Deep Space Missions: Challenges of Long Duration Human Space Travel

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***Abstract*—This paper aims to discuss the mission, human and socio-political aspects of the challenges faced in deep space missions that expose human life to extraterrestrial environment for extended periods of time. Deep space travel, or human spaceflight in general, is a difficult task, and requires us to overcome certain fundamental challenges and face inevitable threats to those missions and the lives of the people in it. A good understanding and analysis of these challenges and threats is vital before we can begin to devise solutions for them. The first and foremost challenge is to develop a moral and political will to explore and experiment through international collaboration and contribution. Then there exist technological challenges to sustain life in space over long periods of time, travel astronomically large distances and communicate meaningfully in space. And lastly, there are biological challenges which are concerned with the human life and its healthy survival in space. In this paper, we shall discuss these challenges in detail and explore present and future solutions to some of them.**

Keywords*—*Human spaceflight, Radiation, Isolation, Micro-gravity, Long distance communication

I. INTRODUCTION

Since the day of their very existence, humans have looked up on the heavens in awe and curiosity, to unravel the mysteries of the universe. Lack of technological resources prevented them from realizing this goal, but the common will of exploration has existed forever. But the dawn of space age broke many technological barriers, and made possible to achieve feats which were previously undreamed of. At its peak, man walked its first step on our moon, marking a preliminary, but giant leap in deep space travel for mankind. But ever since then, the human species has constrained itself to the low earth orbit and deep space travel has become content for the fiction writers.

Space is hard, and it tries its best to kill you. The space age was motivated by the space race [1] [2], and had political will at its disposal, which allowed us to drive technological advancements and take great risks to achieve so much in so less time. But to solve the hard problem of space today, we require a moral and political will in the form of an international collaboration and contribution. We require more adaptation than any other habitat, which requires huge scale technological innovation and invention. This can only be achieved by a planned development of the solution to this problem, which requires a detailed analysis of the challenges in the problem. In this paper, we shall identify, categorize and classify these challenges and try to understand them in all aspects.

Section 2 identifies the various categories of challenges faced by a deep space human travel mission, and provides a brief description for each one of them.

Section 3 to 5 dig deep into the broad categories of these challenges, and further classify each one of them, and discusses every one of them in detail.

Section 6 and 7 summarize the paper and provide ending remarks before closing the conversation.

II. IDENTIFYING CHALLENGES

There are three broad types of challenges in deep space travel and human spaceflight, which arise due to the socio-political, mission and human aspects of these programs. Each category deals with its own list of issues and we shall discuss them one by one.

a. POLITICAL AND SOCIETAL CHALLENGES

The large scale of deep space missions require a strong political will to fund the innovation, invention and production and drive the technological advancements essential for this feat. It requires international collaboration, which in turn requires intent as a society to reach out for the stars. To build this intent and will, these missions should provide monetary and non-monetary benefits in the long run and should be perceivable by taxpayers and stakeholders, as doing good for the entire human race. In later sections we shall further classify these challenges and discuss some short term and long term solutions.

b. MISSION CRITICAL CHALLENGES

These are the technological challenges intrinsic to every space mission which include design challenges, travelling in space, communication over astronomically large distances, resupply, return and rescue, automation challenges and power generation. We shall keep our discussion constrained to only describing these challenges and classifying them meaningfully.

c. HUMAN LIFE CRITICAL CHALLENGES

These are the most obvious type of challenges associated with human spaceflight, that deal with survival of human life in the harsh environment of space. The threats to human life in space arise from lack of gravity, space radiation, physical health problems due to limited nutrition and mental health problems due to isolation and confinement. We shall discuss these problems and possible solutions in detail in the upcoming sections.

III. POLITICAL AND SOCIETAL CHALLENGES

Although one might think that socio-political issues are what we create for ourselves and it is just a matter of time that we decide to eliminate these issues, they are actually more intrinsic to civilization itself than we think they are. These are real problems, and we cannot simply claim control over them just because we created it. The economics which drives our society, itself is driven by real math problems and deserves to be solved like one. Let us further classify these challenges and discuss them one at a time.

a. FUNDING SPACE RESEARCH

Most of the leading space research organisations are government institutions and are funded by the national budget [3] of their respective countries. This means that the people responsible for conducting the research are not the same people who get to decide which research work should get funded. Furthermore, the people who get to decide which research work should get funded are not the same people who actually pay for it. There is a visible interdependence between the researchers, leaders of the house and taxpayers, and the synergy of this relationship needs to be maintained to continue space research in the long term. One way to maintain this healthy relationship is by decentralizing manufacturing and production required by this research work, in order to create jobs not only local to the place of research but throughout the country. The Apollo Space Program [4] and Space Transportation System [5] are perfect examples for the same, which generated jobs by outsourcing manufacturing and decentralizing production, and therefore employing tens of thousands of people in the process. This generates public interest, which drives the political will and intent to fuel such operations.

