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Manned Mars Mission Risks Evaluation

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Abstract

Mars missions can be seen as a natural step in space exploration, as Earth-like environmental conditions and the length of the interplanetary flight are the most crucial for planetary exploration compared to other celestial bodies of the Solar System. On the other hand, these missions require detailed planning and worldwide collaboration, because of the need of extremely high financial resources and technical capabilities. Many researches focused on different aspects of Mars missions are being conducted in these recent years. They include flight preparation, lift-off, interplanetary journey, habitat and Life Support Systems (LSS) design, Extravehicular Activities (EVA), precise landing, planetary exploration, etc. This paper summarizes identified safety issues that can arise during future Mars missions. Based on the analysis of previous studies, where conditions of the interplanetary flight were studied, including environmental issues, Mars habitat and the spacecraft design were discussed and the spacesuit concept was analyzed, the most critical hazards have been defined and the whole mission has been taken into consideration. In particular, possible failures and hazards for the habitat on Mars, space station and spacesuit, including off-nominal situations and their influence on the safety of the astronauts have been investigated. This work is based on the results of previous projects carried out within the Space Generation Advisory Council's (SGAC) Space Safety and Sustainability project group, which aims to bring an international and interdisciplinary vision to this topic and discuss it from different perspectives, creating a foundation for further studies on safety risk assessment. Technological gaps are identified for further discussion and possible solutions for risks reduction are proposed with regard to onboard systems (including LSS) and layout design.

Keywords: safety, risks, Manned Mars Mission

Acronyms/Abbreviations

Extravehicular Activity (EVA)
International Space Station (ISS)
Low Earth Orbit (LEO)
Life Support System (LSS)
Nuclear thermal propulsion (NTP)

1. Introduction

This paper summarizes reviews made by the authors with regards to their experience and the previous project dedicated to the One-way mission to Mars. This study is mostly focused on the mission itself with the priority of human safety during the journey, as the most important element in a manned mission is the astronaut. The spacecraft, Life Support Systems (LSSs) and the environment inside the space station are designed to provide humans with essential elements to live and to guarantee their working efficiency during the mission. Therefore, the man-made ecosystem for the interplanetary journey is built for human existence and survival.

There are many technological gaps related to the mission. This work stresses challenges of advanced closed-loop LSS design with the view to the breakthrough made by ESA [1] taking into consideration approximate calculation of needed supplies. Results of our previous project regarding the spacesuit design [2] act as a basis for this study on EVA with an accent to human safety and medical aspects.

The human health topic combines challenges rising particularly in space (gravity and radiation effects) with psychology. Offered astronautical hygiene solutions based on Health Stabilization program [3] for astronaut are combined with overview of supplement and nutrition effects. The biggest challenges related to radiation protection are still open, but offered solutions by “Radiation shielding of composite space enclosures” (SIDER) project [4] were taking into consideration.

Power system and engine play crucial roles in the mission and broach an ethical topic because of nuclear power usage, radiation debris, and consequence of accidents [5]. Results of the Kilopower project [6] which was offered for Mars Mission are discussed. As there is no off-the-shelf technology, the paper gives an overview of nuclear thermal propulsion, chemical and electric propulsion systems including its pros and cons.

2. Methods

The man-made ecosystem includes an LSS combined with the environment. The key element is the human who lives in it. Together LSS, environment and human can be defined as a complex system [7].

A man-made ecosystem is significantly different compared to a natural ecosystem. The human is a decision-making element and his/her safety is a key issue. At the same time it is important to control human’s actions in case of an emergency, as stress can affect human control and behavior. Moreover, redundancy should always be adopted for higher safety [7].

As the ecosystem is geared towards the outer envelope, the importance of the materials used for spacecraft is taken into consideration as well as resources analysis.

Radiation effects are analyzed from different points of view: human health, electronics behavior and spacecraft protection.

Engine and power systems are discussed, including existing solutions and solutions that are being developed.

This paper summarizes the most important risks stressing their correlations and demonstrates that they have to be analyzed all together.

3. Theory and risks description

Considering previous experience on hazard analysis, the following points were taken as the basis of the whole mission analysis: human health, LSS operation, EVA, radiation influence, power systems and engine solutions, and resources analysis.

3.1 Risks associated with human health

Risks related to stress can be divided into five categories: gravity fields, isolation/confinement, hostile/closed environments, space radiation, and distance from Earth [8].

