Low Mass Human Mission to Mars Blue Team - Human Aspects Report

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***Abstract*—As a part of the CRIMSON (Crewed Return Interplanetary Mission for Surface Observation and New research) Project with the aim to help two explorers and adventurers, Tina and Tom Sjögren to explore Mars, one of the essential parts to discuss is the human aspect. Human Aspects is a vital area in any mission as this focuses on the health and safety of the astronauts. This report covers the specific topics of the training required for the crew before mission, the life support system on the shuttle to Mars, and the key health aspects. Inspiration form the International Space Station (ISS) was used for several systems in the Life Support System (LSS) within this mission. Due to the proximity of the launch date only systems and theories that are currently in use were included. This paper summarizes these areas and touches on their functionality and reasoning as to why or why not each of these were chosen to be included.**

***Index Terms*—Interplanetary, Human Spaceflight, Human Aspects, Life support systems**

NOMENCLATURE

ARS Air Revitalization System

$ATCS$ Active Thermal Control System

$CDRA$ Carbon Dioxide Reduction System

$ETHOS$ Environmental and Thermal Operating Systems

ISS International Space Station

LSS Life Support System

OGA Oxygen Generator Assembly

OGS Oxygen Generating System

$ORCA$ Oxygen Recharge Compressor Assembly

PBA Portable Breathing Apparatus

PFE Portable Fire Extinguisher

$PTCS$ Passive Thermal Control System

RSP Respiratory Support Pack

UPA Urine Processor Assembly

VCD Vapor Compression Distillation

WPA Water Processor Assembly

WRS Water Recycling System

I. INTRODUCTION

Even before the moon missions there have been ideas of sending humans to the Red Planet, Mars. The reason why Mars is so interesting for space research is the fact that there is evidence that indicates there exists water on Mars, which in turn most likely means that there existed or exists life on mars. There is now a race between different companies and different countries on who will be first to send humans to Mars. One of those companies is Pythomspace, and this project is performed to help them design their mission.

There are a lot of aspects to take into consideration for this type of long duration interplanetary mission. The aspects are even more comprehensive and complex when sending humans to Mars, compared to the earlier unmanned mission. That is what this report is going to treat, what has to be considered for the human aspect. This project has been carried out by a team, consisting of six different groups, who have designed this mission for different aspects. The different groups were Overall coordination, Logistics, Transfer, Mars operations, Mission design and Human aspects, the topic of this report.

When traveling to mars there are two different transfer options, one for a long stay and one for a short stay. For this project the long stay option is going to be considered, with a total mission duration of 1007 days, where 23 of those days are going to be spent on the Mars surface.

This mission is a two human crew mission with the vision to go to Mars within the next five to six years and to make it as simple and low-mass as possible. The two-man crew will be Tom and Tina Sjögren, who are two explores and adventurers, and founders of Pythomspace.

For the human aspects of this mission there is a lot to take into consideration. No human has ever been in space for this long, which makes it hard to predict what effects this will give on the human body, both in a physical and psychological aspects. The micro gravity makes a lot of everyday activities much more complicated than they are on Earth and for those, solutions have to be found.

This report will handle issues such as the necessary training before the mission. Also, what LSS that are required to complete this mission, such as the air management, thermal control, water, food management, clothes, hygiene and waste. The report will also include research about the health impact of this mission, handling topics such as the psychological aspect, medical aspect, exercise and radiation. A brief discussion about a off-nominal case is presented before the conclusion. The report is finished up with the workload of this project.

II. Crew training

In this section we will discuss in detail the training we have considered necessary for the two members of this mission, Tina and Tom Sjögren. First of all, we consider it necessary, even if these two adventurers are already very experienced, to give them psychological and medical tests to make sure that they are able to carry out this long term mission (knowing that they will be about 66 years old at the time of the planned departure of our mission). Next, we have listed the main areas that require specific training so that the two astronauts are able to react in any situation. The list is as follows: maintenance and repair, handling of emergencies, medical issues, piloting, robotics, etc.

It was decided to build a training program divided into 3 phases, based on the ESA program [1]. It has been taken into account that Tina and Tom Sjögren already have many scientific and technical skills that do not necessarily require additional training, including strong skills in hostile environment survival, software and hardware technologies and mission design. So, initially our astronauts will have to do a short first phase called Basic Training to review some of the science that might be useful during the mission and also to do the first parabolic flights and learn how to do an EVA, a duration of about 6 months (maybe less) was set for this phase. Next, was established a 24-month phase called Pre-Assignment Training to train the astronauts in more specific areas where they may have less initial skills, such as robotics, maintenance, medicine, or to learn the operation of systems that will be used during the mission. During this phase, numerous EVA training sessions will also be carried out (probably in NASA's Neutral Buoyancy Laboratory in Houston, USA). Finally, until the departure of the mission, a phase of specific training for the mission begins (lasting about 12 months) in order to learn and organize what experiments they will have to carry out during the mission, to prepare for the tasks they will have to carry out once on Mars, and any other training necessary for the successful completion of the mission. All the proposed duration are estimates that may vary according to the progress and skills that the astronauts have already achieved, so it was conclude that the duration of the training should be around 3-4 years.

