The "Farm:" An Inflatable Centrifuge Biology Research Module on the International Space Station

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As the sole manned laboratory in Low Earth Orbit, permanently operating in microgravity and largely unprotected by the Earth's atmosphere, the International Space Station serves as an unparalleled platform for studying the effects of low or zero-gravity and the space radiation environment on biological systems as well as developing, testing and certifying sturdy and reliable systems for long duration missions such as ambitious interplanetary expeditions planned for the future. Earth-bound research, automated research aboard satellites and short missions into low-altitude orbits cannot replicate long-term ISS experiments. Abandoning or de-orbiting the station, even in 2020, leaves the international scientific and engineering community bereft of a manned station in orbit and destroys any opportunity for conducting long-term microgravity and radiation experiments requiring human oversight in space. The United States should invest in extending the station's life by a minimum of 15 years from present by attaching an inflatable "Farm" centrifuge module to equip biologists, psychologists and engineers with the tools required to investigate these questions and more. At a time when humankind has only begun exploring the effects of the space environment on biological systems, it is essential that we not abandon the only empirical research facility in operation today and instead begin vigorously pursuing research in this area that is of vital importance to all humanity, not only in the basic and applied sciences but also in international collaboration.

I. Introduction

In June 2010, President Barack Obama announced a novel vision for NASA and proposed extending the life of the International Space Station (ISS) until at least 2020. As a response to President Obama's call to "utilize the ISS for scientific, technological, commercial, diplomatic, and educational purposes; support activities requiring the unique attributes of humans in space; serve as a continuous human presence in Earth orbit; and support future objectives in human space exploration..." the United States should invest in extending the station's life by a minimum of 15 years from present and attaching an inflatable "Farm" centrifuge module.[1](figure 1) Installing such a module equips biologists, psychologists and engineers with the tools required to investigate the effects of microgravity and the space environment - research fundamental to facilitating long-duration and far-reaching manned missions beyond Low Earth Orbit. It will also allow for the development, testing and certification of sturdy and reliable manned systems such as the Closed Ecological Life Support System(CELSS) that are essential for successful long duration missions.

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According to NASA Administrator Charlie Bolden's plans for the ISS, "There's so much we need to know before we can venture safely out of low Earth orbit for the long term. We're going to address practical medical questions about astronaut bone density and the effects of radiation; how we can reach destinations sooner to mitigate the effects on space travelers of long journeys. In addition, NASA will support a broad array of biological, materials, and combustion research aboard the ISS, which will advance our spaceflight capabilities, as well as benefit those disciplines more broadly."[2] Current ISS facilities need vast improvements to fully explore and settle these queries. While the ISS contains a number of centrifuges, these only allow for small, short-term experiments. The addition of the Farm module first supplies a location for short- and then long-term experimentation on a larger scale. Then, it provides the location for implementation of a greenhouse and complete biologically based life support system that will prove instrumental for future interplanetary travel. In the Farm, scientists will explore questions including whether the side effects of living in a zero-gravity environment can be overcome with simulated gravity, how to sustain living plants and animals in a space-bound greenhouse to provide nutrition for astronauts, and how to integrate these same plants and animals into a closed life support system.