3.1.1 Gravity challenge and physiology

Most of the exploration missions so far have been carried out in Low Earth Orbit (LEO). This environment does not allow to study and explain many unknown situations and behaviors that would occur during a long-duration interplanetary mission [8].

During a mission to Mars, astronauts transition from a gravity pull of $9.807\ m/s^2$, to microgravity and then to $3.711\ m/s^2$ on the Red Planet. This will have important physiological effects on their body. The most important and known consequences of long permanence in a microgravity environment are: shift in body fluids, space motion sickness, muscle atrophy, bone demineralization, immune system deregulations [9] and disruption of senses such as vision and taste [10]. Upon arrival on Mars, the astronaut’s body will have to adjust to its level of gravitational pull. This will also affect the astronauts’ bone density, muscle strength, and circulation.

3.1.2 Psychological issues

Several psychological and social issues have been demonstrated to affect the crew in an isolated and confined environment during long periods of separation from society. In particular these elements have been identified: cultural aspects, interpersonal stressors, effects of long-term microgravity and radiation, extreme isolation and loneliness, limited social contacts and novelty, lack of support from Earth due to communication delays, problems including negative news coming from Earth (such as a family member or close friend's death), increased home sickness, depression, food, sleep, sexual attraction/tension, ethical issues, etc [10].

Much is known about the psychosocial issues that affect astronauts in space from anecdotal reports, scientific studies performed in space analog environments on Earth [7] (e.g., Antarctica, submarines, analog missions (e.g. isolation studies)), and experiments conducted during space missions. However, there is still a big knowledge gap to fill due to new stressors that appear only during the real long-duration missions and new flight conditions. Researches show that astronauts could experience a serious form of adjustment reaction called "asthenization", which is related to a psychiatric disorder called neurasthenia [11]. This disorder is defined as a weakness of the nervous system that produces fatigue, irritability and emotional liability, attention and concentration difficulties, restlessness, heightened perceptual sensitivities, palpitations and blood pressure instability, physical weakness, and sleep and appetite problems.

3.2 Life support systems

Life support systems can be divided into 3 categories: environmental monitoring, atmosphere management and water management [12]. A malfunction, damage or exhaustion of technical equipment, for example: filters, regenerating cartridges, water supply (tanks) or different gas balloons could compromise the spacecraft environment, making it unsafe for humans [7]. Combining with a challenge related to food supply a huge supply issue rises as it is not possible to receive additional sources support from Earth during an interplanetary flight.

The approximate time for a mission to Mars with the current level of technologies is 240 days of travel and 240 days of return. Summing the time that the astronauts will spend on the Red Planet, the mission would take from 2 to 3 years [11, 13].

An average calculation of the most important resources for a mission to Mars is based on human and equipment needs. The astronaut in space needs 30.60 kg of food, water, and air daily to stay healthy. A crew of 3 astronauts on a 2-year mission will need 66,000 kilograms of food, water, and air [14, 15]. It would be impossible to carry that amount of supplies from Earth.

Water is the most important resource for human beings. The amount of drinking water would be 2.3 kg-4.6 kg and washing water would be 1.1 kg-5.4 kg per person daily in the mission approximately. The approximate O_2 needed per day is 0.8 kg-0.9 kg per person [16]. An astronaut needs approximately 1.56 kg of food (1.83 kg including packaging) per day. [15] According to these data, a thousand-day mission to Mars will require 1,830 kg of food and packaging for each astronaut. [14, 15]

Depending upon the degree of recycling that can be achieved by the life support system, these requirements can be reduced by carefully using waste products, which are given per person per day:

- CO_2 : 0.8 kg-1.1 kg
- Water (H_20): 1.8 kg-2.5 kg
- Solid Waste: 0.13 kg-0.2kg [16]

The transportation of so much waste and so many resources would be almost impossible.

Current LSSs implemented on the International Space Station (ISS) are not fully closed-loop systems [12]. In addition, systems' elements of the heating or ventilation units have a limited service life [7]. These parameters should be taken into consideration.

3.2.1 Environmental monitoring

The first fundamental difference between a long interplanetary travel and the ISS in Low Earth Orbit (LEO) is the distance from a mission control center.

