# Mount Olympus Mons Ascension Mission Mars Operations - Team Red

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***Abstract*—A human presence on Mars will prove very valuable for the progress of humanity. Once the first several people have stepped foot on the planet, the race will soon begin to see who will be the first to summit its tallest mountain, Olympus Mons. Olympus Mons is a shield volcano that stands more than 21 km tall and over 620 km wide, making it the tallest mountain in the solar system. A summiting of Olympus Mons would be a monumental achievement, and a testament to humanity's capabilities and excellence. The purpose of this project is to design, on the conceptual level, the Mars operations aspects of the Tantalus mission, a hypothetical mission with goal of summiting Olympus Mons some time after the year 2038 with the following restrictions: no flying above 10 km altitude below the summit and no vehicles above 1 km altitude below the summit. There are also various methane, water and oxygen-dispensing outposts available to use for the mission. This paper looks at the Mars environment, crew selection, possible itineraries, landing sites, equipment, suits and rover design as well as some risks and off-nominal scenarios. The resultant mission makes use of an outpost at the Gusev crater to refuel for the return to Earth and carefully chosen landing site on Olympus Mons derived from the location of the crater, the summit and analysis of topographical maps from literature. The rover and suit designs are obtained by reviewing pre-existing designs and designs in literature, making some alterations bespoke to this specific mission. A combination of climbing with a pressurised, battery-powered rover and on foot using methods and designs outlined in this paper allow two astronauts to summit Olympus Mons and return to the spacecraft in 4-10 days which is within the time frame of a short-stay Mars mission.**

## I. Introduction

As technology advances and spaceflight options increases, so does the demand for Mars missions [1]. There are many reasons for this, from scientific in order to help determine how life originated on Earth, to exploratory in order to expand the achievements of mankind. Many robots and unmanned rovers have already roamed the surface, however there are many more complicated additional challenges that must be faced when it comes to sending humans to Mars and back. These include the requirement for extra safety in the form of more redundant systems to protect human life, the additional mass brought about by life support systems as well as greater medical risk due to the longer radiation and microgravity exposure.

The task has been set to form the conceptual design of a manned Mars mission, dubbed the Tantalus mission, starting from the year 2038, to let the first humans to scale Olympus Mons (OM) using current capabilities as well as technology that will likely be available at the time. There are some constraints and assumptions, primarily that flying vehicles are not allowed above 10 km altitude from the summit and no vehicles are allowed above the corresponding 1 km line. It is also assumed that robotic and human missions have already been performed and outposts producing reservoirs of oxygen, water and methane exist at various locations. These are available as long as politics of the respective outpost owners can be resolved. There will be an outpost at the Gusev Crater belonging to a NASA-lead international partnership and following correspondence between various sub-teams, it has been decided that this will be used as it is the closest to OM and the resources have been deemed necessary for the mission [2].

The role of the Mars Operations sub-team is to design and make possible the astronaut's activities while on the martian surface, from landing to take-off. This includes looking into the landing site location, time spent on the surface, crew capabilities, summit itinerary and road map, equipment and extra-vehicular activity (EVA) suits and rover design as well as consideration of risks and an off-nominal scenario.

## II. Mars Environment

Mars provides a harsh environment for human operations. The planet lacks a magnetic field meaning incoming radiation such as from solar particle events is not deflected. This means that astronauts will be subjected to a relatively high dose of radiation and should aim to remain in shielded environments whenever possible. However, since the stay on Mars is relatively short compared to the time spent in the spacecraft, protection from radiation will not be the primary concern of the mars operations procedures and therefore not of this report.

Due to the lower mass of Mars, the gravity is a third of that on Earth. This makes heavy objects easier to carry and Mars operations less strenuous in general. There is however the medical effect of reduced muscle mass meaning the crew should exercise regularly to mitigate this and make the walking section of the climb easier.

The martian atmosphere is very thin (6 to 7 millibars of pressure at ”sea level”, lower on OM) and composed of 95% carbon dioxide 2.8% nitrogen and 2% argon with a negligible amount of oxygen [3]. This means that the atmosphere is unbreathable, so pressurised environments with sufficient oxygen have to be used, as well as oxygen tanks for EVAs and emergencies.

Lastly, the surface conditions on OM is largely unknown at this time, since no rover missions have landed on the mountain. However, there are topographical maps with estimates and analysis of geological conditions, using satellite data [4].

These indicate that the ground is soft and covered in fine dust with rocks of various sizes scattered around meaning equipment must be resistant to abrasion, high in surface area if making contact with the surface to prevent sinking and a rover should be capable of traversing tough terrain if the rocks are unavoidable. There are also geological features such as smooth set lava flows which could speed up rover travel and thrust faults which are likely impassable and should be avoided. Although OM is the tallest volcano in the solar system, on the surface, the average slope is about 3 degrees. Therefore, the shallow incline should not pose an issue.

## III. Mission Timeline

When travelling to Mars, launch windows for reasonable interplanetary flight durations are limited. There are long and short-stay possibilities that vary widely from a month on the surface to 600 days on the surface. Having estimated climb durations (discussed further in section VI), it has been decided with collaboration with Mission Design that a short-stay trip with 25 on Mars is the option to go with [2]. This allows for mass to be saved by not needing the extra systems and resources that would be required for a long-stay mission.

After landing directly on OM, 10 km of altitude from the summit, the first couple of days on the surface is spent preparing for the climb. Then the summit attempts starts, with one astronaut staying behind in the rocket and the other two performing the climb. First, there is the driving section of the climb. from the 10 km line to the 1 km line, which is estimated to take between 1 and 3 days. After that, the astronauts will attempt to hike to the summit and back in one day. If they fail, they can return to the rover and make additional attempts in the following day. The overall climb should therefore take around 4 to 9 days, leaving plenty of time for uncertainties. Following the climb, the astronauts are to fly by rocket to the Gusev Crater to refuel and leave the planet. [2] With 10 days allotted to the mission and 2-3 days of preparation beforehand, this leaves some margin of error, allowing the crew to correct for unforeseen delays during surface operations while not jeopardizing the success of the mission.

