

# Future sustainable space exploration: space conditions adaptation and self-sustaining system

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**Abstract.** Creating regenerative systems onboard space vehicles is the next technological breakthrough to reduce cost, efficiency, and sustainability of space exploration. Near future projects include NASA's plan to set up moon base as soon as 2028 in one of the Artemis missions. Upon architectural and structural maturation, focus is shifted to maintaining presence. This includes minimising astrological impacts on the crew and building self-sustaining systems that would be the key to a new era of ambitious missions. ALS and HLS will provide transportation for the missions from the Earth to destinations, with impacts on the crew during journey discussed. Ways of minimising effects are vital to missions in the long run. Process of activation and operating core modules is portrayed on blueprints. Details of development and current technological advances that could be utilised may offer potential on the system, new advancements by the time of liftoff is expected for taking pioneering space missions to a new level.

## 1 Introduction

The Development of Bio generative/Biological Life Support Systems has been under consideration for sustainable lengthy explorations in outer space. In recent years, the advancements in both commercial and governmental companies' HLS and ALS as well as heavy-lifting rockets like starship, have made setting up a base on the moon more possible than ever before. While current space travel addresses temporary exposures to sources such as radiation, a journey like that to Mars could take anywhere between 7 months and 2 years [1]. Intensifying the accumulation of issues from basic LSS to crew physiological health, when focusing on the biology aspect of it. As a gradual approach, currently researched conditions in space exploration are investigated. Next, the challenges of a prolonged space flight will be reviewed concerning man-made ecosystems on board the spaceship. With an extension analysis of blueprinting a manned extra-terrestrial base.

## 2 Role of genetic engineering and similar technologies in maintaining the health of astronauts

### 2.1. Issues of muscle, bone loss and causations

The issue of bone loss has received considerable critical attention in space exploration. Humans' adaptive ability leads to negative consequences in microgravity. As a result, these lead to signs of after-flight weakness and a greater chance of lower back ache before flight to outer space and after arrival on Earth. Studies [2] show

process of bone demineralisation occurs right after arrival in outer space. Adaptation to space conditions leads to an approximately 65% increase in calcium content of faeces and calcium, persisting over duration of mission.

A degree of 1-2% bone density loss every month occurs in weight-bearing bones as shown through study [2]. The range varies greatly between bones of interest and individuals. In addition, greater calcium excretion increases the risk of nephrolithiasis. Preventative measures are taken since a very long duration is needed to recover lost bone mass through rehabilitation programs. This leads to a vacancy for the application of genetic engineering technology.

**Table 1.** Space conditions impact on human body [2].

Variable	N	%/Month	SD
BMD Spine	18	-1.06*	0.63
BMD Neck	18	-1.15*	0.84
BMD Troch	18	-1.56*	0.99
BMD Total	17	-0.35*	0.25
BMD Pelvis	17	-1.35*	0.54
BMD Arm	17	-0.04	0.88
BMD Leg	16	-0.34*	0.33
Lean Total	17	-0.57*	0.62
Lean Leg	16	-1.00*	0.73
Lean Arm	17	0.00	0.77
Fat Total	17	+1.79	4.66

\*p<0.01

### 2.2. Space-travelling caused diseases related genes

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The current application would be limited to genetically modifying yeast, lab rats and other entities already in use for testing of drugs. However, as declared by George Church, a Harvard geneticist: “One likely path for risk reduction in space does seem to involve biological engineering in the far future.” The application gene related advancements could play important role in future space missions [3]. He and the current scientific community have picked some 40 genes with these potentials. These are CTNNB1, LRP5, and ESPA1 that could provide varying characteristically adaptations.