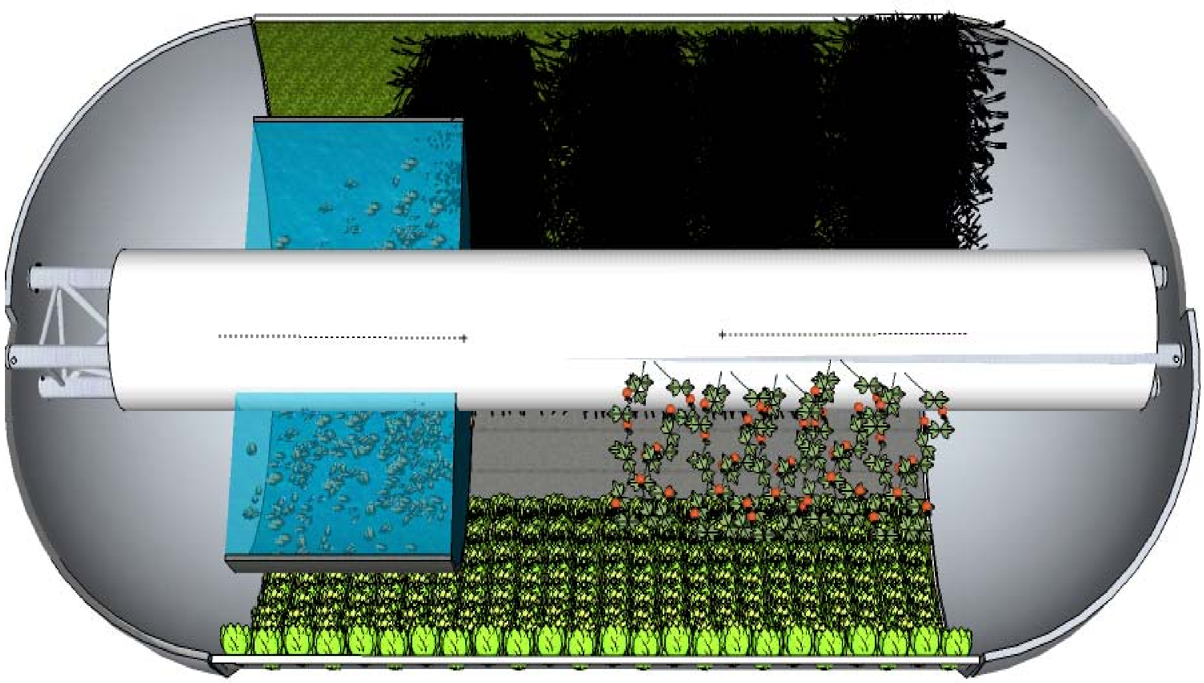

Figure 1: The Farm Module. *The Farm module evolution in its second and third stages when it serves as a greenhouse, life sciences laboratory and life support test bed. Shown above are the greenhouse sections and enclosed fish tank. The upper section of the outer growing region contains wheat while the lower contains lettuce. Tomatoes grow hanging from the right half of the central lattice structure.*

Figure 2: Concept drawing of NASA's Centrifuge Accommodations Module

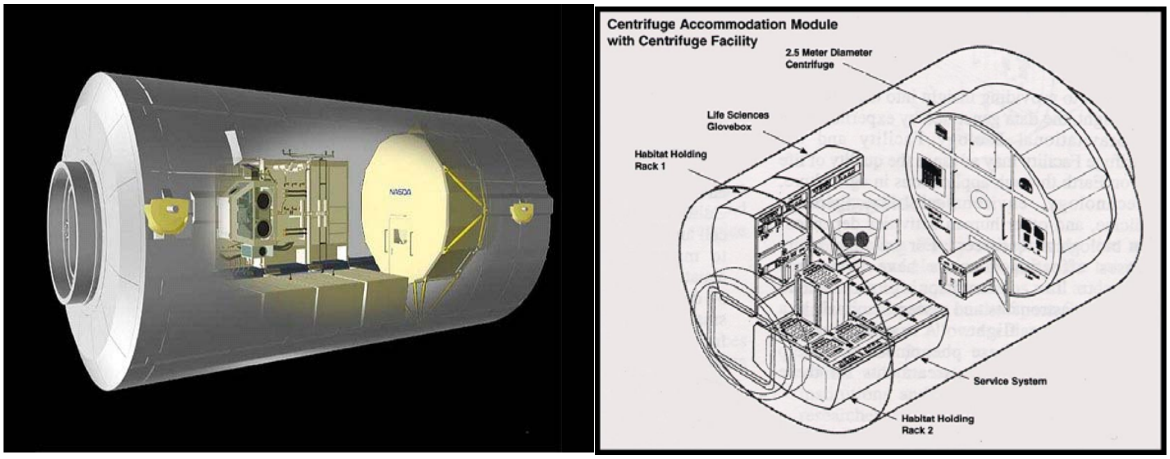

Figure 3: Images of NASA's proposed Centrifuge Accommodations Module. *Seen above left is the instrumentation previously proposed to fill NASA's Centrifuge Accommodations Module (CAM), including a centrifuge, life sciences glovebox, service system and multiple habitat holding racks.*[1] *Seen above right is a more detailed schematic of that proposed CAM.*[2]

