SD2905 - Human Spaceflight
Human aspects and Life Support Systems for a Mars mission

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***Abstract*—This report has been written to summarize the work done by the Human Aspects group of the Red Team during the Human Spaceflight course at KTH University. Its purpose is to make a feasibility study on the Life Support Systems and Human aspects to keep 38 people alive, safe and comfortable on their way to and from Mars in 2032. The takes 189 days forth and 199 days back, estimations were made for 200-day travels.**

First, focus is directed to Life Support Systems, and more precisely on key parameters like air, water and food. Next, the Human Aspects field is looked into, especially the radiation problem and the medical and exercise equipment. Eventually, selection and training of the passengers has to be planned to prepare them for deep space exploration - this is the subject of the last part of this report.

I. Introduction

When it comes to Life Support Systems and Human Aspects, not only are the techniques used important, but their assessment is as well. It is crucial to consider the overall mission details to know how much food, water, oxygen and other equipment are to be brought. Unlike ISS, the spacecraft will not be equipped with many scientific modules; therefore, almost everything inside the living space will be used for passengers to live. Additionally, no resupply will be possible during the journeys. The focus was on this aspect, along with important estimates for feasibility. Furthermore, the passengers have to be selected, trained and monitored to avoid any problems, whether they are psychological or physiological. Special equipment and planning is also dedicated to this task.

The assumption made is that some other human missions to Mars would have already been performed. Consequently, it can be assumed that some facilities have already been built there, and that global ISRU techniques have now been acquired.

II. Life support systems

All the cargo estimates have been put into the Table I for centralization of information and better understanding as they may be a lot of subsystems (appears at the end of the paper).

A. Atmosphere revitalization

The goal of this prime system is to replicate the Earth's atmosphere on board, including the usual mixture of gases which are assumed to be N_2 at 79% and O_2 at 21%, at a total pressure of 101.1 kPa, and nominal partial pressures $ppO_2 = 21$ kPa and $ppN_2 < 80$ kPa[1]. One human needs 0.85 kg of O_2 and exhales 1 kg of CO_2 daily (standard metabolic rates)[1], making the basic need in oxygen of 32.5 kg/day for all the passengers, and 38 kg/day of CO_2. The oxygen has to be produced at a minimum rate of 1.3 kg/hour, whereas the CO_2 removed at 1.6 kg/hour to avoid both hypoxia and hypercapnia [2], and assuring the wellbeing on board. The assumed CO_2 level must be lower than 0.3% to avoid the unnecessary respiration rate and problems with the acid-base balance of the body[1]. Of course, the air has to be clean and safe. Additional obligations have to be taken in account, such as degradation factors or longevity, but have not been studied. On the other hand, for redundancy, a 30% safety margin for cargo considerations, and additional equipment brought in case of emergency repair of the main system have been considered.

The atmosphere system will rely on two main reactors based on chemical reactions: Sabatier for CO_2 reduction, electrolysis for O_2 production. A third reactor using pyrolisis will supply the Sabatier reactor in additional H_2. As the mission duration is more than 3 months without any resupply considered, the loop will be as closed as possible[1].

For the CO_2 reduction, the Sabatier reactor has been evaluated more reliable and longevible than the Bosch or Reverse Water Gas Shift reactors, thus it has been chosen for the mission. The solution relies on the reaction Eq.1.

$$CO_2 + 4\,H_2 \longrightarrow CH_4 + 2\,H_2O \qquad (1)$$

The exhaled CO_2 will be collected using a sorbent bed that absorbs the pressurized gas at low temperatures, for instance zeolite, then heated up for the reaction [3]. The hydrogen is brought from Earth or Mars in cryogenic tanks, or supplied by the pyrolisis and electrolysis reactors defined below. The reaction occurs at a temperature of 350°C in presence of a ruthenium catalyst to assure the right CO_2 reduction rate and CH_4 selectivity[4]. The great advance in research could improve the efficiency to be larger than 90 % in the near future, but has been assumed at a more realistic value of 80 % in the current study.
The produced water from Sabatier will either be utilized for the electrolysis reactor to produce oxygen, or be filtered and stored for utilization as potable water (or inversely, the water will be taken to produce oxygen, see II-B) to adapt the day-to-day needs from the passengers.

The methane/water mixture is separated in a condenser, whereas the water is deoinized. The electrolysis reaction is using solid polymer and relies on Eq. 2

$$2\,H_2O \longrightarrow 2\,H_2 + O_2 \qquad (2)$$

The electrolysis is a mature technology with a rate of transformation assumed to be at 97%. The oxygen will be stored in a tank or directly available for the passengers to breathe. The oxygen will be produced at the desired rate of 1.3 kg/hr but will not be sufficient, therefore an external tank with a certain quantity of oxygen will be brought from Earth/Mars to fulfill the needs. One can notice that the supply in hydrogen is not sufficient for the Sabatier reactor to work on a closed loop basis entirely, therefore a pyrolisis reactor has been considered.

