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Isolation and Integrated Testing: an Introduction to the Lunar-Mars Life Support Test Project

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"Present technologies on the shuttle allow for stays in space of only about two weeks. We do not limit medical researchers to only a few hours in the laboratory and expect cures for cancer. We need much longer missions in space – in months to years – to obtain research results that may lead to the development of new knowledge and breakthroughs."

– Dr. Michael DeBakey, Chancellor Emeritus, Baylor College of Medicine, U.S. House of Representatives, June 22, 1993

"One test result is worth one thousand expert opinions."

– Wernher von Braun

Spectacular advancements in life on Earth can be made with the knowledge gained through research on long-term space flight. In order to achieve long-term space flight, however, there is much we need to determine. We began these chamber studies to develop technologies, methodologies, techniques, and the knowledge needed to make such flight possible. Before efficient long-term stays in space can occur, NASA must determine how to best solve the issues related to a closed living environment; these chambers studies were a test bed for such potential solutions.

Space flight has progressed rapidly from the territory of dreams, to tentative steps of exploration, and now to an established endeavor and pursuit. We have experienced great success sending humans into space, and we have currently made substantial headway toward building and utilizing the International Space Station (ISS), where humans can remain on orbit for months at a time. This platform in space will be instrumental in gathering information on the human body and its response to the microgravity environment. Important studies of materials and physical sciences will be conducted, allowing us to examine how matter behaves in the absence of a dominant gravity vector. Implicit in the Space Station's viability, and of paramount importance, is the testing of technologies that ensure the health, safety, and well being of the crew. These technologies create the conditions which allow humans to survive in space – the provision of clean air, water, food, and waste removal.

The primary goal of the Lunar-Mars Life Support Test Project (LMLSTP), conducted from 1995 through 1997 at the NASA Johnson Space Center, was to test an integrated, closed-loop system that employed biological and physicochemical techniques for water recycling, waste processing, and air revitalization for human habitation. As an analogue environment for long-duration missions, the conditions of isolation and confinement enabled studies of human factors, medical sciences (both physiology and psychology), and crew training. The results of these studies provide a wealth of important data not just for Space Shuttle and ISS missions into space, but also for other populations who experience similar conditions – Arctic and Antarctic expeditioners, submariners and crews of other submersibles, and other ground-based test beds – as stressed by the following:

> *"If large numbers of people are to spend extended periods of time isolated and confined in space, the goal must be to discover or to establish positive conditions under which psychological functioning and social life can prosper and flourish."*
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> – Philip Robert Harris, *Living and Working in Space* (3)

Research on closed-loop human life support began in the 1950s, with studies of oxygen regeneration using algae. Interest became more focused in the 1970s when the success of the emerging space program called for support of future long-term missions. NASA has since developed plant-based systems to yield food, regenerate oxygen, and process waste into usable products. The primary goal of ground-based test beds such as the LMLSTP is to test integrated, complex systems that support life and to qualify them for life support during space flight.

The LMLSTP studies were a major accomplishment and met the goals of NASA's Advanced Life Support (ALS) Program. Air and water systems were monitored for efficiency of function and for microbiological content, crew members were monitored for health and performance, and medical systems and technology were tested. In conducting these studies, the LMLSTP met the ALS Program goals of 1) providing self-sufficiency in advanced life support for productive research and exploration in space, for benefits on Earth and 2) providing a basis for planetary exploration. More specifically, the data also met the research goals of the Space Human Factors Program (1):

1) to expand knowledge of human psychological and physical capabilities and limitations in space through basic and applied research tests and evaluations
2) to develop cost-effective technologies that support integrating the human and system elements of space flight
3) to ensure that mission planners use space human factors research results and technology developments to increase the probability of mission success and crew safety, and
4) to make NASA technology available to the private sector for Earth applications and to use new technologies developed by private industry where appropriate.

