Mount Olympus Mons Ascension Mission Human Aspects - Team Red

Louise Fischer, Hanlin Gongzhang, Andrea Mussita, Florian Steiner
MSc students, KTH, Royal Institute of Technology, Stockholm, Sweden, March 20, 2021

***Abstract*—Determining the human aspects of the Tantalus expedition is critical to its success. The starting point for the Life Support System analysis was the minimum human metabolic requirements. From those, it is then possible to design all the systems necessary for a human mission of ascent to Mount Olympus. The concept of this study is to divide the Life Support aspects and other primary requirements from the secondary aspects and requirements. This division is motivated by priorities when it comes to the life and safety of the crew. The study was based also on assumptions of technological developments that are expected to be satisfied upon the mission's start. In the design of life support systems and primary aspects, different loop strategies and countermeasures were investigated considering the mission duration and the best balance in terms of efficiency and mass reduction. For air and water systems the loop will be partially closed with partial recycling. An open-loop strategy has been chosen for the food. Radiation and thermal control are the other primary aspects analyzed in the first place to protect the crew. Effective shielding and coating have been selected. The secondary factors presented in this study are related to the psychophysical performance deterioration that the space environment produces to the crew. These aspects, along with the radiation exposure, lay the foundations for determining main mission duration limits, and are used to provide the main requirements for the mission. Countermeasures against a variety of health-related aspects have also been considered, such as intensive exercise, workload division, crew selection, and training.**

NOMENCLATURE

4BMS-X 4 Bed Molecular Sieve for Exploration
ACS Atmosphere Control and Supply
AMS Air Management System
AR Air Revitalization
ATCS Active Thermal Control System
CDRA Carbon Dioxide Removal Assembly
CG Center of gravity
CRS Carbon Dioxide Reduction System
ECLSS Environmental Control and Life Support System
FMARS Flashline Mars Arctic Research Station
GCR Galactic Cosmic Rays
HDPE High Density Polyethylene
ISS International Space Station
LEO Low Earth Orbit
LSS Life Support System
MDRS Mars Desert Research Station
OGS Oxygen Generation System
PLSS Portable Life Support System
PSA Pressure Swing Adsorption
RAD Radiation Assessment Detector
SEP Solar Energetic Particle
SPE Splar Particle Event
THC Temperature and Humidity Control
VCD Vapor Compression Distillation

I. INTRODUCTION

The report focuses on the necessary human aspects to consider when planning a specified manned Mars mission - to reach the summit of the Martian volcano Olympus Mons. The objective is to consider vital human aspects, estimate the specification requirements for the life support system and determine the relevant mission constraints. During the mission the crew will need a life support system, that will keep them alive, safe, and prepared to complete the mission. With a long duration in space, this will be a challenge to construct. The system must be robust enough to not breakdown and the supplies must also be enough for the whole trip.

II. LIFE SUPPORT SYSTEM AND PRIMARY REQUIREMENTS

The primary requirements for human spaceflight comprise all the aspects that are essential in order to keep humans alive in the space environment. In this case of study, the crew will face not only the deep space environment but also the Martian one which is less extreme but not less harsh for human life.
A Life Support System has to be engineered with special care for the Tantalus mission. The different purposes and utilization times of the space vehicle, the Martian rover, and the spacesuits require different approaches when it comes to designing the LSS. In both the vehicles and in the suits the LSS will provide the crew with all the vital functions such as air management, water management, food, safety, and emergency equipment. Waste management is strictly connected with water and food management and for this reason, this problem will be addressed in those sections. In addition to the LSS functions the thermal control, and radiation exposure is part of the vital aspects that have to be addressed in order to protect and support the crew.

A. Air Management System

Within every phase of the mission, the crew will always be protected by a pressurized, breathable, and controlled atmosphere whether it is in the spacecraft, in the Martian rover, or in the spacesuits.

The AMS functions are multiple and can be divided into three main categories where the dedicated subsystems will operate. It is important though to remember that the majority of the systems in a space vehicle that must provide an ECLSS are usually in mutual connection. The AMS can be described as a subsystem of the ECLSS [1] and every subsystem should be at least two-fault tolerant. The AMS is in turn divided in three main subsystems as presented in Figure 1.

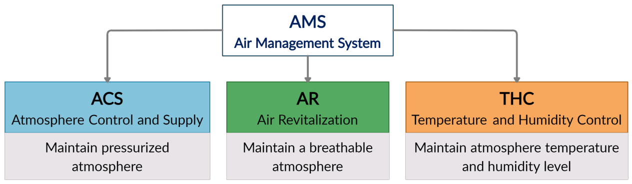

Fig. 1. Air Management System structure

The main functions of this subsystems are:

1) Maintain pressurized atmosphere: The atmosphere must be kept in the correct range of pressure in order to provide not only a habitable environment for the crew but also to allow the appropriate functioning of all the systems in the spacecraft that are sensitive to pressure. It is important to reproduce in the spacecraft an atmosphere that is as much similar as possible to the Earth's atmosphere. The design pressure value for the spacecraft environment is 101.3 kPa but the pressure could range between 97.9 and 102.7 kPa as it does the ISS. The atmosphere composition must be 21% O_2 and 79% N_2 with an O_2 partial pressure of $19.5 - 23.1$ kPa [2]. A small concentration of other gases can be neglected at this stage of the design but will be taken into account by the contaminants tracing apparatus. Nitrogen is a diluent gas and is not absorbed by the human body through respiration but through food in the digestive system. Since it can not be generated or recovered by recycling the amount of N_2 necessary for the whole mission must be stored in tanks from the beginning of the expedition. Nitrogen is also needed to make up for atmosphere leakages and airlock losses.The main subsystem that is designated to the control of the total atmospheric pressure, the maintenance of the correct partial pressures, and the providing of gas support to users is the Atmosphere Control and Supply (ACS) subsystem of the AMS.

Since the O_2 daily requirement is $0.84\ kg$ per person, the crew will need $0.84 \cdot 3 = 2.52\ kg$ of oxygen every day. The presence of three habitable bases on Mars with automated facilities for oxygen, water, and methane production allows the crew to refill the tanks before leaving the Martian surface for the return flight. For this reason, the oxygen supply needed at the beginning of the mission for the 420 days outbound flight to Mars is $420 \cdot 2.52 = 1058\ kg$. Considering a 10 % safety margin the oxygen amounts to $1165\ kg$. Nitrogen supplies have to last for the whole outbound and return transfer because it is not provided by the automated facilities. The Martian base is habitable and thus the nitrogen is already provided there. The average density of the vehicle atmosphere can be approximated to $1.2\ kg/m^3$ and the pressurized volume of the vehicle provided by the Space Vehicle team is $150\ m^3$ [3]. Given the 79 % nitrogen composition the total nitrogen required for the cabin is $0.79 \cdot 1.2 \cdot 150 = 142.2\ kg$. Considering leakages ad airlock operations a margin of 10 % has been considered, bringing the total nitrogen mass to $157\ kg$.