The methane produced in the Sabatier reactor will be used in two simultaneously working pyrolisis reactors based on Eq. 3.

$$CH_4 \longrightarrow C + 2\,H_2 \qquad (3)$$

The rates of production of hydrogen suit the needs for Sabatier. Nevertheless, because of the low efficiency of the pyrolisis reactors (assumed to be 65%) it will still need a little more of hydrogen to work so an additional cryogenic tank of hydrogen will be be brought storing a defined quantity of H_2. As the temperature of the reaction needs to be more than 1000°C [5] and the technology is juvenile, some safety precautions, such as putting the reactors in a safe place, and bringing additional H_2 in case of breakdown, are important. The crew will also need to service the collected carbon when the deposit plate is full (once a month).

The total pressure will be controlled due to cryogenic tanks storing a buffer gas - N_2. The needed quantity has been evaluated on the basis of the volume of pressurized areas (see II-E), including margin needed for special airlocks or more generally leakage - 4% monthly (the Zero-Boil Off aeroshell technology has been deemed meaningless for such a journey) [4].

The air circulation will include quiet fans (cabin & intermodule), pressure equalization valves, ducting, mufflers, filters for surface dust. The contaminant system for detection and suppression of leakage, offgasing vapors from working equipment relies on ISS' like technology Potok [6] and a volatile organic analyzer by chromatography and spectrometry to detect, identify, and quantify a selected list of volatile organic compounds that are harmful to humans [7].

[1]The economy in terms of mass between closed and open loop for both way travels has been calculated to be 60%.

In case of emergency breakdown, a quantity of LiOH canisters for CO_2 removal, and a system like ISS' Vika (based on perchlorate generation of O_2) can be operated for 3 months, to repair the equipment, abort or finish the transit mission. The summary of the air revitalization system is given Figure 1.

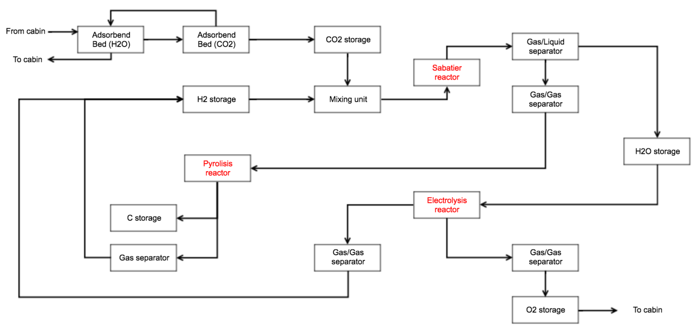

Fig. 1: Air revitalization

B. Water recovery and management

The water subsystem utilizes the metabolic outputs of the passengers, in particular their urine and perspiration condensates, in order to provide the necessary hygiene and potable water on board. The objectives are numerous and include recycling, storage and distribution, as well as a link to the electrolysis reactor in the air subsystem to adapt the passengers' needs from day-to-day. Respecting the water standards is important, so the water quality is constantly monitored to eliminate the pathogens and keep the level of certain elements (mainly acidity and ammonia) at acceptable levels.
The baseline for the estimations relies on standard metabolic needs per person per day[8] :

- 2.10 kg for drinking
- 0.76 kg for food preparation
- 1.80 kg for hygiene purposes. The shower is not included: disposable wet towels and dry shampoo will be offered instead. It prevents problems from breakdown and severe loss of water.
- 0.33 kg for washing clothes. A trade-off study revealed that it is better to wash clothes monthly (1 machine per person per month) than bringing all the clothes and throw them after use. Hand-wash was considered but the economy of water was negligible.

The daily evaluation of recoverable wastes per person per day is [8], without efficiencies included yet:

- 2 kg of atmospheric condensate
- 1.3 kg of urine
- 1.7 kg of hygiene water

If no additional oxygen is needed (in case of overproduction) : a water buffer is available because the water needs may vary from day to day. Also if there is a problem with the recycling, the crew will have time to repair it in a few days, and will use the buffer in the meantime.

The technology used for collecting the urine and humidity condensates is gas/liquid spin separators.
The humidity condensates are initially very pure, but are treated by multifiltration based on activated carbon adsorption beds (for suspended organics) and ion exchange resin beds (for inorganic salts) [9]. The water is then potable, and the filtration efficiency is evaluated at 95%. It establishes the first water network.
The urine first needs to be filtered using the same activated carbon beds, for removing urea and alcohol. It is pretreated for microbial control and ammoniac levels in solution prior to a vapor compression distillation (VCD) [10]. A process of forward osmosis [11] with a semi-permeable porous membrane allows to clean the urine water for re-use. An efficiency of 93% can be expected [8].The clean potable water then joins the first water network.

All of the grey water coming from hygiene is collected and filtered using the same technology but has lower standards, as it will not interact with the potable water, and only used for washing and hygiene. Thus an efficiency of 99% can be assumed. This constitutes the second water network.
Both networks are linked to a storage tank which is also used by the electrolyser if there is an overproduction of water. Reversely, the Sabatier reactor can also furnish water to drink. The networks allow distribution of the water over the whole spacecraft.

