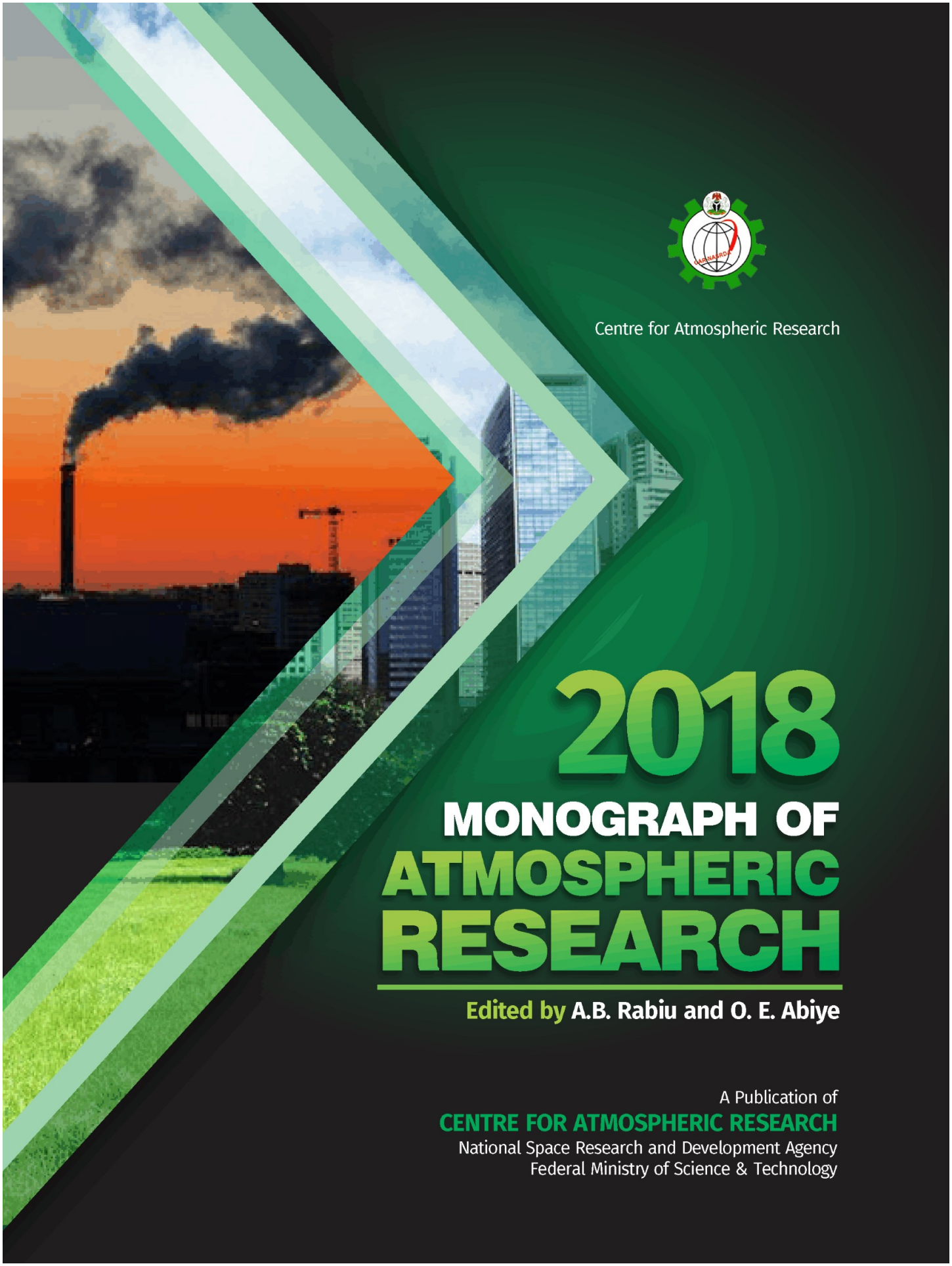

Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

A Publication of
CENTRE FOR ATMOSPHERIC RESEARCH
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First Published in 2018

ISBN: 978-978-972-859-6

Printed in Nigeria
by Simplicity Press
Tel. +234 (0)803 085 1374
Email: dapoashaolu@yahoo.com

PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

Microgravity effect in a long-term manned mission

F. A. Oluwafemi*[a], D. Patel[b], Y. Lakmal[c], A. De La Torre[d], G. R. Kamaletdinova[e], J. Lousada[f]

*[a]Space Life Science Unit, Engineering and Space Systems (ESS) Department, National Space Research and Development Agency (NASRDA), Km 17 Airport Road, Abuja, Nigeria, P.M.B. 437, oluwafemifunmilola@gmail.com, +234 8065035799.
[b]CQU-SGAC (Central Queensland University-Space Generation Advisory Council (SGAC)), Sydney, Australia.
[c]SGAC (Space Generation Advisory Council), c/o European Space Policy Institute, Schwarzenbergplatz 6, 1030 Vienna, Austria.
[d]Marist College, Marcelino Champagnat 2981 Guadalajara, Mexico.
[e]Scientific Laboratory of Design and Modelling of Complex Engineering Systems, Tambov State Technical University, Russia.
[f]DLR (German Aerospace Center).

ABSTRACT

Long-term space missions have a high interest within space industry specialists as it needs collaboration of all scientific forces. This research is focused on Mars Mission and all its aspects: flight stage, habitat, extravehicular activities, lives on Mars, and transition stages. Microgravity effects and environmental differences with Earth are one of the key issues of these studies as they are crucial as for human existence in general and especially for health conditions, operations as well as for technical side because microgravity has impact on micro-electronics. Planning a long-term mission, it is important to study microgravity effects from a wide side paying attention to plants, animals and materials. These studies could be done in preliminary experiments. There could be severe essential impacts on humans such as weakening the bones and elongating spinal cord. Human brain expected to work at intense consciousness and requires high attentiveness so effects of microgravity on nervous system, brain and cardio are dominant to study. There are long term and short-term effects of microgravity. Under short term microgravity experiences such as in the Space Laboratories, the body experiences shift in body fluids, space motion sickness, muscle atrophy, bone demineralization, immune dysregulation and disruption of senses such as vision and taste. The long-term effects of microgravity and the biggest hazards on human physiology discovered to be encountered in Mars mission are discussed, including possible solutions. Having identified numerous hazards related to microgravity, solutions will be discussed in this paper.

Keywords: Microgravity impact, Human body, Nervous system, Cardio, Psychology.

Citation: Oluwafemi, F. A., Patel, D., Lakmal, Y., De La Torre, A., Kamaletdinova, G. R. and Lousada, J., 2018. Microgravity effect in a long-term manned mission. Monograph of Atmospheric Research 2018, Edited by A. B. Rabiu and O. E. Abiye, Centre for Atmospheric Research, Anyigba, Nigeria. pp. 116-122.

INTRODUCTION

As the next giant leap for mankind, the colonization of Mars receives a great deal of attention. When discussing the settlement of Mars, it is important to consider how the Martian environment will affect the human bodies in the long-term – a subject that does not receive as much coverage as colonization itself yet is vital to ensuring man's survival after getting there. Space is not a single destination; the Earth orbit, the Moon, and Mars involve very different voyages and challenges. Since the dangers were more immediate and dramatic for earlier missions – catastrophic explosions that no one could hope to survive. For the planning of a space mission, such as that of Mars, a very important factor must be considered: microgravity. This exists in the environment in which the mission is carried out and directly affects all aspects of it.

The essential parts of the short-term or long-term space mission are human body and all those factors which help humans to survive in space. Space exploration has main two hazards which are high ionizing cosmic radiation and solar energetic particles (SEPs) which cause damage to spacecraft and electronics components by creating single event upsets. Another challenge is microgravity which results into severe health risks such as tumour, circulatory diseases, damage to central nervous system, and loss of life (*International Academy of Astronautics, 2004*).

Microgravity is becoming a contentious issue among the scientists. It has impact on daily food intake, water intake, humans' body, material science and crystal formations. Importantly, it has deteriorating effects on bones, eye-sight and other key body parts. To maximize the scientific performance of the experiments that are carried out in space, both in time and money, one must first make test studies on Earth. These studies can be carried out in laboratories, drop towers or on board the International Space Stations (ISS) and MIR. Space agencies such as NASA and other companies and private institutions such as SpaceX, conduct studies on microgravity with the aim of preparing a better investigation in space orbit or simply skip that step and solve the issues that microgravity causes from Earth.