II. The Farm Module: History

The Farm combines an array of scientific and engineering components from previous NASA projects and current industry programs to fashion a cutting-edge module with the greatest usability, durability and efficiency. For example, precedent has been established for both the need for and feasibility of using centrifuge and inflatable modules on the ISS. At the beginning of the decade, NASA engineers designed and planned to launch the rigid-walled Centrifuge Accommodation Module (CAM) to the ISS to house an assortment of biological and engineering experiments (Figure 3).[3] The large centrifuge module would have held dual centrifuges that could simultaneously produced gravity levels between 0.01 and 2 g. Like the Farm, CAM was intended to provide scientists with the space and basic tools required to investigate fundamental biological questions and eventually facilitate future long-duration or far-reaching space missions. With enough space to hold 8 experiments at any given time, the CAM was designed to house research on microorganisms, plants and animals as large as rats.[4] In terms of engineering designs, the module overcame possible problems regarding connecting a spinning module with a stationary ISS through the use of slip-ring technology.[5] But, although it was set to launch aboard a space shuttle in 2006, the 8.9 by 4.4 meter module was cancelled in 2005 due to budgetary short runs and schedule issues.

Similarly, NASA thoroughly developed the foundations of an inflatable module during the 1990s in its Transition Habitat or TransHab project. NASA engineers originally strove to design an air-inflated replacement crew module for the International Space Station's current rigid-shell units to provide astronauts with more space to move about.[6] However, the vision altered to a longer-term goal of designing an inflatable module that could house astronauts on long-duration interplanetary missions, for example

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[1] "ISS Centrifuge Accommodations Module.jpg," http://en.wikipedia.org/wiki/File:ISS_Centrifuge_Accommodations_Module.jpg

[2] "Centrifuge Accommodation Module with Centrifuge Facility" http://ti.arc.nasa.gov/projects/ssrl/centrifugeclose2.html

Figure 2: A conceptualized drawing of NASA’s TransHab Module

a trip to Mars.[7] According to designs, a central rigid-core structure would protect experiments and equipment during launch. Once in orbit, a multi-layered Kevlar blanket surrounding the rigid core would inflate to a predetermined pressure using compressed oxygen and nitrogen stored in preinstalled tanks.

Figure 4: NASA's Proposed TransHab Module. *Above is a conceptual drawing of the compartmentalized inflatable TransHab module that would have replaced current crew quarters onboard the International Space Station.*[3]

Inflatable modules proved enticing because of the advantages they hold over their conventional rigid counterparts. Most significantly, inflatable modules increase their volume in orbit beyond that possible using conventional hard-shell modules (which are limited in size because their finished volume must fit within the rocket payload fairing)

[3] http://www.life.com/image/50703432

and weigh less per unit volume upon launch (lowering launch cost). Furthermore, some of the materials available for use in the walls of inflatable modules prove more durable in withstanding dangers like space debris and micrometeorite impacts than current rigid-wall-module constructions. In a break-though design, the skin of the TransHab module was made up of 12 different layers, with the outer ones breaking up any debris or space objects that hit the module through a combination of the materials Nextel and open-cell foam. The inner layers, composed of Kevlar, Combitherm and Nomex, maintained the module's pressure.[8] However, TransHab was abandoned in 2000 due to NASA budget constraints.

The private industry quickly continued development where NASA left off. In particular, Bigelow Aerospace bought the rights to patents developed in the TransHab project in hopes of designing an inflatable module for later use in space hotels orbiting the Earth and beyond.[9] During the following years, Bigelow engineers developed two 3-meter-long by 2-meter-diameter modules, Genesis 1 and Genesis 2.[10,11] These modules consist of an inflatable, flexible and air tight multilayered (including vectran, a material twice as strong as kevlar) skin surrounding a 1.6 meter diameter rigid core structure that protects vital components during launch. To increase the module's durability, the outer shell is covered with Micro Meteorite Orbital Debris (MMOD) shielding, which is seen on most spacecraft.[12] Tests run by Bigelow aerospace have shown that simulated micrometeorites that rip right through the side of an ISS module only pierce about halfway through the combination of vectran and MMOD on the inflatable modules.[13] Furthermore, Bigelow engineers found that even if a micrometeorite were to penetrate the walls, astronauts would have approximately 24 hours to find the hole and patch it before the structural stability of the module was compromised.[14]

So far, their calculations have proven correct as both modules have launched and are still demonstrating the reliability of the design. Genesis 1 launched on a Dnepr rocket on July 12, 2006 and remains in orbit today.[15] Its success proves that inflatable modules can survive the stresses of launch and remain pressurized regardless of such dangers as orbital debris and radiation. Then on June 28, 2007 Genesis II launched, again proving that inflatable modules can withstand launch and the stresses of space.[16] The module completed its 10,000 orbit in April 2009 and remains pressurized.