It is important that the crew monitors the aspect of water including: color, odor, foam and taste with

weekly samples analysis. Finally the VCD requires 15 min of crew time every two weeks to replace the filter cartridges in the filtration unit [12].
In the case where the multi-filtration unit fails, a 45-day supply of iodine tablets will be brought and can be used to treat hygiene water, making it ready for consumption while the crew repairs the system [13]. After 45 days iodine becomes harmful to humans. A waste water drainage system, which is needed to dispose of excess water into space in case the water processing equipment is defective, is available. The summary of the water recovery system is given Figure 2.

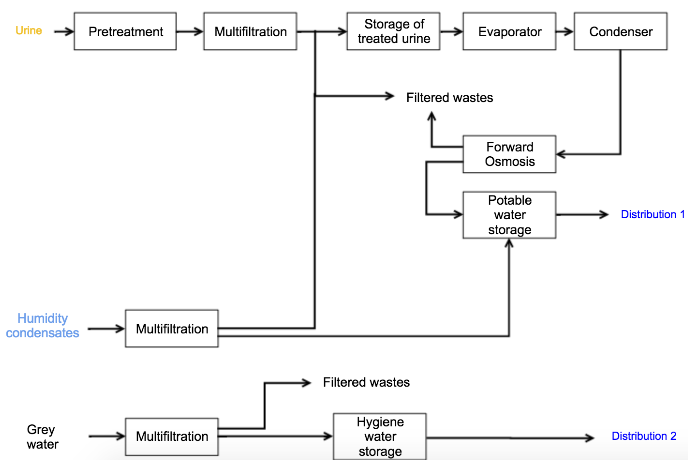

Fig. 2: Water recovery and management

C. *Thermal control and humidity*

The thermal control group maintains relative humidity between 25% -75% and temperature between 18.3°C - 26.7°C, adjustable by the passengers. The dominant humidity sources onboard comes from the passengers who constantly exhale moisture and perspiration and from drying laundry. The cabin air has to be dried. This is accomplished by a condensing heat exchanger which cools and dries the air of the cabin for maximum comfort. The minimum value for humidity was chosen for no risk of electrostatic charge, and the maximal value was decided so the condensates can not form damp substances that lead to microbial growth and mold (like on the Mir Space Station).
The heat from human metabolic output is assumed to be 23 kW, and the equipment for life support is 40 kW [14]. A set of cold plates for collecting the heat, fluid loops and pumps, heat exchangers and finally the radiators have been designed (see Table I) to ensure the correct thermal control.

D. *Food and Beverage*

a) Food characteristics:

The food brought in space has particular characteristics.
First, there is a concern about the weight it has to be brought, as lighter is better. Even though occasional 'regular' meals can be taken, most of those will need to be rehydrated. Dehydrated food has the benefit of avoiding the microorganisms to thrive, which is a major concern for long journeys such as going to Mars. One example of space food during Apollo's missions is shown figure 3.

Fig. 3: Space food for the Apollo missions

Secondly, specific conditions in space (microgravity, isolation, radiations, ...) led nutritionists to choose and design special food, with high vitamins and sufficient caloric intake, while being accepted by the passengers and the crew. Indeed, it may not be palatable, they could be reluctant to eat the food and drink from waste processing, and the diet choice may not be large.

b) Type of food:

The following choices for the food are based on the ISS and the Space Shuttle programs. Many different categories of menu exist, but hereafter are summarized as the essential features.
In a first approach, the journey is considered too short to grow plants. Additionally, the spacecraft already

has a heavy payload so it would be difficult to add extra mass and volume.

Passengers will be proposed to have meals by cycles of 2 weeks. Each cycle will provide the amount of calories and vitamins necessary. Many of the beverages will be in the dehydrated form and food will be heated to a serving temperature in a microwave or forced air convection oven.

There are 3 main types of food: Daily Menu, Safe Haven, and Extra Vehicular Activity (EVA) food. Usually, an astronaut requires 0.68 kg of dry food per day, with 2338 calories when considering a safety factor of 10%. The equivalent volume is in average for rehydratable food of 1.28×10^{-3} m^3 per person. One can categorize three main types [15]:

- *Daily Menu*
  Based on the commonality to everyday eating. It has the calories, mass and volume as described above and has been chosen before flight with respect of the 2 weeks cycles.
- *Safe Haven Food System*
  The Safe Haven food system is provided to sustain the passengers under emergency operating conditions resulting from an on-board failure. It is at least 2000 calories daily per person (for 22 days). The Safe Haven food system will be stored at ambient temperatures.
- *EVA food*
  It consists of food and drink for 8 hours (500 calories of food, and 1L of water) which will be available for use by a crew member during each EVA activity.

For the entire crew and passengers, 8.3 tons of food (15.4 m^3) is needed during the trip.