III. Life support system

A. Air management system

Ideally, a fully closed loop system would be the optimal life support system for deep space travel however, as the technology is still in development this is not possible and will not be ready by the launch deadline. As a result, it was determined that it was necessary to choose from systems already in use as they have been proven to be safe and reliable. The International Space Station (ISS) is the perfect example. This spacecraft usually houses 6-7 astronauts for extended periods of time, it protects them from the vacuum of space, provides air for them to breathe and removes carbon dioxide all while maintaining the atmospheric environment. The two main systems on the ISS that are responsible for the above are the Air Revitalization System (ARS) and the Oxygen Generating System (OGS). The ARS contains several subsystems that optimize the air quality as well as links to the water recycling. This system removes trace amounts of dangerous contaminants from the environment, it monitors levels of various particles in the atmosphere such as nitrogen and oxygen, and it selectively removes carbon dioxide [2] [3]. Systems such as the Environmental and Thermal Operating Systems (ETHOS) will also been integrated in order to ensure that the cabin is maintained in a way that resembles Earth. This means that the Nitrogen and Oxygen levels within the cabin are monitored and kept to be around 78% Nitrogen and 21% Oxygen as breathing in pure O2 over extended periods of time is very harmful to the human body [4]. The mass of this system is estimated to be 337.8 kg and spares associated with this system will be touched on in section H, 'Additional Supplies'.

From a study utilizing the current ISS LSS on a mission to Mars [5] it was concluded that the OGS was inefficient due to its mass as well as the amount of extra components required to be brought along in order to reach certain risk margins. In the study, the duration of the mission was shorter than the length determined for this project and the amount of people was double. Using the same calculation process as in the study, if 4 people were travelling to Mars in this project then the OGS might be an asset however as there are half the number of people, the amount of oxygen needed is much less and therefore makes it lighter to supply rather than trying to produce it by means of the OGS. The Carbon Dioxide Reduction System (CDRA) is currently not efficient enough as it only has the capacity to recycle less than 50% of the carbon dioxide in the cabin back into oxygen and the remainder must be produced from electrolysis [6]. The benefit of not utilizing the OGS is that the two systems within it, the Oxygen Generator Assembly (OGA) (which performs the electrolysis) and the Sabatier, will both not need to be flown out. The Sabatier is no longer useful as its purpose is to take carbon dioxide and the hydrogen from the electrolysis and produce methane and water which then gets filtered and goes through the electrolysis cycle again. If there is no OGA, there is no hydrogen production for the Sabatier reaction. A clear mass breakdown of these systems can be found in Reference [5] under Appendix A. It should be noted that the mass calculations would not change as the same system would be used in this mission however, the machines would not be working as hard as there are less people using it compared to on the ISS, thus further extending its mass break-even date which was determined to be up to 100 days longer than the study's mission length which translates to roughly 100 days past this mission length as well [5]. The complete mass of the OGS, the mass of the necessary spares, and additional water that would need to be brought to produce the majority of the oxygen from electrolysis was approximated to be at least 3985 kg. The mass of just supplying the oxygen was approximated to be 2834 kg making that a 1151 kg mass savings. Comparing the volume of the OGS system and the volume of all the oxygen tanks, supplying the oxygen would also reduce this from 5.63 m^3 to 5.2 m^3. The mass of the oxygen supply including the tanks that would contain it is displayed in Table I. It should also be mentioned that the crew will be transferred to different vehicles, such as during landing on the Mars surface, and in order to transfer oxygen a system such as the Oxygen Recharge Compressor Assembly (ORCA) should be used.

B. Thermal control system

Exploring Mars is challenging because the temperature during travel and on the Mars surface itself is harsh. As a reference to the ISS, when it faces the sun, the temperature will be around 121 °C, and when it is on the shady side, the temperature plunges to –157°C [7]. In addition, the temperature in deep space can be at absolute zero, with an average temperature of 3 Kelvin due to no heat transfer [8]. A thermal control system and protection are required to ensure that components in the spacecraft work within an acceptable temperature range and also ensures that the cabin is comfortable and livable.

In the ISS, the thermal control and protection system consists of a Passive Thermal Control System (PTCS) and an Active Thermal Control System (ATCS). PTCS consists of external surface materials, multilayer insulation, thermal isolators, and heaters [9]. External surface material usually consists of protection paint or coating. Multilayer insulation is made from aluminized Mylar which functions as thermal protection and radiation protection.

Equipment and systems within the spacecraft will produce heat that must dissipate to space to prevent overheating. Heat will be dissipated by a cold plate or heat exchanger. ATCS works by pumping fluid such as ammoniac or water in a close loop circuit in the system to collect the heat, then transport the heat, and finally will be dissipated to space through the radiator [10].

Mars has relatively low temperatures compared to earth. It occurred because Mars has a relatively thin atmosphere where 95% consists of Carbon dioxide. In addition, Mars is farther from the sun than earth. The temperature on Mars will vary, with the lowest temperature being –140 °C and the highest temperature being 30 C, and on average, the Mars temperature is about –63 °C [11]. With this condition, the spacesuit for the crew should have a heating element to withstand this cold temperature.