The main elements of an oxygen generation system on the space vehicle were firstly considered similar to those in use on the ISS. They comprise a carbon dioxide removal system (CDRA), a carbon dioxide reduction system with a Sabatier reactor (CRS), and an oxygen generation system with an electrolyzer (OGS). Considering the mission duration it is possible to verify if such systems would give a relevant mass payback ratio and save launch mass [4]. The OGS and CRS are connected systems and have a total mass of $2391\ kg$ which is more than double the mass of oxygen needed for the outbound flight. A drastic decrease of this systems' weight in the future under the $1165\ kg$ of O_2 is not predictable. Moreover, the break-even date of the OGS exceeds the transfer time to Mars. If the OGS system is not used, the CRS systems would not be necessary. For this reason and considering the possibility of a refuel at the Martian bases it has been decided to directly supply the oxygen for the transfer to Mars and provide the vehicle with a carbon dioxide removal system.

The Martian rover will require a pressurize atmosphere as well as the spacesuits for EVAs. Different solutions have been considered in collaboration with the Mars Operation team [5]. The safest and most efficient solution is to pressurize the rover. The oxygen and nitrogen will be provided by tanks in the vehicle while the space suits will have a pure O_2 atmosphere. The rover pressurized volume decided with the Mars Operation Team is $13.5\ m^3$ [5]. Therefore the nitrogen needed is $0.79 \cdot 1.2 \cdot 13.5 = 13\ kg$ that increase to $14\ kg$ considering a 10 % margin. Since the rover has to support a crew of two for 10 days the total oxygen needed is $2 \cdot 0.84 \cdot 10 = 16.8\ kg$, hence 18.5 with 10 % margin. The spacesuit will be equipped with a PLSS that can provide O_2. The Mars Operation team [5] required a suit that can provide consumables for 16 hours. The solution will be a PLSS similar to the one on the EMU suits with the assumption that, by the time the mission is planned for, the systems will be lighter and smaller. The suit will provide $800\ L$ of oxygen. Considering an increased breath rate during the walk of about 50 liters per hour the tanks will last for 16 hours [6].

2) Maintain a breathable atmosphere: $1\ kg$ of CO_2 is produced per person per day and must be removed and processed in order to maintain a breathable atmosphere. The main tasks are to monitor the partial pressures of atmospheric constituents, remove carbon dioxide and trace contaminants. These operations are accomplished by the Atmosphere Revitalization (AR) subsystem of the AMS.

The technology selected for the CO_2 removal is very similar to the CDRA system in use on ISS. The operating principle of this system is based on two parallel pipelines that force air through two canisters for each line. The canisters are filled with aluminum and silicon zeolite that absorbs and desorb humidity and CO_2. This system has been operated for several years with different levels of success and reliability. Studies are in progress to upgrade the CO_2 removal assembly, in particular in the area that proved to be more subjected to failures. Improvements in reliability and performance have been addressed such as new sorbent beds geometry and materials and an updated heater geometry. The upgraded assembly has been named 4BMS-X which stands for "four Bed Molecular Sieve for Exploration". This system will be capable of providing $4.16\ kg/day$ of CO_2 removal, a representation is shown in Figure 2 [7]. The 4BMS-X selected for the mission

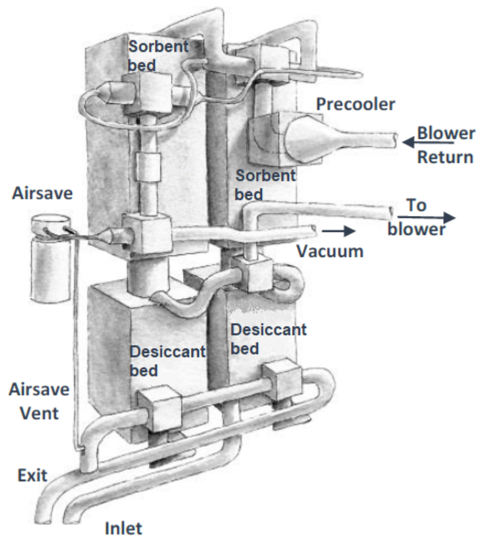

Fig. 2. 4BMS-X, 4 Bed Molecular Sieve for Exploration.

will have an partially closed-loop configuration and thus the carbon dioxide removed from the cabin will be vented into space while the clean air will be redirected to the cabin. Once again, this solution has been adopted after considering a mass-payback ratios analysis of the CRS's Sabatier reactor and OGS's electrolyzer [4] and the possibility of refueling at the automated facility on Mars for the return trip.

Another aspect of the AR system is the tracing, filtering, and removal of contaminants. Gaseous contaminants can derive from astronaut's metabolic processes or off-gassing from the equipment. A really dangerous gas contaminant is ammonia, a product of the protein metabolism which is released through sweating or by the thermal control system. Since ammonia is produced by the crew metabolism its concentration is variable during the mission, hence it is more difficult to set a regulation system. The atmosphere scrubbing is operated by the Trace Contaminants Control System (TCCS). This system has to work continuously and consists of a charcoal bed, a catalytic oxidizer, and a lithium hydroxide post sorbent bed [8].

On the Martian rover the CO_2 removal will be carried out by metal hydroxide cartridges which are easily replaceable and proved to be efficient. Using a CDRA system in the rover for such a short-duration mission is not convenient. The spacesuit will be designed with a PSA system that removes CO_2, as assumed by the Mars Operation team [5].

3) Maintain atmosphere temperature and humidity level: The spacecraft will be equipped with appropriate air distribution and air conditioning system. This comprises an elaborate piping network with valves and filters between every segment of the vehicle. The tasks of this system are to circulate air within and between modules, cool air for crew and equipment, remove humidity and particles. These are accomplished by the Temperature and Humidity Control (THC) subsystem of the AMS.

The temperature will be kept between 20 $°C$ and 25 $°C$ by the thermal control of the spacecraft. In order to recover water from the air, the VCD will work as a water separator. The purpose of this system is to separate water vapor from the air in the cabin. A heat exchanger and a centrifugal assembly will direct the water to the Water Management System. Particles in the air can originate from astronaut's bodies such as hair and hairs, from the tissue of the clothes, from food crumbs, and also from the equipment and systems onboard the vehicle. In order to avoid failures, an appropriate filtering system will be predisposed in all the vents of the vehicle. Filters can be cleaned or replaced when necessary.

For the Martian operation, the rover won't be equipped with a sophisticated ventilation system due to the small volume of the vehicle. However, there will be vents and filters to control the particles of Martian dust that the astronauts will carry inside the rover. The spacesuit will have an air circulation system and filters as well.

A summary of the masses, volumes, and power required by the space vehicle's systems is provided in Table I. The values presented include 3x redundancies for the 4BMS-X CDRA and the VCD and 2x redundancies for the TCCS [9].

TABLE I
MASSES, VOLUMES AND POWER REQUIRED FOR THE AMS

System	Mass [kg]	Volume $[m^3]$	Power [kW]
4BMS-X CDRA	540	2.70	0.30
TCCS	360	2.70	0.05
VCD	300	1.20	0.03
Total	1200	6.6	0.38

B. *Water Management System*

For human survival, we need water every day, and the basic survival we need 2-3 liter of water every day [2]. Water is used for food, drinking, hygiene, and humidity inside the spacecraft. The astronauts will do a lot of training and water is a very important part of life support, so for more than just basic survival, the astronaut will have 3 liters every day just for the food and drinking. To add the hygiene which includes oral hygiene and hand and face wash we will need 2,5 liters per day more. This would result in the total volume of water used every day per astronaut 5,5 kg, and total for the whole mission 10 tons of water and just for the transit 6,4 tons.