## IV. Crew

How large the crew was decided to be was based off various criteria: requirements for completing the mission, the safety of the astronauts, cost and mass budget. This assessment was done in close collaboration with all other mission teams, since the number of crew members greatly affects a lot of choices for all parts of the mission.

After much deliberation, a crew of three was decided upon with two making the summit and a third one stationed at the landing site during the surface mission. It was decided to have two to make the final trip in the rover and the final walk to the top based on the risk evaluation of the mission. Having two astronauts go together means they will be able to assist each other but should also be able to perform the mission independently. This way, if one of the two is unable to make the summit, it is not an immediate failure of the mission since the second astronauts might be able to pursue the final goal, as well as assisting their fellow astronaut.

Crew selection is made with a few things in mind. The task could be described as being similar to a hiking mission executed at a fairly high pace but controlled manner. Mountaineers could therefore make good candidates for the mission, people familiar with traveling off-road on foot and on there own make their path to a set goal. Crew members are required to be in good physical shape and to have high determination. They also need to be able to perform under highly stressful situations. Mars being a hostile environment for humans means that incidents regarding malfunctioning oxygen supply or suit rupture could lead to situations where correct measures need to be taken very quickly, lest the situation may evolve into a fatal one leading to loss of crew.

For the two crew members doing the summit attempt skill and experience in driving in rough terrain is also a requirement, as well as a high degree of adaptability and ability to improvise. The drive up to the summit is on mostly unknown, rough terrain, putting high pressure on the astronauts to drive the rover safely up the mountain. These two astronauts also have to have some technical proficiency, to be able to perform emergency repairs on the rover and its systems if needed.

The one staying at the landing site is expected not to be exposed to high risk operations. The person will however be helpful in the case of having one of the other two incapable. In an emergency happening to one of the crew members during the summit, the crew can rendezvous at the landing site so that workload can be distributed among the two remaining members. This third crew member will also be the pilot of the descent/ascent vehicle, to distribute the important task among the crew members.

In addition to these special skills, crew members of course need to have the usual capabilities of an astronaut: communicative, focused, capable of good teamwork, very good knowledge of all systems used in the mission, high psychological endurance and many more. All of these necessary skills will need to be selected for in an extensive astronaut recruitment process, selecting a team of highly capable astronauts to receive the proper training and perform the mission.

## V. Landing site

At the time of the mission, three bases are already established at close-proximity to OM. All three, as well as OM itself represent potential landing sites. Out of the three bases, the Gusev Crater is the closest one, about 3400 km away from the summit of OM. Given the content of the mission it has been chosen that the crew would land directly on OM, using the Gusev Crater base only as a point of resupply for the return to Earth. [2] With the 10 km limit, above which the landing is impossible, it leaves a potential landing area of roughly 200 000 km². The mission timeline and the importance of resources make the choice of the site a crucial aspect.

Using a very precise topographical map of OM, the 10 km line as well as the 1 km line can be drawn [4]. Given that the slope does not increase too much with altitude, the most logical option is to look for a landing site right outside 10 km line. What is looked for is an area that is as flat as possible, as close to the summit as possible and one that allows a short and practical itinerary to the summit.

The wide crater located on top of Mount Olympus makes any idea of landing on the northern side of the Mount illogical. Moreover, because of the numerous thrust faults and because of their length making them impossible to bypass, a large area outside the 10 km line could be ruled out. Among all of the remaining areas, it has been decided together with the Space Vehicles team that the closest to Gusev Crater would be chosen. It is not the closest area to the summit, but landing closer to the crater saves fuel, a critical resource, and only adds about 4 hours of driving. The final choice of landing site has martian coordinates 15.5° N, 134.5° W, and can be found in context with the summit drive in figure 1.

## VI. Itinerary to the summit

The itinerary between the landing site and the summit, found in figure 1, has been chosen to be not just a straight line, because the nature of the ground has to be considered. Using the topographical map, it is clear that some areas are easier to drive on. In particular there are long, narrow, pristine lava flows (the dark pink areas in figure 1) that can be used to save time on the way up. Luckily, one of those is close enough to the 'straight line' path, making it worth the detour.

The total distance between the 10 km line and the 1km line is about 126 km. With a very conservative estimate of 5 km/h for the mean rover speed, the driving part of the mission should be achieved in 25 hours. Most existing rover concepts that have been considered for this mission allow speeds higher than 5 km/h, sometimes up to 20 km/h. However, since resources are so important, it is safer to take a conservative estimate, in case anything goes wrong and time has to be spent fixing an issue. 25 hours means 3 days of driving. It is unlikely that the astronauts will be able to drive more than 12 hours a day. In case nothing goes wrong the 25 hours can be cut down to 15-20 hours, which is doable in two days. At last, the rest of the journey is to be done on foot. No considerations other than trying to get the itinerary as short as possible is to be considered. In total, the walking part should be 26 km long, which can be covered in 6 to 8 hours for walking speeds between 3 and 4 km/h. 6 to 8 hours up, and 6 to 8 hours down means that every attempt to reach the summit should take a day.

If and when the summit attempt is successful, the astronauts will spend a small amount of time documenting the achievement, planting the mission flag at the summit and celebrating their success before heading back to the rover. Using cameras and drones as described in section VIII-C of this paper, the astronauts will film the summit attempt from the moment the crew embark on board the rover. Communication delay with Earth can climb up to 24 min in the worst case, which means that live broadcasting of the events can hardly be achieved. However, low quality footage will be sent in real time, while high quality footage will be recorded and saved for later use.