The detailed thermal control system and dissipated heat on the spacecraft is described in the Logistic Team report, and the detailed space suit design is described in the Mission Design Team report.

C. Water

The Water Recycling System (WRS) was taken from that being used on the ISS. It was decided to use this system as it is quite efficient. It is able to recycle approximately 93% of the water, making it a huge asset in long term space travel [12]. This system provides clean water to the astronauts by collecting cabin humidity condensate from crew sweat, respiration, hygiene, and water from the ARS and ATCS as well as recycling their urine. This machine is made up of two parts, these being the Urine Processor Assembly (UPA) and the Water Processor Assembly (WPA). The UPA is the component of the WRS that recycles the urine while the WPA recycles the grey water [13]. The UPA is able to do this function by using Vapor Compression Distillation (VCD) technology to recover water from the pretreated urine where it then gets fed to the WPA [14]. The WPA treats the water by various technologies that consists of filtration, ion exchange, adsorption, catalytic oxidation, and iodination [15]. This process can be seen in Figure 1.

The WRS was a chosen system to include rather than others such as the OGS due to its mass payback period. The period for this device was around 200 days less than that of the OGS. Again, the mass breakdown for this machine can be found in Appendix A of Reference [5]. In the mass calculations for the amount of extra water needed for this mission, it was decided that 6.47 L overall per day per crew member was essential. This amount includes water for drinking, dehydrated food preparation, urine flush water, and wash water. Due to the system being able to recycle most of this, only 0.647 L per day per crew member is actually needed to be brought. The total weight of the WRS system along with the additional water that would need to be brought is approximately 2048.4 kg. Spares for the WRS are not included in this calculation as they are touched on later in section H, 'Additional Supplies'. In order to transfer water from the main shuttle to another vehicle Contingency Water Containers (CWC) will be used.

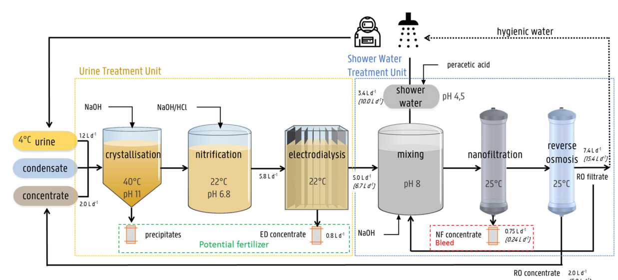

Fig. 1. The 5 stage treatment for water recovery [16]

D. Food management

One of the essential factors to support humans in space exploration is food. Failing to provide appropriate food risks hampering the space exploration mission and threatens the crew's performance [17]. During space travel, being exposed to microgravity for a long duration can also lead to adverse effects to the astronaut, such as muscle atrophy, weight loss, fluid loss, and osteoporosis [18]. Then, to help counteract that effect, providing sufficient nutrients is essential.

With only two crew members during the mission, it is not suitable to grow food during the travel. It will add additional workload and stress to the crew and extra mass for the growing equipment. Therefore, all the food will be prepared and brought from the earth.

Generally, humans require a 1900-3200 calorie intake per day to maintain their health [19]. However, the exact calorie intake per day varies based on age, gender, metabolism, and activity. For the long-duration mission, the nutritional requirement for food daily intake should contain balanced nutrients with $\leq$ 35% protein, 50%-55% carbohydrates, and 25%-35% fat each day [17]. In addition, space food should also be lightweight, compact, easy to prepare, tasty, and crumb-free. Food should have a long shelf life of at least three years to prevent nutrition degradation, risk of food spoilage, and illness.

The food that is suitable for this mission is rehydratable and thermostabilized food. Rehydratable food is processed food that has been dehydrated or freeze-dried. Thermostabilized food is heat processed food to destroy pathogens, microorganisms, and enzyme activity. Combining both food types is suitable because they have a long shelf, are easy to store, and are easy to prepare. Food will be pre-packaged into single servings and stored at room temperature. Before being eaten, food can be prepared by rehydrating with a rehydration station like in the ISS or simply heating it. The example of various space food can be seen in Figure 2.

Since not all nutrients required cannot be fulfilled during the mission, crews should take supplements or vitamins such as D and K. Vitamin D is required because the spacecraft is shielded to block ultraviolet from the sun, and the body is unable to create any vitamin D. Also, vitamin K is required to help counteract bone loss and muscle loss due to microgravity.

Instead of only having a nutritional function, food can also help counteract the psychological effects to avoid boredom. Food will be given as eight menu cycle days like on the ISS [20], and special occasion food such as for birthdays and cultural days will also be provided.

An astronaut requires about 0.83 kg of food per meal each day [21]. Then, the total food mass required for the entire mission can be estimated with the assumption that the worst scenario of the mission will last about 1007 days and with an additional safety margin of 10%. The food required will be 5.58 tons, with 16.75 m^3 volume.