Mars Environment and Microgravity Studies

There are cultural, scientific, and political imperatives that contribute to the drive to explore space. The cultural imperative is embodied in the innate need of humankind to extend its boundaries and move forward into new domains, in the process gaining a sense of progress and common accomplishment *(International Academy of Astronautics, 2004)*. Current interest in planetary and long duration space exploration such as to Mars requires further understanding and research. Long term space missions have a high interest within space industry specialists as it needs collaboration of all scientific forces. Due to the development of technologies and population of ideas of colonization, the idea of Mars mission is becoming more and more feasible. Based on data from decades of observation and robotic missions to Mars, many agencies and organizations around the world started planning the first manned mission to Mars *(Lousada et al., 2017)*.

There are several risks in the Mars mission. One of the categories of risks on space traveller is gravity fields' transition. Gravitational pull varies and differs from one celestial body to the other. On the way to Mars, there is gravity variation by transition from one gravity type to the other, such as from the Earth gravity (9.807m/s^2), to microgravity (μg), and to the gravity of Mars (3.711 m/s^2). Microgravity is an experience in the outer space where the gravitational pull is very low. It is a state of weightlessness. Microgravity effects and environmental differences with Earth are one of the key issues of these studies as they are crucial as for human existence in general and especially for health conditions, operations as well as for technical.

Planning a long-term mission, it is important to study microgravity effects from a wide side paying attention to flight stage, habitat, extravehicular activities, life on Mars (plants and animals), materials and transition stages. These studies could be done in preliminary experiments.

Weak Gravity Challenges on Mars

Physiological effects aboard the ISS range from muscle atrophy to osteoporosis and negative effects on the balance and cardiovascular system. With these mitigated for to some extent, such signs of the body adjusting to daily life without gravity are in synchrony with those likely to be experienced on a journey to Mars. As a result, the trip itself will not be so different to living on board the ISS — however the consequences of travelling beyond low Earth orbit and then living on Mars is far less familiar territory in space research. After a long space flight, astronauts find it difficult to stand and orientate them in the weight of Earth's gravity. A crew of post-mission specialists are ready to assist astronauts upon landing on Earth, but this will not be the case for the first settlers on Mars. The surface gravity of Mars is 38% that of Earth. That might make it slightly easier on landing, but in the long run, the full force of gravity that human bodies have adapted to will not be presented to re-strengthen the astronauts' cells, bones, and muscles as they readapt to a gravity environment. Adjusting to this lower level of gravitational pull on Mars may cause a physiological change in the astronauts' bone density, muscle strength, and circulation making it impossible to survive under Earth conditions if they were to ever return.

IMPACT OF MICROGRAVITY ON SOME SELECTED LIVING AND NON-LIVING THINGS

Impact of Microgravity on Non-Living Things

Microgravity has significant impact on non-living things such as electronics, materials, crystal formation of any object, and overall operation of spacecraft as a whole. This section will explain microgravity's impact on some non-living things in details.

Impact of Microgravity on Electronics

Microgravity doesn't alter the way electronic devices/components work in space, however, it may impact on the mechanical systems with which they are connected. The only concern is how to handle the higher temperature limit in space which is -70 to 140 ˚C. The heat can be removed by extending aluminium or heat carrying metal up to the surface of the spacecraft. The internal temperature is maintained equal to room temperature *(Google Books, 2017)*.

Material Science and Crystal Formation in Microgravity

To design unique material for space which can work efficiently in microgravity, one needs very good knowledge of fundamental of physics and chemistry, different phases of objects and their conversions (solid to gas, gas to solid, gas to liquid and vice-versa). The unique material can be used as a benchmark. Researchers are also interested to study the crystal from object and various forms of crystallization. For example, the way candy forms, the solution of water and sugar in refrigerator, and frost formation; gravity is involved while one material changes into another one. So, if scientists can study these transformations in microgravity then it will help to study crystallization process *(Melissa et al., 1997)*.

