Olympus Mons Mission
Blue Team - Human Aspects Report

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***Abstract*—As part of the *Hephaestus* project, the aim of this report is to consider system requirements and payload mass of the human-centered part of a long-duration mission to Mars, culminating in climbing Olympus Mons, the highest peak in the Solar system. The mission was designed for six crew members and a duration of 985 days, with 646 days in transit and 339 days on the surface of Mars. Considerations regarding environmental control and life support systems, food and water, exercise equipment, clothes and hygiene, expected medical impact due to microgravity and radiation exposure have been made. A final payload mass of 24 125 kg was found, and discussions about further savings and considerations were included.**

I. Introduction

EVER since Yuri Gagarin's first flight to orbit in 1961, man has always wanted to go further into space. In 1969 the first man walked on the moon and now the next challenge is Mars.

This report, as part of the *Hephaestus* project, looks into the feasibility of bringing the first human to the top of Olympus Mons on Mars, with an emphasis on the *human aspects* of space travel. Though not a complete list of requirements, this report covers some of the immediate needs of a human crew on a long-duration mission in space and the payload mass required to fulfill them.

The *Hephaestus* project is expected to last for 985 days, with 646 days in interplanetary transit and 339 days on the surface of Mars. Such a long-duration undertaking offers challenges not seen in Earth-orbit missions, such as the inability to perform a direct abort and the lack of Earth-based assistance should anything go wrong. Not to mention the technological challenges of maintaining a stable, habitable environment for the astronauts, keeping them healthy, happy and able to work for extended periods of time without direct communication with Earth. The human-centered payload must include environmental control and life support systems, enough food and water to last the full mission, tools for on-board repairs, exercise equipment, and everything else needed to ensure that the six astronauts can complete their mission safely.

The baseline and constraints for the mission are:

- 6 crew members
- On Mars there are facilities that produce water, oxygen and methane
- Last 1000 m altitude climb must be done without vehicles

Beyond the main goal of the mission, there will be ample opportunities for scientific research and exploration of the Martian environment.

II. Psychological aspects

Extensive research has been carried out to assess the effects on the psychology of the ISS crews during their missions [1], and of long isolation and particularly stressful situations such as polar expeditions in the 20th century [2] or from experiments, such as the HERA (Human Exploration Research Analog) and [3] and Mars500 [4], that simulated crew isolation in confined habitats and remote, high-workload conditions in exploration scenarios. The long duration of the proposed interplanetary mission to Mars - which at 985 days far outreaches the duration of the mentioned situations and is characterised by highly hazardous space and Martian environments, adds uncertainty and unreliability around the available psychology research.

Depression symptoms have been observed after long periods of isolation, confinement, and remoteness and have been linked to boredom, lack of meaningful work, and the feeling of not being in control of the mission [1], [5]. To mitigate this a varied, but strict routine is required. This should include mission-critical everyday tasks such as routine checks, repairs to life support systems and exercise routines. It is also suggested to involve the crew in various scientific experiments. On the other hand, workloads and work schedules should be planned and limited taking into account chronic stress symptoms the crew may experience due to the dangerous environment characterised by chronic physiological and psychological stressors. Plenty of time should be allocated to entertainment and free time. Following activities are most effective against boredom, lack of morale, and early depression symptoms [1]:

- Daily journals or video journals, that can also be used for further research or education, inspiration, or PR;
- Given the lack of live communication with Earth, regular video-recordings of family and friends;
- Social media presence could be effective to maintain contacts and feel connected with what happens on Earth [6];
- Movies and books, that could be stored in a local multimedia library or streamed;
- Routine social activities like movie night or board games nights;
- Celebrate important events, such as birthdays, religious festivities, and national holidays, and plan for special tastier foods on these occasions.

For these reasons, it is suggested to allow the crew to bring valuable personal items, which have negligible mass compared to the total launch mass, as long as they do not pose threat to their life or the integrity of the spacecraft.

NASA has conducted research on behavioural health related to working and living in confined spaces during a long-duration interplanetary mission and has produced documentation showing ideal living and working environment designs but more importantly defining a minimum acceptable net habitable volume (NHV) [7]. They recommend a NHV of 25 cubic meters per person. This value takes into account a zero-gravity environment, which enables the use of every wall on the spacecraft and should therefore be increased as the spacecraft will be used also as the living habitat on the surface of mars where gravity is present.

Research has also shown that the crew's morale goes through a significant decline during the final third quarter of the mission, showing how mitigation measures are especially important during the return trip to Earth and in the unfortunate event of a failed climbing mission. To tackle this, the rate of social and free time activities must be increased during this final period. It is also suggested to frame the mission as a multi-objective endeavour, which importance and relevance go beyond the climb to the top of Olympus Mons.