Using the conservative estimates, the summit trip will take 3 days up to the 1 km line, 1 day up and down the walking part and 3 days back to the rocket: 7 days in total total. In case several attempts have to be performed for the final hike, it is best to have 10 days worth of resources. This also allows for more of a safety buffer in case of off-nominal scenarios such as failure of the rover or injury of any of the astronauts. Therefore, 10 days of supplies is deemed an appropriate amount to bring with the rover to increase both the chance of mission success and the safety of the astronauts.

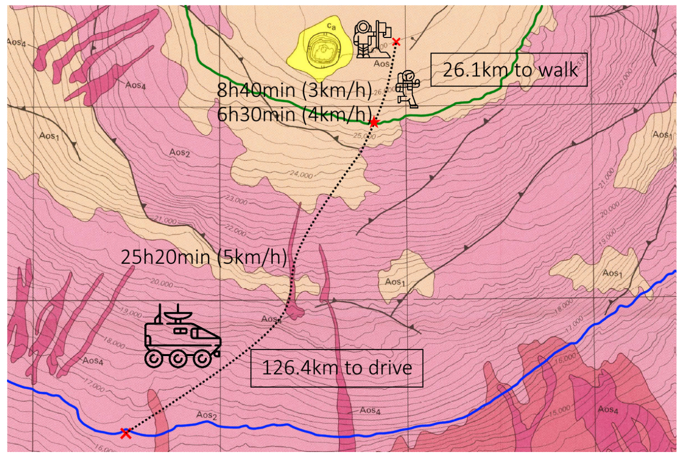


Fig. 1. Summit attempt itinerary [4]. The red crosses are the landing site and the estimated summit location, respectively, the blue line represents the 10 km line, and the green line represents the 1km line.

## VII. Rover

Because of the relatively gentle slope of OM it was quickly realised that landing 10 km below the altitude of the summit corresponded to a travel distance on land of over 140 km. Thus it was decided that the summit journey would be divided into two parts with different means of travel. The first part is to be taking a rover from the landing site up to the 1 km mark. Once arriving at the 1 km mark, the rover will be left behind as the two will make the last bit on foot. This rover will be sent ahead to the OM landing site together with some supplies, and will rendezvous with the crew when they land on Olympus Mons for the summit attempt. [2].

To make sure the ride on the the rover can be made successfully from start to finish and under the time required as well as accommodating the needs of the crew a custom rover design was made based off of already existing ones given in [5], providing a variety of design for lunar as well as martian surface exploration.

The selected design to work as a template was the Pressurised Lunar Rover [6]. This fulfills desired requirements such as having a fully pressurized cabin, a fast enough nominal speed, sufficient operational range and habitability for the duration of the mission. Specifications are provided in table I Some elements of this design are for our purposes not necessary and were thus rejected onto our rover design. It is worth noting that this design is made for exploration as well as research and is, as such, equipped with a laboratory. Additionally the original design is made to hold a crew of 4. Our design is envisioned to be significantly smaller since it will contain only the bare systems required to complete the mission.

To reduce overall weight much of the ”Pressurised Lunar Rover” design is either removed or scaled down. Beds are completely removed and instead the driver and passenger seats are to be designed with a reclining function for sleeping. The laboratory section is removed. The trailer carrying the power supply (a radioisotope thermoelectric generator) is replaced with a battery which is installed directly onto the car. The ground clearance of 0.75 m and the six wheels have double Ackerman-arm aluminum suspension that allows for 1 m of vertical motion [6]. Since the surface up close is yet do be surveyed there is no detailed information of what obstacles, such as rocks of varying size, may be encountered. Observations of rock fields around OM caldera [7] scarps have been made but little else is known. Assuming similar environment as what the Pathfinder rover explored we could expect rocks with a diameter 1 m and over to be rather uncommon [7]. Any smaller rocks should be of no difficulty for the rover and easily driven over and the flex composite wheels will provide further shock absorption and traction. Any larger rocks closer to 1 m and above should be navigated around if deemed necessary and is left to the drivers discretion.

To allow for multiple EVAs without having to perform depressurisation of the whole interior of the cabin an airlock is desired. This will also help in reducing the volume of oxygen needed during the trip.

The Envisioned concept design is shown in figures 2 and 3. The interior design is shown in figure 4.

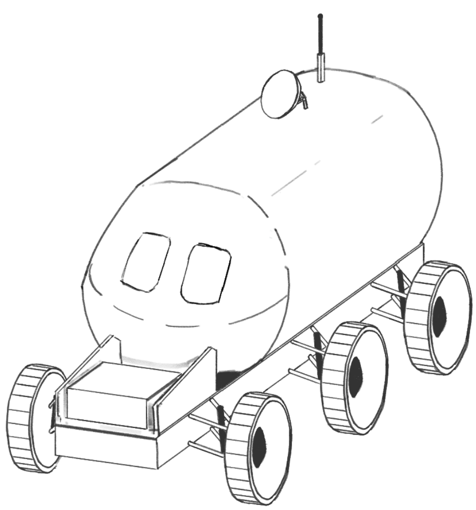

Fig. 2. Martian rover design

The life support systems of the rover are similar to those present in the main spacecraft, with $CO_2$ removal, $O_2$ and $N_2$ supply systems and human waste removal systems. The main difference is the $CO_2$ system, which instead of the pseudo-closed loop CDRA system used in the orbiter [8] will be an open-loop system with dispensable cartridges similar to the ones used in the Space Shuttle missions. This is to save weight and space in the rover since the CDRA system is very heavy, and can be motivated with the short time spent in the rover