Another important aspect is the societal aspect, which is the ambition to see a better future, and create an even better one for our off-springs. As abstract as this may seem at first, it is a force strong enough to drive the masses into a mindset that is inspired by space research. More and more people come into this field, seek education to conduct this research work and most importantly generate appeal as voters for those leaders who are in support of funding this research in the first place. This preliminary step decides what level of advanced space technology our society will develop in the coming decades, and can throw off a country, or the entire human race for that matter, by decades if not cared for with caution.

b. PRIVATIZATION OF SPACE

One of the major reasons for the decline of human spaceflight is the attempt to contain all spaceflight activities and space research in the hands of government institutions. This has lead to more mundane tasks like ferrying astronauts to the ISS being conducted by the government organizations of which the private organizations are very capable of [6], and has diverted their attention from real space research where the greatest threats lie. In a successful model, the private organizations should continue to perform the tried, tested and trusted space activities [7], which they can actually do more easily at a lower cost, while the government organizations should work in the frontier of space research, since they have the resources to conduct them and the acceptance to the threats which come alongside. This prevents failures and delays in these missions and increases the efficiency of the best minds working on them. Missions of very large scale, such as deep space human travel, will require the contribution of not only one government space organization but all of them, which can be achieved by making sure that these organizations devote all their resources to the common cause.

On the other hand, privatization of space takes off the financial burden from the taxpayers and distributes it among the stakeholders, which promises to generate profit for the stakeholders while decreasing cost of operations at the same time, making it a win-win situation for the government and the private organizations [8]. These organizations not only handle government contracts, but also indulge in private contracts for transportation, communication and broadcasting, tourism and surveillance, hence fulfilling the second requirement of generating public interest as discussed previously.

c. BENEFITS FROM SPACE MISSIONS

We have so far discussed short term benefits of research work in space, both monetary and non-monetary, such as generating employment and promoting education in the field. But large scale space missions, such as deep space human travel, should be the promise of a great future with much bigger benefits [9] in the long term for humanity. One visible benefit from space research is the advancement of military technology, which serves as the testing ground for that technology before it lands in the hands of the common people. All kinds of technological devices such as cell phones, cars, computers etc are tried and tested as military equipment developed for space applications. Because this technology is usable by the general public through commercialization, there is a huge financial and corporate interest in funding space research, and a public excitement on the topic as well for they want to use the latest and greatest piece of technology. This also triggers an argument for militarization of space, but we shall avoid it for the sake of the domain of this paper.

A second long term benefit is regarding exploitation and mining of resources in space, for commercial use on earth. This includes asteroid mining [10], communication and broadcasting, transportation and tourism [11].

IV. MISSION CRITICAL CHALLENGES

Deep space missions involving human space travel for extended periods of time will have to be planned and executed with high rate of caution and precision, for there is no turning back once the launch is a go. There are thousands of things that can go wrong individually and result in mission failure, whereas they have to cumulatively go right for the mission to be a success. From a probabilistic view, this is a very narrow slice of success which makes the mission aspects of human spaceflight more than critical. We shall now classify and discuss these challenges one by one.

a. MISSION DESIGN

Space missions have to be perfect at one go, which is also the first go. A full scale space mission, specially human spaceflight, cannot be tested before the actual mission since every attempt is very different from the previous one because of the large number of unknown variables involved. For long distance deep space missions, lasting for several years or even decades, plans have to be well thought of and designed for the future in a robust and modular fashion.

The four major parts of any mission are launch, cruise, stay and re-entry. The launch is probably the most critical part of any mission, and the most violent event in the entire journey. A bad launch of a rocket can have immediate effects such as deviation from planned trajectory, loss of cabin pressure, failure or damage of components, power loss etc which will force the mission control to abort the mission, thus ending the whole mission before it begins. Not only this may cause loss of life of the crew members on-board, but huge financial losses and severe backlashes or total cancellation of future missions. There can also be delayed effects of a bad launch, which remain unnoticed and silently exist on the mission hardware as time bombs, that can cause catastrophic failures in later stages of the mission. Great examples would be mission failures during Apollo 13 [12] and the Columbia disaster during STS-107 [13], when complexities introduced during launch resulted in a failed mission later on.