Fig. 2. Various Space Station Food and Eating Utensils [22]

E. Clothes

The use of clothes in space differs a lot from how they can be used on earth. Laundry of clothes in space is not possible in the same way that it is done on earth. The reason is that the amount of water brought up to space has to be as small as possible, therefore doing the laundry in the same way as on Earth will use too much water. On the ISS the clothes are used until they are too dirty, they are then thrown out and burn in the atmosphere, that is not possible for this Mars expedition. There is instead two ways to handle the clothes for the Mars expedition, either the used clothes are compressed and stored on board or they can be sanitized or washed by using special methods. One drawback of the sanitizing methods is that the clothes can only be sanitized a few times and not hundreds of times like water washing. One way to reduce the mass of clothes is to use clothes called Advanced Clothing Items instead of baseline clothes. Those types of clothes are made of advanced antimicrobial fabric, mod-acrylic fibre and merino wool and can be worn up to 14 days. Compared to the baseline clothing items, the advanced clothing items, will decrease clothing mass per day with 23%.

There is a system called the Simple Micro gravity laundry system from [23] which has shown to be the best solution for this mission. A disadvantage with the Simple Micro gravity laundry system is that there is no heated air dryer, which means that the crew will have to hang or spread wet clothes in the vehicle to let it air-dry, which will temporarily take some space in the vehicle. Also, this type of water dependent laundry system will increase the amount of wastewater, which means that more water has to be brought up to space. The system has a mass of only 14 kg and a volume of 0.14 m^3. By doing laundry three times per week for the two person crew, the total weight of clothes for the two astronauts will be 49 kg and 26 kg for the non-clothing items which includes wipes, towels, sleeping bag liners etc, which gives a total volume of clothes and non-clothing items of 0.4 m^3. The Simple Micro gravity laundry system has a power of 90 W and produces 103 kg of wastewater per year which gives an amount of 285 kg for the entire trip. This means that 30 kg of extra water has to be brought to Mars because of the 90% recycling rate of the water.

Figure 3 shows the Simple Micro gravity Laundry system where the clothes are placed in between the laundry belts which are rotating, driven by the spring roller. Between those bands, the small amount of water needed for the laundry, is injected. Most of the water supplied into the system will be in the wet clothes when finished, which will be taken up by the air when drying, the water vapor is then sucked up by the air management system, which transfers the vapor to the WRS to be fresh water again. The remaining water in the laundry system is sucked up by the drain tube, which also is transferred to the WRS.

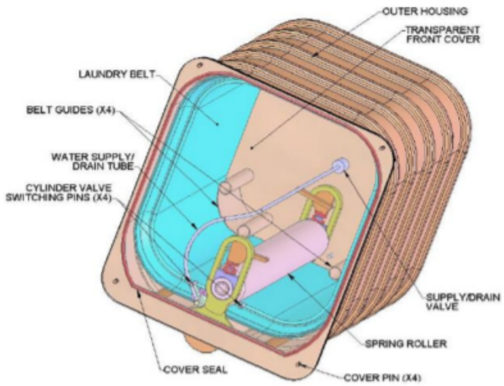

Fig. 3. Simple Microgravity Laundry System [23]

F. Hygiene

All the hygiene aspects that are taken for granted on Earth are much more difficult in space, due to the lack of gravity. As soon as water or other liquid is let out of its container it is floating around in the air and can later cause problems by damaging electrical objects for example. The way showering is done differs the most. The gel is applied on the skin together with water and is then rubbed onto the skin. The soap is of a kind that does not need to be rinsed of, instead it is enough to just wipe it off with a dry towel. This method is quite time consuming, so when in a rush it is possible to apply the soap on a wet towel and rub your skin with that one. The shower gel is provided into containers that are supposed to be enough for two weeks of showering. When washing the hair, a no rinse shampoo is used. First water is applied in the hair and then the shampoo is massaged, as it would be done on earth, and finally the hair is dried by using a dry towel. [24] Tooth brushing is done almost the same way as on earth except that the toothpaste is swallowed when finished [25]. It is assumed that the total weight of the hygiene articles for the two crew members for the whole mission is 47 kg, and volume is assumed to be 0.04 m^3. This includes 1.3 kg toothbrushes, 5kg toothpaste, 20 kg showering gel, 17 l shampoo and 7 kg of deodorant.

G. Waste

During a space mission there are a lot of waste to handle, especially for this type of long duration mission. There are wastes such as the food packaging, wipes, hygiene packaging etc. On the ISS waste is stored on board and then thrown out into the atmosphere where it burns up, like the used clothes. But this is not possible for a Mars mission. Instead all of the solid waste will be manually compressed and stored on board the spaceship. On the ISS classic plastic bags are used to pack the waste, those will also be used during this mission. [26] When those bags are filled with waste they are collected inside containers. It is important that those containers are fully airtight, so the crew does not get harmed by the decomposition process gases. There will also be waste generated by the toilet, which for this mission is the Universal Waste Management System (UWMS) and is the latest space toilet from NASA. This system is made to reduce mass and volume compared to the previous space toilet, with a weight of 50 kg and volume of 0.14 m^3. [27] Also, it has improved usability for female crew members, which is important for this mission where half of the crew is female. For the urine waste a shaped funnel and hose are used. The urine is then sent into the WRS, where it is cleaned and made to be drinkable water. For the faeces a seat is used. The faeces are collected into individual water tight bags that are compacted in a removable faecal storeable container, which are then stored on board the spacecraft. For both urine and faeces airflow is used to collect it. The faecal containers are able to collect 18 kg of faecal waste which means that it has to be replaced every 18 days. The total number of containers for the mission is then 56. Each container has an assumed weight of 1 kg each giving a total weight of 56 kg. The volume for each container is approximately 20 dm^3, which gives a total volume of 1.1 m^3. [28]

