Human Aspects and Life Support System Group Report
Human Spaceflight - Blue team

Manil DJOUADI, Aurore GAMBA, Sébastien RUHLMANN and Nicolas TANGUY

***Abstract* — The focus of the report is a conceptual spaceship for a mission to Mars intended for passengers. The spaceship is designed to take 30 passengers onboard, along with a crew which size is determined hereunder, from Earth to Mars and back. It is to be built for multiple trips and be ready by the year 2032. It is assumed that several human missions to Mars have already taken place and that all infrastructure needed on the Red Planet already exist. Particularly in this report, the aim is to make such a mission feasible from a human aspects and life support system point of view.**

Given assumptions mentioned above and some more taken, a crew of 10 astronauts and a working group division with 10 groups for passengers have been decided. The needed equipment related to human aspects which includes Advanced Life Support Systems, consumables (food, water, oxygen), crew accommodation, clothes, EVA equipment, IVA pressurized suits, is estimated to weigh 99 tons for a volume of 843 m3. These figures are included in the overall mass and volume of the spaceship designed by the concept vehicle group. The cost comes to $795 million. More detailed figures are presented in the report.

An off-nominal case has also been studied. It deals with both individual psychological troubles and disagreements between two people or more. To solve these issues that are likely to happen during such a long mission, several protocols have been put in place.

CONTENTS

I. INTRODUCTION

Human missions to Mars are the next big step in human spaceflight. The Red Planet seems like the next luxurious destination with plans to send people to colonize it in the early 2030-ies.

This project has goal to take 30 passengers to Mars and back to Earth. A team of about 20 people has worked on it to design the best spaceship possible. Divided into 5 subgroups, they focused on vehicle concept, propulsion and power systems, human aspects, operation and logistics as well as overall coordination.

The main goal of the group working on human aspects was to come up with a habitat that would make such a trip to Mars feasible, safe and enjoyable for everyone. First, a focus on crew and passengers taken for the mission to Mars was made. Thereafter, what the onboard life would be like for them was decided. Lastly, the Life Support System needed onboard, with all its components, was studied. An off-nominal situation of psychological emergencies was presented along with suggested solutions. Finally, volumes, masses, costs and power consumptions have been estimated thanks to available data and some assumptions.

Regarding life on the Red Planet, it has been assumed that all infrastructure needed was already present since other human missions to Mars have taken place beforehand.

II. CREW AND PASSENGERS

A. *Description of crew*

It has been decided to bring 10 professional astronauts whose mission is to safely take the passengers to Mars. They are divided into two groups of five, each group taking care of one half of the passengers in priority. This means they share the living and sleeping hours of the group they have been assigned to. For that reason, several of the crew members have double competencies with one major and one minor skill. Each crew of 5 members is thus able to handle all the necessities that concern both the passengers and the spacecraft while the other is sleeping.

The crew can be described as follows:

Table 1: Description of the crew members

Team	Major competency	Minor competency
Team 1	Mechanical engineer	In charge of EVAs
	Nuclear engineer	In charge of EVAs
	Doctor/Surgeon	Psychologist
	Computer scientist	Pilot
Team 2	Mechanical engineer	In charge of EVAs
	Physicist	In charge of EVAs
	Doctor/Surgeon	None
	Pilot	Engineer (nuclear/electronics)
N/A	Commander	None
	Psychologist	None

The commander and one psychologist will follow the shifts as well but have not been assigned to any team. It has been determined that their role can require to be available at all time. Their schedule is then more flexible than the others'.

B. *Passengers*

1. Selection [1]

Even though passengers are not part of the crew and therefore do not need any particular professional skill, a trip to Mars is a challenge for the body as well as for the mind. Thus, not everyone is fitted for such a trip and there needs to be a selection beforehand.

Since spending time in microgravity induces bone loss and changes in fluids repartition inside the body, it is necessary to be in good health condition before the space trip, meaning all passenger candidates must hold an aviation class 2 medical certificate also known as JAR-FCL 3 class 2. It is the same certificate as astronauts need. Besides, since the complete journey is approximately three-year long, it has been decided to establish an age range to minimize health issues during the trip. Applicants must be between 25 and 60 years old. There is no specific criterion about the gender.

Once these requirements are fulfilled, potential candidates are called in to take psychological tests. Anyone showing no honest motivation to be a part of the mission or any reluctance to maintain their physical condition by exercising when in space will be excluded. Afterwards, a medical examination is carried out by physicians qualified by space agencies. Finally, given that passengers will spend a high amount of time in a confined space with several people, personality tests and interviews take place to choose the thirty best-suited candidates.