On the ISS, if an emergency that could compromise the health of the crew (such as leakage, malfunction of air filtering systems, unexpected chemical reactions etc.) occurs, current environmental controls alert crewmembers as well as the mission control center instantaneously. Current monitoring procedures include the shipping of air and water samples back to Earth. This procedure is not possible during long-distance spaceflight. Therefore, it is important to have the capability of continuously analyzing the air enclosed in the space station and the water available for the crew autonomously and in near-real time. [12]

3.2.2 Atmosphere management

The most critical function of an LSS is maintaining the atmosphere inside the vehicle safely breathable by humans. It must remove carbon dioxide and add oxygen, as well as prevent some gases that humans produce in small quantities (i.e. ammonia and acetone) from accumulating. [12] The LSS must also detect and remove potentially dangerous gases accidentally produced by chemical reactions in on-board scientific experiments or equipment. [12] The trace contaminant system on board the ISS currently uses absorbent media and catalysts that are commercially obsolete. Some alternatives are currently being identified and evaluated. Scroll filter technologies for particulate filtration are also under study. [17] Although all the atmosphere revitalization systems on board the ISS have reached TRL 9 [18], improvements must be made for long interplanetary missions [7, 17, 18].

Currently, the LSS system of the ISS generates/recycles about 40% of the total amount of oxygen needed by the astronauts using a Sabatier process reactor that extracts about 42% of O_2 from CO_2. It is essential that this percentage dramatically increases for interplanetary missions [12, 14].

In addition to maintaining an optimal oxygen level, the LSS must reduce the amount of carbon dioxide that is mostly exhaled by the astronauts with their breath. Both improvements on the current ISS system and assessment of alternate technologies are now being examined by NASA [12]. Current ISS systems can support about 2.3 mmHg $ppCO_2$ for 4 people crew. The objective for interplanetary missions is to reduce it to <2 mmHg $ppCO_2$. Reliability must also be increased from the current <6 months mean time between failures [14].

Another key technology that has to be improved is the trace contaminant and particulate control system. Its aim is to keep the concentration of chemicals and particulates/aerosols below the spacecraft's maximum allowable amount. To improve this technology it is essential to increase its performances and reduce the consumables that are typically used in technologies such as filters and scrubbers [12].

3.2.3 Water management

The Water Recovery Subsystem of the ISS has reached TRL 9 [18] and is currently capable of recycling about 93% of the crewmembers' urine, wastewater and humidity [17]. The Urine Processing Assembly currently recovers about 80%; brine is stored for disposal [14].

The goal is to reach 98% of water loop closure. This value cannot be reached unless major developments on the water extraction from brine are achieved. This is challenging because the process of extracting water from wastewater brine causes a cascade of other problems and faults on traditional systems. [17]

Another aspect to consider is the water potability conservation during storage periods. Some developments with respect to the state-of-the-art ISS system are currently undergoing technology testing. It has been demonstrated that low concentration of silver can kill bacteria and maintain the water potability over long periods. Silver also brings a great advantage in terms of reducing consumables, as it is not necessary to remove it from the water before consumption. [17]

3.3 Extravehicular Activities

EVAs will play a crucial role in a Mars mission. EVAs will help to run maintenance activities supporting the whole operation of the habitat or station and carry out all needed scientific activities. Based on [19], the most relevant hazards for the spacesuit design include structural failures, power, thermal control and life support systems off-nominal situations, communication problems, loss in data management and problems related with humans in the crew.

Spacesuits are required to ensure the safety of the astronauts (from radiation, to supply oxygen if needed) and at the same time the efficiency of the planned operations.

Thermal extremes must be considered. Contacting an external hardware, which exceeds the touch temperature limit, can cause injury or even a loss of crewmember.

When touching a hot surface the pain threshold of the crew is reached before the physical injury. However, when the crew gets in contact with a cold surface, his hands and feet become numb before the injury or frostbite [19, 20].

All EVA spacesuits currently in use are designed to operate in microgravity and vacuum, since they are only being used in LEO. Even with a perfectly functioning suit, the astronaut's condition in the suit is important as uncomfortability in suit may lead to mission failure or to dangerous situations [20].

During the EVA, the reasons for potential electrical shock are identified as molten metal concerns. If the voltage is greater than 32V that can be a potential electrical hazard. [19, 20]

Due to the failure of the EVA safety tether, there is a potential to detach the EVA crew member. The safety tether has been designed to withstand the load of a crewmember. Before the crewmember reaches the end of the tether, the crewmember will be slowed down by the safety tether to reduce the load coming to the underlying structure. The crew members are trained to identify the structure that the safety tether can be attached. A test is performed to confirm that the EVA crew could get out of the articulating portable foot restraint easily and use the safety tether to return to the structure. If safety tether becomes snarled with the Orbiter Boom Sensor System, the EVA crewmember should release the safety tether and return.