Similarly, cruise and re-entry have their own obvious challenges, such as maintaining cabin pressure and an artificial atmosphere, recycling of waste and providing reliable and repeatable performance from the hardware on-board. One way to achieve reliability is to send a lot of redundant hardware on-board, but it compromises with the payload capacity of the mission.

b. SPACE TRAVEL

Space travel has been a thing of science fiction for the most part of modern human history, and for good and obvious reasons. Space travel is hard, time taking and constrained by some practical limits which are very difficult to overcome and some theoretical limits which are impossible to touch. But for deep space human travel within our Solar System, only the engineering limits are of significance, and there is no need to cross any theoretical limit whatsoever. The first problem is of power generation, which has been discussed in a separate section. The second problem is to accelerate, brake and steer in space [14] while staying within the constrained power budgets. A proposed solution is to use the tidal forces [15] of heavenly bodies and use gravitational sling shots [16] for accelerating, braking and steering in space. But this can only be done during certain windows when such an alignment of those heavenly bodies is available, and the flight trajectory is completely dependent on this alignment only. Any mistake in maintaining the defined trajectory would directly mean mission failure and loss of life of everyone on-board.

Another solution is to build space ports throughout the solar system, which are like miniature space stations orbiting the planets in high altitude orbits. Incoming spacecrafts can dock into the ports at one place in the orbit and un-dock at another place in the orbit, changing their direction of travel. The kinetic energy of incoming spacecrafts are used to increase the orbit of the port, and outgoing spacecrafts are provided kinetic energy by decreasing the orbit of the port. The obvious challenge with this solution is of course building the ports in the first place. But since no humans are involved in building these ports throughout the Solar System, it is a easier task with less threat involved and with a great return on investment. The basic idea is to create a modular design and automate the construction process, either by sending raw materials from earth or mining them from the host planet/satellite of the space port.

c. COMMUNICATION IN SPACE

Almost real-time communication services are available to the astronauts aboard ISS, and a communication service with a propagation delay of a few seconds was available to the astronauts who went to the moon [17]. But the propagation delay in communication during deep space missions will be too large for interaction and the information will be obsolete by its time of arrival for both the parties. One thing is very clear that deep space human travel missions cannot rely on interactive and feedback based communication services for mundane tasks like course corrections, equipment failure, repairs and routine activities. Communication services, using the Deep Space Network [18] [19], will mostly be used for sending consolidated mission reports and receiving flight plans and software updates. Most of the working of the spacecraft will have to be automated, and based on the received mission status and report, the ground mission control will have to send the updated automation codes. The crew will have to conduct independent operations and will have to troubleshoot the problems mostly by themselves. Even tasks such as extravehicular activities might have to be conducted without supervision and permission in case of emergencies. This is only possible with an advanced on-board data handling software which is artificially intelligent and computationally powerful hardware that can be relied upon.

Another challenge with communication over such large distances is transmission loss. This problem will require a network of repeaters and amplifiers already in place around planets in high altitude orbits throughout the Solar System. Our previously discussed solution of space ports can be used to overcome this challenge while solving the space travel problem simultaneously.

But the problem of propagation delay seems to be fundamental and unsolvable by any means in the near future. It is true that communication through transmission of electromagnetic waves is limited by the laws of physics in its ability to carry information. But with advancements in quantum computers, we might be able to solve this problem with the help of quantum entanglement [20]. In theory, it is possible to transfer bits of information between two quantum entangled particles with zero latency across any distance [21], and is not constrained by any actual physical barrier between those particles unlike electromagnetic waves. If we can exploit this quantum property of entangled particles, instant communication can be made possible over astronomical distances and open new doors for space exploration.

d. POWER GENERATION

Power is the most important resource that needs to be conserved and constantly generated to support human life and mission hardware on-board. This includes electrical power and mechanical power, to run the on-board computer, communication system, life support system, cold thrusters, boosters and attitude control hardware. At large distances from the Sun, generating all of this power using solar cells is almost impossible and impractical. The two present technologies in action are fuel cells [22] and thermoelectric generators [23] [24], which convert chemical energy and thermal energy into electrical energy respectively. But greater power requirements will require better sources of energy, for which the top candidate is a nuclear fission reactor. These reactors are small scale nuclear reactors that more or less perform similar to nuclear reactors in power plants on earth but more efficiently. The residue heat and heavy water from these reactors are used to drive thermoelectric generators and fuel cells.
Mechanical power is more difficult to generate and mostly needs to be carried on the mission in another form of energy. Instead of generation of mechanical power, spacecrafts focus on efficient conversion of other forms of power to mechanical power. As previously discussed, mechanical power for propagation can be generated from the potential energy stored in the space ports, and can be used to power propagation over long distances in space. Another way to drive a spacecraft engine is by using cold ion thrusters [25] [26], which are very efficient in converting electrical energy directly to mechanical energy. There are some advanced methods involving anti-matter particles that can generate huge amounts of thrust and acceleration, but these are purely theoretical concepts as of now, and are a promise to power generation in the future generation of spacecrafts [27] [28].