2. Training

Selected passengers then take part in a one-month training to learn the basic elements of life in microgravity and deep space, learn to work together as teams in extreme environments (expedition camp and leadership/followership training [2]) and on the spaceship's systems that they will take care of during the mission. Indeed, passengers will help astronauts in the maintenance and management of the spaceship to stay active during this long trip and not suffer from depression or other psychological troubles. Passengers also train for EVAs on ground to have this opportunity again in space. Finally, the team training is supervised by the astronauts who will decide on how to create the groups and shifts based on matching personalities.

III. ON-BOARD WORK

A. *Psychological Aspect*

Research has been done to find out how astronauts were psychologically impacted by their 6-month-long missions on the ISS [3]. Isolation was actually found to be an aspect that impacted astronauts' mental fitness the most. It was also found that the crew members' moral went through their most significant decline during the third quarter of the mission.

Moreover, our mission brings new specifications to take into account. Going on a trip to Mars takes more time than a classical 6-month mission on the ISS.

Plus, communication with the ground is made harder as the spacecraft gets further from the Earth. Finally, a space travel including 30 members that are not as trained and prepared as professional astronauts is much bigger and complex than anything that has been experienced so far.

Some clues may help passengers fight against psychological decline throughout the trip. Writing in a journal for the needs of a study has helped some astronauts, as well as communication with the outer world, whether it is with family, friend or mission control. Communicating through social media seems also to be a good way to keep contact with the ground nowadays [4]. Focusing on their working activities is also a good way for them to keep up.

B. Working group division

The passengers will spend around 500 days on board the spaceship (roundtrip) with initially no attributions, which could quickly give them a feeling of non-control of the situation and encourage psychological troubles as well as boredom. To counter this, it has been decided to give passengers managerial and maintenance missions of their everyday life on board to help them socialize and bring support to the crew, relieving some of the crew workload. The missions have been designed to be non-critical (i.e. without risks for safety or space ship integrity) so that there is no need for constant crew supervision; to be easy to handle so that any passenger can circle in between tasks with minimum training prior to the mission; and to be performed as teams to ensure that at least one person is capable and available at any time.

Each task is performed by the same group for two consecutive weeks. Then, a rotation cycle takes place, allowing for less routine sickness and more understanding of everybody's role in this confined and isolated system. Crew members serve as specialists for each task (can be asked for help or advice).

Food: Plan the meals, account for calories / vitamins / nutriments balance, cook the meals, keep the food storage inventory updated, check that everyone attended the meals.

Oxygen: Perform routine checkups of the recycling and air circulation systems, change the filters if needed, keep the indicators updated and report to the crew.

Water: Perform routine checkups of the recycling systems (cleaning suits, toilets, air humidity, clothes dryer), change the filters if needed, keep the indicators updated and report to the crew.

Cleaning Suits (See section IV.C): Operate the suit when people use it, maintain its functionality and dry it off after use.

Toilets: Perform routine checkups, keep the facilities cleaned, perform maintenance operations if needed.

Sport: Install the exercising machines, perform maintenance operations if needed, check that everyone attended their exercise routine.

Clothes: Plan the clothes rotation cycle, retrieve clothes from the storage, keep the clothes storage inventory updated, gather used clothes and put them in the dryer, vacuum seal them and put them in the "used" storage. Two groups of passengers needed.

Wastes: Take care of all possible wastes (plastic bags, containers, fecal matter, etc), compact them, keep the inventory updated.

Overall Coordination: Make sure that no one gets out of balance in their everyday cycle (meal, exercise, hygiene, sleep, nominal work participation), plan information meetings and EVAs with the crew, plan whole fleet group entertainments (movie nights, etc).

The preliminary training to perform all these tasks includes a knowledge of every involved device or machine plus a fair audit performance capability. Based on today's need for astronauts' training at the EAC (European Astronaut Center), every piece of equipment requires a two-hour training [5]. This leads to a 40-hour training load to be able to perform all these activities (audits considered).

C. On-board activities

1. Entertainment

For such a long trip in a confined space, it is of the utmost importance that passengers and crew members do not get bored. Such as working routine, entertainment is necessary to preserve their sanity which is why it must not be neglected.

Even with group work and exercising, passengers have lots of free time. Live communications with Earth not being feasible, their scope of activities is restricted to who and what is accessible on board the spaceship. Therefore, a virtual multimedia library with all sorts of books, music and movies is available for each passenger on their personal tablet computer. Furthermore, according to a study regarding leisure activities among Antarctic Research Station members [6], it appears that movies are the favorite one for all the members. Thus, planned film sessions where one is free to attend or not are organized to resemble cinemas at least once a week. Playing cards, board games and video games are also at the passengers' disposal as well as Frisbees and balloons.