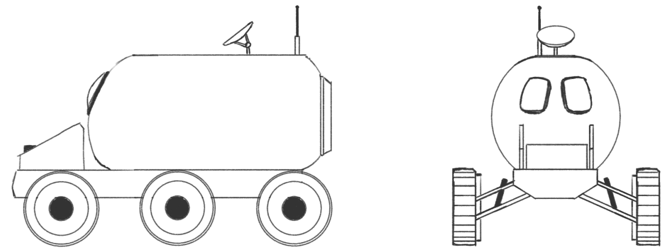

Fig. 3. Martian rover design, side & front

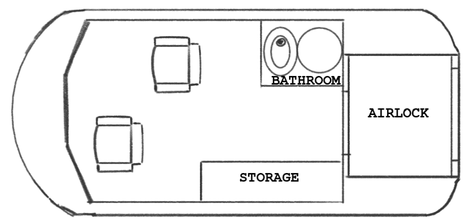


Fig. 4. Rover interior design

compared to the orbiter. The other life support systems will be more similar to the ones used in the orbiter, and hence we will not go into great detail on the systems here. However, weights of the systems are included in table I.

| **Nominal / Maximum Speed** | **Operational Range** | **Crew Support Duration** |
|---|---|---|
| 10 / 18 km/h | 500 km | Crew of 2 for 10 days |

TABLE I
MARTIAN ROVER SPECIFICATIONS

The estimated weight of the subsystems and the total weight of the rover are summarised in table II.

## VIII. SUITS AND EQUIPMENT

### A. Requirements

Mars is a distant, dangerous and still mostly unknown world. Therefore, human exploration on Mars comes with numerous challenges. Our crew needs a space suit as well as additional equipment in order not only to successfully achieve his mission, but also to survive the inhospitable Martian environment.

Simply put, the crew needs a spacesuit to survive during the last part of the itinerary which will be achieved on foot. If anything should happen to the rover, the suit would also be crucial for the astronauts to be able to repair it or get back to the base. As assessed in section VI, the walking part of the journey should take between 12 and 16 hours. Therefore, it is necessary that all systems of the suit are operational during up to sixteen hours. The requirements for the suit are presented in the following section.

First of all, the suit needs to provide Mars-adapted life support to the astronaut. The requirements for this part are gathered in table III [9].

In addition to these crucial requirements, the Mars suit needs to provide additional systems to enable success of the

| **Subsystem** | **Mass [kg]** |
|---|---|
| Body shell | 150 |
| Suspension | 120 |
| Wheels | 240 |
| Motors | 122 |
| Gear units | 60 |
| Controllers | 68 |
| Interior | 200 |
| Oxygen supply system | 15 |
| $CO_2$ removal system | 25 |
| Food | 32 |
| Water | 64 |
| EVA suits | 20 |
| Power generator | 200 |
| Wiring system | 150 |
| Radiator system | 150 |
| Shielding | 20 |
| Electronics | 35 |
| Transponders | 13 |
| Data Storage | 4 |
| Antenna | 25 |
| Control system | 150 |
| GNC | 65 |
| Occupants | 140 |
| External equipment | 100 |
| **Total mass** | **2130** |

TABLE II
ROVER & SUBSYSTEM MASSES

| **Problem** | **Requirements** |
|---|---|
| Low pressure on Mars: 30 Pa – 1.24 kPa | Pressurization (superior to 6.3 kPa) |
| Temperature on Mars: -100°C – 25°C | Temperature control for long-term comfort (4°C – 35°C) |
| Low oxygen in Martian atmosphere: 0.13% – 0.14% | Oxygen supply |
| Human $CO_2$ exhalation | $CO_2$ removal |
| Human nutritional needs | Water and food supply |
| Production of urine and feces | Waste management system |
| Galactic Cosmic Rays and Solar Particle Events on Mars | Radiation shielding |

TABLE III
REQUIREMENTS FOR LSS OF MARS SUIT

mission. The astronauts must be able to communicate with each other, the third astronaut at the landing site and the Mission Control Center on Earth. Even if the slope of OM seems gentle, a walk on Mars would require much more mobility and flexibility than what the current spacesuits allow, especially with the action of Mars' surface gravity which is about 38% of Earth's. It is also important that the astronauts have a wide and clear field of vision over their environment, without being annoyed by solar rays. Dust on Mars is another point of concern: the suit parts need to be robust and resistant to scratches and abrasions, and to provide minimal dust retention. To operate all these subsystems, the suit must also include a control system and a way to provide power.

Concerning the equipment, the crew needs to be able to provide first aid in case of medical issues. Moreover, it is necessary that the astronauts can repair and maintain the equipment, especially the suits and the rover. The achievement of climbing OM itself also plays a major role in the mission. Therefore, the crew needs some equipment for filming their challenge. Finally, even if the purpose of the mission is not scientific, it can be useful for the astronauts to be able to collect samples or to carry out some experiments.

### B. Mars suit

For the design of the mars suit, the assumption is made that some kind of mechanical counter pressure space suit (MCP), as the BioSuit currently developed by MIT [10], will have been developed by the time of the mission. A MCP suit has indeed significant advantages for Mars exploration compared to a more traditional gas-pressurized suit. The MIT BioSuit concept can be seen in figure 5

Fig. 5. MIT BioSuit

The MCP suit provides pressurization to the body by utilizing tight, form-fitting garments to physically compress the body, up to one-third of sea-level atmospheric pressure. Only the helmet requires gas pressurization.