The Mars500 psychosocial isolation experiment simulated a 520-day six-crew mission to planet Mars and provided precious data not only on the physiology of the crew but also on the psychological and social effects of close-quarter long-term isolation. The facility was divided into a interplanetary spacecraft, in a descent spacecraft and an environment simulating the Martian surface. Studies on the experiment found that one crewmember experienced depression symptoms, two others experienced abnormal sleep-wake cycles, while another reported insomnia and physical exhaustion [4]. Furthermore, the two crew members who had the highest stress and exhaustion levels were involved in more than 80 percent of the perceived conflicts with colleagues and mission control, showing how just one stressed crew member could potentially compromise a mission. Performance deterioration was also observed: the crew became increasingly sedentary and needed to spend more time resting. These problems, however, arise pretty early on, showing how pre-mission simulations could help find suboptimal candidates or identify the crew members who need extra support. The research data from this mission, however, has some limitations as the crew was not subjected to stressors like weightlessness, extreme danger and radiation, which has been shown to cause behavioural changes and reduce performance [8].

Sleep cycle disruption during the trip and on Mars is also a source of concern [9]. A Mars rotation, called "sol" takes 39 minutes and 35 seconds longer than the 24-hour day experienced on Earth. This added time has been shown to cause cognitive performance deterioration, irritability and sleepiness. Sleep disruption due to stress, noise and light causes health problems, such as increased cancer and diabetes risk. To mitigate this a pre-journey training to adapt the internal clock to the Martian sol might be is needed. On the spacecraft, blackout curtains and light simulation should be implemented and sleeping pills should also be taken into consideration in case of insomnia.

Taking into consideration psychological aspects, it is clear that the main selection criteria for the crew are the ability to work well in teams and understanding how to live peacefully in a group, as well as emotional stability and composure under stress. While mind-enhancing supplements, which improve memory and mood [10], as well as computer-aided treatments to mitigate depression and interpersonal conflicts show promising results [11], it is suggested to recruit someone with advanced knowledge in psychology and behavioural sciences. Crew sizes of the aforementioned isolation experiments range from 3 to 6 and experts in human factors also suggest that a Mars mission such ours could be feasible with 3 people but a diverse, mixed gender crew of 6 is a safer, more reliable and appropriate choice [12].

III. Physiological aspects

A. Atmospheric regulation

Maintaining a breathable, stable atmosphere is one of the most immediate requirements for human-rated missions. Every astronaut needs 0.83 kg of oxygen (O_2) per day [13], with a partial pressure of at least 0.2 atm to be able to saturate the the haemoglobin in the red blood cells, [14]. Furthermore, every crew member exhales around 1 kg of carbon dioxide (CO_2) per day, along with trace amounts of other metabolic contaminants and water vapor which has to be dealt with, [13].

Space missions lasting days-weeks usually handle atmospheric regulation by bringing pure oxygen stored in tanks along with lithium hydroxide canisters for CO_2 filtration. The duration of the proposed mission at 985 days requires far more sophisticated solutions in order to save mass.

The components chosen for this mission are the proven technologies of the Environmental Control and Life Support Systems (ECLSS) on the American part of the ISS. This ECLSS currently consists of; Oxygen Generation System (OGS), Carbon Dioxide Removal Assembly (CDRA), Carbon dioxide Redyction System (CRS), and the Water Recovery System (WRS) mentioned later in this paper, [15].

The OGS works by electrolysing water (H_2O), producing pure O_2 and H_2. The CDRA absorbs CO_2 from the atmosphere. The CRS closes the loop of the atmospheric regulation by reducing the captured CO_2 to H_2O and methane (NH_4) using the Sabatier reaction.

No system is 100% reliable, and for a mission of 985 days plenty of spares must be brought to increase the robustness of the mission. Based on recommendations from NASA, [15], 3 spares should be enough for this project. Based on this paper a total mass for the atmospheric regulation system including 3 spares could be calculated, recalculating from 4 crew members to 6.

OGS	Daily [kg]	Full Mission [kg]
	5.04	1 873

CDRA	Daily [kg]	Full Mission [kg]
	10.5	663

CRS	Daily [kg]	Full Mission [kg]
	4.92	986

The current efficiency of O_2 recycling on the ISS is around 40%, [13]. Thus, 60% of the oxygen required for a crew of 6 for 646 days of Earth-Mars transit needs to be included in the total mass. With a daily need of 0.83 kg/person and an aditional 10% margin added for safety, an additional 2123 kg was added to the total mass.