Each passenger is allowed to bring personal belongings such as photos, letters and any other thing they desire as long as it does not pose a threat to others nor to the integrity of the spaceship. Personal belongings are limited to the equivalent of two shoe boxes. Besides, for the passengers to maintain a semblance of normal life during the trip, events such as birthdays, Christmas and New Year's Eve shall be celebrated as usual in accordance to the passengers' belief. As such, special food shall be served. All of the above also relate to crew members who, even though they have less free time, have access to the same items and facilities as the passengers.

Finally, there is an observation module and it is possible for passengers to perform EVAs during the trip. This particular activity will be discussed in more details in part III.D.

2. Exercising

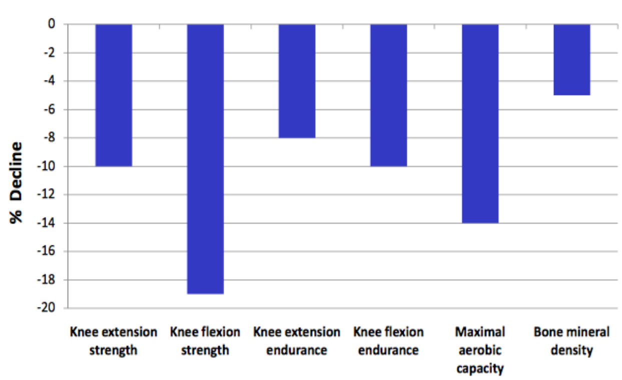

Figure 1: Fitness declines with a 24-week-long ISS mission [7]

Space travel has harmful physiological consequences for human beings, that are mainly caused by the weightlessness travelers experience in space. Figure 1 shows that astronauts spending 24 weeks on the ISS suffer from significant losses in terms of muscular strength, aerobic capacity and bone density.

The best way to fight against such a physiological impact that has been found so far is exercising. Researchers investigate ways to increase efficiency of workouts and recently came up with a specific study called Sprint [8]. It has been found that raising the intensity of the astronauts' workout sessions would make it possible to reduce consequently both duration and frequency of sessions.

A program that includes resistance and aerobic training has then been designed. It would give the possibility for each passenger to earn 3 hours per week compared to the classical exercise program. This means more time which can be dedicated to other activities as well as a longer lifespan for the equipment.

Three kinds of machines have been selected to fulfill the needs of all the passengers: the ARED (Advanced Resistive Exercise Device) [9] for resistance training and a treadmill -COLBERT, or Combined Operational Load Bearing External Resistance Treadmill- [10][11] and bicycle -CEVIS, or Cycle Ergometer with Vibration Isolation and Stabilization System-[12] for aerobic training

Table 2 gives some features concerning the equipment that shall be available on board and its utilization.

Table 2: Description of exercise devices available on board in the Trident

	Quantity Q (based on old training program: more secure)	Mass (lbs) per machine (Total)	Volume occupied (m^3) per machine* (Total)	Lifetime	Utilization (hours/week) (old program [13])
ARED	3	700 (2100)	11.3 (33.9)	Certified for 15 years, max 40 (calculated)	120 (240)
COLBERT	2	2200 (4400)	8.6 (17.2)	150000 miles, 470 weeks per machine	58 (120)
CEVIS	2	59 (118)	4.2 (8.4)	Certified for 15 years	58 (120)

**The necessary volumes have been estimated by analyzing images of the machines being used [14].*

The equipment has been chosen so that it also makes it possible to provide the old program to each passenger. This gives a security margin in case an off-nominal situation occurs.

It has been decided that the exercise schedule will cover 16 hours out of 24 each day, 8 hours being dedicated to maintenance and possible to free use by the passengers.

D. EVA

Astronauts' training in the NBL (Neutral Buoyancy Laboratory) has several goals [15]: learn to maneuver large objects, repeat 5 to 7 times each EVA protocol before the actual EVA in outer space and repeat the emergency maneuvers. Considering that no passenger will be allowed to operate and maintain exterior installations during EVAs, only the latter is of importance; namely, the emergency maneuvers. Unfortunately, the NBL around the world are used for all types of space system testing, not only astronauts' training, and the schedule is already so tight that the NBL have to work in shifts [16]. Implementing an intensive emergency training for 30 passengers every two years can but increase the schedule problems. Thus, a solution would be to simplify the EVA suit life support system to minimize the training requirements.