In terms of temperature control, we followed the recommendations from the Human Aspects team [8] and focused on heating systems delivering heat especially to the gloves. Even if the temperatures on Mars are often low, it is still necessary for the suit to enable cooling of the human body. Natural sweating of the body is compatible with the MCP suit because of the porous characteristic of the garment. Therefore, the skin is passively cooled by evaporation and body heat is dissipated thanks to conduction and convection phenomena with the Martian atmosphere [11]. If warming is required, the external layers of the suit could be sealed in order to trap metabolic heat. For heating of the gloves, a system similar to the one currently in use in EMU suits was chosen: flexible thermofoil resistive heaters powered by electricity are incorporated in one of the layers of the garment. Moreover, such heaters can also be placed in every part of the suit to cover the whole body and provide backup heating in case of extreme coldness.

The life-support system of the Martian suit needs to provide oxygen supply to the astronauts for up to sixteen hours.

Therefore, a system similar to the one currently used for spacesuits will be used, with larger oxygen reserves. Oxygen bottles are stored in the portable life support system (PLSS) on the back of the astronaut, and a fan allows its circulation to the helmet [12]. Following the recommendations from the Human Aspects team [8], about 800 L of oxygen is necessary for an EVA of sixteen hours. For oxygen supply, it is current to take into account a safety factor of 1.5. Therefore, about 8 kg of oxygen main resources will be included in the portable life-support system. Moreover, as it is the case for current EMU suits [9], a backup life support system is added to the main one. This one contains a backup oxygen supply for up to 30 minutes in case of emergency, which could allow enough time for the crew to get back to the rover or find a way to fix the main oxygen supply system. A schematic representation of the chosen configuration for the portable life support system is shown in figure 6.

$CO_2$ removal is achieved thanks to the Pressure Swing Adsorption (PSA) repeatable process. The assumption was made that such a process will have been developed for spacesuits by the time of the mission, which is not the case yet. Via this process, the $CO_2$ can be separated from the exhaust gas more efficiently. Thus, by regenerating the sorbent (which is a material that allows absorption or adsorption of $CO_2$) during the EVA, the size and weight of the sorbent canister can be greatly reduced. Once removed from the gas, $CO_2$ is vented into space together with water vapour [13] [14]. This system accounts for 6 kg in the PLSS with a safety factor of 1.5.

Drinking water in the form of on In-suit Drink Bag containing 3 liters of water will be included. A small straw fits up next to the astronaut's mouth and allow him to drink. Traditionally, food is not consumed by astronauts during EVAs because they never exceed 8 hours. However, for a whole 16-hours day of climbing a mountain and making physical efforts, the astronauts will need to eat about 800 g of food. The assumption is made that liquid food is available, for example in the form of nutritious powder mixed with water for example. Therefore, about 1 kg of liquid food is added to the drinking water, and the system remains similar.

The human-body produces urine and feces, which makes necessary the presence of a waste management system in the suit. Rather than designing a complicated and heavy system, the choice was made to use a Maximum Absorbency Garment (MAG), a diaper that can absorb up to 2 liters of waste. Although this system is not necessarily comfortable for astronauts, it is lightweight and should not be a problem as the suit will be worn by astronauts for long duration only during the last part of the climbing.

The dose of radiations received on Mars will surely be negligible compared to the dose received during the long duration round trip journey. However, the suit still needs to provide a minimum protection to radiation. This is achieved by the use of different layers made of resistant materials, further explained below. Some highly radiation resistant polymers are used for the external layer of the suit, as well as for some parts of the helmet [13].

In order to keep track of the health and vital signs of the astronauts, a health-monitoring system is included in the suit. It consists of a set of communications wires and bioinstruments for measuring respiration rate, heart rate, body temperature, blood pressure and other vital parameters. Body-worn monitors like the Life Guard system have been developed by NASA for extreme conditions [13]. Some studies have also shown that such systems could be powered merely by using body heat energy [15].

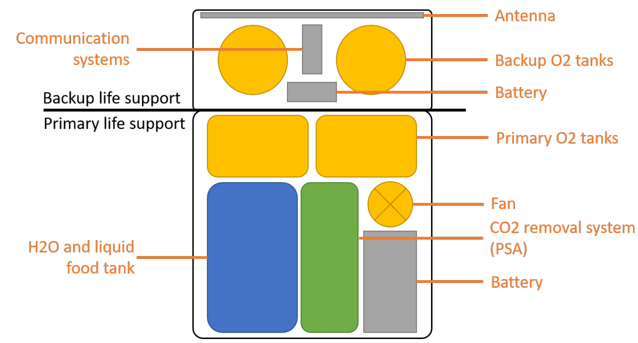


Fig. 6. Simplified schematic representation of PLSS

The main advantage of the chosen MCP suit is that it allows for a degree of mobility for the full body impossible in a gas-filled suit. Therefore, the astronauts can easily walk rather than jump and can perform more complex movements such as kneeling, turning around, picking up something or using a tool. As the helmet is the only gas-pressurized part, the wearer can also easily turn his head thanks to the movable neck part (see figure 7). Thus, the suit greatly contributes to reducing fatigue and offers better chances to reach the summit of OM without incidents [11].

Thankfully, flexibility and lightness does not necessary mean fragility. On the contrary, the suit might be safer than a gas-pressurized suit. Indeed, a puncture in a gas-pressurized suit would probably lead to a sudden and fatal decompression. A tear on a MCP suit would result in a very localized depressurization, with effects limited to a small area thanks to the elastic feature of the suit [11]. Some kind of bandage could even be sufficient for temporary repairing the suit. However, it is safer to design the suit to allow for replacing of outer coverings that could suffer damage (see figure 7). Moreover, more emphasis is placed on the design of the most likely stressed parts such as gloves, boots and helmet. The boots need indeed to be both flexible, strong and to provide friction and grip because they will be in permanent contact with Martian abrasive soil and rocks (see figure 8).