There are three different types of water on the spacecraft:

- *Greywater:* This includes water from the condensate water and also the water that has some contaminations from the hygiene part e.g. cleaning and showering. This is the easiest one to recycle and can be recycled almost 100%. This is done by using first a system of multi-filtration to clear the water from impurities and then the catalytic oxidation reactor which removes volatile organic compounds and eliminates bacteria and different viruses [10].
- *Yellow water:* This comes from urine and is more difficult to reclaim than greywater. When recycling the yellow water a Vapor Compression Distillation (VCD) will be used. When using this, the proceeder for the natural cycle of water on earth was the inspiration. Instead of

the power of the sun, the water gets boiled, and instead of gravity, a centrifugal force will be created [11]. By using the VCD and after that the multi-filtration system, 70% of the yellow water can be reclaimed. One of the byproducts produced is ammonia, which must be handled very carefully.

- *Blackwater:* This type is not that large amount as the other two wastewaters. Blackwater has the risk to contain pathogens [12]. That is why this type of water will not be reclaimed at all. The risk of not eliminated all the dangerous organisms is a risk that could destroy the whole mission.

As mentions, the total volume for needed water is 6 tons which is too much for one launch. If looking at the Nasa Mars Reference Mission and the Mars Pathfinder, the cost of a mission with an open-loop system is over $11 billion [13]. Therefore, it's not feasible to bring all the water without recycling the water. The system should be able to recycle two of the different water types, greywater and yellow water. An assumption that the astronauts will feel good with drinking all kinds of recycled water. Right now the ISS recycles approximately 80% [14], by 2038 the system has had a long time to develop so the assumption was made that the system now could reclaim 90% of the water in the cleaning system. The water recovery system will be able to recycle 14,85kg of water every day. This means 16,5 kg will then go into the system, which means that 1,65 kg will be waste from the cleaning system. The total mass of water to bring on the mission will be 720 kg, and this is with a 10% margin if something would happen. On mars, the water will be taken from there and the tank will be filled again with water for the transit back to earth. On the way back to earth 380 kg will have to be brought back. During the climb on Mars, the crew will be equipped in the rover with enough water to cover the whole climb, so there will be no recycling at that time. This is because the reclaim system too is heavy to bring on that part of the mission.

C. Food and nutrition

Just like on Earth, food is essential for the life of astronauts. However, it is more challenging to eat in space, mainly because of microgravity, limited time, and food conservation. Because our mission has to be successful, no unnecessary risks will be taken regarding food. Even though closed-loop technologies are developed like MELISSA, and might be ready by 2038, it will be more reliable to use more traditional methods. The crew will not be growing food during the mission because this time-demanding activity is risky, might not produce enough food, and is limited to a few types of food only [15]. For all these reasons, all the food will be canned or freeze-dried (see Fig 3). The crew will use machines that rehydrated the food using hot water coming from the water loop like it is currently done in the ISS [16]. The major advantages of this method are that it is not time-consuming to warm up the meals and the storage of the food can be done at room temperature, thus saving energy. However, this requires a lot of packaging, usually plastic, which mass becomes considerable for such a long journey and becomes trash after use. That is why we assumed edible packaging available by 2038. Such packaging already exists and research is conducted to improve its conservation performances [17]. Once the food is eaten, the packaging can be eaten too, avoiding trash and saving mass. Nevertheless, to make this assumption more realistic, we estimated that only 50% of the traditional packaging mass will be saved thanks to edible packaging, considering that vulnerable food like meat needed plastic packaging for safety.

Fig. 3. Food available in the ISS, *Source: NASA*

NASA explains that each person needs 0.83 kg of dehydrated food per day [18]. With our assumption, 0.1 kg of packaging is used per person per day. 1 liter of water is needed to rehydrate the food and 2 are needed for drinking water. The mass of the machines rehydrating food and all the utensils related to food (cutlery, basic cleaning material) has been estimated to 200 kg for the main ship and 30 kg for the rover. We considered a 5% margin in the mass of food. So, for the outward trip with three astronauts, 1300 kg of food is required, which takes a volume of 3.8 m^3. For the return trip, it is 800 kg stored in 2.2 m^3. The food for the return trip will be sent by a cargo mission before the crew's arrival. No resupply mission is planned after the crew's departure. The trash from the outward trip can be left on Mars in sealed packages to avoid biological contamination.

Food is not only important for nutrition but also for its psychological impact. As no resupply mission is planned, fresh products will not be available like on the ISS. So, special meals for events like Christmas eve can be brought to avoid boredom in the menus. Pre-flight tasting sessions will be organized for the astronauts to choose their menus according to their taste and the validation of a nutritionist. During EVA, liquid food has been assumed to be available. It can be in the form of a powder mixed with water, which has the advantage to be eaten inside the suit. This method will be used for lunch and only during the few days of climbing. It is not a comfortable solution for the astronauts but it will be quick and practical.

One off-nominal case that has been studied is a delayed departure from Mars. Deciding how many extra consumables to bring with is a difficult question. If the departure is delayed by only a few days, the 5% margin for food will be sufficient for the crew to survive. However, if the stay on Mars is increased by months the crew can start eating the food originally planned for the way back, which is already on the planet. During that time, a new cargo ship will be launched from Earth, bringing supplies for the return trip. In any case, water and oxygen will be produced by the Martian facilities. So it is unnecessary to bring too much extra food because if it is needed, this means that the problem is big enough to immobilize the crew for a long time. That is why only 5% margin is considered with food. In a critical scenario, the crew will have rationing. Such a situation would be closely monitored from Earth and nutritionists will decide the rationing according to the crew's needs, mission duration, and remaining food.

D. Safety and Emergency systems

Preventives, redundancy, and backup systems to prevent and counteract failures of life-supporting systems and on-board avionics and are a necessity for manned space explorations. The most vital aspects are covered in this section.

1) Radiation: Cosmic radiations, in particular those in the span of the electromagnetic spectrum, are known to cause harm to humans and various types of electronics if not properly shielded.

Countermeasures against such radiations can be performed active- and passively. Active protection systems involve forecasting outbursts of high energetic radiation arrays from potential emitting sources in the near future (such as SPE:S and gamma-ray bursts from supernovae), and henceforth alert the crew for further preparations [19].

Passive protections are physical shielding that is usually consisted of protection layers around the equipment of interest, which is the most relevant for on-board astrionics. This is extra important for computational devices, as they become more prone to calculation errors and data corruptions if exposed to energetic radiations. More detailed information about radiation regarding types of shielding technology, evaluation of lethal radiation doses, and health effects are presented in the subsection Radiation.

2) Flammability: Electrical short circuits and equipment operating at high temperatures increase the likelihood of fire incidents. Hence, extra precaution is required for space explorations, in particular, self-sustained manned missions with longer travel time.

Countermeasures take form in excessive crew training, flammability testing of equipment and materials of interest, and on-board fire detection and suppression systems. It is worth noting that fire detection systems rely purely on the circulation path of the air in the cabin, rather than the Archimedes principle on Earth due to zero gravity. Extinguishers have been on board the ISS for a long time and have been proven to be a necessity, which also agrees with this mission.