	Full Mission [kg]
Atmospheric regulation	5 645

B. Water

Having a reliable supply of potable water is the most important life support element after oxygen [13]. A minimum of 2 kg of water per day per crew is needed for survival. A mass of drinking water is also needed for food preparation and rehydration, depending on the dehydration level of the food that will be transported. Finally, water is also used for personal hygiene (washing, shaving, flush water, etc.).

To save on launch mass and to design a highly reliable life support system, the system chosen for water supply and water recovery is the ISS's ECLSS Water Recovery System (WRS) [15]. The system is a partially closed loop and consists of a Urine Processor Assembly (UPA) and a Water Processor Assembly (WRA). The UPA implements a low-pressure vacuum distillation process to extract the water contained in urine. The process occurs within a rotating distillation assembly - needed to compensate for the absence of gravity - that separates liquids and gasses in space. Processed water from the UPA is then combined with gray water - that is respiration and perspiration condensates and used wash water - and is sent to the WPA. The water is filtered and gases and solid material such as hairs are removed and the remaining contaminants and microorganisms are eliminated thanks to a high-temperature catalytic reactor assembly. Water purity is finally checked with electrical conductivity sensors and sent back for filtration if the levels of contaminants are unacceptable, while clean water is stored in tanks.

To calculate the amount of water that needs to be stored at launch, the efficiencies of the UPA and the WPA are assumed to be 80% and 99% respectively [15]. By computing the inputs and outputs of the system and adding a safety margin of 10% a daily 0.5 kg per crew member is needed to be stored.

For the onward trip (341 days) this equates to 1013 kg. For the stay on Mars (339 days) and the return trip (305 days), 1007 kg and 906 kg need to be extracted or produced using the available facilities on the Martian base, respectively. Solid, non-recyclable waste is stored and expelled only when in space, to not contaminate the Martian environment with microorganism.

The WRS system has a total mass of 1383 kg. To ensure the system will work for the entire mission duration, a sufficient number of spares are carried on board and the total mass of the WRS including them is 5082 kg [15].

	Mass / CM day [kg]
Drinking, food preparation	2.38
Urine flush water	0.50
Wash water	1.29
Water consumption	4.17
Waste water	5.57
Water recovery output	5.12
Water stored with margin	0.50
	Total mass [kg]
Launch mass	6095

For the climbing phase of the mission on Mars, carrying the ECLSS and the spares would not be mass effective. It is therefore assumed that the ECLSS racks (shown in Fig. 1) can be disassembled from the spacecraft and safely stored with the spares on the base facilities. The necessary oxygen and water for this short phase will, therefore, be simply stored in tanks on board.

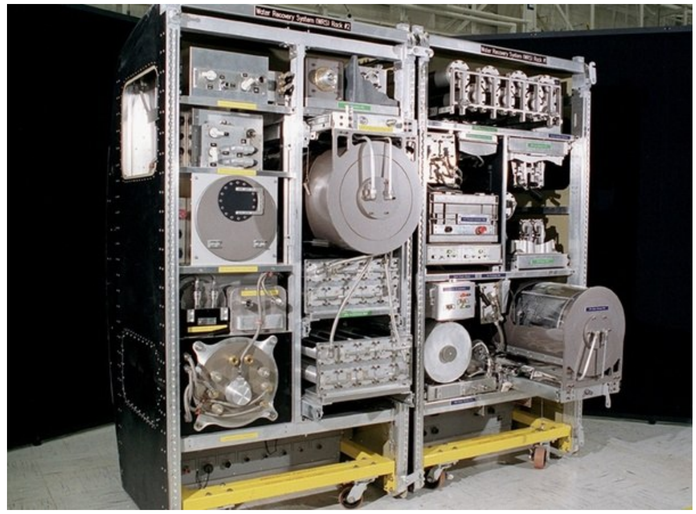

Fig. 1: WRS system housed in two of the three ISS's ECLSS racks

C. Food

To be healthy, humans need a balanced and nutritious diet. The importance of a healthy diet becomes even more apparent in the harsh environment of space. It can help counteract negative physiological effects of spaceflight such as loss of body mass, as well as having positive effects psychologically [16] [13]. The food should contain approximately 12-15 % protein, 50-55% carbohydrates, and 30-35% fat. Other nutrients, such as vitamins and minerals are also important and generally follow the same levels as Dietary Reference Intake on Earth [16] [17].

While the total required caloric intake will vary somewhat and depend on age, gender, and weight [17], the necessary food can be approximated as 0.7 kg of dry mass and 2.3 kg of water per person and day [13]. It is clear that the amount of water has the biggest impact on the total mass, and it can be reduced through dehydration. For dehydrated food, the water is removed during processing and then re-added before consumption on the spaceflight [18]. An average dehydration level of 75% was assumed for this mission, thus bringing the water content down to 0.575 kg per person and day. While it is possible to increase the dehydration further, this gives room for a larger variety in the menu.