### 2.3. Development of technologies as potential solutions

Despite ethical and technological limitations, options for genetic studies have been identified. In response to counteracting radiation, an interdisciplinary team led by the Ames Research Centre has published an operation guidance [4] on specific mechanisms for integrating radio-resistance technologies for astronauts. Future targets of these research include experimenting gene therapy with genes known to confer radio-resistance on organisms without ability to sense pain, isotopic substitution with organic molecules as well as upregulation in endogenous DNA repair for protection against radiation. Alternatively, there has also been extensive research on the generation of artificial gravity [1] within spaceships to address effects of gravity on human.

Only recently, it has been reported that a medicine (AGN-151587) currently in experimental stage, has been tested in patients with an inherited genetic disease caused by CEP290 gene mutations, called Leber congenital amaurosis. Despite necessary cautions of gene therapy, this example and many others suggest the already growing technology involving genetics in space [5], but also the possible dangers of it.

Another promising gene-editing technique is CRISPR gene editing. Currently acknowledged as the most versatile and adaptable genetic engineering technology, the system has been utilised in various fields ranging from agricultural plants increased yield, biofuel-producing microorganisms, anti-malaria mosquitoes, and many others. However cautious approach is still to be noted. A resourceful study [6] recently shows that the deletion section of the technology, involving many thousands of bases could result in further complications of detrimental effects.

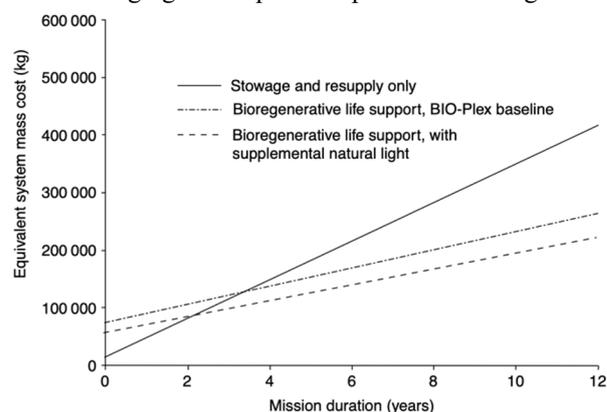
Moving on from the biological perspective to the “essentials provision”, 3D bioprinting [7] shows promising results in bioprinting cells, tissues, and organs. The current applications of printing tissues envision an important role in space medic establishment onboard spaceships. Different bioprinters have varying characteristics that could be prepared for different situations in space. Applications include the creation of bones, tendons, vascularized tissues, and ear cartilage through a mixture of human cells, hydrogels, extracellular matrices, and growth factors.

## 3 Generating a sustainable system on board spaceship

### 3.1. Introducing plants in space

Basically, all conditions for long-term habitation of space-vehicle or colonisation of extra-terrestrial structures involve plants, as a vital part of the existing ecosystem, to sustain humans. Experiments conducted in space, especially the ISS (International Space Station) provide valuable insights. The ISS is the primary site for pioneering research. One article circles the idea and explains how missions conducted by NASA bring concept of plants in space into clearer focus and how their experimental data pave the way for space exploration.

A prompt to the construction of plant ecosystem in space would be the: Underlying Premise: The ALS Concept [8]. As its name suggests, the current as well as future technological development of such type by NASA, SpaceX, Chinese Tiangong Space Station has one main objective: create practical human occupation of contained systems. The current supply mode of the ISS, for example, relies mainly on resupply by a cadence of one resupply mission every couple of months. This prove costly if humans were to move beyond Earth orbit, where most current operations are limited to after Apollo 17’s journey to the moon in 1972. Early studies of regenerative systems, or man-made ecosystems onboard space exploration vehicles introduced algal systems [9], where oxygen - vital for human survival, and palatable food were hypothetically produced. However, the process of converting the minuscule organisms to food was challenging and required improvements altogether.



**Fig. 1.** The graph shows the breakeven point for space exploration with regenerative system. For missions of less than about 2 years in total duration, cost for operation of plant-based system actually costs more than resupply systems. BLSS only becomes the stronger candidate in lengthier missions, such as one operated on Mars, and proves even more conservatively efficient if natural light is supplemented [8].