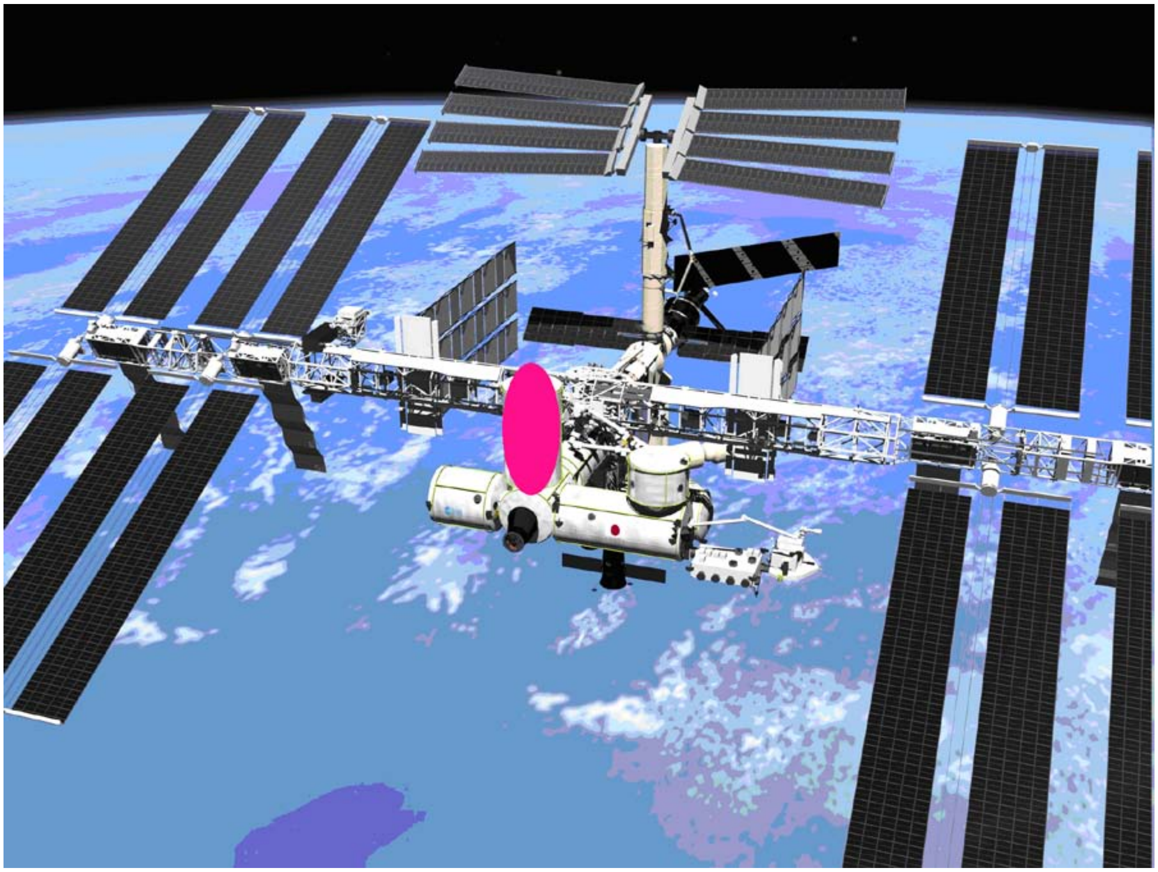

Figure 5: Layout of modules on the ISS. *The pink oval shows a currently unused port originally slated for use by the Centrifuge Accommodations Module. In this location, the "Farm" would sit next to the Japanese Kibo module and be ideally located to include additional solar panels.*[4]

III. Module Layout

The Farm module builds on Bigelow's next human-rated inflatable structure, the *Sundancer*, and serves as a lower-cost, larger-volume alternative to NASA's previous Centrifuge Accommodations Module. With 180 cu meters (greater than 6000 cu ft.) of habitable interior volume after inflation, the Farm proves large enough to concurrently accommodate both an array of experiments and astronauts.[17] This means the module will contain a conglomeration of automated experiments, those requiring human oversight and those managed by the astronauts themselves.