The total mass for food can now be calculated for a crew of six and a 985-days long mission. A 10% redundancy is added for safety.

Food	Daily [kg]	Full Mission [kg]
Individual	1.275	1 382
Crew of six	7.65	8 289

To make the handling and preparation of food as effective as possible, items are pre-packaged as single servings. Failure of the packaging could potentially damage the entire food supply and thus devastate the mission [16]. The packaging therefore has to be stable to endure variations in temperature and pressure, leakage-proof to avoid contamination and spoilage, minimize risk flammability and off-gassing etc. All this while remaining as lightweight as possible [17]. The mass of the packaging is assumed to be 0.25 kg per person per day. The mass for packaging is then calculated in the same way as the food. However, it is possible that future improvements in material sciences could reduce this weight further.

Packaging	Daily [kg]	Full Mission [kg]
Individual	0.25	271
Crew of six	1.5	1 626

The total mass for the food is thus 8 289 + 1 626 = 9 915 kg. This number agrees well with other studies. For example, a 2.5-year Mars mission with a crew of six and using NASA's current food technologies was estimated to require 9 660 kg, out of which 8 220 kg was for food and 1 440 kg for packaging [18].

Besides being highly nutritious, the food brought on this mission has to last for a long time. It therefore has to be treated. Dehydration will be the main strategy for prolonging the shelf-life of the food, in addition to reducing the mass. However, food products with higher water content can be thermostabilized instead. Some natural form foods, such as nuts and biscuits, as well as intermediate moisture foods such as dried fruits will also be allowed [17] [18].

Variety in the menu was mentioned earlier and is another important factor for a long mission such as this one, since it is vital that the astronauts remain interested in the food and keep a normal appetite. If the food is deemed too boring and the astronauts lose interest in eating, the risk of severe body mass loss is increased which in turn carries many other risks [16] [18]. Even though a combination of food preparation technologies will be used to increase diversity in the food products, that might not be enough to keep the astronauts interested.

Fig. 2: Sample of packaged dehydrated space food

Alternative technologies, such as sounds and lightning can affect how food is perceived and improve the enjoyment [19]. Virtual reality systems could perhaps be used for this. In addition, having things to look forward to can help psychologically [20]. In terms of food, this could possibly be achieved by having 'special meals', for example traditional foods for cultural holidays and birthdays.

The alternative to bringing all the food is a closed or partially closed food system, i.e. producing food during the journey. The main strategy for this would be to grow different kinds of crops. However, those systems do not become advantageous in terms of mass and costs until after 6-8 years [13]. As this mission is less than three years, the open loop system remains the best alternative. Nevertheless, the crew should still perform experiments with growing plant-based food both during transit and on Mars. This will mainly be for psychological reasons, rather than nutritional, as tending to plants and having access to fresh produce can improve the mental state of astronauts [13] [18]. For the transit, the aim should be to grow plants with as high edible biomass as possible, short growth period, and high satisfaction when consumed. Examples for this could be lettuce and strawberries [13] [21] [22]. While this can continue on Mars, there it may also be possible to try to grow other types of plants such as potatoes or wheat. The technology which will be used for plant growth is aeroponics which does not require any soil [23]. The aeroponic garden will has a volume of approximately 1 m^3, a water requirement of 1.8 litres per day, and a mass of 100 kg [24]. It may be possible to reduce the mass by using an inflatable system [25].

IV. Bone loss and muscle deterioration

In general, bone is lost at a rate 1-2% per month in microgravity, mainly in weight bearing bones such as pelvis and femur. After 6 months, the loss is often around 8-12%. Do note that these numbers are when two hours daily exercise is included. Recovery of bone mass takes a long time once back in Earth gravity. Most recover within 3 years, but some never recover fully [26]. The percentage and location of bone loss during space flight is very different from person to person, the same with the reformation after return to gravity. There are also individual differences regarding the ratio of lost trabecular bone to cortical bone [27].

Medically, bone density is often described in terms of a T-score, where the basis is the bone mass of an average, healthy 30-year-old. A higher score means a density higher than the average, and the reverse for a lower score. Osteoporosis is defined by WHO as a T-score 25% or lower than the average. A score 10-25% below is defined as osteopenia [28]. A mission to Mars (approx. 2.5 years) might lead to bone densities at levels of osteoporosis. There are also concerns that the bones might deteriorate so far that it will no longer be possible to rebuild the internal architecture, i.e. the trabecular bone, once returned to gravity [26].