3.3.1 Medical Risks of Extravehicular Activity

Decompression sickness known as "the bends" or "caisson disease" occurs when the human body is exposed to a low ambient pressure environment. When the crewmembers exit the pressurized spacecraft into the vacuum in a spacesuit for EVAs, decompression sickness can occur. Pressure reduction happens when spacewalkers exit the spacecraft. This can produce inert gas in the human bloodstream and tissues to come out of solution and form bubbles. These gas bubbles can embolize different body tissues including skin, lungs, joints and even brain damage. Also a nitrogen poisoning appears and affects body [19, 20].

3.4 Radiation effects

Due to the absence of magnetosphere, one of the biggest hazards associated to journeys between Earth and Mars is the exposure to high doses of radiation. Especially it becomes relevant for passing the Van Allen radiation belts [13, 21].

Galactic Cosmic Rays come from Milky Way or other distant galaxies. These particles are mostly protons and some of them are heavier ranging from Helium to heaviest elements. They come with the speed of light and knock apart the material they contact such as hard spacecraft wall, spacesuit of astronaut, habitat on Mars, and vehicle. This radiation is known as secondary [22].

Along with solar flares, the Sun's rapidly traveling rays expose astronauts to high levels of ionizing radiation. This form of radiation can damage the DNA in human cells, leading to mutations and higher risk of cancer as well as for cataracts, cardiovascular diseases, musculoskeletal issues and damage to the central nervous system and even impact of space radiation on neurodegeneration, in particular, the biological processes in the brain that contribute to the development of Alzheimer's disease. Exposure to radiation and high-energy particles were found to be associated with cognitive problems [13].

Another issue related to radiation is its influence on materials, its damage and human protection. The material damage could happen at atomic level. Moreover, charge accumulation and surface erosion could damage the whole satellite. The localized damage could be in the form of solid-state microelectronics failure or malfunctioning of a component. The macro-level failure could happen due to accumulation of localized damage that could lead to the failure of the overall mission [21].

Another risk that may cause failures during a mission is the accumulation of electric charges on the satellite surface. The main sources of spacecraft charging are ambient plasmas, sun rays, and the Earth's electromagnetic field. Charging happens when the spacecraft is traveling in space and interacts with external ionic environment. Accumulation of charges on the surface of satellite can cause electrostatic discharge and electronics components could stop working. Dielectric thermal coating and composite spacecraft structure are the main risk factors behind charging [23].

The following effects can appear:

- *Operational anomalies*: they include component failure, degraded sensor performance, phantom commands, missing signals, logic upsets, and telemetry glitches.
- *Physical damage*: spacecraft's surface can be damaged due to arc discharge, that causes surface heating and ejection of surface material from the discharging site. The ejected material can contaminate other surfaces of the same spacecraft.
- *Degradation damage*: the overall electrical and thermal properties of the satellite can be degraded. The highly charged (negative) surfaces will accelerate other positive ions towards it and this event will cause physical removal of top layer atoms.

Spacecraft has to be in the darkness to discharge itself. The charging of spacecraft is mainly for bigger satellites as the surface area increases, the possibility of charging increases [23].

3.5 Risks and Challenges associated with using Nuclear Power

One of the most important risks is dispersion of radioactive material in the atmosphere in the event of a catastrophic failure during launch. Due to multiple accidents in the past, the government and general public might oppose the use of nuclear power in spacecraft and satellites [24, 25].

As was said in Section 3.4, radiation shielding is very important to prevent problems with onboard electronics. However, onboard electronics systems are already complicated and to cover them with another layer is very difficult. Any small mistake leading to interference with the electronics might lead to failure of the system that can lead to accidents [26].

Another challenge is related to the crew. For safety of the crew members their compartment needs to be provided with radiation shielding which adds up to the total cost and complexity of the entire ship. Important to note that Uranium and Plutonium as well as all the systems required is expensive due to which funding becomes a big hindrance.

3.6 Engine

The engine is a critical as well as the biggest element of an interplanetary mission. Chemical and non-chemical propulsion systems, advanced and supporting technologies have been analyzed in [27].