Like the Genesis modules, the Farm initially launches in a deflated state with its multi-layered vectran sleeve wrapped tightly around a central rigid truss containing basic experimental payloads. In orbit, astronauts connect the module to the open dock originally slotted for the Centrifuge Accommodations Module, leaving the Farm sitting adjacent to the Kibo module (Figure 5). Oxygen and nitrogen stored in onboard tanks then inflates the module to 101.3 kPa or 14.7 psi, to match the environment onboard the ISS.[18]

[4] http://www.astronoo.com/images/images_du_mois/iss.jpg

Figure 6: Farm module with pole structure extended. *The above image shows the extended pole structure, which will deploy using a spring-loaded system, Once the structure has deployed, experiment boxes will fit between the poles and lock into place.*

After pressurization, an internal pole system deploys from the central core via a spring mechanism (as seen in Figure 6). This serves as the support structure that attaches experiment boxes (most launched from Earth and ferried to the ISS at a later date) to the module core. ISS astronauts then enter the module to remove an original set of experiment boxes from the central truss and secure them to the support structure. LED systems are also attached to the outer layer of the support structure by the astronauts to provide lighting that can be tuned to the frequency maximizing growth for various plants within the module. The outer meter of the cylinder (also a meter at the end next to the airlock) contains free space left open for astronauts to maneuver while the entire central core contains experiment boxes.

Once astronauts install the first experiments, they initiate rotation with a simple computer panel controlling the module's environment (humidity, temperature, ventilation, light levels, air pressure) and angular velocity. They must now tether themselves to the central structure while working with various experiments to keep themselves rotating at the same rate as the module. The core is separated into four distinct segments, each housing motors simultaneously providing distinct gravitation levels between 0.1 g to 2 g. For larger experiments, the four core regions combine and spin at the same angular velocity.

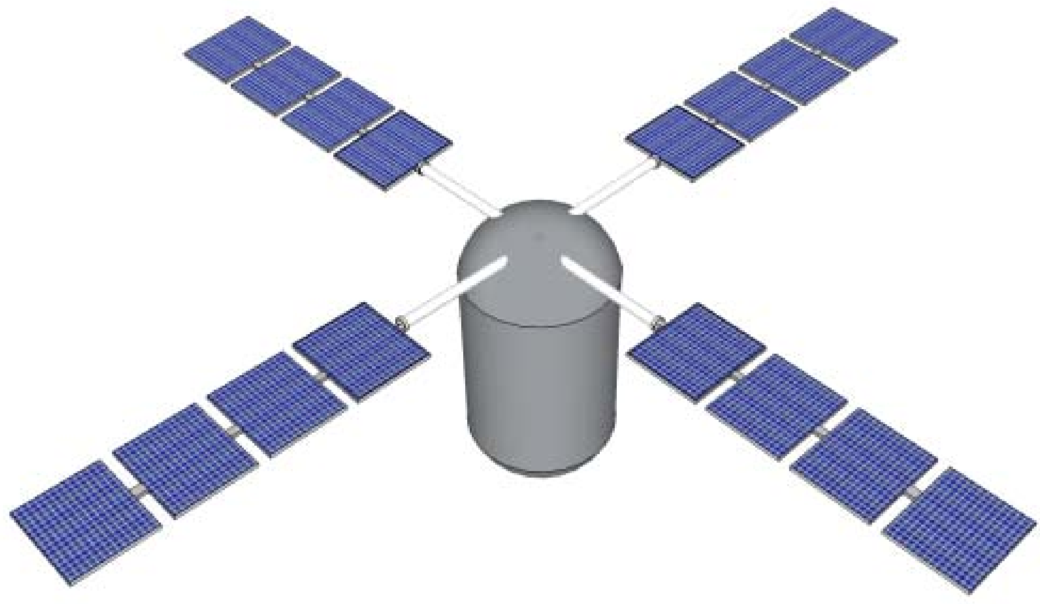

Figure 7: Solar panels on the Farm Module. *The above picture shows a possible layout for the utilization of solar panels at the far end of the "Farm" module to augment power provided from the ISS.*

IV. A Stand-Alone, Self-Sufficient, Energy-Independent Architecture

The power consumption necessary to maintain rotation and the strict environmental controls (for air and nutrient circulation and LED lighting necessary for biological experimentation) requires the Farm module incorporate its own means of power generation. With the module's location in the port originally slotted for the ACM, the options include a set of solar panels or an RTG cluster and radiator tucked at the far end of the Farm module.(figure 7) The Farm is designed to utilize auxiliary power from ISS main power system only if there is an emergency.