V. HUMAN LIFE CRITICAL CHALLENGES

The phrase *Human Spaceflight* is self explanatory of its meaning, and the first two categories of challenges concern with the *Spaceflight* part of it. The third category deals with the *Human* part of Human Spaceflight, and is the most critical and vital part of any space mission involving humans. They are called the *Hazards of Human Spaceflight* [29] and the challenge is to keep the crew alive and healthy, while space tries its best to do the opposite of it. Let us further classify these challenges into four broad categories of threats to human life in space.

a. RADIATION IN SPACE

Space radiation [30] is the streams of high energy particles present in all of space, mainly of three types namely solar radiation, interstellar radiation and galactic cosmic rays. These are high energy electrons, protons, alpha particles and other small nucleons and nuclei, which are strong enough to break chemical bonds and strip off atoms from their electrons. Because of this property, they can damage the cells by disrupting the cell membrane and damaging the DNA molecules inside human cells. This disruption can cause irritation, radiation sickness, loss of immunity to diseases, cancer and in worst case, death [31]. Deep space human travel exposes the crew to these radiations, and without the protection of earth's magnetic field and the ozone layer, can cause severe health issues and fatalities to the crew members causing mission failure and loss of life. Radiation can damage the nervous system, alter cognitive systems, reduce motor function and prompt undesired behavioural changes. Clearly this is one of the most obvious and unavoidable threats to human life in space, and hence requires necessary counter measures if we ever wish to enable deep space human travel. Deep space vehicles will have intense protective shielding, active dosimetry and alert systems to prevent any catastrophe. Extensive research is ongoing for developing pharmaceutical countermeasures in the form of drugs and vaccines to restore immunity to diseases and reduce the effects of radiation in the body.

b. LACK OF GRAVITY

Our bodies have evolved for hundreds of thousands of years on earth, and has developed a cardiovascular system, a respiratory system, a skeleton system and a nervous system that is tailored to work best under earth's gravitational pull, and is accustomed to this pulling force. Long term exposure to micro-gravity or reduced gravity can force the body to lose bone mass and muscle mass because less effort is now needed to carry around the body, and can seriously slow down the cardiovascular systems as pumping blood throughout the body is much easier in micro-gravity. The bodily fluids move up in the body in lack of a downward pulling force causing swelling of the face and the chest in the early days. Swelling around the eyes make it difficult to see [32], and makes it difficult to focus on the most mundane tasks. In worst cases, it can affect the nervous system causing hallucination, headaches and undesired behavioural changes. After a few months, the body gets very skinny and weak but lack of gravity makes it difficult for the brain to perceive that change. In a few years, the body adapts to the micro-gravity environment and the meal patterns, consumption and excretion further deteriorates, which in turn contributes to further decrease in mass and strength. This change can be deadly during return and re-entry [33].
The re-entry of a spacecraft is a violent event and takes its toll on the body by exerting large tidal forces and impulses on the crew, which is magnified many folds given the state of the body from outer space. This can result in internal bleeding, bone fracture, paralysis and coma or in worst cases a sudden death. Even if the crew survives re-entry, it takes a lot of

time to restore the strength and stamina required to conduct the most routine work in a normal gravity environment. This same effect can be caused by gravitational sling shots used to accelerate, brake and steer the spacecraft in space.
The present solution to this problem is extensive pre-mission training, routine on-board exercise and short term post-mission therapy. The crew is supposed to perform routine workouts everyday for several hours to introduce labour and physical work into their lifestyles, which reduces loss of bone and muscle mass and retains the body strength to some extent. Future solutions would revolve around evolving the crew with the help of prosthetic attachments, and developing better life support systems to eliminate some of the fundamental root causes of this problem.