Supporting technologies support an in-space propulsion system or subsystem but are not directly propulsive. The supporting technology areas are given significant consideration by the ISPSTA team including pervasive technologies (Integrated System Health Management, Materials and Structures, Heat Rejection and Power) and Cryogenic fluid management for propellants [27].

4. Possible solutions

Section 3 described the main challenges and hazards of a manned Mars mission. Based on this and following the sources review, the following solutions were marked.

4.1 Solutions to the risks associated with human health

Protecting astronauts' health from microgravity effects includes eating antioxidant-rich and high nutritious foods [13] and having required daily exercise to keep muscles and bones from deteriorating. Also the use of system of straps and buckles to help maintain an upright position should not be underestimated.

Plant growth will be helpful for the crew as a relaxation procedure and as an Earth-like activity.

Space medicine has unique challenges, as space environment is characterized by microgravity and radiation as well as by isolation from the mission control with a time-delay.

4.1.1 Astronautical Hygiene

Astronautical hygiene and space medicine are the duet that ensure the health of astronauts in space travel.

Pre-travel infection control education should be given to astronauts. As part of the current Health Stabilization program [3], astronauts are isolated from others in the community for a period of time greater than the incubation period for most common viral upper respiratory tract, gastrointestinal, viral, and bacterial infections. Interventions for mitigating the risk of infection prior to flight include: health screening, including a complete dental exam, tuberculosis [3], Staphylococcus aureus [28], human immunodeficiency virus (HIV), fungal infections [29] and parasitic infections that may be endemic in the astronauts' home countries.

Consideration should be made for positive or neutral pressure within the containment vessel to reduce the risk of airborne microbes entering the containment vessel after docking if technically feasible.

Astronauts with signs or symptoms of respiratory tract infection should wear surgical masks to mitigate risk of transmission to other astronauts [30, 31]. Astronauts routinely take a vitamin D supplement, which may enhance immune function [32] and reduce risk of reactivation of herpes viruses [32, 33], and this practice should continue.

An unmet need that is currently being investigated is for astronauts to have access to equipment needed to detect microbial pathogens that cause infections, in order to direct appropriate therapeutic interventions and mitigate transmission risk [30, 31]. Challenges include testing for common viruses and bacteria, ease of use, durability of reagents, and output that does not require incubation.

Other hygiene practices include frequently sampling the space-cabin air and surfaces to detect early signs of a rise in microbial contamination, keeping surfaces clean using disinfected clothes, ensuring that all equipment is well maintained (in particular the LSSs) and regularly vacuuming the spacecraft to remove dust etc.

4.1.2 Psychology

Homesickness prevention should include sufficient, effective and suitable workload, coupled with frequent opportunities for private communication with families and self-controlled individual schedules [11].

The "Earth-out-of-view phenomenon" theorizes that when humans are traveling in outer space they might start to feel unconnected to the Earth and to those left behind [34]. This can be dealt with by having a telescope on board with which the crewmembers could clearly see Earth and its features.

Psychiatric screening needs to be done on people who apply to be astronauts or who are selected for important space missions to prevent suicidal and homicidal intent [11].

4.2 Existing and possible solutions for LSS

Resource management will play a huge role in the mission preparation. Supply calculation should be made based on the possible failures analysis and lifetime of the equipment. LSS should be tending to the close-loop concept [12, 14, 17].

Reaching 100% recycling is one of the top technical challenges that were identified by NASA in [17], as well as improving reliability (close to 100%) and making repairs easy to implement. In addition, it is extremely important to reduce faults with respect to the high fault rate of the ISS equipment, both on the US and Russian segments. Current fault rate is unacceptable for long duration interplanetary missions.

Regarding the analysis of the air in the station, NASA is currently developing modular integration of multiple sensing modalities, employing a combination of simple and rugged technologies, and using highly capable complex approaches where needed. [12] The objective is to achieve on-orbit identification and quantification utilizing non-culture based systems, with a fast response and a minimal crew time requirement.

In addition to air and water monitoring, an automatic sound monitoring system with alerting capabilities, currently implemented on the ISS with a hand-held sound level meter and manual crew assays, is foreseen to be developed for interplanetary missions [14].

Water has to be re-used. Water from baths, washes, sweat, urine, and air humidity is going through a catalytic oxidation system [35], which kills bacteria and viruses. The waste is removed from the water, producing purified water. When the water is received it can be used for drinking or for technical needs.