E. *Pressurized area*

The design of the pressurized spaces is based on the current existing technologies. It has been divided into four main areas:

a) Cockpit:
Based on new generations of crewed capsules (Orion) [16], as presented figure 4. It can be used by the crew to launch the piloting procedure, to control the parameters on-board, and to communicate with the Earth and Mars stations, or other spaceships. In average, each person from the crew has 2.25 m^3 inside, which represents 22.5 m^3 for the entire crew. This is one of the area where EVAs can be performed.

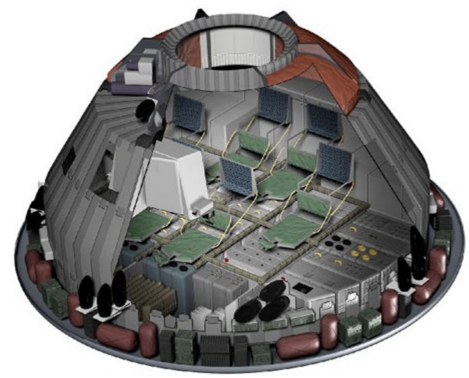

Fig. 4: Orion capsule

b) Personal cabins:
Each passenger or couple has his or her own private cabin. They are based on the “Capsule-apartments” [17] designed for big cities to optimize the living space in reduced volumes, as illustrated figure 5. Passengers and crew members can stay in those capsules to sleep, relax and potentially in the case of emergencies or especially high radiation exposure (for instance during exceptionally intense solar flares). On average, each passenger has 2.53 m^3, which represents for 38 people a total of 101 m^3.

c) Logistic rooms:
This section presents the stewardship during the trip for the passengers and the crew. It contains:

- A room for minor and regular medical checks. It can also be used as a pharmacy. ($2.5 \times 2.5 \times 2.5$ = 15.6 m^3).
- An emergency surgery or quarantine room for critical situations ($3 \times 3 \times 3 = 27$ m^3)
- Storages for luggage, reparation tools, food, ... estimated around 284 m^3 in total.

One can note here that there is no kitchen or laundry. Indeed, passengers just need to rehydrate their food and warm it up with microwaves, there is no need for special rooms for that purpose. In order to wash their clothes, passengers have one machine per person. It is especially suitable for space environment, it requires

Fig. 5: Example of 'Capsule-apartments' in Hong Kong

little water and takes negligible volume inside the spacecraft.

d) Common rooms:
It represents the areas that can be used by anybody onboard, and it contains most of the pressurized volume with:

- Relaxing common rooms ($3 \times 3 \times 3 = 27$ m^3), 1080 m^3 for 38 people. It includes TV rooms, one bar, lounges and open spaces for work.
- Bathrooms, one per person ($2 \times 1 \times 2 = 4$ m^3), 160 m^3 in total.
- Sport rooms, 6 machines (75 m^3).

In total, the pressurized volume is estimated to be around 1765 m^3.

III. Human aspects

A. Radiation

Radiation is one of the major concerns for a Mars mission. Three main sources of particles that passengers would be exposed to can be identified:

- Solar Particle Events (SPE)
- Galactic Cosmic Rays (GCR)
- Trapped particles (Van Allen Belts, etc.)

In our case, we also have to consider the radiation coming from the nuclear engine, as the whole team chose this type of engine for the spaceship. The objective of this part is to quantify the mass of the shield needed to protect the passengers from the radiation on the way to and from Mars.
Planning to make 38 people go to Mars requires the consideration of all different sources of radiation in order to shield them to make sure people can live in good shape after the journey. Here, the chosen criteria is that a passenger must not reach the ESA dose limit for an astronaut's whole career (1000 mSv [18], which implies an extra 3% risk of getting a fatal cancer many years later) before he/she turns 68, which is the worldwide average age for which a cancer is detected [19]. This limit was chosen in order to both get a reasonable total mass for the shield and to make sure the passengers are safe and confident. Based on this criteria, we tried to estimate a maximum value for the amount of radiation produced by the nuclear engine. Here is the data that have been used: the amount of background radiation on Earth is equal to 2.4 mSv on average per year [20], it is 11 mSv per year on Mars considering one hour of spacewalk a day according to Curiosity results [21]. In modern times, it is believed that it would be possible to build a suitable engine to go to Mars which would make people exposed to 100 mSv for one journey. The exposure level was determined with this number. The duration of the journey was decided to be 0.53 year and the stay on Mars to be 1.49 year by the rest of the Red Team. Assuming 1 hour of spacewalk per day, and that the indoors amount of radiation is equal to 30% of the level of exposure during a 1 hour spacewalk (some suitable habitats could have built during previous missions to Mars, but it would not likely be perfect protection), the total amount of radiation that a passenger going to Mars would be exposed to when he/she turns 68 years old is:

$$r_{max} = 1000 - 2.4 \times (68 - 0.54 \times 2 - 1.49)$$
$$-11 \times 1.3 \times 1.49 - 2 \times 100 = 624 \text{ mSv}$$

According to Curiosity mission, the amount of radiations into space during one journey to Mars is around 330 mSv. This means that the passengers would be over-exposed. What is the best way to protect them? Let's look into each source one after the other.