3) Leakage of gases and liquids: Internal and external leakages are also potential risks for long space journeys. This has proven to be a concern as the ISS and various orbital vehicles have suffered multiple leakages of cabin air as well as varieties of hazardous gasses [20]. There have been two reported incidents of coolant-related ammonia leakages during 2009 and 2013, three gradual cabin decompression dating between 2004 and 2020, and one involving flammable gas (potassium hydroxide) from an oxygen vent. Such events have been considered as one of the off-nominal scenarios of our mission. They are deemed unlikely probability-wise, but vital, nonetheless.

Prevention and response against gas leakages mainly rely on crew training, i.e., knowledge about the characteristics and danger of respective gas and how should it be dealt with under different circumstances. Sealing of gradual leaks is usually performed by injecting chemical sealant (solidifies on contact) into the leaking source [21], rather than containing them with mechanical seals, which is time-consuming and often require additional tools. As for the leakages of hazardous gasses, one can use suction to redirect the contaminated regions away from the affected cabin and isolate the gas with airlocks. The crew can from thereon depressurize the isolated region and re-pressurize it with fresh air. By equipping the ventilation system with filters would further improve the safety and ease of troubleshooting. The crew can then contain the leakage of hazardous gasses by sealing the leak source and thenceforth increase the air circulation in the cabin; letting the filter do its job. But like every other safety aspect, this comes at a price of additional cost and mass. Such severe scenarios are deemed highly unlikely under the given time constraints ($>$ two years), assuming that the vehicle in question holds a similar frequency of occurrence of such events as the ISS ($>$ once every four years). Hence, in favor of minimizing the total mission cost and vehicle mass, it may not deem necessary to invest in such an advanced ventilation system.

4) Uncontrolled rapid decompression: Uncontrolled rapid decompression is one of the worst off-nominal scenarios, which may result in structural damages beyond the limit to repair. The only prevention is to ensure that such an event will not happen during the course of this mission by reducing its likelihood of occurrence by as much as possible.

E. Thermal control

Space is a rough environment, especially for its high-temperature differences. It can vary from $-150°$ to $+150°$ in space when exposed to the Sun and from $-150°$ at the Martian poles to $+20°$ at the equator at noon. So a regulation system is required for every space vehicle and spacesuit. The passive method is to use multi-layer insulation, which can also shield from micrometeoroids. But this is not sufficient, an active method such as the Active Thermal Control System (ATCS) is required [22]. An ATCS uses a fluid in closed-loop circuits to collect, transport, and reject heat. Heat is removed by radiation, the only heat transfer possible in space. Ammonia is the cooling fluid used in the ISS and it circulates through large radiators releasing the heat. Ammonia is very toxic so maybe by 2038, a less toxic alternative could be found.

Skintight spacesuits have been assumed available for the mission. Their thermal regulation will be based on transpiration through the suit. Electric heating elements will be found in sensitives parts of the body like in the gloves. More information about the spacesuit can be found in the Mars Operations team report.

F. Radiation

Radiation exposure is probably one of the biggest problem to address when designing a human mission to Mars. When traveling in deep space outside Earth's magnetosphere there is no protection from two types of radiation that are harmful to humans, SEPs emitted during SPEs and GCR.

GCR are radiation made up of high energetic particles particularly high energy protons and high charge end energy nuclei [23]. This radiation is difficult to shield outside the Earth's magnetosphere but is modulated by the heliosphere. As a matter of fact, GCR intensity is in an inverse relationship with SPEs. When the solar activity is at its minimum the GCR contribution to the total radiation exposure is the highest and when the solar activity is at its maximum the GCR radiation decreases. The main issue regarding GCR during deep space missions is that the radiation, being highly energetic and highly penetrating, is not stopped by the thin shielding of the typical spacecraft built up to now. Moreover, Mars has not a magnetic field like the Earth and high-energy particles can travel easily through the Martian thin atmosphere and reach the surface of the planet. Evidence from the MSL Curiosity Rover suggests that radiation from GCR can also penetrate in Martian surface down to $3\ m$ in depth [24].

SPEs are responsible for the emission of SEPs which are comprised mainly of protons with lower energies than the GCR particles. [23]. The lower energy of this radiation has a direct implication on the shielding technology which is more effective than it is with GCR. Space agencies, universities, and other institutions are still conducting researches about the effects of radiation in deep space on the human body. Despite new methods and technologies for shielding the spacecraft are being developed, some aspects of the radiation environment in deep space are yet to be completely understood. Risks of high dose exposure are well known but the major issue is to establish the consequences of low dose prolonged exposure to GCR on biological tissues and its relation with late degenerative diseases and cancers. Radiation is known to be responsible for different forms of carcinogenics but is not clear how GCR could affect the central nervous system and the cardiovascular system [25]. Another aspect that is generating debate on the research is the different models that different agencies apply to calculate the maximum exposure limits. There is a unified consent about the dose limit to prevent harmful effects on human tissues but there had been differences regarding the maximum career effective dose limitation for astronauts. Furthermore, these limits are referred to as space missions in the LEO where the magnetosphere has a key role in shielding partial cosmic radiation. Different National Space Agencies career effective dose limits are presented in Table II [25]. Recently a conventional risk assessment for space radiations has been adopted by several agencies and the value of $1000\ mSv$ has been considered to have career maximum effective dose limitation. However, NASA has a different method that defines the limitation to a 3% risk of exposure-induced death for cancer and takes uncertainties into account evaluating it at the upper 95% confidence interval [26].

TABLE II
CAREER EFFECTIVE DOSE LIMITS (IN SV)

Space Agency	Gender	Age of exposure (years) 30	40	50	60
NASA	M	0.78	0.88	1.00	1.17
	F	0.60	0.70	0.82	0.98
JAXA	M	0.60	1.00	1.20	1.20
	F	0.60	0.90	1.10	1.10
ESA	M / F	1.00	1.00	1.00	1.00
RSA	M / F	1.00	1.00	1.00	1.00
CSA	M / F	1.00	1.00	1.00	1.00

The probable international crew of such a mission could also represent a source for debate. There is also ethical consideration that can be made especially for an exploration mission to climb Olympus Mons. The exploratory and competitive nature of the mission could support the opinion that the effective dose limits should be fixed according to astronauts' personal acceptable risk. Many estimations have been done concerning the radiation exposure during the transfer to Mars and during Martian operations. Currently, the only measurements of deep space radiation during a flight to Mars and on the Martian surface had been registered by the Mars Science Laboratory's RAD and Curiosity rover. Results are highly dependant on the solar cycle at the time of the mission and a human spaceflight would differ in terms of shielding technology but under a similar radiation environment assumption, they are considered for the purpose of the Olympus Mons climbing mission. RAD and Curiosity measurements were:

- 1.84 mSv/day during transfer to Mars;
- 0.64 mSv/day on Martian surface;

Again, since the solar cycle will cause a difference in these values, the highest radiation exposure of $1.84\ mSv/day$ was considered for the maximum mission duration to remain within astronauts' career effective dose limits. The result was:

$$Days_{max} = \frac{1000 \quad \text{mSv}}{1.84 \quad \text{mSv/day}} = 543 \quad \text{days}$$