Nowadays the suit's backpack is the main LSS [17]. An idea would be to make it the emergency system and instead use an umbilical cable to circulate oxygen, carbon dioxide, electricity and water between the suit and the spaceship. The LSS would be operated onboard by a crew member, enabling astronauts on EVA to focus on their mission and passengers to fully enjoy the experience. EVAs would be performed when astronauts have to maintain a piece of equipment, one or two astronauts per EVA who would have the possibility to bring a passenger along. The latter would be able to follow the maintenance mission, listen to communications and ask questions without much disturbance. He/She would be trained to stay on certain zones of the spacecraft free from equipment to avoid any non-intentional damage when moving around the structure, and would not have to worry about safety since the umbilical would bring all necessary support. In case of emergency, the backpack would automatically activate itself and the passenger return to the airlock, plus could receive support from the astronauts.

In any case, the astronauts and passengers would be harnessed to the spaceship thanks to a tether. Such an improvement on the suit could reduce immensely the stress on passengers during EVAs and reduce the training time in NBL.

The typical EVA team would then be:

- 1 or 2 crew astronauts
- 1 passenger
- 1 IV crew member (onboard the spaceship, responsible for giving instructions to astronauts, their LSS and getting them out and back)
- 1 IV crew member (onboard the spaceship, responsible for giving instructions to the passenger, his/her LSS and getting him out and back)

Concerning radiations, being out of the Earth's magnetosphere on the trip to Mars means less protection against Solar Particle Events (SPE) and Galactic Cosmic Rays (GCR) both inside the spaceship and during EVAs. Thus, EVAs for astronauts would not last as long as the typical eight hours in LEO, and even less for passengers. See section IV.G. for further explanations on radiation shielding.

IV. LIFE SUPPORT SYSTEMS

A. Food

1. Types of Food

Food is one of the most essential need for astronauts. In the last decades, it implicated some mission failures because astronauts didn't have a sustainable nutrition. In this way, food has to deal with several criteria [18]. It has to be compact to reduce the volume taken for its storage. It has to be lightweight in order to reduce the cost of the launch. Obviously, it has to be nutritious to contribute to the healthy diet of the crew. Another criterion is that food should be tasty: the sense of taste is reduced in space, and from a psychological point of view, astronaut should appreciate the food they eat in space. The last criterion is that the space food have to be sticky or wet because in a microgravity field, particles and crumbs float freely in the habitat and it would damage any support life system like ventilation for example.

As it is a trip of 515 days, menus are prepared before the mission. Every day, an astronaut will have three meals and one snack a day in order to ensure a total of 1900-3200 calories per day depending on his weight, his gender and his specific needs. There will be a rotation of the meal every fifteen days [19].

Every passenger will test the different meals during their trainings so that they can choose the meals they prefer. For special events, like New Year or Christmas, special food will be served to them like special drinks, in order to make them feel more comfortable during the mission. The meal preparation consists in reheating the meal in a microwave oven or rehydrate it. Beverages often are in the dehydrated form and they have to be rehydrated before being consumed.

The meals will be packaged individually to make it easier for the consumer: the mass of one meal without packaging is 1.8kg and with packaging 2kg. For a total duration of 515 days, the total mass of food needed for 40 crewmembers is 41.2. The time spent on Mars orbit is not taken into account in this value.

2. Preservation

Nowadays, space food is often fresh (fruits and vegetables), in its natural form (nuts, tortillas…) or dried (spinach, juices, and beverage), these are the easiest ways to store food in space [20]. However, the current pre-packaged food system has an ambient-temperature shelf of life of approximately 1.5 years which is unfortunately not enough for this mission of 545 days. Indeed, the nutrients in food are damaged through processing and storage in space. It can be seen as flavour changes due to lipid oxidation or loss of volatiles, texture changes due to staling or structure loss, and color changes due to enzymatic browning and it may lead to crewmembers nutritional deficiencies.

In order to counter this loss of nutrients, different methods have been chosen [21]. First some refrigerators and freezers will be used in the spaceship to store food. Indeed the capability to refrigerate (4°C) and to freeze (-20°C at least) the food can increase significantly the shelf life of the current food system. Another way to increase the shelf life of the current food system is to add a bioregenerative component in food but it is still in progress. Besides, the use of cans to package thermostabilized foods reduce the shelf life and so it won't be used for long-duration missions.

B. Air

1. Production [22]

Breathable air is crucial for the sake of the people on board. Nitrogen, which represents 78% of the ambient air on Earth, is an inert gas that does not serve any physiological need of the human body. Therefore, it can be easily stored on board the spaceship. It is mainly used to ensure that the spaceship pressure is at 1 atmosphere. Oxygen, on the other hand, represents 21% of the ambient air on earth and is necessary to humans. It is then consumed and thus, it needs to be continuously produced on board the spaceship.