1) Solar Particle Events: As we know, SPE are mainly protons and electrons that come from the Sun at some points. As they are small particles, they are easily blocked by the structure of the spacecraft itself. The Vehicle Concept group has planned to use aluminium for the structure of the Mars ship with an amount of 6.8 g/cm^2. This quantity is approximately the same as the one used for the Apollo mission [22]. It is thought to be enough to protect against most of the SPEs.

2) Galactic Cosmic Rays and nuclear engine emissions: These types of radiation are formed of heavier elements, such as helium. When they collide with the structure of the spacecraft, they separate apart atoms from it, causing sub-atomic particles to shower into the structure. This is why classic shields are inefficient in this case. Let's estimate the quantity of GCR radiations passengers would be exposed to. Based on a NASA report, astronauts on Apollo and Skylab missions received on average 1.2 mSv/day and 1.4 mSv/day respectively [23]. Let's take an average exposure of 1.3 mSv/day for our mission. Considering the radiation coming from the engine as well, the level of exposure is: $r_{GCR+Engine} = 1.3 \times 2 \times 0.53 \times 365 + 200 = 703$ mSv > 624 mSv. This quantity is pretty high and has to be reduced. Indeed, Some material whose particles' size is approximately that of these heavier elements is needed.

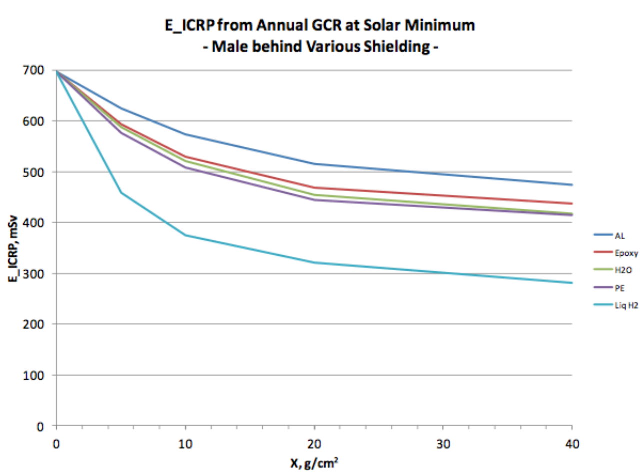

Fig. 6: Comparison on depth-efficiency dose estimates versus shielding thickness for several materials. Calculations are for 1-year GCR exposure at solar minimum

Figure 6 shows the efficiency of some materials to protect from GCR [24]. It is easy to see that liquid hydrogen is the most efficient one. Besides, our spaceship will carry some since it is used as a propellant and also for the Sabatier reaction (see II-A). However, it is well known that it is very difficult to store liquid hydrogen (very high pressure, very low temperature). Besides, it will be used as a propellant, and so, this means that the corresponding shield would become weaker and weaker over time. The same argument can be brought up for water, as it is used by the passengers. On the other hand, polyethylene is very cheap and is even a bit more efficient than water. Although water and liquid hydrogen remain good alternatives for future protection, the use of polyethylene seemed a good trade-off to us, and that is why we chose to use polyethylene to shield from GCR and nuclear radiations.

It is important to remember that the maximum total level of exposure was set to 624 mSv. Most part of it comes from GCR and the nuclear engine. Moreover, it is a good idea to leave a safety margin when determining the quantity of polyethylene to use. So, we decided to allow 600 mSv exposure. According to Figure 6, this gives around 5.5 g/cm^2 of polyethylene (against 7 g/cm^2 of aluminium, and polyethylene is lighter). Since the pressurized area is 1765 cm^3, a simple calculation gives us a total mass of

$$43.5 \text{ tons of polyethylene}$$

3) Trapped particles: Eventually, some particular events can be really dangerous for people going to Mars. It is the case for solar flares, or the passages of the Van Allen Belts for instance. These events can expose people up to 60 or 70 mSv, which is a considerable amount. Luckily, they are very rare, and when they occur, they usually last only a couple of days. To protect from them, passengers would have to be able to shelter into special places, namely personal cabins (see II-E0b). A good idea would be to make a smaller model of the magnetosphere in the spaceship (which is what protects us from these emissions on Earth). This concept is currently investigated, but it seems far too ambitious to be ready to use by 2032 (it would require very heavy materials, and an extreme amount of power) [25]. It seemed more realistic to us to use extra material for these cabins. Once again, the choice was made to use polyethylene. Since these events are far more energetic but also far shorter, the quantity of material to us is difficult to evaluate, but a global thought is that using a bit more than twice as much material as it is used for GCR should be enough. Thus, an extra polyethylene ratio of 7 g/cm^2 will cover the walls of the personal cabins, which gives a total of 12.5 g/cm^2 (plastic already used for the walls of the overall spacecraft). The extra mass is then: 9.1 tons. Finally, the estimated total mass to shield from radiations is:

$$52.6 \text{ tons of polyethylene}$$

which is given with a $\pm 20\%$ error margin. This number is only an initial estimate (many simplifying assumptions have been done), and all that has to be considered is the order of magnitude.