Recently oxygen onboard of the ISS has been received from water by electrolytic process [35] and one of the most challenging issues was the extraction of O_2 from CO_2. USA as well as Russia have been working on the maturation of several technologies that can reach much higher recycling percentages. For example, NASA is working with *pH Matter* on the utilization of the Bosch process, that is able to theoretically provide the highest percentage of oxygen recovery from CO_2, with the objective of reaching >90% of recycling. Also Sabatier-based processes have been studied to increase the oxygen recovery level because of the extraction process of hydrogen from methane. This process can reach similar recycling percentages with respect to the previously mentioned Bosch process [17]. Recently [1], ESA has finished the Advanced Closed Loop System for the ISS and it successfully works onboard of the station. This solution could be used for the Mars Mission reducing risks of the lack of water and oxygen supply.

Major improvements must be made to reduce at a minimum the required amount of water that has to be carried on the spacecraft during the multi-month interplanetary cruise as well as the mass and power consumption of the entire system. [12] In particular, the water management system must become closed-loop as much as possible, as water accounts for the highest percentage of material by mass.

4.3 EVA requirements

The LSS of the spacesuit controls the atmosphere inside the suit, providing CO_2 removal, oxygen supply, and backup oxygen to restore pressure in case of leak. The correct functioning of the LSS is critical to the suit, since its usual failure mode can lead to a quick death of the astronaut (due to CO_2 build-up or suffocation, for example). Also included in the LSS is water provision for consumption, although this usually consists of a simple bag attached to the astronaut's body [36].

A technology under development that can be considered for application in future Personal/Portable Life Support System include Pressure Swing Adsorption, a process by which CO_2 can be separated from gas more efficiently, and through a repeatable process, as opposed to the current LiOH canisters, that saturate with each use, and are limited to around 8 hours. By regenerating the sorbent during EVA, the size and weight of the sorbent canister can be greatly reduced. Pressure Swing Adsorption accomplishes this by venting CO_2 and water vapor into space [12, 14, 17]

To prevent main hazards regarding the spacesuit it is recommended to ensure all potential sharp edges are controlled before assessing the EVA worksite and tools. Moreover, the spacewalker has a warning in the procedures to avoid contact with the baffle. To eliminate the risk, the tools with sharp edges have to be avoided as much as possible during the EVA. To avoid this risk all repair and inspection tools should be thermally assessed to identify whether their use can reach a thermally hazardous extreme [37].

4.4 Radiation protection

To reduce the radiation effect, medical research suggests that astronauts can be given some medications (for example vitamins A and C, Radiogardase) [3]. Some diet foods such as omega-3-rich fish oils, pectin fiber from fruits and vegetables are countermeasures to damage from long-term radiation exposure. Another solution could be a medication, which can give faster recovery from radiation damage. It stimulates and balances the number of stem cells and progenitor cells in the body as they are impacted by high-energy radiation, but it gives some side-effects on the human body, as hypotension and weakness. [38]

To protect the crew from the outside environment it is important to closely monitor the radiation levels. It is suggested to use dosimeters. Their data can suggest which part of spacecraft is highly shielded and which part is under high radiation [13].

There is no final solution on protection in these cases, but the "Radiation shielding of composite space enclosures" (SIDER) project's researchers have found two different ways to produce light nano-conductive materials [4]. One utilizes nano-conductive materials and another one Tungsten (high in density) foil into a carbon fiber-reinforced plastic.

Composite materials were tested and produced good results. These results were showing such shielding materials are stronger than Aluminum. These materials can reduce whole satellite's weight along with providing enough shielding. In result, it will also reduce total amount of fuel. Some remarkable properties of carbon fiber-reinforced plastic are lightweight, high in strength, enhanced durability, extremely low thermal shrinkage and expansion [4].

Future spacecraft can be made of materials such as polyethylene plastic (RFX1, made of lightweight carbon and hydrogen atoms) and water particles (hydrogen) or a combination of both. According to [39], polyethylene is better at stopping solar particles (50% more) and cosmic galactic particles (15% more) compared to Aluminum. Nevertheless, water is composed of heavy oxygen elements, that make the satellite structure heavier compared to plastic structure. Concisely, light materials are very good at tolerating radiations but they cannot fully eliminate it.