Whether in daylight or in low light, the helmet needs to provide maximum visibility and clarity to the astronauts. Therefore, the helmet provides two visors: a permanent robust transparent one and another one used for radiation filtering. The permanent faceplate needs to be resistant to be resistant to abrasions and designed for buffing so as not to reduce the astronaut's visibility even when dust is hitting the visor [13]. As it is the case for current spacesuits, lights are included on the helmet to help the astronaut to see even in poor lighting conditions (see figure 7) [9].

Concerning communications and navigation, the PLSS will will include dedicated subsystem together with the required antennas (see figure 6). Rather than the traditional Communications Carrier Assembly (CCA or "Snoopy Cap"), the helmet will be equipped with integrated speakers and voice activated microphones that allow the astronaut to communicate without any effort (see figure 7). Information for navigation are displayed on the wrist computer visible on figure 9 or on the "head-up displays" system of the helmet. These two subsystems also provide several kinds of information concerning the health of astronaut or status of the suit. They can also be used for control together with the display control module on the chest of the astronaut (which allows control of LSS for example). The presence of these several systems is also to achieve redundancy in case one of the system would be defective or unusable due to dust (against which they obviously should be protected).

Dust is a concerning source for the design of a Mars suit. Even if it is less abrasive and finer grained on Mars than on the Moon, it can still damage equipment, and particularly the suit, in a dangerous way. Moreover, it comes with health risks. Therefore, the Mars suit needs to be as slightly affected as possible by dust. For example, it should have a minimum of seals and bearings (which is the case for a MCP suit), be made of material with low dust retention times and of layers preventing the enter the inner suit [11].

As seen in the first parts of this paper, the climb of OM will be closer to hiking than to proper climbing. However, it could still be useful for the astronauts to have some basic climbing gear with them, such as a harness, a rope and a few carabiners (see figure 8) [16]. In addition to being useful in case of encountering a steep slope or stay attached to the rover or another crew member, this kind of equipment would facilitate carrying additional equipment like tools and medical equipment (see section VIII-C).

The suit requires many layers made of different materials in order to fulfil the mentioned requirements especially about increased mobility, thermal control and radiation shielding. The suit will therefore be composed of at least 8 layers [13] [9] described below.

1) Soft fabric tricot for astronaut's skin (2 mm thick)
2) Nylon/spandex layer including thermofoil resistive heaters for heating and ventilation of the astronaut (4 mm thick)
3) Memory alloys for mechanical pressurization of the body (7 mm thick)
4) Dacron with cotton restraint layer to prevent premature wear of other layers (5 mm thick)
5) Neoprene-coated nylon for chemical stability and flexibility (4 mm thick)
6) Nylon lined with urethane and dacron for internal pressure, high resistance to wear, low moisture absorption (3 mm thick)
7) Aluminum/mylar/dacron layer formed by six sublayers for protection against micrometeorites (0.4 mm thick)
8) Gore-Tex/kevlar/nomex polymers external layers for radiation and dust shielding (2 mm thick)

These layers add up to a total thickness of 27.4 mm.

All the subsystems mentioned previously require power. The power requirements were estimated in table IV.

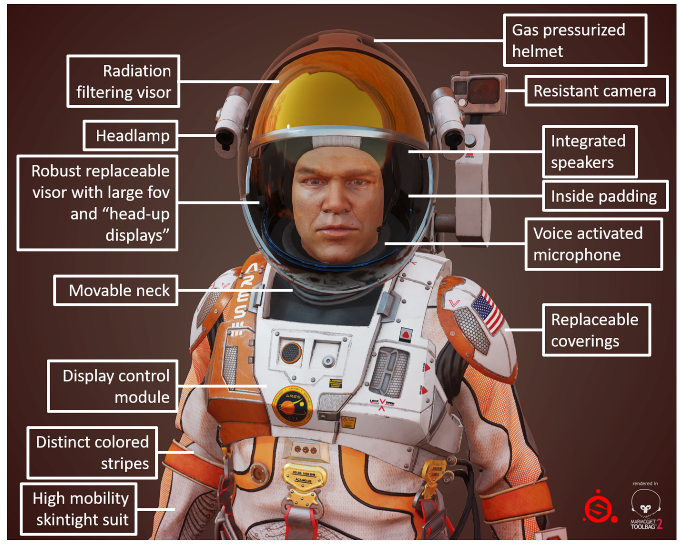


Fig. 7. Tantalus Mars suit concept (upper part) (original image from "The Martian" film)

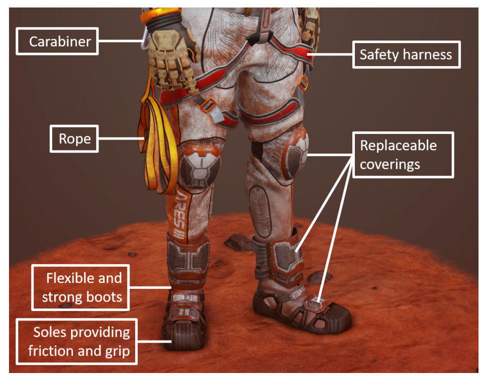


Fig. 8. Tantalus Mars suit concept (lower part) (original image from "The Martian" film)

The suit requires power for up to 16 hours. Therefore, 1360 W-hr is required. Li-Ion batteries with an energy density of 250 W-hr/kg are placed in the PLSS backpack to power every subsystem [17]. The battery can be charged on the rover before the walking expedition. In addition, flexible solar cells will be integrated on the chest area in order to provide an auxiliary power source.