Shielding completely from space environment radiations is not possible and it probably won't be possible even when the mission is planned for. The current technology in use on the ISS is aluminum and High-Density Polyethylene (HDPE). The standard density of aluminum protection is $20\ g/cm^2$ and one could think of increasing this density. The main issues with this solution are that it increases the mass of the vehicle and the shielding effectiveness has no improvement even with an increased thickness [23]. As a matter of fact, GCR doses are not sensitive to the increasing thickness due to the interactions between the shielding layer's atoms and high energetic particles of GCR produce secondary radiation that is still harmful to humans. However, the radiation shielding

technology has been assumed to be really improved by 2043 and allowing a longer mission duration than 543 days. A really promising solution is Lithium Metal Hydride Materials [27]. This material provides a better shielding and has a lower specific mass than Al or HDPE.
The solution for the transfer vehicle is a 20 g/cm^2 of Lithium Hydride coating on the crew capsule that can be orientated with the shield in the direction of origin of the solar event to better protect from SEP. The crew will be informed by the mission control or by the spacecraft systems when an SPE occurs. The crew capsule will be the better-shielded compartment of the vehicle but all the habitable segments will have a material that is assumed to be light and well developed by 2043, providing a good shielding. Furthermore, the crew will be able to move around the equipment bags, tools, and water tanks on board to increase the shielding as shown in Figure 4 [28]. In order to assess the risks of long radiation exposure and reduce the risk of induced diseases the role of genetic heritage is being studied since it could have a role in determining the individual sensitivity to radiation exposure. If results will be achieved by 2038, the individual sensitivity to radiation will be a key factor in the selection process of astronauts and thus a valuable countermeasure for the radiation exposure harmful effects [25].

Fig. 4. Demonstration of the radiation protection plan in a Orion spacecraft mock-up. During an SPE, the crew will use stowage bags on board to create a denser shield against radiation.

III. Secondary requirements

When designing a long-duration mission like the Tantalus one, there are some human aspects that require equal attention to details even if they are not vital for the survival of the astronauts. We called them secondary requirements. These comprise the psychological effects of long-duration space travel, medical aspects, hygiene, workload division, and crew selection and training.

A. Psychological effects of long-duration space travel

When planning a spaceflight to Mars, lasting months or years, the crew will be exposed to many stresses due to the space environment, isolation, danger, goal of the mission, group dynamics, to name but a few [29].

To get prepared for such a journey, people have organized Mars analogs on Earth to simulate aspects of living and working on Mars. The biggest experiments conducted yet are the Flashline Mars Arctic Research Station (FMARS) in the Canadian Arctic, the Mars Desert Research Station (MDRS) in Utah, and MARS-500, an extensive isolation study conducted on a six-member crew [2] (see Fig 5). These provide crucial information to get prepared for the mission. However, some situations cannot be simulated and that the crew can only face during the real mission, like the *'Earth-out-of-view phenomenon'*, microgravity or mission risks.

The psychological health and the cohesion of the crew have to be considered. In order to limit the risk of psychological disorder or crew tensions or fights, the astronauts will be selected not only on their technical capabilities but also on their behavior in a group. This selection is already used for the current astronauts but it can be improved with a system similar to the one used for the MARS-500 mission. More participants than needed were fully trained and the final crew was selected only a few weeks before launch. Therefore, psychologists had as much time as possible to observe group behavior and find the best crew.

The composition of the crew will also be influenced by geopolitical interest at the time of the mission. Climbing the highest mountain in the Solar System is such a big achievement that many nations would like to be represented. This will lead to a crew of mixed genders, nationalities and cultures, completely the opposite of the early space missions. This diversity may be the cause of many conflicts but it is also a strength for the crew and is long-term beneficial for the mission, according to Romain Charles, a crew member of MARS-500 [30].

Fig. 5. MARS-500 crew celebrating 2011 new years eve. From top left to bottom right : Diego Urbina (Italy), Alexandr Smoleevskiy (Russia), Sukhrob Kamolov (Russia), Alexey Sitev (Russia), Yue Wang (China), Romain Charles (France). *Source*: [31]

One other issue that the crew will face once onboard is boredom, especially on the way back when the mission's goal is completed. Even if scientific experiments and the landing preparation will keep the astronauts busy for a big part of their days, what to do with the rest of the time available?

Scientific experiments will be planned to fund the program and to keep the crew busy during the trip. Advertisements such as books, movies, and video games will probably not be an option as they allow the crew to spent enjoyable moments [30]. Special events like birthdays and New Year's Eve allow to break the routine, see Figure 5. Other ways to avoid boredom and strengthen the crew relationship have been imagined. Fake accidents could be triggered from Earth. The crew, not being aware that it is a simulation, will have to cope with the issue as a team. However, if not announced properly to the crew by the ground station, these incidents can weaken the trust of the crew in the ground station [30]. This trust is the only link that the crew has to Earth and it is crucial that the communication is flawless. Usually, the person on the ground talking to the crew is an astronaut, so that he knows the best how it feels to be up there. The communications with the crew can be live when the spaceship is close enough to Earth, but soon enough the communication delay forces the crew to be more autonomous. Videos or written instructions will be sent and the crew will then work on another task while waiting for the response. The delay can reach up to 20 minutes. It has also an impact on personal communications with the crew's relatives.

According to Romain Charles, humans are ready to experience such a long journey, as many experiments on Earth have shown, at least from a psychological aspect [30].

B. Medical aspects

There are many medical aspects to be considered for interplanetary journeys, with some more vital than others. The objective is to justify and prioritize the aspects with respect to its severity and its likelihood of occurrence; in order to minimize the redundancy of crew and equipment as well as the mission cost. One may presumably estimate the risk of various medical incidents as expected values (EV) with arbitrary data, such as registered medical cases/evens on-board the ISS throughout its years of operation. As an example:

According to data set A, case X occurs with probability Y and has an average severity unit of 3 on a scale of 0 to 5, thus case X has an expected value of Y multiples of 3 severity units

The severity of the respective plausible case is furthermore justified with respect to the magnitude of its corresponding EV. This procedure is often applied in decision theory and is widely used in combination with optimization under constraints.

1) Emergencies: In case of medical emergencies aboard ISS, the crew mainly relies on ground control; by communicating with medical experts. This is not always the case for interplanetary travels due to the vastly increased signal latency caused by the shear distance between the spacecraft and Earth. The average signal latency ranges from 5-20 minutes from Mars to Earth depending on the signal type [32]. If a medical emergency was to occur on- or close to Mars, the crew will have to act upon their own while awaiting further instructions and recommendations from medical experts on earth.

A solution relies upon the selection and training of the crew; by partially selecting candidates with field medical experiences, while also providing medical training for the entire crew. These aspects are already considered to an extent among many national and private space agencies today. Several medical pieces of equipment are also available on the ISS, such as defibrillators, an ultrasonic scanner, and first aid kits. Such equipment are deemed necessary for this mission, mainly due to its is abnormal duration and the aspects mentioned above.

2) Effects of weightlessness: Health effects due to zero gravity is still an area of research, hence there are still big uncertainties regarding the long-term effects of living in weightless environments. Some well-known side effects of weightlessness are listed below.

Substantial risk of decreased bone density, leading to increased bone fragility; complicating operations on Mars. However, this process can be decelerated by maintaining physical exercises, pressurizing the bone structure.