H. Additional Supplies

Some extra supplies were also deemed necessary to have on board for the health and safety of the crew. The first of these being spares for the various systems. The spares are extra parts that are more prone to failure or have a lifetime shorter than the mission duration. Through contact with various groups within this team, 2 sets of spares were chosen as the failure rate falls within the risk tolerance and any more would surpass the mass and volume allowance [5]. The risk calculations for this can be found in Reference [5] Appendix B. The mass of these spares is 1750 kg [5]. The second supply is a Respiratory Support Pack (RSP), and this provides oxygen for emergency, usually medical, situations [29]. Next is two Portable Breathing Apparatuses (PBA) which provides at least 15 minutes of 100% breathing Oxygen and protects the wearer's face and eyes in order for it to be used during emergency situations such as contamination clean up tasks [30]. Lastly, a fine water mist fire extinguisher. This was chosen over the CO2 Portable Fire Extinguishers (PFE) as those create an unsafe breathing environment when being used and would require the astronauts to bring their own oxygen supply when using this equipment [31]. The mass of all these additional supplies, not including the spares, is 149.16 kg. A complete breakdown of the masses for each of these supplies can be found in Table I.

IV. Health aspect

A. Psychological aspects

It is of big importance to be aware of the human behavioral issues when planning and designing an interplanetary space mission. Studies show that the psychological impact of a longer stay in space is noticeable, for astronauts that have been placed on the ISS for longer than 4+ months some humanitarian behavior could therefore have changed. Operations, simulations, and studies have shown that the isolation in such rough environments may cause some psychological down effects. Some of the down effects are as follows, motivational decline, fatigue, somatic complaints, and social tensions. [32]

A benefit with the crew consisting of Tina and Tom is that they have a lot of experience in challenging environments, long term isolation and demanding exploration. Having so much experience in these similar fields will be a key to succeeding. However, the duration for this mission is longer than the previous explorations they have ever done before. The transfer vehicle and the habitat on the Mars surface will allow communication with Earth, by allowing communication with Earth this can reduce the isolation. Furthermore, the communication will suffer from delays for up to 20 minutes. The delay has several down effects such as the difficulty of communicating with family and friends, which can lead to increased anxiety and depression. The delay in communication also requires that Tina and Tom are autonomous and can handle both medical and technical emergencies on their own since it's not possible to get real-time guidance from mission control [33]. Studies of isolation such as the MARS-500 study and the global pandemic of COVID-19 both have similar effects of long-term isolation, namely the same as mentioned earlier. To reduce isolation during the pandemic some people have found social media platforms helpful to stay in contact with family and friends. Also, to reach out and talk to people in the same situation. Therefore, Tom and Tina could use social media platforms to raise funding for the project and to let the people on Earth follow the mission with its unique content. A positive side effect would be that followers might interact with them through the platforms, and this could in some terms lead to a less isolated state. The comments and interactions that occur on the platform might reduce the feeling of isolation. [34]

Since there is such a distance between planet Earth and Mars the shortest time for a trip back and forth will take at least two and a half years. The record for the longest stay in space is 437 days and it's held by the Russian cosmonaut Valeri Polyakov. [33] Since no one has never been so far from Earth before, the impact of the distance is still unknown. To not be able to see Earth might have a big impact on the crew or it might not impact them at all. A solution to this kind of problem that might occur if the impact of not seeing Earth is big, would be the possibility to bring a virtual reality. Where Tom and Tina can visualize a safe and relaxing environment on Earth for a moment. To stimulate thoughts, reduce boredom and to reduce homesickness, Tom and Tina will be allowed to bring 10 kg of personal items each, totaling approximately 0.1 m^3. By bringing personal items the transfer vehicle will in some way remind them of home and therefore it might reduce the loneliness and homesickness.

B. Medical aspects

For approximately 50 years NASA has studied how staying in space impacts the human body. With this kind of research space travel has evolved and is becoming safer by each trip. However, the effect of long-term travels in space are still rather unknown. Some studies have been made and they lasted for approximately a year, so for Tom and Tina who will be away for almost two and a half years, the impact that such a stay will have on the body is still unknown. For the interplanetary travel to Mars, NASA has summarized five main humanitarian hazards related to space travel, namely, R.I.D.G.E.. Where: R-(space) radiation, I-isolation and confinement, D-distance from earth, G-gravity fields and E-(hostile/closed) environments. [35]

This section will include topics such as physical and cardiovascular effects of micro gravity for a long duration in space, emergency kits and what they need to contain in both medical and surgical aspects and the long-term isolation effect on the immune system.