Finally, the mass of the suit including all subsystems can be estimated. This is done in table V. An average packaging factor of 1.4 is assumed for the PLSS, which means that every kilogram of actual life support or other system in the PLSS has 0.4 kg of structure and other packaging.

53 kg is still quite heavy, but including every life support system always comes with unavoidable mass addition (mass of current suits is about 145 kg [9]). However, this mass can be put into perspective. With the gravity on the surface of Mars, the weight of the suit would be equivalent to carrying a 20 kg suit on Earth. This is comparable to the weight of the gear carried by mountaineers on Earth. If this figure can seem still high for a climbing mission, one can think that the supplies of the suit will diminish as the astronauts get closer to the summit. Besides, the mass of the suit is distributed over the


Fig. 9. Tantalus Mars suit concept (gloves) (original image from ”The Martian” film)

| Subsystem | Power required (W) | Subsystem | Power required (W) |
|---|---|---|---|
| Communication | 10 | Cameras and lighting | 15 |
| Information display | 10 | Heating | 25 |
| $O_2$ supply | 15 | Control system | 5 |
| $CO_2$ removal | 5 | **Total power requirement (W)** | **85** |

TABLE IV
POWER REQUIREMENTS FOR MARS SUIT

| Subsystem | Mass (kg) | Subsystem | Mass (kg) |
|---|---|---|---|
| Suit (layers, gloves, boots, helmets, display control module) | 8 | Temperature control | 3 |
| Communication and information | 2 | Food and drink supply | 4 |
| Cameras and lighting | 1 | Waste management (MAG) and health monitoring | 0.3 |
| Climbing equipment | 1 | $CO_2$ removal | 6 |
| Solar panels | 0.5 | $O_2$ supply (bottles and fan) | 8.5 |
| Battery | 5.5 | Backup life support | 3 |
| **Total mass of suit and PLSS (packaging factor 1.4) on Earth** | **53** | **Total ”effective” mass of suit and PLSS on Mars** | **20** |

TABLE V
MASS OF MARS SUIT AND PLSS

full body. Finally, it just adds some requirements on astronaut selection and physical condition. One can argue also that if everything goes well, this physical challenge would be only a one time effort.

To conclude concerning the suit, MCP suits seem to bring lots of advantages over gas-pressurized suits. However, it comes with some limitations. First of all, the concept of MCP garments itself can make the donning and doffing process long and difficult, because of the constrictive characteristics of the powerful elastics of the suit. It could take up to 30 minutes to don such a suit. Moreover, as the suits are skintight, they would need to be tailor made to work efficiently, and as such, it would likely be impossible for the astronauts to exchange suits between them if need be. Concerning mechanical pressurization of the body, some areas are more difficult to compress and uniform compression seems difficult to achieve. Finally, contamination of the Martian environment seems unavoidable, namely with perspiration and other gas rejection by the human body [11].

### *C. Equipment*

In addition to the suit and rover, the crew members will need to carry with them some equipment to successfully fulfil their mission.

First of all, the crew will need to have a first aid capability. As the stay on Mars is quite short, we can assume that more sophisticated medical equipment to diagnose and treat more serious injuries will remain in the spacecraft and not be carried by the astronauts that are aiming for the summit. The first aid kit needs to provide the crew with ability to treat small issues like scrapes, burns by cold, solar event radiation exposure, sprains, breaks, lacerations... [16] The kit could be inspired by the medical kits used during Apollo missions (see figure 10 or by more recent military kits. In the unfortunate event of the death of one of the astronauts during the mission on Mars, the crew should have a body bag in order to carry the body and isolate it from the Martian environment in order to satisfy planetary protection. Besides, these bags could also initially be used for carrying gear, as they can carry up to 150 kg.

Fig. 10. Apollo first-aid kit

Having equipment also comes with being able to maintain and repair it. Therefore, the crew will need spare parts for the suit, the rover and all gear to maintain their capabilities as long as possible and ensure them not to fail. As said in the previous part, the suit includes many replaceable coverings for the parts that are most likely to be damaged [16]. Together with spare parts, the astronauts will carry tools to perform repairs. Both conventional tools (wrenches, screwdrivers, hammers, tape... while adapted to use on Mars) and Mars equipment dedicated tools will be included in the tool kit. Some kind of PGT (Pistol Grip Tool used by astronauts on ISS) designed especially for Mars conditions (capable to withstand quick fluctuations in temperature and easy to use with and without a suit) will be used in order to drive bolts accurately and avoid contaminating the Martian environment by dropping bolts [9].

In order for the climbing crew to find their path on OM (in addition to GPS-like systems), two drones will be included as well in the equipment in order to scan terrain ahead of the astronauts. Assuming Mars Helicopter Ingenuity (see figure 11) succeeds in flying in Mars environment, many other Martian drones concepts will surely be developed in the coming years [18]. Moreover, these drones will be used together with cameras mounted on the suit (see figure 7) to film the arrival at summit and provide high-quality footage for spectators on Earth. Needless to say, this equipment will need to be particularly resistant to Martian conditions in order to fulfil its function.

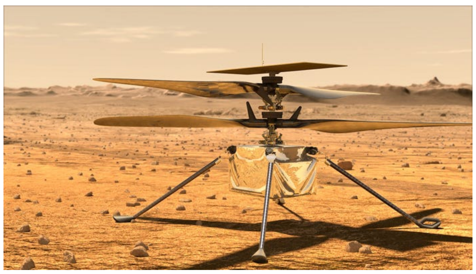

Fig. 11. Mars Helicopter Ingenuity

What would a space exploration mission be without its own flag? The Tantalus crew will carry its Martian Flag Assembly kit up to the summit of OM, and plant it in a spectacular way to mark the success of the challenge. The flag will display the logo of the mission, as well as the name of every person who contributed to the project.