As of now, there are three different ways to produce oxygen in space. The first one is oxygen generators that use electrolysis of water. The second method is pressurized oxygen tanks, it does not really produce oxygen as the gas is rather delivered from Earth. However, this will be used at the beginning of the mission as the main oxygen source. Finally, solid fuel oxygen generators also known as oxygen candles make up the third way to produce the precious gas. It is currently used as a backup system on the ISS and will too on our spaceship. The Oxygen Generation System on board the ISS is designed to produce between 2.3 and 9 kg of oxygen per day for a crew of 6 people [23]. A similar but bigger system will be used on the spaceship to Mars.

Recycling the air is crucial for the viability of the mission. In 2015, using Sabatier method which enables the reutilization of hydrogen – produced during the electrolysis of water along with oxygen – and of carbon dioxide – produced by people when breathing – to generate water and methane, about 50% of oxygen is recovered [24]. Indeed, a part of the water produced is then electrolyzed to produce more oxygen while the rest goes into processing and is available for reuse (see Figure 2).

NASA is working to improve the method to be able to recover 75% in a first phase. For the mission to Mars, such a number has been assumed. A person in space consumes around 1 kg of oxygen per day – the real value is lower but to take into account safety margins, 1 kg is considered for the following calculations. With 75% of recycling, for the round trip – 515 days and a 30 day margin for safety – and for the 40 people on board, 5.45 tons of oxygen will be needed (4.58 tons if we take the real value 0.84 kg per person per day).

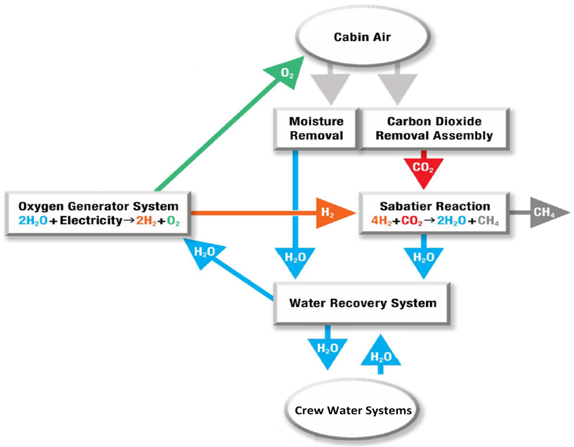

Figure 2: Oxygen recycling principle

2. Ventilation

The spaceship is a closed environment where air does not circulate naturally. During breath, people create carbon dioxide which could become toxic if it is not removed. Especially in the gym modules the generation of carbon dioxide is very high and ventilation is essential [25].

The ventilation system of the spacecraft is the same for the three different parts. For each part, it is composed of a blower who can provide sufficient air supply for the modules, five supply and five return vents. There is an additional supply and return vent in the gym module where the amount of carbon dioxide will be higher than the rest of the spacecraft. The air revitalisation system contributes to the removal of carbon dioxide and potential contamination all over the spacecraft [26].

In private cabins, the noise has to be reduced for a better living environment. Two ideas have been developed to do it. First acoustic abatement volume will be added around exhaust fans, and also acoustic blankets. Moreover, the supply vents will be connected with derivers so that the crew can reduce the mass flow passing through the vent and then reduce the noise in cabins. Nevertheless, derivers cannot be entirely closed to prevent from formation of gas bubbles in the cabins [27].

C. *Water [28]*

Water has a major role in the spacecraft as it is necessary for drinking, food, hygiene or even radiation protection. Unlike food, it can be recycled, which means that the quantity initially carried can be limited with adequate and efficient water recovery systems.

Water can be recovered from three main resources: urine, waste and carbon dioxide rejected by human bodies.

Urine allows to recover the highest amount of water among the three. An efficient urine processor can reach up to 85% recovery.

A Sabatier processor makes it possible to produce water from the carbon dioxide rejected by the passengers added to dihydrogen –which is produced by the oxygen generator system. The chemical reaction associated to the processor is:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad [1]$$

A Sabatier processor is a heavy and power consuming device. Yet, is has been decided to bring one, mainly because of its utility for carbon dioxide removal.

Finally, a waste dryer make it possible to recover water from the waste produced by passengers. Nonetheless, a relatively low amount of water can be processed by it.

However, these three processors provide gray water. It has to go through an additional water processor to filtrate it and make it potable. This operation is power consuming, thus only the necessary amount of potable water –3.53kg per person and per day [29]– should be processed.

It has been calculated that 15.34 tons of water should be initially carried on board. Calculations are developed in Appendix B.