Over centuries the body has adapted to 1g and with space travel the body needs to adapt to the micro gravity. This will of course have a major influence on the body and the most noticeable physical adaption is the bone atrophy and the muscle deterioration. Where the postural muscles are the muscles to deteriorate first [36] since this is the muscle group that keeps humans standing up, sitting down, and walking all day, every day. In micro gravity these muscles will not carry any loads and will therefore deteriorate first. Similarly for the bone atrophy, the skeleton gets stronger every day on Earth by impacts from the surroundings such as walking or running on the ground. Exercise on Earth is important to ensure that the skeleton and muscles are in good condition to avoid osteoporosis and muscle deterioration. Another thing that will be affected from micro gravity is the cardiovascular system. Due to evolution the cardiovascular system has adapted to 1g. By pumping around and by closing flaps in the veins (legs) the system allows the blood to flow around in every part of the body. In micro gravity the cardiovascular system needs to adapt. This will impact the cardiovascular system in different ways. The blood will not gather in the feet or lower body as it does on Earth. The cardiovascular system adapts so that the blood volume decreases, since the lower body does not gather the blood anymore. The blood will primarily circle around the upper body, causing the blood to flow slower and increase the risk for blood to clot.

If a medical emergency would occur a medical emergency kit will be brought on board the vehicle. The kits are like the ones that are on the ISS where the medical kit will include bandage materials, capsuled medications such as tablets for headaches, fever etc. and topical medication such as lotion, foam, and gel. There will also be a surgical emergency kit that will include injections, items for performing minor surgeries, and diagnostic/therapeutic items. [37] The emergency kits should be optimized so that they don't exceed a size of 20 dm^3 and a weight of 2 kg.

To maintain a healthy immune system the body needs to be exposed to microbes, since the immune system is a learning system. [38] To help maintain a healthy immune system and overall good health the sleep routine is important. Therefore, the transfer vehicle will, in the same way as the ISS, have light settings that will simulate Earth's day rhythm. With complete brightness for 16 hours, and dimmed lights for 8 hours. Also, if they get ill in space the immune system would have to work harder to overcome the illness compared to being on Earth. This is an effect of physiological stresses, radiation, micro gravity, and other spaceflight factors. By going to space the immune system will be put out of balance. [39] In space the immune system will weaken due to the abnormal activation of T regulator cells. These cells are immune cells and the main task for the T-cells in the immune system is to ramp down immune responses when an infection no longer threatens it. This can lead to the T-cells suppressing the immune response for an ongoing illness. [40] So, when returning to Earth Tom and Tina will be very sensitive for infection and they would need to slowly adapt to the microbes on Earth.

C. Exercise

As seen in the previous section, the loss of muscle mass is one of the most important issues for a long-duration mission on Mars. Indeed, to compensate for this loss, the astronauts will have to do about 2 to 3 hours of sports per day, so doing sports in space is a major challenge for this mission. For a mission of this type it is necessary to have a training machine with a mass and volume that is not too high and with sufficient solidity so that the machine does not break during the stay. These constraints make the use of machines that are currently used on the ISS such as the T2 treadmill, the ARED weight machine or the CEVIS exercise bike complicated, which led to the need for another solution.

The solution found to allow the astronauts to train physically throughout the mission was the MED-2 (Miniature Exercise Device) [41], seen in Figure 4. This machine weighing only 30 kg and developed by NASA especially for long stays in space seems to be a perfect compromise. Indeed, the advantages of this machine are numerous, first of all it is a compact and all in one exercise device that has a resistive exercise mode and an aerobic exercise mode to work on strength and cardiovascular. This machine also recharges itself during aerobic work so it does not really need power to work. Finally, a tablet is used to collect exercise data so that the astronauts' training programme can be adapted and organized more easily and accurately. [42]

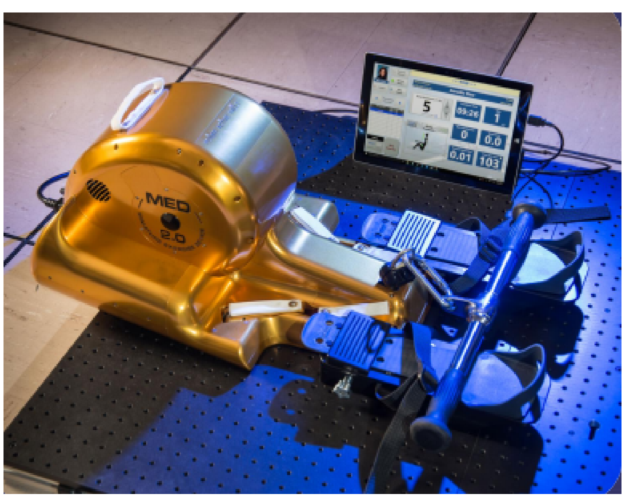

Fig. 4. MED-2 Miniature Exercise Device [43]

A more detailed description of the two different training modes can now be given: resistive and aerobic. For the MED-2 Resistive Exercise mode, it is known that the current configuration provides a constant force that can be modified in real time by the user on the tablet, and that the current exercises are performed using a T-bar (other exercises requiring harnesses are currently being studied). In addition, the MED-2 is able to monitor the user's work, energy expenditure and number of repetitions. Secondly, for the MED-2 Aerobic Exercise mode, the proposed exercise is rowing, to do this the machine simulates rowing conditions (boat weight and drag) and provides a restoring force so that the cable does not get tangled. [43]