V. Fundamental Questions/Time Scale

A. First Five Years:

During its first five years of operation, the Farm houses an array of short- and long-term biological experiments building on results from previously completed Earth-bound and short-term space-based research. Varying rotational settings onboard the Farm allows scientists to examine the effects of assorted gravitational levels for plants and animals and determine whether rotational forces can replace the zero-g space environment without triggering adverse side effects similar to space adaptation syndrome. After establishing the lower limit of the “comfort zone,” or the lowest angular velocity negating the side effects of zero gravity for animals and plants, experimenters can establish optimum gravity levels for plant growth. Concurrent multigenerational biological studies can explore the effects of microgravity on basic biological mechanics, for example whether mammalian reproduction is possible in space and whether microgravity affects embryonic development.

Once scientists grasp the basic mechanics underpinning the growing of plants and animals in space, they can explore optimizing the limited space devoted to a "farm" in space. For example, tissue-culture techniques may be used to grow plants and scientists may be able to bioengineer new breeds of plants and animals better fit to survive in the low-g atmosphere or produce food more quickly. Some experimentation has already been conducted on these topics in microgravity. For example, experiments aboard the MEKADA space shuttle mission (STS 107) demonstrated that fish might be bioengineered to use light rather than gravity to orient themselves.[19]

Bioengineering has also been applied to select plants, such as a space-age wheat known as USU-Apogee. Developed at the Crop Physiology Laboratory at Utah State University, the dwarf red spring wheat produces the equivalent of nearly 600 bushels of grain per acre, three times that of normal varieties of wheat. Apogee was developed to thrive under "space farm" conditions, including constant artificial light and high carbon dioxide levels. In a mere 23 days after germination, the plant produces heads. It takes most varieties a full week longer. Furthermore, USU-Apogee is space-efficient, standing only 18 inches tall when mature. In addition, botanists have created varieties of sweet potatoes, rice, peanuts, and beans that prove more productive than their natural counterparts. [20]

B. Following Ten Years

During the following ten years, the Farm module will transform into a functioning greenhouse where astronauts cultivate both plants and animals. From studies completed onboard the ISS and in various closed environments, we know that meal time plays a vital role in the social atmosphere.[21] As one of the few times astronauts set aside work, relax and interact, meals help to create and reinforce the station's social hierarchy. In addition, the ability to garden or simply relax in a greenhouse module greatly improves morale during long-term missions in harsh, barren, hard technology environments. Similar effects have been seen on Earth when the inhabitants of the South Pole Station seek out comfort in the greenhouse module during the six months of darkness between March and September.[22]

Astronauts themselves should thus be added into the equation as an integral part of the experiment on both a psychological and biological level. Psychologically, scientists must determine the effect of eating animals the astronauts have possibly grown accustomed to see as pets, whether the psychological boost provided by familiar foods increases productivity or social interaction, and whether spending time in the Farm module increases productivity. Biologically, scientists can examine the level of comfort for humans residing in a centrifuge module, explore the side-effects that occur when space residents spend only a few hours a day in a spinning module, and determine whether working in a rotating module affects productivity and biological functions or physiological parameters such as bone and muscle mass. Based on experiments where people lived in centrifuges and slow rotation rooms on Earth, it appears that the module should provide a maximum rotation rate between 1.5 and 1.8g.[23] However the completion of previous experimentation on Earth is not a guarantee of success in space. If spinning the Farm module leaves astronauts disoriented or otherwise incapable of completing their work, another solution must be sought regardless of how well plants and other animals acclimated to the rotating environment.

But the most basic question will be whether astronauts respond well to having fresh fruits, vegetables and meat at each meal. Once it is up and running, the Farm module will produce a good percentage of the astronaut's diets. Just like on Earth, the dietary requirements vary from one astronaut to the next; however NASA estimates that a small female astronaut consumes approximately 1900 Calories per day while her large male counterpart consumes about 3200.[24] Assuming seven astronauts live onboard the station (three small women and four large men), the greenhouse would need to produce the equivalent of 18,500 Calories of food to serve as the sole source of food for all seven astronauts.