This mission consists of 646 days in microgravity (341 + 305 day) and 339 days on Mars where the gravity is 0.375 that of Earth [29]. To estimate the levels of bone loss, a loss rate of 1-2% per month while in microgravity, a regeneration rate of 0.375 compared to Earth, and a 3 year recovery period on Earth are all assumed. The loss can thus be estimated:

Phase 1: Earth to Mars, 11-22% bone loss.

Phase 2: On Mars, 11.5% bone reformation.

Phase 3: Mars to Earth, 10-20% bone loss.

Using these estimates, a best case scenario for remaining mass is calculated as

remaining mass = $1{\cdot}0.89 \cdot 1.115 \cdot 0.9 = 0.893 = 89.3\%$,

while a worst case scenario is calculated as

remaining mass = $1{\cdot}0.78 \cdot 1.115 \cdot 0.8 = 0.696 = 69.6\%$.

In other words, the best-case scenario is a total bone mass loss of 10.7%, while the worst-case scenario is a total bone mass loss of 30.4%. If it is assumed that the bone density of all the astronauts is that of an average, healthy 30-year-old, the best case leads to light osteopenia, while the worst case would lead to osteoporosis. The main risk for this mission is the high levels of bone loss on the way to Mars. While it will not reach full osteoporosis, it will be quite close. This means an increased risk of fractures, which in turn could pose a huge risk during the summit of Olympus Mons. This risk is returned to in the off-nominal scenario below.

It is obvious that countermeasures are necessary. Apart from resistance exercise, some potential countermeasures are

- exposure to UV light as Vitamin D is formed in the skin when exposed to sunlight, and Vitamin D in turn stimulates calcium absorption,
- making sure the CO_2 levels are as low as possible decreases the risk of acidosis, as acidosis increases bone resorption due to the neutralizing effect of carbonates and phosphates in the bone,
- dietary supplements with calcium, vitamin D and vitamin K,
- vibration therapy with low magnitude and high frequency [26],
- antiresorptive drugs such as bisphosphonates [30].

Muscle mass is also reduced during spaceflight. However, after 4 months in microgravity it seems the muscle mass and strength has adapted and reached a steady state. At this point, the mass has been reduced by 30% and the strength up to 50%. Once again, this is with daily exercise included. When returned to gravity, there is often muscle soreness and tightness and once returned to Earth gravity, muscle recovery takes 1-2 months [26]. If the muscle mass regenerates at 0.375 the rate of Earth once in Mars gravity, it should then take approximately 3-5 months for the astronauts to regain their strength. From this perspective, it was therefore proposed by Human Aspects that the first five months on Mars will be spend training and regaining strength after which the climb of Olympus Mons can be attempted.

Even though the muscle mass is not as affected by microgravity as the bone mass, countermeasures are still necessary. The main countermeasure is a combination of resistance and aerobic exercise. A nutritional diet is also very important. Other potential countermeasures are dietary supplements with protein and amino acids, and pharmaceuticals such as testosterone or myostatin inhibitors [26] [31].

It would be preferred if both bone loss and muscle mass deterioration could be reduced using the same countermeasure. One such could be neuromuscular electrical simulations (NMES), [32]. The NMES technology uses adhesive skin electrodes to evoke muscular contractions. However, it is yet to be tested in a space environment.

A. *Exercise equipment*

To mitigate muscle deterioration three different machines will be brought. They are all similar to the equipment that is currently used on the NASA side of the ISS. The idea with bringing several machines is to provide means of exercising both cardiovascular endurance as well as muscle strength. It will also allow for the astronauts to exercise together as a social activity.

The first machine is the Combined Operational Load-Bearing External Resistance Treadmill (COLBERT), [33]. This is a treadmill with a built in Passive Rack Isolation System (PaRIS) that use two-stage isolators to absorb the shocks and keep them from interfering with other equipment on board. Apart from the isolation system and the elastic harness that keeps the astronaut from floating away it is very similar to a generic treadmill used on Earth. The main usage of COLBERT is cardiovascular exercise but it is possibly also helpful for mitigation of bone loss. One big drawback of COLBERT is that it is very heavy, one treadmill weighs almost 1000 kg.

For exercising the muscles of the astronauts the Advanced Resistive Exercise Device (ARED), will be brought. Usage of the ARED allows the crew to exercise all major muscle groups and the idea is that it mimics free-weight training on Earth. With the use of piston-driven vacuum cylinders and a flywheel the astronauts can do dead lifts, squats and calf raises. The ARED is very heavy, it weighs 700 kg, but since it is the only weightlifting machine available it is deemed necessary to keep the muscle loss at a minimum.