This much water includes the one used in the “space shower” device. Cleaning yourself in space is done today by using wet towels to rub your skin with, which might not be pleasant for everyone in the long term on a 500-day trip. The psychological impact on passenger’s happiness to feel washed was taken into account when designing the “Cleaning Space Suit” pictured below.

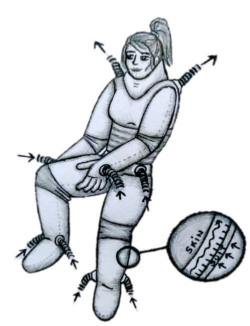

Figure 3: Cleaning suit design and principle schematics

The suit's principle is that one enters a suit filled with water, the water circulates to wash away dead skin and dirt, and the inner layer composed of semi-rigid hair can be used to brush oneself when pressing the suit against one's body. All the water used by this method can be recycled so there is no shame in using this much water, and people feel washed because they are literally bathed in water. Three of these cleaning space suits would be on board the spaceship, for an approximate 100kg total with filtering and circulating machine, allowing for several people washing at the same time.

D. Medicines

Health care of the astronauts is one of the most important concerns during space missions. Astronauts live in an environment very different from the one on Earth because of microgravity, radiation, etc. In this way, medical kits and medicines are essential for a long-duration trip, especially a trip to Mars.

The health care system is the same as the one used in the ISS [30], this is the Health Maintenance System (HMS). This medical kit is composed of the Ambulatory Medical Pack (AMP), the Advanced Life Support Pack (ALSP), the Crew Contamination Protection Kit (CCPK), a defibrillator, the Respiratory Support Pack (RSP), the Crew Medical Restraint System (CMRS), and the Medical Checklist. The total mass of the medical kit is about 1000kg [31]. It has to be added medical consumables for the trip from Earth to Mars, which is equivalent to an additional mass of 500kg. It is supposed that medicines will be developed on Mars's surface in the next twenty years.

Besides some types of fungi are sent to space to be subject to the extreme environment in order to discover new treatments [32]. New medicines are based on a type of molecule called secondary metabolites that are produced by some kinds of fungi. For example, Aspergillus nidulans is used to make some types of drugs to treat osteoporosis. Astronauts often suffers from osteoporosis due to microgravity. Thus, some drugs will be made on board.

A surgical system can be used in the medical lab [33]. It consists in a clear dome that is in watertight contact with skin. The dome is filled with a saline sterile solution and pressure is controlled by a monitor system. The surgeon can work thanks to the watertight ports. This system prevents from any loss of fluids such as blood during the operation because the surface tension in the fluid stops blood. This device is still in progress but it is likely to be operational for the mission [34].

A medical check-up will be carried out by the doctor on board every week on every people. It consists in a physical and a psychological tests.

E. Clothes

As for now, the clothing system on board the ISS consists of disposable clothes as it is the most convenient. However, for a mission to Mars, there is no way to continuously send clothes from Earth to the spaceship. Therefore, all the needed clothes as well as the non-clothing items for the whole duration of the trip are to be brought at the beginning. Based on the results of study [35], it has been decided that both steam sanitizing and vacuum sanitation will be used for the IMS Trident mission. Thanks to these technologies, items will be de-odored and microbes will be eliminated from clothing allowing crew and passengers to wear their clothes around five times before disposal. The advantage compared to laundry is that they do not require water nor generate foamy wastewater which can be hard to recycle.

Besides, NASA is developing clothing items with advanced materials such as antimicrobial fabric with longer wear duration. For instance, an advanced sleeping T-shirt can be worn 11 days instead of 7 with basic material.

Sanitation laundry and advanced clothing reduce considerably the quantity of clothes needed. For a 300-day trip – the way back from Mars to Earth being expected to last 290 days, the upper limit is taken – approximately 12 kg of clothes per person are required which represents a volume of $0.06m^3$. This results in a total of 480 kg for clothes with a volume of $2.4m^3$ for 40 persons. Using steam sanitation, 10 sanitizing per week are required which represents around 14 hours of crew time per week. Given 10 steam sanitizing and 40 vacuum sanitations per week, 1 steam sanitation box and 2 vacuum chambers are taken on board the ship. The first one has a mass of 106 kg and a volume of $0.7m^3$ while the last one has a mass of 177kg and a volume of $0.4m^3$. The total mass and volume of the sanitation laundry are then respectively 460 kg and 1.5m^3. For the systems to work, 5kW is needed per day. While the sanitation systems add mass and volume to the spaceship, it is small in comparison to the mass and volume needed with no sanitation option as it saves around 900kg and 6m^3.