Using Earth-bound analogues, it is possible to estimate the percentage of an astronaut's diet that can be grown in a greenhouse. McMurdo Station, which encloses 200 square meters, produces up to 140 kg of food each month and 250 heads of lettuce every 10 days.[25] Considering the Farm module will enclose approximately the same volume, it can be assumed astronauts will produce approximately the same weight of food. If the greenhouse is devoted to growing one-quarter wheat (339 kCal/ 100 g), one quarter lettuce (12 Cal/ 100 g), one quarter cucumber (12 Cal/100 g) and one quarter tomato (18 Cal/ 100 g), the Farm will yield approximately 4445 Cal/day, or 24 percent of the astronaut's diet. This calculation neglects any volume devoted to rearing animals and will change based on the particular types and amounts of foods grown in the module.

After proving the technology needed to grow a variety of foods needed for both nutrition and comfort, the greenhouse will be integrated into a larger program to create a closed life support system. This system will provide astronauts with everything they need to survive (air, water, food, etc.) with a minimal input of consumables. Dr. Ray Wheeler of NASA has posited that a lunar greenhouse providing 50 percent of the caloric intake of astronauts inhabiting a lunar base would provide complete air revitalization and water recycling.[26]

Similar methods can be employed in the Farm module to test out possible Closed Ecological Life Support Systems that(CELSS) will be integral to future interplanetary transport vehicles as well as Lunar and Martian bases. Integrating plants and animals already growing onboard into the life support system will save mass and space on long-term missions. Furthermore, replacing a complicated mechanical life support system with plants and animals negates the need to repair or replace complex electromechanical systems while beyond Earth re-supply capability. For example, using regenerating plant or algae lungs to purify air negates the need to replace and repair air filters.

To accomplish this complex task, throughout the period of experiments and evolution, the Farm will also serve as a platform for the evolutionary integration of a reliable closed ecological system(CELSS). This will be done in stages, by emprically hooking up and switching over waste management and filtration systems, CO_2 scrubbers and O_2 replenishment from proven physico-chemical systems used in the ISS today.

VI. Future Studies:

A number of specific questions can be answered onboard the Farm, including but not limited to:

- Window studies of plant reactions to ultra-short photoperiods (60 minutes of light to 30 minutes or darkness) to validate the use of sunlight to grow plants in earth orbit. This would lower the power dependence of the module and leave astronauts with food in the case of an emergency.
- Exploring the possibility of genetically engineering plants that would better survive short photoperiods to facilitate the use of sunlight to grow the plants.
- Discovering the gravitational "comfort zone" for humans and animals.
- Uncovering the effects of artificial gravity on biological systems.
- Determining the effects of long-term rotation on growth and life cycles.
- Exploring how plants and animals adapt to life in space over multiple generations. What are the long-term effects?
- Ascertaining how plants and animals can be bioengineered to better survive in space.

VII. Beyond the Science

The "Farm" module fulfills more than just the scientific and engineering goals set forth in the National Space Policy - it also facilitates the realization of numerous political and social goals. In particular, the Farm triggers commercial involvement, academic participation and international cooperation with NASA on a large scale.

A. Commercial Involvement

The new National Space Policy particularly emphasizes a close coupling between NASA and the commercial space industry. In the document, President Obama argues NASA must "Seek partnerships with the private sector to enable safe, reliable, and cost-effective commercial spaceflight capabilities and services for the transport of crew and cargo to and from the ISS" thus freeing NASA to focus on sending astronauts to locations beyond LEO. [27]

The Farm module provides private companies with a vested interest in supporting ventures to and from the ISS by providing them with information necessary for their long-term venture plans. Burgeoning commercial space tourism corporations around the world are planning a variety of far-reaching enterprises that run the gamut from Earth-orbiting hotels to lunar vacations. For example, engineers at Bigelow Aerospace are developing the *Sundancer* inflatable module in hopes of creating a space hotel in Earth orbit. InterOrbital Systems CFO Randa Millron dreams of creating a lunar hotel where adventurers can relax in their hotel rooms while basking in the other-worldly environment. As all such enterprises involve crew members living outside the reaches of Earth's gravity and atmosphere for long periods of time or possibly even permanently, scientists and engineers must understand the long-term effects of the space and microgravity environments on the human body before their dreams can truly be realized. Furthermore, providing food in space and on colonies will be essential to making space hotels and permanent colonies feasible and cost-effective endeavors. Developing a

Controlled Ecological Life Support System (CELSS) and answering the biological questions needed to successfully grow plants and animals in zero- or partial g-environments proves essential to the commercial space community, meaning NASA can use the commercial industry's need to create a better working relationship through the Farm module.