In addition to these physical protections, some medicines could be given to passengers either before launch, to prevent radiation effects, or even during the journey to counteract these effects. This solution is also currently investigated. It seems to us that the best solution would be to mix all these aspects to provide the most possible efficient protection for the crew and the passengers.

Eventually, we assumed that a suitable EVA suit would have already been developed since other Mars missions would have enabled to build some facilities on Mars by 2032.

B. Medical and Exercise Equipment

Medical equipment is required for a safe journey to Mars. The main goal of deciding on what types, and how much, of medical equipment and supplies to bring was motivated by knowing that there must be a measured balance. This balance was between bringing enough equipment to keep people alive and well, while also attempting to bring only the minimum equipment needed in order to minimize mass on board. To do this, the team agreed that the passengers must pass a medical and dental health screening, as mentioned later in this report. This requirement ensures that no one is at risk of developing any significant medical issues on board that would require intensive or extensive medical care; therefore, it was safe to assume that only basic medical equipment should be brought on the journey to Mars. This "basic medical equipment" was taken to be general check-up objects, such as an exam table [26], a stethoscope, reflex hammers, a sphygmomanometer, and a scalpel, just to name a few. Given that these are relatively compact tools, it was assumed that all tools and the table can fit within 1.2 meters cubed of space, while weighing no more than about 47 kg, due to their basic characteristics. Note that the mass of an examination table is included in this figure.

To ensure that the medical equipment mentioned above does not cause undue harm to passengers, the team made sure to factor in a sterilization agent to prevent any possible spread of disease. Assuming that each passenger and crew is required to get at least one monthly check-up (and accounting for a few extra well-being checks), and that 0.5 liters of solution is an acceptable amount to use to disinfect the tools and workstation, then approximately 147 L of solution is needed [27]. Since the solution will be quite close in chemical composition to water, it can be said that 147 kg of solution in needed.

The last classification of medical needs that is considered is in the area of medicines. It was calculated that the maximum anyone will need is 1 kg of personal medicines each, such as for headache, upset stomach, etc. This is assuming that if each person takes one 500 mg pill per day for 200 days, then there should only be 4 kg needed for the entire ship. However, it would be reasonable to factor in extra for redundancy, as well as for the fact that people can have worse days than others; therefore, 1 kg of medicines and other necessary personal medical effects are allotted to each person on the spacecraft.

The next main consideration when planning a long-duration spaceflight is the physiological changes the human body will undergo if exposed to extended microgravity. This situation can be detrimental to many biological systems if not properly counteracted. It has been shown that for each month spent in the absence of gravity, approximately $1-2\%$ of total bone mass is lost [28], and about 2% of muscle mass is lost [29]. This loss must be mitigated in order to ensure the functionality of the passengers upon arrival on Mars, which has about 38% of the gravity on Earth. This can be done by implementing an exercise regime into the passengers' daily lives. Initially, the exercise equipment calculation was based off of what is done currently on the ISS to mitigate physiological losses. As of today, the astronauts on the ISS exercise about 2.5 hours per day in the microgravity conditions [30]. Our team was tasked with calculating the exercise time and equipment needed in order to maintain healthy biological systems. The ISS's information and current operation in this area were used as a baseline for the subsequent calculations. It was found that if each person must exercise for approximately 3 hours per day with three types of machine [30], then each machine will be in use for 40 hours per day, which is not possible. After several optimizations and adjustments of the types and numbers of machines, their masses, and the number of usable hours in a day (accounting for time taken to eat, sleep, bathe, and entertain), along with the trade-offs associated with these parameters, it was determined that three of each type of machine mentioned in [30] would be needed to provide for everyone while also ensuring that the machines are not overused and suffer damage.

The Red Team's Vehicle Design group then decided on a design that could impart artificial gravity to the ship, so the team then had to calculate this new case for exercise time and equipment. Assuming that bone and muscle decay is linear, it follows that the time needed to upkeep physical health in the new gravity condition would decrease by 40%. Therefore, similar calculations to the ones mentioned above were performed with the new boundary conditions to determine a new feasible configuration.

During the calculations, a new exercise machine was recommended to the team that had a high probability of being commonly used in microgravity environments by the year 2032. This machine is the flywheel, which is very multifunctional in addition to being relatively lightweight [31]. Therefore, changes were made to the decision of exercise machines to reflect a more optimized system. This new machine was used to calculate possible exercise machine combinations at different levels of artificial gravity. An important point to note is that it was found that at 40% gravity, the advantage of having artificial gravity was equivalent to the amount of mass saved in exercise equipment. In other words, the machinery needed to provide more than 40% gravity would weigh more than would be saved in exercise equipment, thus negating any gains made by having artificial gravity. Therefore, 40% gravity was definitively chosen as an attribute.