However, this solution has the disadvantage of still being in the test phase on the ISS by NASA (since 2016 and until March 2022) and therefore still being a prototype at the moment so there really is not any data on how it works yet. It is believed that it is nevertheless possible to consider that within 3-4 years this prototype or one similar in many respects could be functional, given that the test phase for this one will soon end and that long-duration missions are becoming an increasingly important objective in the plans of private and public companies. Finally, given the low weight and volume of these machines, it could be considered that it would be possible to take 2 or 3 of them in the ship to have a spare in case of breakdown or malfunction, which would be between 50 and 100 kg.

D. Radiation

Finally, one of the most important parts of this mission was studied: the effects of radiation and the solution chosen to limit this during the mission. First of all, it is important to define where the radiation comes from, as there are 3 types of radiation, each with its own effects. Figure 5 illustrates the 3 types of radiation. The two types of radiation that will interest this mission are SPE (Solar Particle Events), a type of radiation that comes from the sun, and GCR (Galactic Cosmic Rays), a type of radiation that comes from outside the solar system (the third type of radiation will not be taken into account: trapped radiation in the Earth magnetic field, because most of the mission is located far enough away from the Earth). These radiations can then have different impacts on the health of the astronauts, on the one hand acute effects such as radiation sickness caused by very intense SPE, and on the other hand late effects such as cancers, hereditary diseases or normal tissue complications caused by chronic exposure to small doses of GCR. In addition, there is also secondary neutron radiation formed by GCRs and SPEs after interactions with matter, which in the past was often neglected in the design of the spacecraft, has the ability to cause high levels of damage and is difficult to counteract with magnetic or electric fields. All these types of radiation, in addition to having the potential to cause severe damage to the health of astronauts, can also cause severe damage to electronic instruments and degrade solar arrays.

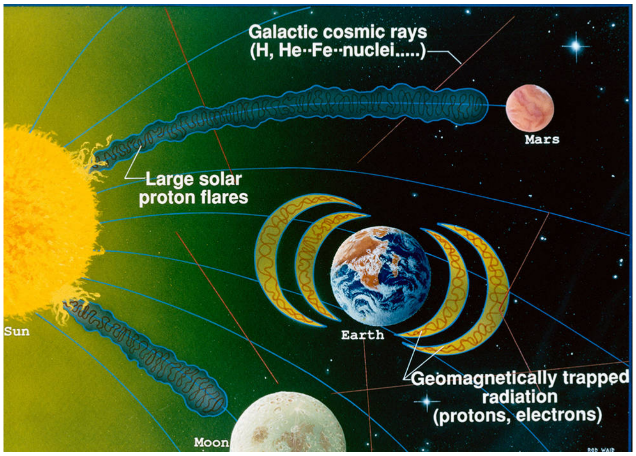

Fig. 5. Artistic concept of the space radiation environment [44]

Then it was necessary to calculate an approximation of the radiation dose in Sievert that each astronaut will receive during the mission of about 1007 days to Mars and back in order to estimate the risks more precisely and to be able to find the most coherent solution. To do this, the RAD radiation data was used, recovered from the Curiosity mission, which shows that an astronaut exploring the surface of Mars will accumulate 0.64 mSv of radiation per day. In addition, other known data shows that during the journey to Mars astronauts will accumulate about 1.84 mSv per day [45] . In conclusion, knowing that our mission is composed of only about 30 days on Mars, and in order to take as much precaution as possible, it is judicious to make the calculations by taking a constant value of 1.84 mSv per day, where then results of about 0.67 Sv for one year and 1.85 Sv are obtained for the entire mission of 1007 days.

These results cane then be compared with the maximum acceptable values given by NASA, which can be seen in Figure 6 below. It can be seen that, given that the astronauts will be about 66 years old when the mission starts, the calculated radiation doses seem acceptable. However, it can be considered that since the radiation will still reach about 50% of the maximum dose for Tom and about 60% for Tina and that the current accepted limit is about 1 Sv for most of the world's space agencies (e.g. the limit for NASA today is about 1.5 Sv for men and 1.1 for the woman, the values shown in the Figure 6 being the maximum accepted values calculated by NASA for the case of a long term mission such as a Mars mission, because in the case of a mission of this type the radiation limits will necessarily have to be revised upwards by the different agencies), the calculated value remains high all the same and it is still interesting to think about and implement a solution to reduce the radiation received during the voyage in order to limit the risk for the two astronauts and also to protect the electronic instruments.