Decreased muscle mass and fitness, which leading to increased weakness, making the Mars mission more punishing at the beginning (Assuming no artificial gravity is generated by the space vehicle). This issue is closely linked with decreased bone density, hence physical exercises during the journey will have a positive effect to an extent.

Loss of vision due to redistribution of body fluids is believed to be another side effect of longer habitation in zero-or microgravity environments. It is suggested that due to the uneven distribution of body fluids, some astronauts suffer from a syndrome know as impairment inter cranial pressure syndrome, or VIIP. Studies have revealed that microgravity of the ISS was building up pressure in astronauts' heads, causing roughly 2 liters of vascular fluid to shift towards their brains [33]. There are strong correlations between this phenomenon and the deformation of astronauts' eyeballs on-board the ISS; the excessive fluid pressure in their heads is believed to be responsible for flattering of eyeballs (resulting in a less spherical shape) as well as inflaming of optic nerves.

Increased risk of blood clot is also one health concern that is believed to be linked with the redistribution of body liquids. However, this is still an area under research.

C. Hygiene

Hygiene is important both for the physical but also for psychological of the astronauts. The hygiene part is both the oral hygiene and washing face, hands, hair, and body. Because this is an exploration and not a normal mission, the assumption was done that the astronauts should have the bare minimum to still have the ability to clean themselves. The assumption was made that the crew will not consist of a menstruating women.

The packing list of hygiene is:

- Toothbrushes, *9 psc*
- Toothpaste tablets, *1776 pcs*
- Small towels, *63 pcs*
- Soapbar, *21 pcs*

D. Exercise

The astronauts have to exercise a lot during the transit to Mars. Just by being in space, the is no gravity that will affect the body, so you have to use your muscles in another way. And as the goal is to claim a mountain on mars the 2 astronauts that go up there have to be well prepared. Onboard we will have one treadmill, to train the walking part of the mission. The astronauts should not go to mars and have not walked for all those days. Also, they will have to exercise other muscles, and for that, a yo-yo flywheel will be used on the spacecraft.

On ISS now, normally the astronauts work out 2,5 hours every day. But because the astronauts here, the explorers, have another goal they have to exercise even more. Because the explorers have to be walking for a long time during the climb, they will have an exercising schedule that is with some of the blocks that are 4h. Every day the astronaut will have a new muscle area to focus on, and on top of that a workout on the treadmill for cardio. While climbing the mountain the astronauts will have to be in their spacesuit for approximately 12 hours, and by that not resting for almost 12 hours. So this is why they have to be well prepared. Their training schedule is based on, how mountain climbers prepare before a climb, and how the astronauts on the ISS schedule look. The exercise schedule for one astronaut is presented in Table III:

TABLE III
EXERCISE SCHEDULE FOR ONE OF THE ASTRONAUTS

Weekday	Treadmill (cardio)	Yo-yo Flywheel (strenght)
Monday	4h	1h
Tuseday	2h	2h
Wednesday	4h	1h
Thursday	2h	2h
Friday	1,5h	1h
Saturday	4h	1h
Sunday	2h	2h

E. Workload division

Given the exploratory spirit of the Tantalus mission, the workload division focuses on ensuring that every astronaut is in good shape upon Mars arrival. This because the Martian stay is short and therefore the crew has to be ready to climb Olympus Mons within days from landing. This is accomplished by dedicating several hours to physical exercise. The rest of the day time will be spent maintaining the vehicle, managing the systems, and doing experiments commissioned by paying clients. Some time will be also dedicated to personal hygiene and meals. Eight hours of sleep time will be considered. Workload will be divided equally between the astronauts with free Sunday where the only duty of the crew is to workout.
In order to have a balanced weekly schedule and fit every activity in it, some considerations have been made. Each crew member will start the day with a workout twice a week, there will be 6 hours of experiments every day divided into 2 hours shifts. Short experiments can be done in the 2 hours morning session. Longer ones can be done in the afternoon when there are 4 consecutive hours dedicated to experiments with 2 hours per astronauts. Since there are walking training sessions that last 4 hours in preparation for the summit push of Olympus Mons, some early lunches and late dinners occur. Every crew member will only have one early lunch and one late dinner per week but not on the same day. In order to ensure the psychological wellness of the crew 2 hours of free time are available. Since the mealtime is a great moment of sharing and fellowship, on Sunday the crew will have all the meals together. The weekly schedule for the mission is presented in the table in Figure 6.

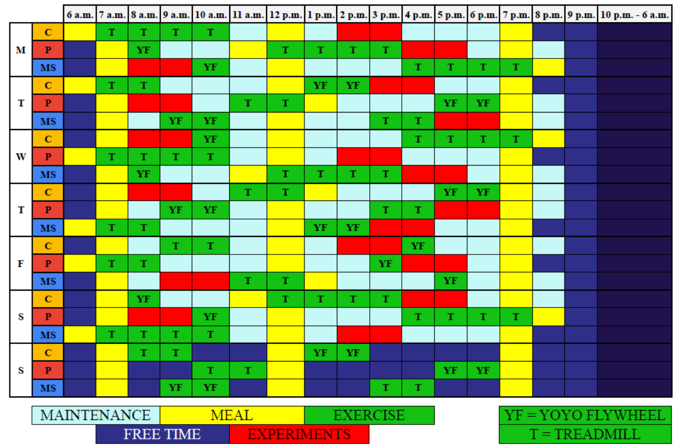

Fig. 6. Weekly Schedule

F. Crew selection and training

The Tantalus mission to ascent Olympus Mons for the first time will be a masterpiece of engineering solutions. As with all long-duration space missions, failure is not an option. Considering the competitive spirit of the challenge, the high risks of long interplanetary travel, and the climbing operations on Mars, a perfectly trained crew is essential. There could be two strategies to follow when defining the crew selection process: selecting from a unit of experienced astronauts who have previously flown in space or selecting from a new astronaut selection campaign. Both the approaches have advantages and disadvantages.

1) Experienced crew: Experienced astronauts will be already prepared to face the space environment and Mars transit, especially if they have already flown in long-duration missions. They would be almost *"ready to fly"* just after a specific mission training. Indeed, they won't need the basic and pre-assignment training. Astronauts who have flown on short-duration missions would be already trained and would not have accumulated too many days of space radiation exposure. On the other hand, they would have already accumulated relevant radiation exposure during their career if they have flown on long-duration missions, and this could be an issue. If genetic heritage relation with individual sensitivity to radiation will be determined, the reduced number of candidates would lower the probability to find a suitable crew. Moreover, it is not guaranteed that the astronauts in the agencies or private companies corps will have the required skill for the climb, in particular the summit push. Anyway, there will be plenty of time to train the crew since 5 years are assumed to pass from the challenge proclaim to the launch of the mission.

2) New astronauts recruitment: Considering an astronaut selection and new recruits will allow the organization to select highly specialized people with the required skill for the climbing mission, setting all the selection parameters from scratch. The crew would have no previous exposure to space radiations and therefore higher limits of permanence in space. A larger group of candidates would also increase the probability to find the perfect crew for the mission in terms of skills but also individual radiation sensitivity. The main disadvantage of this choice is that complete astronaut training will be necessary. After the selection, the conventional training program of the ISS crew can last up to $4/5$ years and the pre-mission schedule could be tight since 5 years of preparations are expected before the launch. A desirable asset for astronauts preparing for a long interplanetary mission would be to have done at least one previous spaceflight. Fitting a preliminary mission as part of the 5 years training program would be difficult.