Taking into consideration all parameters and boundary conditions, the machines that were finally decided on were four flywheel devices with two interchangeable Olympic bars to allow for various different exercises and two low-gravity treadmills. The final mass, volume, and power requirements of the equipment were as follows, respectively: 1.1 tons, 3.37 m^3 (not including the person using the machines), and 1.6 kW. Just as with the medical equipment, machine disinfectant will have to be brought along to protect passengers against pathogens that can be spread through perspiration. It was figured that the best way to use this disinfectant would be in a spray bottle. Then, if each spray releases 3.5 mL of fluid [32], and if each person sprays the machine twice after each use, then the total use of disinfectant comes to 56 kg. Like the medical sterilizer, this disinfectant was assumed to be close in composition to water. It can be mixed with something antibacterial and safe to use but still be relatively inexpensive, such as bleach or white vinegar.

C. *Off-Nominal Case*

The off-nominal case that the team considered was that of a death during the trip. Since the passengers and crew have all passed every medical test required, this case would have a very small chance of happening. If something of this nature did happen, our team discussed how to handle it. There were a few options to consider, like having a small morgue with cooling capabilities on board. There was also the option of handling the bodies in a different way, such as purposeful decomposition or evacuation from the ship. The latter two options would require a noticeable caveat posed to the passengers, and possibly a document to sign that would give consent to the crew to dispose of the remains in this way.

However, it was decided that if a morgue was the a better option in the area of logistics, then volume, mass, and power should be allocated for this cause. It was found in [33] that a two-person device would be 97.5 kg, use 230 V (50 Hz plus a 100 W light), and take up about 6.1 meters cubed of space.

IV. PASSENGERS

A. Selection

From a human aspects point of view, the passengers should meet some requirements so that they can go to Mars safely. To establish these requirements, it was decided to draw inspiration from the main factors used for current astronaut selection. Of course, in this case, the criteria used for the mission are far more flexible since passengers are not required to perform any scientific experiments on Mars or repair anything there. They are only passengers who want to spend time on Mars. However, some requirements are mandatory. They have been established commonly by the Human Aspects and the Logistics and Operations groups:

- Preferred age range: $25-45$ years old. A younger individual is more likely to develop fatal cancers after his/her return from Mars bacause of radiations. A person much older than this may have already been exposed to too much radiation, or may not support launch or landing (high accelerations)
- Mixed genders, possibly couples. In the latter case, both individuals will be selected as a couple, and not as individuals. We don't want to be too stringent, but we have to make sure there will not be any couple issues during the trip.
- Good level of English. Passengers will come from all around the world, and it is important they can easily communicate with other passengers and with the crew in a common language.
- Open-minded and social skills. This is absolutely necessary, since one journey will be at least 189 days long, in a confined space, and the stay on Mars around 550 days long. People have to be friendly and eager to live a great adventure with other international people.
- A medical check-up is required. The effective radiation dose, heart and brain conditions, and vision will be checked. This is to make sure that radiation won't have a too dangerous effects on the passengers. A meeting will be organized with a psychologist and a general doctor, to check general health (preferably the crew doctors of the mission). Additionally, each passenger must have a dental clearance. This ensures that no one is at risk for a significant dental event while on board.
- No special educational level is required. As long as selected passengers fulfill the previous criteria, it is believed that they are well prepared to go to Mars and enjoy their trip with all other passengers.

The selection will take place over several months and in several centers (at least 1 per continent). The main process is described on Figure 7.

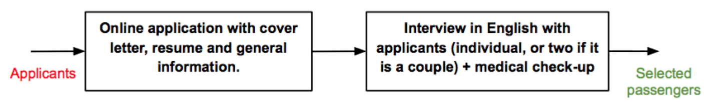

Fig. 7: Selection process for passengers (Mars mission)

B. Training

Because a Mars trip is not just any trip, passengers will need to be trained as well. Here, we assumed that the crew would have already been trained and prepared for this Mars mission. As passengers are only supposed to know how to behave during the journey and on Mars, the training is obviously easier than the one astronauts are used to. Five big activities were decided:

- EVA training. It is good that passengers know how an EVA feels like, and how to behave during such activity. The buoyancy pools will be used to this purpose.
- Parabolic flights. As the spacecraft will only use partial artificial gravity, and that Mars gravitational field is $1/3$ as intense as the one on Earth, passengers need to know how it will be.
- Nutritional prevention. People won't be able to cook as they usually do on Earth once on Mars, or even during the journeys. It is important to brief them and explain them how to keep a good diet in order to stay healthy.

- Healthcare lecture. This is a more general explanation, and it aims at making people aware that space is a harsh environment, and that they need to be particularly careful with their health. Focus will be laid on exercise, radiation, psychological aspects and well-being.

Launch is planned to take place on Mars 15th 2032. It was decided to make them train during 5 intensive weeks starting from January 26th. This way, they won't forget anything and it won't disturb them in their daily life several months before launch. In addition, it was decided to separate them into 3 groups of 10 people in order to get to know passengers more easily and to work more effectively. Each group will be led by 2 or 3 mentors from the crew. At the end of the training, one big week of simulations will be organized, during which passengers will be able to get to know the people from the other groups, and live together 24/7. There will be some emergency drills, as well as simulations, for particular events such as launch, landing, arrival on Mars etc. The final schedule can be found on Figures 8 and 9.