The crew will have sample containers in the rover in order to collect Martian samples and bring them back to Earth. In addition to being scientific assets, they could help the Tantalus project proves that its crew really made it to Mars.

Concerning communication and navigation, the paper from the Mission Design team gives information about the chosen network structure [2]. Therefore, communication equipment on Mars will have to include antennas adapted to this configuration. Moreover, the assumption is made that some kind of Mars GPS-like system will have been set up by previous Martian missions. Even if it will undoubtedly allows less precision in localization than the Earth's system, it will be precise enough for astronauts to find their way to the top.

## IX. Risks and Off-Nominal Scenario

During the duration of the mission on Martian soil, no less than 20 off-nominal scenarios have been identified and their respective risks for the mission and the crew's safety have been calculated. Every scenario has been associated with a probability of occurring and a consequence, both on a scale going from 1 to 5 with 1 the most unlikely scenario or the smallest consequence, and 5 for a scenario very likely to happen, or extremely dangerous for the astronauts and the mission. Both numbers are then multiplied together so that every event is associated with a number that translates both the likelihood and the danger (on a scale going from 1 to 25).

Out of these 20 off-nominal scenarios, five were considered a priority (value above 6): a rover breakdown, a failure of the communication system, a leak of oxygen outside the suit, a shortage of supplies (food, water, fuel) and a leak of oxygen outside the rover. The first two scenarios threaten the mission while the three other threaten the life of the astronauts. It can be argued that for such a mission the crew knows the risk of the mission and that the later is more important that the former, but here priority is given to the life threatening off-nominal scenarios.

Let us take one of these three and see how it could be dealt with. Two astronauts are on their way to the summit, they are on foot (the rover has been left behind) and they are a few kilometers away from the summit. Suddenly, one of the astronauts' suit starts leaking oxygen. The rover is too far away to be of any help, and a solution has to be available quickly. Given that only the helmet is pressurized, the total volume of oxygen is about $V = 0.1$ m$^3$ or $V = 100$ L.

The leakage rate is

$$Q_{\mathrm{L}} = -\frac{\Delta p}{\Delta t} V \tag{1}$$

Moreover, assuming a vacuum ($p = 0$) outside the suit, atmospheric pressure inside ($p_{\mathrm{a}} = 1.013$ bar) and assuming that in case of a leak the air would exit the suit with a speed equal to the speed of sound $u = 330$ m/s:

$$Q_{\mathrm{L}} = p \cdot u \cdot A, \tag{2}$$

with $A$ being the area of the hole in the suit. This together with equation 1 gives:

$$\dot{p} + \frac{u \cdot A}{V} \cdot p = 0, \tag{3}$$

giving the pressure as:

$$p(t) = p_{\mathrm{a}} e^{-uAt/V} \tag{4}$$

The pressure below which the astronaut is in danger is called the Armstrong limit. Below that pressure, the astronaut would lose consciousness as well as all cardiovascular and neurological functions, until death: $p_{\lim} = 6300$ Pa $\approx 0.06 p_{\mathrm{a}}$.

The 'critical time' $\tau$ is defined as the time needed for the pressure inside the suit to drop enough to reach the Armstrong limit:

$$p(\tau) = p_{\mathrm{a}} e^{-uA\tau/V} = p_{\lim}. \tag{5}$$

Solving for $\tau$ gives:

$$\boxed{\tau = -\frac{V}{uA} \cdot \ln\left(\frac{p_{\lim}}{p_{\mathrm{a}}}\right)}, \tag{6}$$

with the critical time as a function of hole radius being plotted in figure 12.

A hole with a radius of 1 mm gives approximately 5 minutes to the astronaut before the pressure inside the suit reaches the Armstrong limit.

Assuming the worst case scenario (the astronauts being at the summit), six hours are needed to come back to the rover. For an urgent situation, this time can be cut in half.

In order for the astronauts to be able to reach the rover before the pressure inside the suit reaches the Armstrong limit,

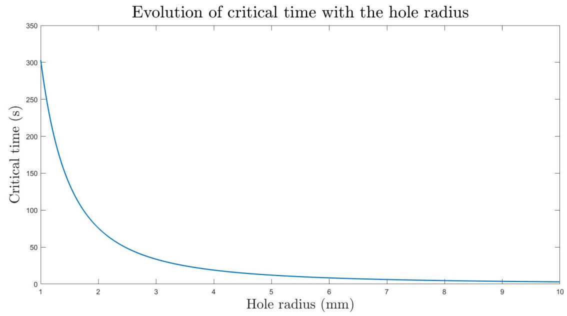


Fig. 12. Critical time as a function of the radius of the hole in the suit

the hole has to have a radius of less than a micrometer. So an efficient solution is needed.

Duct tape could fix the issue temporarily if the astronauts are close enough to the rover, but not for such scenarios. A solution that exists now would be to use a spacesuit repair kit, like the ones that are sent to the ISS when needed. However, if the hole is too big or can not be fixed, the worst case scenario has to be considered: the death of an astronaut. In such a case, the body retrieval is made a priority and the mission has to continue. A body bag will be brought in the rover in case it is needed.

## X. Conclusion

This project has looked at the Mars operations of the Olympus Mons summiting mission Tantalus. By considering launch masses and climb durations, a mission timeline has been decided on. Having looked into the martian environment and the limitations posed by the mission, an itinerary to the summit has been planned. To be able to perform the mission, a rover has been designed and the suit and equipment required has been determined. The risks have also been looked at and all things considered, it has been concluded that on a conceptual level, the operations designed in this paper will allow two astronauts to summit Olympus Mons and return within the time frame of a short-stay Mars mission.

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