### 3.2. Introducing the concept of a sustainable habitat on exploration-level space vehicles

To consider the concept of a regenerative plant-based system in space, a discussion of the work of the ESA’s MELiSSA mission is presented in this section. Aspects

such as gravity, radiation, and magnetic fields - the most researched forms in space are focused in great detail in this discussion.

### 3.2.1 Lighting

Providing adequate lighting is likely the largest physical challenge present in developing a plant-based self-sustaining system on spaceship. It is shown through study that biomass and photosynthetic rate for most crops increase linearly with light, showing that about half dry biomass could be generated with each mole of solar radiation. Hence, the primary challenge is to increase the overall energy and conservatory efficiency of lighting. Hence, the development of customised artificial and solar light supply onboard spacecrafts is a vital part of sustaining space missions.

### 3.2.2 Gravity

Gravity plays an often-overlooked importance in a plant's life cycle. Reduced gravity environments, such as those in space influence how the plant physically transports water and solutes, gas exchange between its surroundings and even their hormonal distribution.

While effects can diminish with proper ventilation and force air movement in aerial plants, problems in the root zone increase in complexity, leading to root zone hypoxia. This suggests developing vertical growth hydroponic system onboard space vehicles could pave a more successful route for the gravity aspect. While shifting focus to aerial sections of plants could speed up set up for plant regenerative systems in space, researches on the plant nutrition's operation mechanisms in space conditions are yet limited while rhizosphere studies might experiment enough in the future to reach a conclusive concept of the influence of gravity on each section of plants.

## 3.3. Creating advanced life support systems on lunar surface

This proportion of the section introduces Canada's research on an advanced life support system that could be integrated into system of choice in space exploration. Most content consists to-date research and data backed experiments on lunar missions. The project started as early as the 1990s, when Canadian technological capabilities [10] for space flight and aerospace grew tremendously. Main factors of the rapid growth include Canada's research and construction on technically sophisticated greenhouse sector to suite their harsh climates as well as strong emphasis and bonds with international collaborators.

This roadmap [10] set by Canada Space Agency has an objective of over half their current food closure by the mid 21st century for space missions. Aims for full-scale lunar plant production systems, terrain modifications, and analogue systems are proposed. One popular such proposition is the lunar "salad machine", also planned by

NASA for dietary/nutrition needs by astronauts to reduce the impact of space conditions on humans.

### 3.3.1 Lunar plant growth lander

In order to get a system [11] set on earth onto another planetary body, factors such as complexity of the system, payload contribution and hardware unfolding preparation stages have to be considered. Collaboration between countries' space agencies would involve a simple version of the system to demonstrated the practicability of landing the system followed by unfolding, and operating it on lunar surface to improve understanding of specific lunar environments on plant growth.

### 3.3.2 Lunar salad machine

By definition, a lunar salad machine [10], signifies a transition between a system reliant on human operation to one that is fully automated and low on maintenance cost. If successful, the landing and operation of this system would provide confidence in lunar BLSS. It would pinpoint further objectives in lunar technological expectations and developments for future missions. Specifically, the currently unfolding lunar salad machine mission, considered by space agencies, would deploy key modules to future programs such as the Artemis program. Further considerations for lunar conditions such as atmospheric, autonomy, resource management would be defined through more extensive trade studies in the future.

## 3.4 Creating life support system on extra-terrestrial planets

A proposed base for lunar or mars habitation is described in current section, with waste management being the primary focus. Despite current strategies for exploring space such as China's lunar exploration program or NASA's Design Reference Architecture [12], advancements have been made on varied grounds. Particularly in the development of nitrogen recovery from urine, animal protein production, bioconversion of solid wastes stowage, resupply and recycling of life support resources, unparalleled opportunities are provided to reach the goal of an ecological environment, open in aspect of energy but closed to the surroundings in aspect of mass.