Electronic materials play vital role and they are heart of on-board computers, communication systems and power systems. To study the semiconductors would be the main target of the microgravity research. The main idea is to create the crystals for use in X-ray, Gamma-ray, lasers, infrared, computer chips, etc. The way crystals form in these materials at normal gravity could help engineers to study the behaviour of crystalline bonds. This will ultimately help make wide range of space based materials with various applications.

Metals and alloys are also important elements of electronic components and electrical cables. By observing these materials under microgravity, scientists can learn material's strength, crystallization and chemical structure. For instance, material capability and corrosion resistance of the alloy can be determined from the atomic arrangements within it. With the help of that, engineers can discover alloy with new properties while solidifying from molten state.

ISS has been designed with intense care to study microgravity experiments and to design high precision clocks, semiconductor materials, improved drugs, detection systems etc. The result of these experiments will help us for long term missions, i.e. Mars exploration *(Google Books, 2017)*.

Some Effect of Microgravity on Living-Things

In comparison to unmanned missions, manned missions are very important as the human lives are involved. Vacuum has very less gravity which is very dangerous for human health and body functions for longer time. Human body can't stay unchanged for long missions like Mars. Human lives have vital role for deep space exploration, therefore microgravity study on living things is paramount. This section will explain it in details.

Solid and Litter Intake in Space

The caloric intake would be the same in space as on the ground. But food intake without care could be hazardous for crews and spacecraft mission. For example, the fluid coming out of the beverage bottle can damage electronic control systems. Eating and drinking needs technique to take out the pressurized food. The same way, the propellant in the fuel tank goes on the sides rather than staying at the centre while floating in space. To take fluid out of the tank, scientists use technique flexible gas pressurised bladder which helps to push the litter out. For example, pushing the tooth paste out *(Google Books, 2017)*.

Activates in space such as eating, sleeping and taking bath are totally different compared to ground. All these things need special care and training. For example, sponge bath should be taken in space rather than shower, sleeping is in vertical/ horizontal aligned bed and eating has to be done by proper way if cosmonauts need their solid food to be stayed on their utensils *(Google Books, 2017)*.

Health Deterioration

The transitions of gravity on astronauts on mission to Mars will have physiological effects on their bodies. Microgravity has the largest effect of the space-flight environment on human physiology; all organ systems are affected to some degree(see Figure 1). The most serious consequences of weightlessness however are: the weakening of physiological systems such as the cardiovascular system; affecting the musculoskeletal system and leading to bone "disuse" symptoms including loss of calcium, nitrogen, and phosphorus and decreased bone size and volume. In microgravity, the body experiences the following: shift in body fluids, space motion sickness, muscle atrophy, bone demineralization, immune dysregulation *(David et al., 2009)* and disruption of senses such as vision and taste *(Wikipedia, 2017)*. Inclusive are severe essential impacts on humans such as weakening the bones and elongating spinal cord. Human brain expected to work at intense consciousness and requires high attentiveness so effects of microgravity on nervous system, brain and cardio are dominant to study.

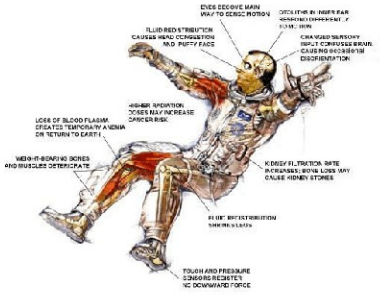

Figure 1. The Different Effects of the Stay in Microgravity Environment Clarified on the Body *(from Tanja, 2002)*

There are long term and short-term effects of microgravity. The above listed microgravity effects on the body are under short term and have being greatly studied and experienced in places such as in Space Laboratories. However, only recent study has suggested the long-term health effects of spaceflight. Furthermore, these studies have only been undertaken in low Earth orbit, leaving many unknowns with respect to deep space flight.

The blood due to lesser gravity in space doesn't float down the body parts but goes towards more in hands and face. That makes the appearance puffy. Longer stay can result into elongation in height due to less weight on their spin (less gravitational force) which may cause spine related problems. It also hampers increment in the white blood cells and reduction in red blood cells. It also causes less muscles formation and weakening bone tissues *(Google Books, 2017)*.