The last machine for this mission is the Flight ergometer (FERGO). This is a bicycle that similarly to the COLBERT has a built in vibration isolation system. This particular model is an updated model of the CEVIS-bike currently in use on ISS. This is a very effective way for the astronauts to exercise and the biggest advantage is its very low mass of only 27 kg.

All of these machines works in μ-g as well as with gravity, this will allow the astronauts to use them both in transit and on the surface of Mars. This is important since the first time on Mars will be spent adapting to the martian gravity and rebuild muscles lost during the travel.

V. Radiation

A. *Introduction*

One of the biggest long-term dangers of space exploration comes from increased rates of radiation. Three major contributors to this are: Solar particle events (SPEs) where charged protons and other elements are ejected from the Sun and launched into the solar system, Galactic cosmic rays (GCRs) which are high-energy particles from outside the solar system, and charged particles trapped in Earth's van Allen belts, [13].

The mechanism behind SPEs is not fully understood and it's not yet possible to predict when they will occur. However, their frequency seems to be related to the solar cycles with more occuring during a solar maximum and fewer during a solar minimum. During a solar maximum, the output of material from the Sun balances GCRs to some extent, leading to a decrease in total radiation levels in the solar system.

The dangers involved with these phenomena revolve around increased risks of developing cancer, cardiovascular disease, and various other medical problems issuing from damage to cell structures and the genetic material of the astronauts. Even acute radiation sickness can occur from short-term exposure to energetic events, leading to nausea, headaches, mood-swings and a general decrease in performance, [13].

The annual dose received on Earth varies depending on where you are, with an average 0.3 mSv/year at standard sea level up to 3-4 mSv/year in the United states, [34].

Going into space dramatically increases the radiation dose received, with a 6 month stay on the ISS leading to an average 80 mSv during a solar maximum and 160 mSv during a solar minimum.

Human journeys beyond the van Allen radiation belts has not happened since the end of the Apollo-program, and as such the effects of interplanetary travel on the human physiology is poorly understood. A multitude of unmanned probes have been sent beyond this point, including NASA's Mars Science Laboratory (MSL) launched in 2011. Data collected with the Radiation assessment detector during the MSL transit to Mars shows a dose equivalent of 1.84 mSv/day, calculated from both SPEs and GCRs during solar maximum, [35]. With the predicted 646 days in space for our mission, a total dose of at least 1.2 Sv is to be expected. This value would represent a lower limit, taking note that our mission will occur during a solar minimum where the radiation dose could increase dramatically. A further 339 days on the Martian surface could add another 0.3-0.4 Sv in an unshielded habitat, based on predictions for surface radiation, [36].

B. *Mitigation*

Current technology of decreasing radiation takes the form of shielding material surrounding the astronauts' habitat. Polymers and metal alloys are common, and layers of 5-7 cm might decrease radiation by about 30%, [13]. However, conventional shielding only works up to a certain thickness, as the interaction between high-energy particles from GCRs and the shielding material has a cascading effect leading to more particles being released, [13] [37].

For this mission, a 5 cm layer of Lithium metal hydride, commonly found surrounding nuclear powerplants, was chosen. This would bring the radiation dose down to 2 mSv/day based on the solar minimum radiation environment of 1977, considered a worst-case scenario for space travel, [38]. With this predicted daily value, a total dose of 1.97 Sv can be expected for the whole mission. See the report for *Vehicle design* for further details on mass and dimensions of radiation shielding.

An additional source of protection could be to use the water-production systems at the Martian base camp to surround the habitat with blocks of ice, creating an igloo-like structure as envisioned by NASA Langley research centre, [39]. Using material on the surface could decrease the mass of the descending vehicle for a future mission, making it an attractive alternative. Water ice provides a moderate 10% better protection than conventional shielding, bringing the total mission dose down to 1.78 Sv, [37]. However, due to the design of the descent vehicle the surface habitat will be the same as during the Earth-Mars transit with LiH shielding, so a closer look into further protection was not considered necessary.

The current ESA career limit for radiation is 1 Sv. Assuming no new technologies arrived that could drastically increase protection, this limit will be surpassed for astronauts going to Mars. Alternative methods for protection include screening astronauts for beneficial genetic traits, skewing crew composition towards older men, and digging into the martian surface to avoid exposure. So far, genetic components controlling radiation tolerance is largely unknown, aged astronauts might suffer more from other issues such as increased bone loss, and digging into the surface of Mars would require tremendous amounts of work and equipment. Although the predicted radiation dose of 1.97 Sv exeeds ESA limits it is not immediately fatal, and keeps within career limits proposed by other space agencies which varies between 1-4 Sv, [13].

