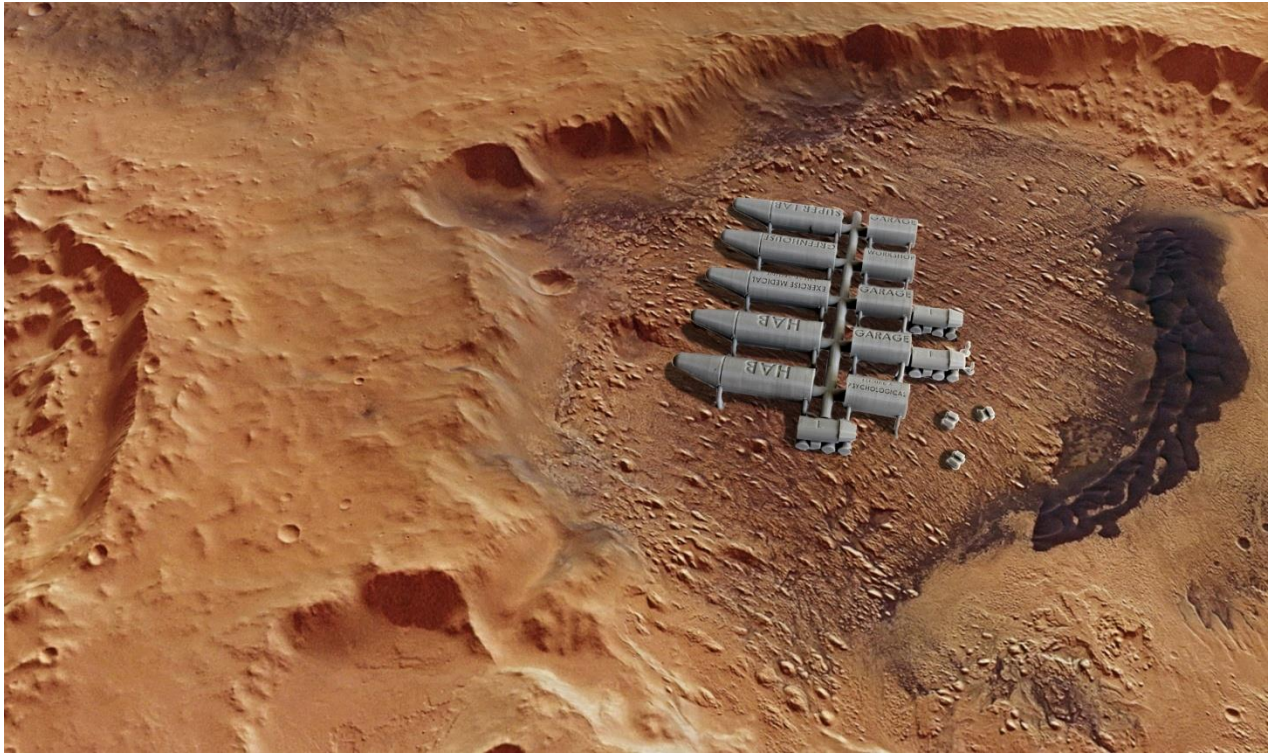


Appendix 8. Artist Impression 3 of the set up HAB module

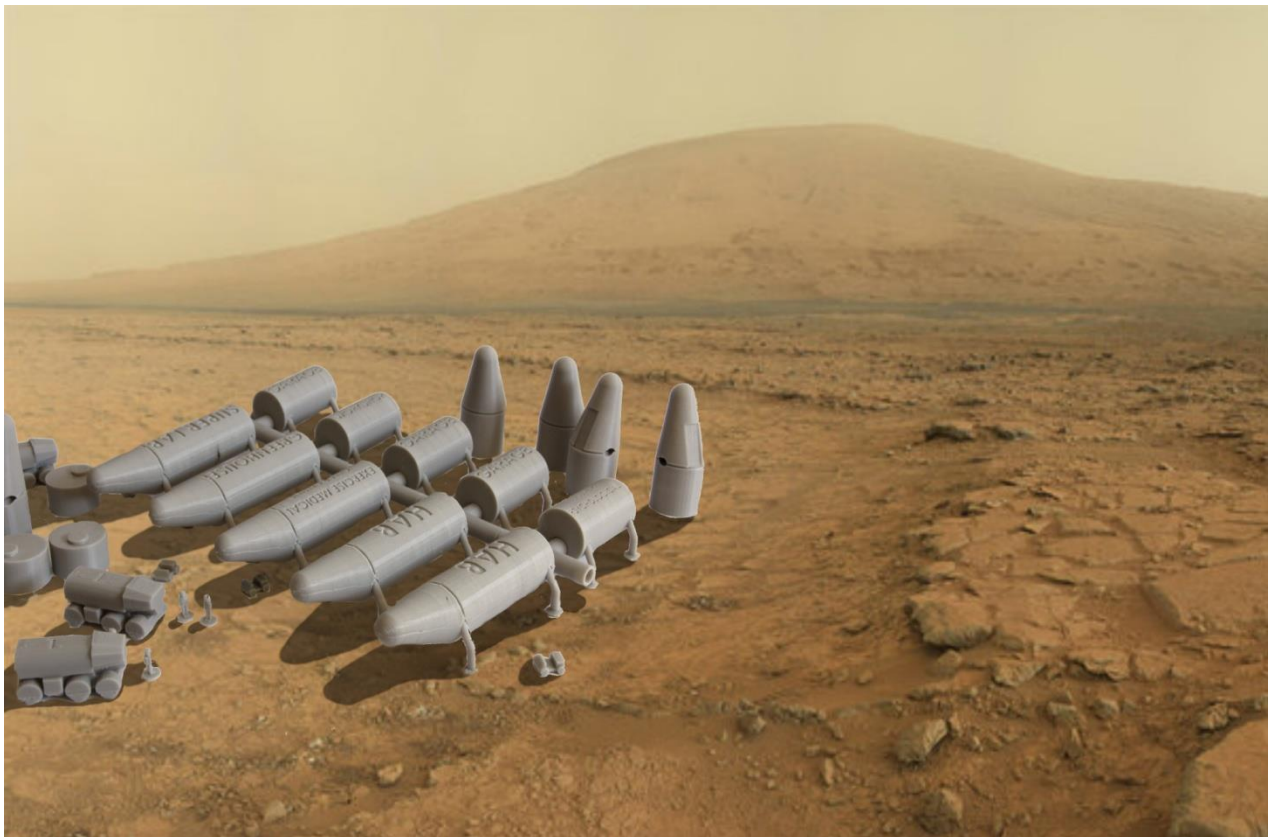


Appendix 9. Artist Impression 4 of the final Mars Station focusing on the Garage modules





### Appendix 10. Artist Impression 5 of the final Mars Station layout and scale



## Appendix 11. Artist Impression 6 of the Final Mars Station layout