Given the equally balanced pros and cons of the two approaches, the selection will focus on experienced astronauts for the commander role and on new recruits for the pilot and mission specialist roles. The parameters for the selection process are summarized as follows:

- General requirements: grade of education, area of expertise, entry profession, professional experience, complementary skills that an applicant may bring to the crew, ability to master multi-tasking capabilities in a complex operational environment, ability to communicate well in a number of languages, the family environment must be highly stressed tolerant.
- Technical skills: exploration experience in harsh environments, experience as a pilot for the pilot role is an asset, hiking and climbing skills, repair skills, off-road driving experience, survival skills, medical proficiency.
- Psycho-Aptitude profile: the ability to remain calm under pressure is crucial, ability to improvise, suitability for participation in public relations activities, communications skills, able to act as an advocate and ambassador of the mission, he/she must be presentable at all times, the ideal candidate should be intelligent, agreeable, charismatic, likable, a good speaker, and a team player.
- Physical-Medical conditions: applicants must be healthy and fit, low individual sensitivity to radiation (if applicable), no sleeping/sleepiness problems, astronauts should be about the same size.

After the selection process which is estimated to last up to 10 months, a crew training program similar to those of the space agencies will begin. The 18-month basic training will be programmed for the new recruits who will be assisted during the training process also by the veteran astronaut selected for the commander role. At the end of the basic training, the pilot and the mission specialist will graduate as astronauts. The selected crew is already assigned to the mission. For this reason, pre-assignment training to maintain the qualifications and operational skills acquired during the basic training is not necessary. After the basic training also the commander will actively train with the pilot and the mission specialist. An 18-month advanced training similar to the ESA's Assigned Crew Training will prepare all the three crew members for the long-duration mission and will end with a training mission to the Moon. This mission would take advantage of the Lunar Gateway which is expected to be operative by the time the Olympus Mons ascension challenge is declared and give a first experience of the space environment to the new recruits. The ideal is a short duration expedition to the Moon lasting around 2 months where the crew can experience landing, rover driving, and ascent operations as well as rendezvous and docking. For this reason, the advanced training will include extensive piloting, Martian rover driving, hiking, climbing, and robotic operations training sessions. The training for the space vehicle operations, experiments, EVAs, launch, and landing will be carried out in the training facilities of the agencies and companies contributing to the mission. The advanced training will be specifically scheduled and customized for each crew member and their respective role. The Martian environment has been emulated on Earth in several locations. The training sites for the Martian operations of the Tantalus mission could be Wadi Rum, also known as the valley of the Moon in southern Jordan, Devon Island in the Canadian Arctic and location of FMARS, the San Rafael Swell located in south-central Utah, and site of the MDRS, the Makhtesh Ramon in Israel's Negev desert and the slopes of the Mauna Loa volcano on the island of Hawaii. After the basic training, the advance training, and the training mission to the Moon the crew will have the last 12 months of specific mission training before the launch. Here they will refine their specific role skills and train intensively for the physical challenge of the mission. A timeline overview of the training program is presented in Figure 7.

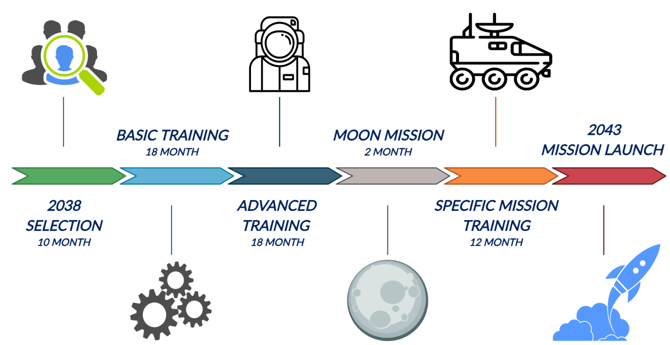

Fig. 7. Training Program for the Tantalus Mission

IV. Conclusion

This paper focused on the human aspects of the Tantalus mission to climb Olympus Mons. Firstly, the primary requirements and the life support system were analyzed. It gathered all the systems essential to maintain life in the short term.

The Air Management System for the space vehicle has been designed with a partially closed-loop concept. This choice was driven by the reduced number of crew members and the necessity to reduce weight. The oxygen will be directly supplied from tanks. The air will be processed by the 4BMS-X CDRA similar to the one in use on the ISS. This system will remove and vent the CO_2 from the spacecraft modules and redirect the clean air back to the cabin. A TCCS will monitor the atmospheric constituents and trace particles. A VCD system will remove and condense water vapor diverting it to the Water Management System. The Martian rover will be equipped with oxygen tanks and CO_2 traps. A filtering system will prevent obstructions due to the Martian dust. The spacesuits will have a PLSS with oxygen tanks and a CO_2 PSA system.

For the water, the system will recycle the grey- and yellow water with multi-filtration, catalytic oxidation, and VCD. None of the black water will be recycled, this is because it could contain pathogens. While on Mars, non of the water used during the climb in the rover will be recycled. On the spacecraft on the transit to Mars, the maximum of water has to be brought, 720kg.

An open-loop system has been chosen for the food, both for its simplicity and reliability. All the food will be canned or freeze-dried and brought on cargo before the crew for the return trip.

Safety and emergency equipment deemed necessary for this mission include radiation shielding (for both humans and astrionics), fire extinguishers, chemical sealants, first aid kits, defibrillators and ultrasonic scanner. These equipment will increase the robustness of the mission if the crew were to encounter abnormal events.

The thermal regulation system will be similar to the one used currently on the ISS, where a fluid is pumped through radiators to remove heat from the spacecraft.

The radiation protection will be provided by passive shielding. For the whole spacecraft, the development of light and effective shielding materials has been assumed to be completed by 2038. In addition to that, the crew module will have a lithium hydride shield to increase the protection. When SPEs will be threatening the crew, bags, tanks, and equipment will be used to create a thicker protection layer.

Then, secondary aspects were studied. These are all the other aspects essential for the success of the mission but are not immediately life-threatening.

A long-duration spaceflight has many stressing factors on the crew, which can impact their psychological state and eventually lead to a mission failure. However, mitigation methods exist to prevent any conflict, and experiments on Earth have shown good results on group behavior.

As for medical aspects, zero gravity and cosmic radiations are the two main inevitable concerns to the human body. Studies have shown a variety of side effects with linkage to space habitats under micro- or zero-gravity conditions. However, there are still deep uncertainties regarding the long-term or everlasting effects of living in weightlessness in conjunction with excessive exposure of high energetic radiations on the human body. Since human spaceflight still is a relatively new area of research (roughly 60 years), the amount of data is still not enough to draw solid conclusions about the true effects of living in space. However, one can assume that long-term radiation exposure in space has parallel outcomes with intensive radiation exposure on earth - proven causation that the risk of various diseases and cancers.

Hygiene is important for the physical but also for the psychological wellness of the crew. Because they are explorers, they will have to bear with the minimum and use everything for as long as possible.