c. PHYSICAL HEALTH AND NUTRITION

Food, air and water are the basic needs to sustain human life and ensure its healthy survival [34], and same goes with human life in space. While power can be generated on-board, food and water needs to be carried on-board to satisfy the needs of the entirety of mission duration. Air needs to purified and supplied into the cabin at a certain pressure and should have a certain composition [35], any failure in doing so would immediately suffocate the crew. A re-supply mission is totally out of question, and a rescue mission is not even worth mentioning, hence the crew has to make do with whatever supplies are present on-board. It is quite clear that food on such a mission will not resemble anything like that we have on earth. It would be a well calculated mixture of bare minimum of nutrients and minerals essential for the healthy survival of human body, wrapped in a substrate of carbohydrate rich fibres to give the sense of eating and provide body mass. In the early mission days, the crew will have to take medications to avoid the feeling of hunger, because even though space food pills will keep the body alive and rationed food will give a sense of eating, the brain will not perceive it as satisfaction to hunger. Same goes for water, which will be purified and recycled several times over and the fuel cells will be a part of this cycle. Together these equipment will constitute the *Life Support System* [36] which will keep the crew alive during the mission period. The main focus will be on efficiency of usage, and nothing will be wasted during the entire process.
Due to the strict rationing of food and intoxication due to over-recycling of resources, some physical health issues are inevitable and will require remedies instead of prevention. Nausea, body pain and body mass loss, ghost starvation and motor dysfunction are just some of the consequences of these challenges related to physical health, and will probably lead to a large proportion of payload mass on these missions dedicated to life support. Over the course of time in the distant future, such deep space missions will be a much more frequent event in the Solar System, in which case a stellar network of re-supplies can be maintained in the space ports, both from earth as well as the host planets, which will help the situation.

d. MENTAL HEALTH AND ISOLATION

When we talk about health, mental health is always of prime concern, specially in an environment as harsh as space where the most amount of cognitive awareness, sensory response and motor function is necessary to take the right decisions during emergency situations and close calls. In fact, the most mundane routine tasks in space seem to take a lot of focus and concentration, and consume a lot of bandwidth of the brain. This dysfunction is caused by the drastic changes faced in the lifestyles of astronauts, which now means living in isolation, confinement, hostility, danger, fatigue, unawareness to news about home and no contact with families for a very long period of time, that could also last forever. Even though the astronauts are selected after rigorous training, are watched closely by psychological experts and are fully educated to what they are accepting to be a part of, no test can simulate the kind of isolation, danger and fatigue of space travel better than space travel itself [37]. As social animals, the feeling of having no connection with the remaining members of your species and being abandoned in a hostile environment in a metal container can be disturbing, and can give birth to a cascade of thoughts which can totally destroy the ability to think rationally and make logical decisions, even for the most carefully chosen and most extensively trained minds. Depression, cabin fever, undesired behaviour [38] and trauma suffered by even a single cabin crew can compromise the whole mission, since the crew members have a very strictly distributed work-space and the success of the mission depends on every member accomplishing the task assigned to them.
Medication can help with avoiding any mental health issues from occurring in the first place, but the ethics behind giving medication for mental health to a person not suffering from those issues beforehand will create societal protest and that situation is better to be avoided. A more simple solution is to decrease work time and introduce group activities into the routines of astronauts, which will although decrease the efficiency of the crew, is justified from the fact that mission success is more critical than mission efficiency and effectiveness. It will also be vital to automate most of the mundane tasks on the spacecraft, and leave only the team related research activities for the crew, giving them ample time for interaction, physical training and relaxation.

VI. CONCLUSION

From our discussion so far, it is crystal clear that the smallest of mistakes in deep space missions can convert it into a one way trip. We have seen that these missions are more about the healthy survival of human life in space, and then about the research to be conducted by humans in space. This is why a large proportion of payload mass on these missions will be the life support system, and a small and highly trained crew will command the mission. The most advanced technologies, both hardware and software, will have to be designed for such long duration space missions, and to drive those innovations will require a strong moral and political will. The role of artificial intelligence, medical science and mechanical engineering will be astronomical, and will require a collaborative relationship between them to achieve such a feat. With a little inspiration from the past and little motivation for the future, the future of human space exploration looks bright and promising.

VII. SUMMARY

We started our discussion by identifying the challenges of long duration human space travel, and defined three broad categories. We then further classified each on of these categories one by one, and discussed in detail the problem statement of every challenge and the possible solutions in near and distant future. We revolved around discussing the mission, human and socio-political aspects of long duration human spaceflight, and carried out careful and unbiased analysis of those problems. Overall, this paper has triggered a productive discussion and has touched upon all the important nodes concerning with the topic, while remaining withing the domain of the paper.

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