The arteries and veins of the legs become weak by time due to reduction in blood count. The muscular physic loss causes loss of body mass. It was reported by astronauts that when they return to earth they feel weakness and loss of balance. Recovery is possible in a week time under doctor's observation though *(NASA, 2017a)*.

The most notable concern of the space flight is that calcium content from the bones reduces and mission time is critical factor as calcium keep reducing. In older age, it is most dangerous for an individual who is suffering from a disease in which bones are weak and fragile. The simulation of Earth's gravity on spacecraft can help one suffering from health problems *[NASA, 2017]*.

The biological adaptations to gravity don't stop there. When standing up, the heart has a muscle pump working against gravity, pushing blood vertically in the carotid arteries that lead away from our heart toward our brain. When deprived of the need to work against the force of gravity, the heart and its system of vessels become deconditioned. The system of accelerometers in our inner ear, the otoliths and semi-circular canals, are engineered to provide the finest detail about movement, sharing their inputs and outputs with the eyes, the heart, the joints, and the muscles.

Research Pioneers: NASA and ISS

Since last 25 years, NASA's microgravity research programme strives to increase understanding of the effects of gravity on biological, chemical and physical systems. It also supports development of Space Enterprise.

NASA conducts microgravity experiments on Earth using drop towers and aircraft flying parabolic manoeuvres, and in space using unmanned rockets, at the NASA Johnson Space Centre Neutral Buoyancy Laboratory (NBL) and the International Space Station.

One of the most prominent studies is that of twins Mark and

Scott Kelly. Scott became the American astronaut of NASA who has spent more time in space, 383 days. The return of Scott to Earth has some changes due to the time he lived in microgravity, such as muscular pains, an increase of 3.81 cm in his height, bad aim, loss of muscle mass, bone density and volume in the blood. Another problem he experienced was an inflammation in the back of the eye while he was in space, which causes him to have vision problems, something that may last for a time once back to gravity. In addition, a DNA study showed that Scott's telomeres grew during his trip, but returned to normal when he returned to Earth. The true impact we will know on six years, when it is estimated that the scientists will publish the results. NASA has a partnership with private industries and academic institutions to ensure that scientific advances in the field continue to produce technical innovations for improved health care on Earth.

Biotechnology research in space focuses on protein crystal growth -- growing organic crystals with thousands of atoms -- and on cell/tissue culturing -- the study of how cells interact in a low-gravity or low-shear environment. The other focus of biotechnology in microgravity is cell and tissue culturing experiments. Located at Johnson Space Flight Centre in Houston, Texas, the goal of this research is to grow cells on a tissue in near-weightlessness, that otherwise is unachievable on Earth.

Other Laboratory Studies

The Zero Gravity Research Facility is NASA's premier facility for ground based microgravity research, and the largest facility of its kind in the world. It provides researchers with a near weightless environment for duration of 5.18 seconds.

The 2.2 Second Drop Tower is "a gateway to space" for many of the microgravity experiments conducted on the International Space Station (ISS) because these experiments often begin on Earth with exploratory testing in the drop tower. This may be followed by further drop testing to verify or optimize the design of the space hardware and to identify the best test conditions for the space experiment. As such, the drop tower is used to maximize the scientific return from experiments conducted in space. This is an important role, given the significant investment required to conduct space experiments in both time and money.

A study conducted with simulated microgravity, in the journal called Nature Partner Journal (NPJ). The researchers describe the changes they observed as 1,000 generations of Escherichia coli *(E. Coli)* were subjected to simulated microgravity conditions right here on Earth.

While it's difficult to replicate microgravity on Earth without blasting off into the cold vacuum of space, we can use the High Aspect Rotating Vessel (HARV) or parabolic flights to produce the "feeling" of free-fall and weightlessness without the costs associated with launching a rocket to the International Space Station.

The goal of the experiment was to learn whether the bacteria would undergo any kinds of genetic changes over the course of the several generations, and to their surprise, they found at least 16 genes having to do with biofilm production had been mutated after exposure to the rotating vessel method.