Non-clothing items are also needed, such as sleeping bag liners, towels and wipes. Unfortunately, sanitation methods are not appropriate for non-clothing items. However, the amount of non-clothing items can be reduced thanks to the "Cleaning Space Suit" presented in IV.C: it has been assumed that towels and wipes can be cut almost by half. Therefore, non-clothing items will account for 1.2 tons for all members of the spaceship for 300 days (2.2 without the cleaning space suit).

In all the calculations above, only a 300-days travel has been considered because it is assumed that each person has their own clothes and non-clothing items that they will keep once on Mars. They will also be able to wash them and therefore reuse them on the Red Planet and for the way back. Besides, an assumption is that sanitation allows clothes to be reused five times but it can be more. Safety margins are not relevant for these items as they are not critical.

F. Waste

In space, it is forbidden to throw waste away from a space vehicle. The question on how waste can be stored is thus essential to be discussed. Indeed, the different types of wastes must stay in the ship but they should be stored so that the volume used is optimized. Moreover, some wastes can be partly recycled. Thus the treatment of waste depends on the type.

First, every food, medical and hygiene waste are compacted and packed together since they cannot be reused. Food packaging will be reused to pack waste [36].

Then, when clothes have to be replaced by new ones, the old ones are vacuum-packed in individual packages. Indeed, each people have a clothes package they will take with them when they will land on Mars. Clothes will be washed on Mars where water can be synthesized.

Besides, water from fecal wastes will be caught thanks to a dryer, and then the fecal waste will be compacted to take less volume.

G. Radiation

Radiations are measured in Sieverts (Sv) [37] and humans usually receive 4-5 mSv/year living on Earth. Nuclear workers are limited to receiving a maximum of 50 mSv/year and astronauts on board the ISS usually receive 80 mSv/year. These numbers are cumulative and the more you are exposed to radiations, the more is your cancer probability. Finally, humans are expected to die over a 2000 mSv (i.e. 2 Sv) exposure.

In interplanetary space, one can face two fierceful radiation sources: Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE). GCR transmit 100 to 800 mSv/year depending on solar cycles (solar radiations naturally block cosmic rays) ; future GCR minima are forecasted around 2025 and 2036. SPE are acute events often raising above lethal dose (> 2 Sv), with an average value of 300 mSv. [38][39][40]

The spaceship's design including a 5cm-thick polyethylene shield can reduce the GCR exposure by 30% (70 to 560 mSv/year) [41]. Its design also features a "storm shelter", or "SPE shelter" where an additional 7.25cm-thick water shield is used to reduce the SPE radiation exposure down to 10 mSv which is about a 2-year radiation exposure on Earth.

Conclusions on radiation shielding are that SPE can be mitigated really well but not GCR… yet. A 90% GCR exposure reduction (10 to 80 mSv/year) would require a 20cm-thick liquid hydrogen shield [42] which would cost a lot to launch into space but the radiation levels would be around those of life on Earth or of an astronaut in the ISS, within the magnetosphere.

Fortunately, a breakthrough in nanomaterials could be used as a last-minute add-on and require less thickness than polyethylene [43]. Boron Nitride Nanotubes (BNNT) [44], a material already used for reentry heat shielding, has the ability to block neutrons better than polyethylene when hydrogen atoms are strapped on its structure according to first researches. This material could ally structural stiffness due to its nanotube structure and radiation protection as previously explained, making it the perfect material for space travel. In addition, being manufactured as a fabric to create composite materials, this material could also compose the future space suits and enable EVAs both for astronauts and for passengers. The actual duration of these EVAs cannot yet be determined based on the published researches.

V. Off-Nominal Situation

The duration of the mission is more than one year in a limited space which is very different from life on Earth. Hence, it is suitable to forecast different types of situations that can occur during the mission. The following tables show different scenarios regarding both individual psychological troubles -Table 3- and disagreements between different people on board - Table 4. Several solutions are suggested.

	Switch working group	Extend sport session	Offer new activities	Psychologist	Extend Earth com	Electroshock	Confinement	More human contact
Isolation	Red	Red	Green	Green	Yellow	Green	Red	Green
Home sickness	Red	Yellow	Green	Green	Green	Red	Red	Green
Question personality	Red	Red	Yellow	Green	Yellow	Green	Red	Green
Sleep disorder	Yellow	Green	Green	Yellow	Red	Red	Red	Red
Depression	Yellow	Red	Green	Green	Green	Green	Red	Green
Social anxiety	Green	Yellow	Yellow	Green	Yellow	Red	Red	Yellow
Anxiety	Yellow	Red	Yellow	Green	Red	Red	Red	Green
Obsessive Compulsive disorder	Red	Red	Red	Green	Red	Red	Red	Red
Schizophrenia	Red	Red	Red	Green	Red	Red	Green	Yellow
Bipolar	Red	Red	Red	Green	Red	Red	Yellow	Yellow
Borderline personality disorder	Red	Red	Red	Green	Red	Red	Green	Red
Hyperactive	Red	Green	Green	Yellow	Red	Yellow	Yellow	Green