### 3.4.1 Solid waste bioconversion

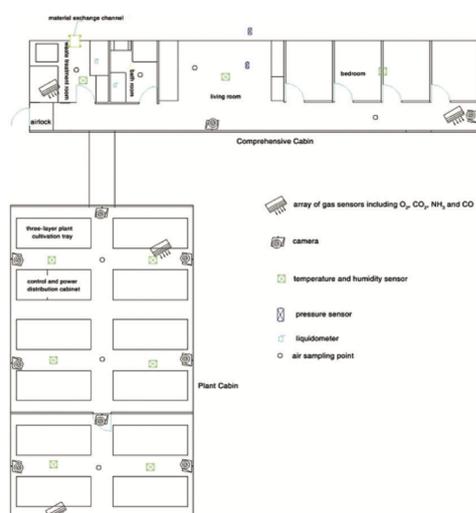
Organic wastes, human excretions and faeces could account for most wastes in the project. One way of converting these would be fermentation of these wastes in a solid waste bio-converter. Which consist of microbial inoculants adapted to degrade plant waste. Processed and fermented waste is then sent to higher plant cultivation module to act as fertilizer. Gas component enriched in CO<sub>2</sub> is released from the organic waste converter through an air filtration system into the crops cultivation module [13]. To facilitate the

absorption of CO<sub>2</sub>, heat units within bio-converter module is regulated to control rate of release of the gas. Solid that couldn't provide functional use to plant growth or other modules is then compressed, stowed and periodically exported from the system through other means.

### 3.4.2 Environmental monitoring

Enclosed environment, especially one on an extra-terrestrial planet requires constant management of internal conditions. Pressure is vital for maintaining a stable ratio to the atmospheric pressure [14,15] of the planet, 0.095 psi for mars. Temperature has to be maintained for functionality of apparatus such as those for scientific research and crew health. Further on, research shows that humidity plays a vital role in long term health of crew members where minuscule variations could lead to detrimental effects in long term habitation.

Air compositions (CO<sub>2</sub>, CH<sub>4</sub>, O<sub>2</sub> concentrations) are continuously monitored by an array of sensors located at various points within the system. Pressure, temperature and humidity is collected at multiple Conditions Monitoring Stations located throughout main structures. Through weekly routine, fourteen types of harmful gases are analysed in a gas chromatography-mass spectrometry apparatus [14]. Air filtration devices installed remove accumulated harmful gases within the main ventilation component connecting ventilation pipes, with two in dorm room and five to six scattered across main modules. These consist of catalytic converter, electrostatic precipitator and could involve integration of newly developed technology at the time of lift-off [13]. To optimise crop yield, three representative air sampling stations are set up in the plant cultivation module [14].



**Fig. 2.** Layout of extra-terrestrial base with main environmental monitoring components [14].

## 4 Conclusion

Space exploration have always been the desire of humans, fuelled by milestone projects such as voyagers

1, and 2, Hubble, and JWST. Each and every one of these are achieved on the basis of new ideas and inspiration adaptations, of which the 21st century promises more than ever. Humans are blessed with the capabilities to suite and adapt to harsh environment, and space presents the future stage for human evolution, as that which took humans out of Africa. The current technologies provide the basis for such ambitious approach to sustaining human life on extra-terrestrial planets and utilising the resources to their benefit. For instance, the day when humans colonise Mars could be close, if not just around the corner. When the day comes, humans would be equipped with the new adaptations unimaginable nowadays. In the far future, when humans successfully conquered those distant planets, they may not be what we call humans nowadays, they would be able to harness the energy of the sun, and travel between planets of the solar system just as current humans do moving by car. In the millions of billions of years, if they were to still persist, they might play a role in the dark forest rule, a hypothetical concept, or they might be greater to prove it otherwise, or discover they are the first civilisation in the universe. The future is open to possibilities unimaginable by anyone. Alas, all shall come to an end, the future is unpredictable, the path forward uncertain. Afterall, it could be both pathetic and fortunate to exist in an era, to witness the first in space exploration in so many fields.

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