Bacteria may mutate more rapidly in space and scientists theorize patterns of those mutations could help predict how pathogens become resistant to antibiotics. Such predictions could, in turn, be used to develop new drugs to use against those pathogens. Antibiotic resistant pathogens or bacteria are growing world-wide health concern. The long-term use of many common antibiotics has led to some diseases becoming resistant to drug therapy, which can lead to longer and more complicated illnesses.

Since long-term space missions will require humans to stay in spaceships for months or years at a time, a day could come where new generations will be born in space rather than on Earth. Understanding how and what resilient mutations are passed on from parent to offspring is essential if we are to get to that point.

MICROGRAVITY SOLUTIONS: ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS) FOR MARS; FARMING ALTERNATIVES; AND RESEARCH OPPORTUNITIES.

Microgravity Solutions

A number of solutions are being explored to help protect astronauts, including antioxidant-rich foods (see Figure 2) *(Lousada et al., 2015)*; required daily exercise to keep muscles and bones from deteriorating (see Figure 3); wearing spacesuit (see Figure 4) and taking along medicine that would be needed to be packed on the three-year trip to Mars without access to a grocery store or pharmacy being an average of 140 million miles from Earth *(NASA, 2017b)*. The use of system of straps and buckles to help maintain a desired position should not also be underestimated (see Figure 5). Simulation of Earth's gravity in spacecraft will also go a long way to be a solution.

Environmental Control and Life Support System (ECLSS) for Mars

Since the 1960s, a multitude of orbiters, landers and rovers have orbited and studied Mars. These satellites and robotic missions are paving the way for future human presence on the Red Planet, as the next logical step in human exploration of the Solar System. Extravehicular Activities (EVAs) will be crucial during each mission not only to achieve scientific goals, but also to help maintain the mission facilities and hardware.

Long time in space also pressurize the eye-ball which can result into weakening of eye-sight. Many evidences reported weaken eyesight of space travellers. Real life evidences suggested that when Chris Hadfield returned from ISS, he felt weight of his tongue and lips which obliged him to speak in a different way *(Kathryn, 2017)*.

As discussed, in space, microgravity adversely affects the bodily functions. One needs regular exercise to keep the body muscles in lubricative motion and healthy. Joints at spine, ankles, and legs become weak and easily get fractured.

The lives of the astronauts are paramount, and the major focus is to keep them alive, happy and healthy on the surface of the Mars. Identifying, designing and predicting technology requirements for ECLSS for colonizing the Mars is the first task need to be

Figure 2. Food and Food Systems that are of high Nutrition to Astronauts. *(from NASA, 2003)*

Figure 3. Astronaut doing exercise on ISS *(from Kelly, 2015)*

Figure 4. Astronaut in Spacesuit. *(from NASA, 1988)*

Figure 5. System of Stripes and Buckles to Help Position Astronauts *(from Steven, 2019)*

performed to keep them alive. Conceptual design of an ECLSS module for the Mars to be used by the crew is very important. Exploring and working in the external Mars environment should also be put into consideration in the design. There will also be a need for stationary experimentation and observatory laboratory on the Mars. These research and experiments will be human benefiting.

The conceptual design for Mars ECLSS assessment can address microgravity effects on crew systems functions such as food, exercise, medical etc. It can address other Habitat Systems such as in-situ resource utilization (ISRU) functions associated with collecting and transporting Mars regolith to the Habitat. Since it can be said that the Mars has no atmosphere, astronauts living there would have to fight for their own protection and survival, for example by burying their habitat underground, especially because of radiations.

The life support system includes food and water production. Therefore, how plants grow on the Mars for the survival of those on mission is quite important. Plant growth will also be helpful to the crew since they can breathe the oxygen the plants are giving out while the plants also take-in the carbon dioxide the astronauts are breathing out. How gravity affect the plant's ability to grow needs to be researched upon.

Farming Alternatives

There is no air on the Mars and other conditions such as radiation may not support germination, growth and development of plants. Therefore, the alternatives for growing plants on the Mars may be by hydroponic, aeroponic and greenhouse methods.

Hydroponic is a plant farming method of growing plants inside an enclosed structure using mineral nutrients solution in water without soil, but in a selected growing medium where the lighting, temperature, and nutrients are closely regulated (see Figure 6).