VI. CLOTHING IN SPACE

A. *Space suit*

Space is a very harsh environment and humans cannot survive there without protection. This protection will for the majority of this mission be the spacecraft or the habitat on Mars. However, the goal of the mission is to climb Olympus Mons and therefore protection is also needed during the climb, i.e. a space suit. There are three main requirements that the suit need to fulfill for it to be suitable for this type of mission.

Firstly, and most importantly, it need to protect the astronauts from the harsh environment on Mars and be equipped with a life support system that satisfies the needs for human life. This will include oxygen, CO2 removal, and a temperature control system.

Secondly, it need to be light weight. Most of the suits currently in use on ISS weigh over 130 kg. If an astronaut were to wear this type of suit on Mars it would be like carrying a 50 kg backpack. This would be to heavy for the explorers and therefore a more lightweight version must be used. Lastly, since the astronauts are walking long distances through rocky, uneven terrain, the maneuverability of the suit is key for mission success.

1) Biosuit: A literature review of existing and upcoming projects was conducted and a suit that is assumed to fulfill all the requirements by 2039, when this mission is to be conducted, is the Biosuit. This is an ongoing project lead by Dr Dava Newman a professor at the Department of Aeronautics and Astronautics at Massachusetts Institute of Technology (MIT), [40]. She has a Ph.D. in aerospace biomedical engineering and has been the principal investigator on 4 spaceflight missions on the Shuttle, MIR, and ISS.

This suit that her team is working on is a mechanical counter pressure suit. It is a skintight suit that is pressurised using elastic-tension, [41], instead of the more common gas-pressurization. It is patterned from 3D-laser scans and is lined with tiny nickel-titanium coils that resemble muscles. When the coils are activated the suit will shrink around the astronauts body supplying the pressure needed. Unlike the normal gas-pressurised suits this suit will be very lightweight and allow for maximum mobility and flexibility for the astronauts.

Fig. 3: Biosuit and helmet concepts by MIT

B. Clothes and washing

Apart from the physiological needs of the astronauts during this mission they will also need clothes and some mean of cleaning them. The comparisons of different materials and methods mentioned in this section is mostly based on the research done at NASA by Ewert and Jeng [42].

The environment on board a spaceship is minutely regulated and the air is very clean. This is a positive thing when it comes to personal hygiene. Since the air is so clean and the temperature is set at a comfortable level the astronauts wont get as dirty and sweaty as people get down on Earth. Therefore it is not necessary to change clothes as often.

Currently on the ISS many of the astronauts use their own normal clothing and when they have used them they simply put them in storage and bring it back to Earth when they return, alternatively they release it so that it burns up in the atmosphere when reentering. For many reasons this is not an optimal method for this mission.

In their report Ewert and Jeng, [42] compare the conventional clothing (baseline) used by astronauts on ISS today with what they call advanced clothing. This is clothes made from antimicrobial materials such as merino wool and bamboo. By using the advanced option of clothing the usage rate, that is the number of uses needed before an item needs to be cleaned, can be increased. For a long duration mission, assuming disposable clothing, simply using better materials the weight of clothing per crew mate would decrease from 220 kg to 150 kg. This is still considered too heavy and disposable clothing is therefore not a suitable option.

Instead different options for cleaning the clothes are compared. As Ewert and Jeng argues the usage of a conventional washing machine that uses water would be the most effective and gentle method and the clothes could then be rewashed up to 100 times. However this method would require huge amounts of water and is therefore deemed unsuitable for this mission. Instead alternative methods are examined and the one that is deemed suitable is a vacuum sanitation chamber designed at Lamar University. Most microbes cannot survive in vacuum and their tests show that E. coli bacteria are eliminated after 45 min of exposure. Since this method is new and not fully tested the number of washes before an item need to be discarded is reduced to 5, note that this is not 5 days but 5 washes after item has been used its full usage time. With this option the mass per crew mate is reduced further to 50 kg for a 1000 day journey. The results from Ewert and Jengs comparison is showed in figure 4. What is important to remember is that the weight of the water needed is not included in the water-based laundry option. If this was included the weight would be higher than that of the sanitizer system that was chosen for this mission.

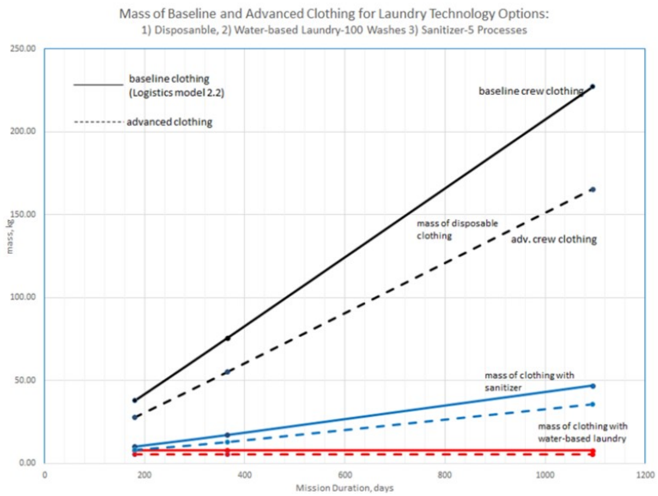

Fig. 4: Image from [42] showing comparison of baseline clothes vs advanced clothing as well as comparison between different laundry techniques.