NASA's researchers are working on electrostatic shielding materials that will generate stream of positive and negative charges to deflect the ionization radiation and charging due to plasma in deep space. However, existing shielding will make satellite heavier and costly to launch. Research shows that such shielding can reduce radiation impact till 30 to 35 percent overall, so undoubtedly astronauts will be exposed to 70% radiation in space [38].

4.5 Power system

Nuclear systems have shown attractive mass scaling with power, but require additional radiation shielding to prevent interference with onboard electronics and crew compartments [40, 41].

While solar power is much more commonly used, nuclear power offers great advantages in many areas. Solar cells, although efficient, can only supply energy to spacecraft in orbits where the solar flux is sufficiently high, such as low Earth orbit and interplanetary destinations close enough to the Sun. Nuclear reactors are especially beneficial in space because of their lower weight-to-capacity ratio than solar cells. Therefore, nuclear power systems take up much less space than solar power systems. Compact spacecraft are easier to orient and direct in space when precision is needed. Estimates of nuclear power, which can power both life support and propulsion systems, suggest that use of these systems can effectively reduce both cost and flight time [40, 41].

As an example, NASA's Kilopower (Kilopower Reactor Using Stirling Technology) project will allow transporting several of the systems on a single landing vehicle [4, 42]. This experimental project, started in October 2015, works on a novel design for nuclear reactors for space travel. The first Kilopower prototype reactor weights 134 kg and contains 28 kg of U235. The space rated 10 kWe Kilopower for Mars is expected to mass 226 kg and contain 43.7 kg of U235 [4, 42].

4.6 Engine Solutions

Engine solutions are widely discussed, but it is important to stress the technological gap behind it. One of the examined solutions is the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) [5]. An electric power source ionizes hydrogen, deuterium, or helium fuel into a plasma by stripping away electrons. Magnetic fields then direct the charged gas in the proper direction to provide thrust. One of advantages of this approach is the mass economy as the spacecraft would not have to lift off carrying all the fuel it needs for the journey. The second relevant advantage is the mission length: the journey to Mars would be much faster [43].

It was shown [44], that a general approach could be feasible, but there are concerns on usage regarding the ethical issues (radiation debris, consequence of accidents etc) and the mission planning approach [43] as for the long-term mission the engine will require a nuclear reactor which will significantly add to the mass of the system.

Nuclear-powered spacecraft could allow human to abort the mission and return to Earth in case of problems [45]. Nuclear thermal propulsion (NTP) has advantages compared to chemical and electric propulsion systems.

Chemical propellants provide a high amount of thrust, but burn up quickly. In this case it is needed to send the fuel for the return trip in advance.

A major advantage of NTP engines is that they can run much longer than chemical rocket engines, such as the Space Shuttle main engines or the Merlin engines on SpaceX Falcon 9 rockets, and still produce significantly more thrust than an electric propulsion system, such as the ion thrusters used on satellites.

An electric propulsion engine—such as a Hall thruster that ionizes xenon gas—has a high specific impulse, as much as 10 times that of NTP. However, t the thrust is very low. This makes the technology good for making minor adjustments to the orbits of satellites. The biggest ion thrusters in space are only about 4 1/2 kW. A much larger, 100-kilowatt ion thruster known as X3 is currently being tested at NASA Glenn as a potential engine for missions to Mars, but even such a big ion thruster has a much lower thrust force than an NTP system.

5. Conclusions

Interplanetary flights can be seen as the future of human space exploration, but the planning of a mission needs a detailed analysis of every step and, at the same time, every element should be analyzed as a part of a whole system. Human is a central element of such complex system and it is a starting point for analysis and this system's disassembling. This strategy allows studying every point systematically taking into account the main reason of system design – human safety.

To realize a Mars mission scientists need to fill many technological gaps and to offer new solutions and approaches, which is not possible to do without global cooperation due to high costs.

This work tried to highlight the most important topics needed to develop as part of a mission and to give a survey of existing solutions or solutions under discussion.

This paper presented astronauts' health issues with regards to astronautical hygiene and psychology, analysis of LSS and resources, reflecting requirements to the closed loop LSS and existing technical opportunities, radiation effects that affects not only the most discussed human or shielding aspects, but also electronic functioning, power system as one of the key systems for the mission and the engine challenge. The work included technical as well as ethical discussions that stress authors' interdisciplinary approach.

The next step of this project will focus on the mission planning phase of a Mars mission. The project group will discuss the topic and propose recommendations.

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