Career Exposure Limits for NASA Astronauts by Age and Gender*

Age (years)	25	35	45	55
Male	1,500 mSv	2,500 mSv	3,250 mSv	4,000 mSv
Female	1,000 mSv	1,750 mSv	2,500 mSv	3,000 mSv

Fig. 6. Radiation exposure limits [46]

The solution that was then considered most interesting and beneficial in this case is Hydrogenated Boron Nitride Nanotubes (Hydrogenated BNNTs) [47]. The material composition is small nano tubes made of carbon, boron and nitrogen with hydrogen interspersed throughout the empty spaces left in between the tubes. Indeed, this solution can be used partially to build the spacecraft and is possibly cheaper than other materials currently used. This makes this solution very attractive in the context of this mission, because as seen previously the radiation does not exceed the limits that could possibly be set, and it would therefore be interesting to have a solution that is neither too expensive nor too heavy or voluminous and that is currently starting to be more and more known and is researched unlike other solutions that are still in the early stages of their development. In addition, this solution also provides ideal protection against secondary neutron radiation, which as mentioned above can cause severe damage, which is a significant advantage of this solution. Finally, according to the study [48], a spacecraft with a thickness of 10 cm or made up of about 25% hydrogen-loaded BNNTs can be considered to offer about 20% more protection than other commonly used materials such as aluminium (AL2195), with this reduction of about 20% it would then reach a value of about 1.5 Sv for the entire duration of the stay, a reduction that is by no means negligible in the context of a mission of this duration.

E. *Off-nominal case*

Since Tom and Tina are above the recommended age for space travel, the off-nominal case in this consideration would be the medical aspects and the increased risks of illness and disease, due to age. Before take-off both will do a full medical check-up to confirm their health, but when in space there will only be the two off them. Some issues with an ageing body are that the body loses elasticity in the skin as well as in the vessels and organs.

Therefore, the off-nominal case would be that one of them would suffer from any disease or cardiac arrest. Which also could lead to, worst case scenario, one of dying. Then, one of them would have to be alone and that will contribute to more isolation and lack of motivation. To reduce the risk of a deadly outcome an AED is brought to help if a cardiac arrest would happen. Also, smaller emergency kits are also brought. Since the terrestrial risk of a significant injury or disease is 6-7 % per person/year and for an injury or disease that requires intensive care is 1-2% per person/year [49], Tom and Tina should manage a trip back and forth to Mars without encountering any injuries or any diseases.

V. Conclusions

In a psychological and a medical point of view this mission will be rather challenging and require a lot of planning. The

transfer shuttle for this mission will stray from the oxygen production system on the ISS and alternatively bring their own oxygen supply to save on mass and volume. The water recycling system however will be comparable to that on the ISS due to its high efficiency.
For the clothes aspect the Simple microgravity laundry system is favorable due to the system's low mass and the possibility to reuse the clothes. The disadvantages with the system is the larger amount of water to bring due to the wastewater and that the clothes have to be hung in the spaceship to air dry which will take up some space. But the total amount of mass saved when using this system instead of bringing disposal clothes definitely compensates for those disadvantages. For the waste management there are systems which recycle some of the waste. Any of those systems could have been brought, but those types of systems are very heavy which is not preferable for this mission, especially since the main focus is to minimize the mass. Bringing all food for the entire mission is the best option since it will reduce the mass of the growing equipment that would also need to be brought and reduces the workload for the crew. A combination of the passive and active thermal control system is required to ensure all equipment in the spacecraft works precisely and creates a comfortable environment.

Table I include the masses required to fulfill this mission.

TABLE I
TABLE OF MASSES FOR THIS MISSION.

Food	5 583 kg
Exercise equipment	60 kg
Medicine	2 kg
Personal items	20 kg
Air revitalisation system (contains Carbon Dioxide Removal System)	338 kg
Water recovery system	1 383 kg
Spares for ECLSS	1 750 kg
Respiratory Support Pack	47 kg
Portable Breathing Apparatus (x2)	47 kg
Extra Water	665.4
Oxygen	2 834 kg
Fire Extinguisher (Fine Water Mist Portable Fire Extinguisher)	8.2 kg
Clothes	49 kg
Non- clothes items	26 kg
Simple micro gravity laundry system	14 kg
Wastewater from laundry	30 kg
Toilet	50 kg
Toilet containers	56 kg
Hygiene items	47 kg
AED	3 kg
Total mass	13 159.2 kg

VI. WORKLOAD BREAKDOWN

A. *Wanda Andreas Widyatmoko*

Worked in research within the food management and thermal control system aspect of the mission. Contributing to this report on the mentioned aspects, and together with the rest of the group writing the abstract and conclusion.

B. *Katja Nordström*

Worked primarily with research within the subject of the medical and psychological aspects of the mission as well as looking into the off-nominal cases. In the report the same topics were covered, the report structure in the introduction and as well as together with the group writing the conclusion.

C. *Mathias Chillet*

Worked on the training of astronauts, the choice of an exercise machine and the problem of radiation for this mission. Contributing to this report on the mentioned aspects, and together with the rest of the group writing the abstract and conclusion.

D. *Karl Persson*

Worked with the aspects of clothes, hygiene and waste for the life support system of the mission. Contribution to this report includes the mentioned aspects, introduction and also the abstract and conclusion, which were written together with the rest of the group.

E. *Laura Murphy*

Conducted research and analysis of the Air Management, Water Recycling System, and important additional supplies within the Life Support System. The conclusions from this investigation were then summarized in this report along with aiding in the abstract and conclusion.

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