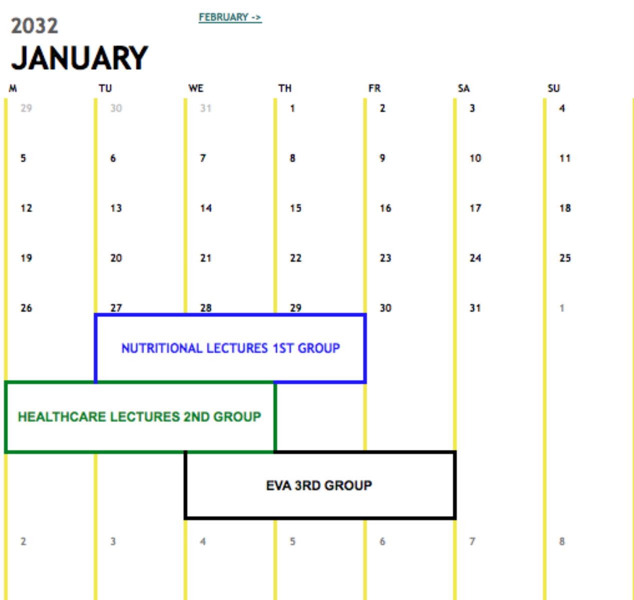

Fig. 8: January training schedule

V. Conclusion

In this study, the issues relative to human spaceflight were presented and one proposed feasible solutions

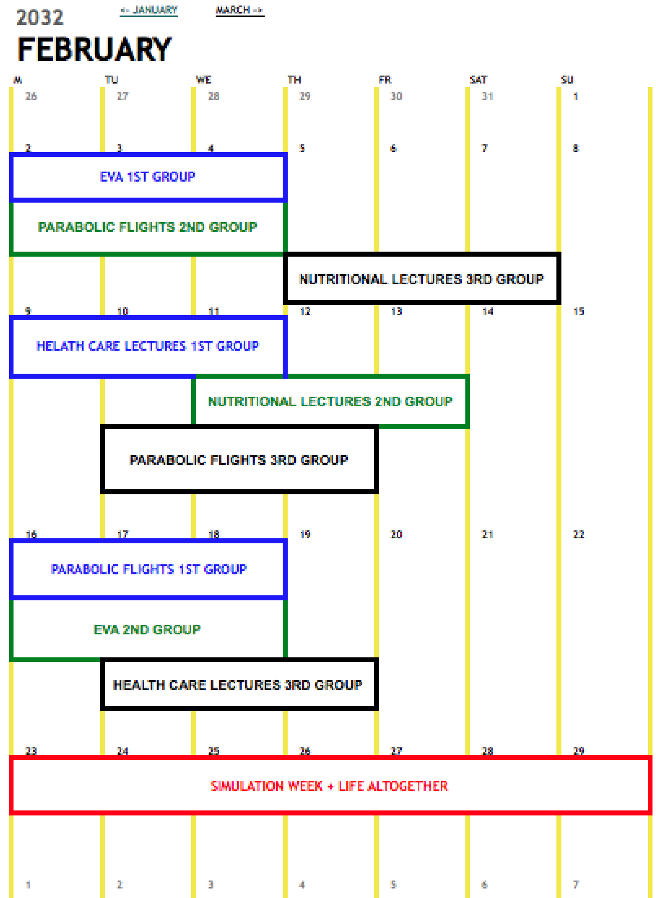

Fig. 9: February training schedule

for them. One realized how complex those journeys are, especially as it involves heavy payload for a long duration trip, and what the main concerns are. As a result, this report has been split into three sections.
First, the "life support systems" part has detailed the resources the passengers and crew members need, and how to provide them. Then, the "human aspects" took care of the health and possible threat by proposing the structure of the spacecraft, the medical checks and equipments required on board. Finally, this rough journey implies a selection and a training of the passengers, which is developed in the last section, "Passengers".
There is no doubt today that mankind will become an interplanetary specie, and the closest target today is Mars. One faces many challenges to achieve it, but this study has shown that current or near future technologies could make it possible by 2032.

Subsystem	Mass (mT)	Volume (m^3)	Power (kW)
Oxygen tank	6.50	4.56	0.05
Hydrogen tank	0.61	6.94	0.05
LiOH canisters	6.30	2.70	0.00
Buffer gas tank	3.05	3.02	0.05
Air revitalization	5.21	32.59	19.68
Water tank	6.33	6.00	0.05
Water processor	2.75	10.00	2.30
Food	8.30	15.60	0.00
Thermal & Humidity	13.33	53.00	4.00
Trace Contaminant	0.365	0.98	0.16
Fire Detect/Suppress	0.15	1.00	0.05
Total Living Area	-	1765.00	-
Sport equipment	1.12	3.37	1.62
Radiation protection	52.60	57.80	0.00
Medical equipment	0.30	21.52	0.00
TOTAL for one trip	**106.91**	**1984.08**	**28.01**

TABLE I: Cargo to bring along - one way

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