Indeed, the information gathered from these studies may have far-reaching applications for other populations. Factors that overlap between space crews and analogous populations (4) are workload, exercise, medical support, personal hygiene, food and provisions, group interaction, habitability of the 20-foot chamber environment, external communications, privacy and personal space, and recreational activities, to name a few. Submarines serve as both a platform for closed-environment living and an environment most likely to benefit from the chambers studies (note: submarines use only physicochemical life support systems). Nuclear-powered submarines can operate submerged for months at a time. Even more than in conventional submarines, the physical and psychological stamina of the crew on nuclear-powered submarines becomes a crucial factor. They must also deal, while on patrol, with being largely isolated from the outside world, including their families, for long periods of time. Similarly, Arctic and Antarctic personnel are isolated for nine to 12 months. Their means of living are self-sustaining, and they are dependent on technology for survival. Moreover, personnel at military outposts and remote oil rigs are also populations where group interactions and confinement adaptations play a crucial role in the success of the project.

The initial phase of this project began as a study of air regeneration using wheat plants, and enough oxygen was generated to support one experimental subject. As Phases II, IIa, and III of the LMLSTP continued, the systems grew increasingly more complex and interdependent. These later phases achieved success in providing life support systems for four crewmembers. The crewmembers provided plentiful data on the human factors evaluated in the project. As a result, some generalizable lessons were learned, such as the kinds of personalities that compose a good crew, complex dynamics that affect group interaction, the kinds of problems (for example, stress) that can be prevented or mitigated, and the kind of countermeasures that would make life easier for people in isolated environments. However, there are some issues unique to space travel which must be addressed.

While in space, the human body experiences a multitude of adaptations in microgravity. There are many systemic responses to the reduced gravity, such as decreases in bone and muscle mass and shifts in the cardiovascular system. The body also experiences changes in the neurosensory and neuromotor systems. In addition, the stresses of the mission and conditions of isolation elicit behavioral changes in crewmembers. Research is ongoing to better understand these adaptations and to mitigate these changes.

Since the chamber studies did not have microgravity conditions that the space crews experience, research focused on the parameters of isolation and confinement. For example, sleep studies were performed as the crew completed their chamber stay to evaluate adaptation to a situation of confinement with its accompanying stresses. The immune system was also monitored, specifically for the occurrence of reactivation of latent viruses. Previous research in space and analogous crews has shown that the stress of confinement can affect the immune system, and the results of this LMLSTP experiment confirm this. This emphasizes the important point that these studies provide data that are useful for space flight crews as well as for populations that experience similar conditions.

In addition to challenges to the human body and mind, the space flight environment poses challenges to an exploration mission; the spacecraft system is a tool to overcome those challenges and allow humans to carry out their mission safely and efficiently. To ensure the safety, productivity, and success of an exploration mission, designers will have to facilitate human performance by creating a system that responds effectively to the challenges of the space flight environment. In the LMLSTP, the standard research and technology advances were validated as an integrated system, well beyond the simplicity of isolated experiments. The support technologies involved were mature enough for integrated testing, and the following tenet emphasizes the importance of this state:

> *"Never underestimate the complexity of closed systems, or the importance of testing in closed systems. Integration and interaction with other systems cannot be ignored in the design and operation of spacecraft life support systems. To badly quote Newton, "for every action there is an equal and opposite reaction." For example, coatings, off-gas products, and trace metabolic products have triggered entirely unexpected responses in a flight environment.*"
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> – John Graf et al., *Basic Tenets for Designers of Life Support Systems for the Space Environment* (2)

These series of integrated tests – human and systems – have demonstrated the quality of data that can result from a test bed such as this. Research is ongoing to find better, more efficient, and self-sufficient systems for advanced life support, such as the growth of foods in space, bioregenerative systems (which provide food and oxygen, remove carbon dioxide, and generate clean water), further research on physicochemical systems, and further studies in habitability and human factors. There is a strong need for a dedicated, long-term facility in which to test and study large-scale bioregenerative planetary life support systems and to integrate more disciplines and components of space flight – training, mission operations, automation and robots, etc. These long-term test beds will continue to produce a wealth of information that will benefit not only the space explorers who depend on these technologies, but also Earth-bound populations who experience similar isolated conditions. In partnership with research conducted in space, the test bed research will yield knowledge that can be applied to further advance our viability in space. With this perspective, the vision that we conceived decades ago of long-term space flight becomes an even greater probability – and soon perhaps even a reality.

References

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