Physical exercise is crucial for the success of the mission. Astronauts will dedicate a lot of time to training during the Mars transit. This in order to keep the crew in shape upon Mars arrival and considering that the short stay won't allow for many days of gravity readjustment. A treadmill will be used for long walks and cardio sessions. A yo-yo flywheel will allow the crew to train all the muscles and stay in shape.

A detailed workload division has been organized. The idea was to prioritize physical training. Several hours will also be dedicated to maintenance as it happens on the long-duration mission on the ISS. Experiments and free time will keep the crew busy and mentally healthy.

The crew selection concept was conceived in order to have a highly specialized crew composed of tough people that can accomplish the challenge. An experienced and active astronaut will be selected for the commander role. A recruitment campaign will select the pilot and mission specialist. The training will be divided into sequential phases including a training mission to the Moon.

All things considered, this study on the human aspect of the mission shows that there are many different disciplines that have to be taken into account. Many experts in various fields have to work together for the success of the mission, that is where good coordination is crucial. This also explains why manned missions require so much time and funding.

This project work allowed us to understand how a human mission to Mars could be accomplished in the future. Technological development is making it possible to solve many problems that such a mission poses. But for some, no solution has yet been found. When they are, the next giant leap for mankind to Mars will be possible. Thanks to science, technology, engineering, and many great people, even Mount Olympus will be conquered.

References

[1] Mission Operations Directorate Space Flight Training Division. *International Space Station Familiarization Training Manual*. NASA, Lyndon B. Johnson Space Center Houston, Texas, 2004.

[2] Carol Norberg. *Human Spaceflight and Exploration*. Springer-Verlag Berlin Heidelberg, 2013.

[3] Ivann Merle, Ettore Scami, Simon Vial, and Brice Metzinger. Mount Olympus Ascension Mission Space Vehicles - Team Red. March 2021.

[4] Harry W. Jones. Would Current International Space Station (ISS) Recycling Life Support System Save Mass on a Mars Transit? *NASA Ames Research Center Moffett Field, CA United States*, 47th International Conference on Environmental Systems (ICES) Charleston, SC, 2017.

[5] Filip Malmborg, Oscar Andersson, Theo Grimonprez, Benoît Logiou, and Adam Parks. Mount Olympus Ascension Mission Mars Operations - Team Red. March 2021.

[6] Tim Peake ESA astronaut. Learning to Spacewalk. https://blogs.esa.int/astronauts/2012/02/18/learning-to-spacewalk/, 2012.

[7] James C. Knox Warren.T.Peters. 4BMS-X Design and Test Activation. *NASA Marshall Space Flight Center, Huntsville, Alabama, 35812, USA*, 47th International Conference on Environmental Systems (ICES) Charleston, SC, 2017.

[8] Ariel Macatangay, Jay Perry, Paul Belcher, and Sharon Johnson. Status of the International Space Station (ISS) Trace Contaminant Control System. volume 4, pages 48–54, 07 2009.
[9] Harry Jones. Methods and costs to achieve ultra reliable life support. 07 2012.
[10] Twila Schneider. Environmental control and life support systems water filtration challenge.
[11] Cindy F. Hutchens. Vapor compression distillation (vcd) flight experiment. https://www.nasa.gov/centers/marshall/news/background/facts/vcd.html, 2021.
[12] Wikipedia. Blackwater (waste).
[13] Christophe Lasseur (ESA). Introduction to life support system, 2021.
[14] ESA. Water in space.
[15] Nasa can't send humans to Mars until it gets the food right Matt Reynolds. https://www.wired.co.uk/article/food-in-space-mars-iss-station-astronaut-eating, 2018.
[16] FS-2002-10-079-JSC Lyndon B. Johnson Space Center. Space food. 2002.
[17] Samira Beikzadeh, Marjan Ghorbani, Nayyer Shahbazi, Farzaneh Izadi, Zahra Pilevar, and Amir Mortazavian. The effects of novel thermal and nonthermal technologies on the properties of edible food packaging. *Food Engineering Reviews*, 12, 09 2020.
[18] Human Needs: Sustaining Life During Exploration. https://www.nasa.gov/vision/earth/everydaylife/jamestown-needs-fs.html, 2007.
[19] Lina Tran (NASA). How nasa will protect astronauts from space radiation at the moon. https://www.nasa.gov/feature/goddard/2019/how-nasa-protects-astronauts-from-space-radiation-at-moon-mars-solar-cosmic-rays, 2019.
[20] Wikipedia. https://en.wikipedia.org/wiki/Maintenance_of_the_International_Space_Station#2004_\OT1\textendash_Air_leak_and_Elektron_oxygen_generator_failure, 2021.
[21] Elizabeth Howell (Space.com). Cosmonauts seal air leak in russian module of the international space station. https://www.space.com/cosmonauts-seal-space-station-air-leak-cracks, 2021.
[22] Communications Boeing, IDS Business Support and MO 63166 Community Affairs P.O. Box 516 St. Louis. Active thermal control system (atcs) overview.
[23] Francis A. Cucinotta, Myung-Hee Y. Kim, Lori J. Chappell, and Janice L. Huff. How Safe is Safe Enough? Radiation Risk for a Human Mission to Mars. *PLOS ONE*, 8(10):1–9, 10 2013.
[24] Hassler. Mars' Surface Radiation Environment Measured with the Mars Science Laboratory's Curiosity Rover. *Science*, 343(6169), 2014.
[25] L. Walsh, U. Schneider, A. Fogtman, C. Kausch, S. McKenna-Lawlor, L. Narici, J. Ngo-Anh, G. Reitz, L. Sabatier, G. Santin, L. Sihver, U. Straube, U. Weber, and M. Durante. Research plans in Europe for radiation health hazard assessment in exploratory space missions. *Life Sciences in Space Research*, 21:73–82, 2019.
[26] C. Zeitlin, D. M. Hassler, F. A. Cucinotta, B. Ehresmann, R. F. Wimmer-Schweingruber, D. E. Brinza, S. Kang, G. Weigle, S. Böttcher, E. Böhm, S. Burmeister, J. Guo, J. Köhler, C. Martin, A. Posner, S. Rafkin, and G. Reitz. Measurements of Energetic Particle Radiation in Transit to Mars on the Mars Science Laboratory. *Science*, 340(6136):1080–1084, 2013.
[27] William Atwell Kristina Rojdev. Investigation of Lithium Metal Hydride Materials for Mitigation of Deep Space Radiation. *46th International Conference on Environmental Systems, Vienna, Austria*, 2016.
[28] NASA website. Scientists and Engineers Evaluate Orion Radiation Protection Plan.
[29] N. Kanas and D. Manzey. *Space Psychology and Psychiatry*. Springer, 2008.
[30] MARS-500 crew member Romain Chales. private communication, 15th february 2021.
[31] Mars-500 website. http://mars500.imbp.ru/en/index_e.html, 2011.
[32] NASA.com. Mars communications. https://mars.nasa.gov/mars2020/spacecraft/rover/communications/, 2021.
[33] BEC CREW. Space could leave you blind, and scientists say they've finally figured out why. https://www.sciencealert.com/we-finally-know-why-astronauts-lose-their-vision-in-space-and-it-s-bad-news-for-mars-missions, 2016.