VII. Off-Nominal Scenario

As mentioned earlier, the astronauts will be subjected to considerably reduced bone and muscle mass. Because of this, they are at a higher risk of accidents such as fractures, sprains, and strains. Out of these, the main concern is bone fractures due to the high risk of getting or at least approaching osteoporosis. While this poses a potential risk throughout the mission, the main risk is presented during the climb of Olympus Mons.

Four astronauts will take part in the expedition to the summit. Most of the climb will be performed in rovers, but in accordance with the rules of the challenge, the last kilometre in altitude has to be performed on foot. During this final leg of the journey, the astronauts will be exposed to rough terrain, where they might trip and fall. Under normal physiological circumstances that would probably not be an issue, but with the reduced bone density they might hurt themselves severely. The lower gravity on Mars could reduce the risk of fractures as a fall would not be as hard, but it remains unknown how the bone loss and lower gravity will counteract each other in terms of risk mitigation.

Since the medical facilities available to the astronauts during the mission will be very limited, potential bone fractures has to be avoided. However, the risk cannot be fully eliminated. A combination of countermeasures and procedures are therefore necessary. The main countermeasure is reducing the loss of bone mass as much as possible. For exact countermeasures, see the chapter on bone loss and muscle deterioration. As already mentioned there, the climb will take place around 5 months into the stay on Mars. At that point, the astronauts will have gotten used to the new environment, working in their suits and walking on the often rough surface. Although the bone mass will not have been able to fully regenerate during this time, the muscle mass should be back to a normal level. Strong muscles will support the astronauts' bodies and thus reduce the risk of accident. It also means that they will not get tired as fast as if the climb would be performed soon after arrival, which in turn also reduces the risk as they can remain focused while walking. Nevertheless, it will be important that the climbers walk slowly and carefully, taking their time when summiting the mountain. If they become stressed and start hurrying, the risk of accidents likely increases. The same thing applies if they become tired, at which point they must rest. The journey therefore has to be planned with a lot of margin in terms of time and thus also oxygen, water, and food. If an accident resulting in an injury such as a fracture was to occur, medical supplies have to be available in the rovers. Examples of necessary supplies includes splints, bandages, painkillers, a stretcher etc. All those participating in the climb have to have the proper education to handle a medical emergency situation and know how to perform first aid on a fracture. If a fracture does occur, the main steps of action will be to stabilize the patient and move them into one of the rovers where further care can take place. Depending on when and where the accident occurs and the severity of it, it may be necessary to abort the climb. However, the exact procedures for when to abort the climb will be developed in collaboration with the astronauts, taking their feeling on the matter into account.

VIII. Results and discussion

The final mass of the human-centered payload ended up at 24 125 kg.The largest contributor, and possible candidate for mass reduction is the water needed to sustain the crew. Since the mission includes a water supply on the Martian surface, further dehydration of the food required for the surface operations would save weight. Having the astronauts grow their own food is a tempting idea, but as it stands today the water required for such a task would be higher than what is needed for prepacked food.

System	Total mass [kg]
ECLSS	10 727
Food	9915
Water	1013
Exercise equipment	1730
Clothes	240
Washing machine	200
EVA suits	300
Final mass	24 125

Refining of the ECLSS technology might lead to some savings. The 90% efficiency of the water reclaimer might be difficult to improve, but today oxygen revitalisation only work at 40% efficiency, offering ample room for improvements in the coming years.

A final way to reduce mass, if it was required by mission design, could be to remove the COLBERT and replacing it with another FERGO. This would reduce the weight with almost 1000 kg and by bringing an extra ergometer the crew could still work out together and they would not loose the social benefits.

These results does not cover the mass of medical equipment and medicine, scientific equipment, personal items and leisure for the crew, or other non-vital aspects of the mission. However, the total mass of these items would likely be much lower than the aspects considered here.

IX. Conclusion

With a final mass of 24 125 kg, the human-centered payload would be able to sustain our six astronauts for the entirety of the mission. Though not a complete list of requirements, the results presented in this paper outlines the order of magnitude of mass for the survival of a crew going to Mars and back.

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