Aeroponic is the process of growing plants in an air or mist environment where roots are continuously or discontinuously kept saturated with fine drops of nutrients solution without the use of soil or an aggregate medium (see Figure 7).

Figure 6. Hydroponic Method of plant farming.
(from Gregory et al, 2012)

Figure 7. Aeroponic Method of Growing Plants.
(from http://www.aeroponics.com/aero17.htm#WHAT_IS)

Use of greenhouse method is the alteration of the microgravity environment to meet the growth requirements of plants. Addition of fertilizer will be required to provide significant nutrient elements that are lacking in the soil (see Figure 8).

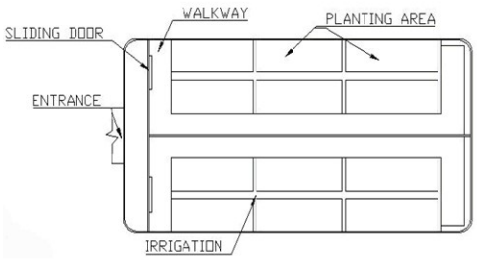

Figure 8. Single Greenhouse Layout

Research Opportunities and Benefits

The new understanding of living organisms can be helpful in the field of medicine and biotech. Biotech companies have flown experiments in space in the field of medicine, agriculture, and industrialization (*Loana et al., 2015*).

Structural information of protein crystals is important part of human immune system. Research shows that generally, protein crystals produced in space are larger and more precisely ordered than those produced on Earth. These improvements are important to scientists who analyse a crystal's three- dimensional structure. Protein crystal research could ultimately aid in the development of more effective drugs and life-saving treatments for many diseases.

The medical benefit of microgravity tissue and culture engineering may lead to new research models in cellular and molecular biology. These studies also are developing new tissues for potential transplant operations.

Research Opportunities and Benefits:

- Very low attenuation fibres compared to ground
- Exploration in new materials, high speed computers and communications
- Improved biotech and biotech services, medical applications
- Varieties in consumer products
- New R&D investments and investigations

CONCLUSIONS

It is clear from the credible resources that microgravity in space is inevitable factor for space exploration. This paper clearly focused on microgravity in space environment, its impact on human's body, food, and water. The Mars exploration is the example of microgravity environment and how it would be challenging to astronauts. In long run, weightlessness can hamper instances of physical damages such as spinal cord problems, bone loss, eye sight loss and cardiac issues. The safety of human is the most important compared to other things. Moreover, it is also important to study effects of lesser gravity on electronics system. The new area of research, material science and crystal formation can help to derive extraordinary conclusions to design new materials. Government agencies are working hard along with academic scholars to find out ways to handle microgravity hurdles in space. The safety concerns should be taken into consideration such as spacesuit, packed health food, strips and buckles for positioning. It is very important to do farming for research purpose and survival as stored food can run out sometime. Some unique farming methods are explained in this paper. The widespread areas of research and future benefits are notable and could pave the way for future habitation plans on other celestial bodies.

Acronyms/Abbreviations

SEP- Solar Energetic Particles
ISS-International Space Station
NBL-Neutral Buoyancy Laboratory
NPJ-Nature Partner Journal
HARV-High Aspect Rotating Vessel
EVAs-Extravehicular Activities
ISRU-In-situ resource utilization
ECLSS-Environmental Control and Life Support System

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National Space Research and Development Agency
Federal Ministry of Science & Technology

Our Mandates

The Center for Atmospheric Research, CAR, is a research and development center of NASRDA committed to research and capacity building in the atmospheric and related sciences. CAR shall be dedicated to understanding the atmosphere—the air around us—and the interconnected processes that make up the Earth system, from the ocean floor through the ionosphere to the Sun's core. The Center for Atmospheric Research provides research facilities, and services for the atmospheric and Earth sciences community.

Contact Address

Centre for Atmospheric Research,
National Space Research and Development Agency,
Federal Ministry of Science and Technology
Kogi State University Campus, Anyigba,
Kogi State - Nigeria.

Telephone: +234 8105793836
Email: info@carnasrda.com
Web: www.carnasrda.com

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ISBN 978-978-972-859-6
9 789789 728596