Table 3: Individual psychological troubles

	Switch working group	Heal injuries	Psychologist
Disagreement between two people	Green	Red	Yellow
Obsession	Green	Red	Green
Physical conflict	Green	Green	Green

Table 4: Social psychological troubles

VI. Volume, Masse, Cost and Power Consumption Estimations

The equipment related to the human aspect have been divided into six parts:

- Advanced Life Support Systems (ALSS):
- Crew Accommodation (CA): Everything that helps to keep the passengers healthy and comfortable, aside from primary needs.
- Consumables: food, water and oxygen
- Clothes
- EVA equipment
- IVA pressurized suits:

The following figure gives some estimations concerning the masses, volumes, costs and power consumptions for all the equipment serving the human needs. These estimations have been made based on the figures given in the literature concerning missions to Mars. These figures have been manipulated to give accurate number for the needs of our mission, our number of passenger and our pressurized volume. [45][46][47][48][49][50][51]

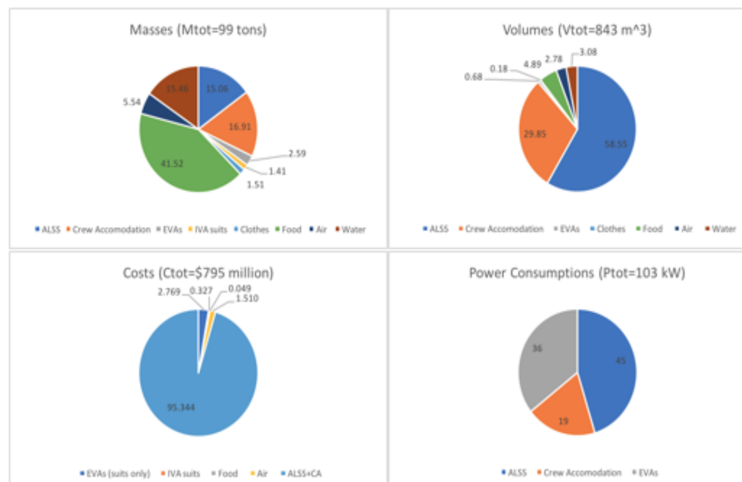

Figure 4: Mass, Volume, Cost and Power consumption estimations concerning the human aspect (figures given on charts are percentages)

It can be noticed that food accounts for a large part of the mass of the habitat. Food cannot be recycled and it has been decided that the best strategy was to not produce food on board, which means that all the food necessary for the trip has to be carried from the beginning. Plus, the decision to carry food for a round trip in case nor a landing on Mars neither a resupply in Mars orbit is possible contributes to this situation.

Another striking element is the large amount of power required for EVAs. This is the estimated power consumption for one EVA provided to each passenger, assisted by two crew members, plus one EVA per week for maintenance –two crew members required each time. A way that has been discussed to reduce this consumption is to provide EVAs only to few members that agreed to pay a significant extra-amount of money.

VII. Conclusions

Several aspects were tackled to make the Trident suitable for humans. Some elements to provide primary needs to everyone were suggested through a robust and partly redundant Life Support System. Some accommodations recommended should allow all the passengers to maintain their physical and mental health, as well as provide them a thrilling and safe experience of space travel. Finally, some perspectives of improvement to make the travel even more comfortable and safe through innovating concepts have been given. Now let us embark on the trip of a lifetime !

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IX. Appendices

A. Task Division

	Sébastien	Nicolas	Aurore	Manil
Crew			X	X
Passengers	X			
Psychological Aspect				X
Working Group Division	X			
Entertainment			X	
Exercising				X
EVA	X			
Food		X		
Air		X	X	
Water	X		X	X
Medicines		X		
Clothes			X	
Wastes		X		
Radiations	X			
Off-nominal Situation		X		
Volume, Masse, Cost and Power Consumption Estimations				x

B. Calculations for water and air recycling

Overall, 93% of the water available can be recycled thanks to the water recovery systems [52]. This means that for every initial ton, 14.286 tons can be used thanks to recycling.

If we consider the recycling possibility as a geometrical sum with term, being the initial mass of water carried on board, and assuming it has to converge towards the mass of water needed for the whole trip that is estimated to 206.3 tons [53] –round trip and 30 days for contingency, like for the oxygen, plus an additional security margin–, it has been found that 15.34 tons of water had to be initially carried on board.