B. Academic Involvement

Closer to home, the Farm will help inspire children to become interested in science and the space program. For years, NASA has endeavored to excite children in the classroom and tap the world of higher academia for novel ideas and willing workers. Such efforts can be enhanced by the integration of plants and animals into the science education program, directly supporting Director Bolden's plans to use "the International Spaces Station as the national lab it was envisioned to be. We will make full use of its incredible potential, and enhance our use of its research and developments capabilities on-board. All kinds of educators, colleges, science institutions, and other government agencies, will be using the ISS for research."[28]

NASA can use the Farm module to inspire children in the classroom through a combination of visual and educational activities. Installing cameras throughout the module will allow students to monitor the growth of individual plants and animals as well as watch astronauts gardening. Combining these visual aids with worksheets on the effects of the space environment will engage students and provide them with a deeper understanding of both the science occurring on the ISS and how much there is still left to learn onboard. NASA can also engage students by periodically holding lotteries to name the plants and animals. Furthermore, long-term student projects should mimic experiments taking place onboard the ISS - for example, students can create a small hydroponics system and grow soybeans during their school year.

On another front, students in higher academia represent an under-utilized and oftentimes willing resource that NASA must utilize to the fullest extent possible. In order to integrate students' novel ideas, NASA will invite them to work with its scientists and engineers on both the front and back end of ISS experimentation. From the outset of this program, students help draft ideas and build experiments already planned for launch to the ISS. Once the experiments have been conducted, students broaden their knowledge base and gain valuable experience by analyzing data. Using students serves multiple purposes - it engages students and helps them to become excited about the future of the ISS and space research as a whole, lightens the work load on NASA scientists and engineers, and ensures data is examined in a timely manner.

C. Aiding Cultural Understanding/International Involvement

Facilitating international cooperation has been a cornerstone of the ISS since its inception and will continue to be so in the coming years -- the future of space travel does not lie with any single nation alone, but with humanity as a whole. President Obama just re-committed NASA to utilizing the ISS as a means of facilitating cultural understanding and aiding nations around the globe. "The United States hereby renews its pledge of cooperation in the belief that with strengthened international collaboration and reinvigorated U.S. leadership, all nations and peoples--space fairing and space-benefiting--will find their horizons broadened, their knowledge enhanced, and their lives greatly improved."[29]

Utilized correctly, the Farm module can help ease international tensions and foster friendship and cooperation. Growing foods that reflect astronaut's cultural backgrounds in the Farm module will provide each astronaut with the comfort of familiar foods. The diversity of foods will also serve as a segue for astronauts from varying cultural backgrounds to share information about their own customs and cultures. For example, soy beans can be grown alongside lettuce and wheat. But the advantages reach beyond the astronauts. When the general population identifies with some of the foods grown in the Farm as originating in their own culture and recognizes others as international cuisine from beyond their borders, they will begin to recognize that space exploration is not limited to individuals from a particular nation, but for everyone. In essence, the Farm provides the means to diminish cultural boundaries between the astronauts and to demonstrate to individuals on Earth that exploring beyond Earth will require a truly international program and partnership.

D. Public Involvement

Plants and animals can also serve as a segue to generate awareness and interest for the ISS and space program as a whole within the general population. Members of the public oftentimes doubt the significance of research conducted onboard the ISS, perceiving the operation as a waste of time and funds. It is easy to see why they have difficulty identifying with members of an astronaut corps conducting research or maintenance tasks onboard an alien and sterile-looking space station. Highlighting projects involving plants and animals onboard the Farm will give a familiar face to the ISS program. Providing live webcasts of plants and animals will allow the public to become invested in ongoing research and create an emotional tie to the space program.

Furthermore, the general population has difficulty recognizing the extent to which the technology developed for and integrated into the ISS is incorporated into their daily lives. The Farm provides the perfect platform for discussions and programs revealing these breakthroughs and how they affect the general populace. For example, highlighting how the transgenic plants modified to produce vegetables more quickly and in a smaller area can be implemented to help abate starvation in developing nations provides a perfect illustration of how products created in the space program directly affect the lives of the general populace.

VIII. Conclusion

The Farm module and the ISS as a whole provide a unique location for experimentation, international cooperation, academic involvement and public understanding and appreciation of the space program in general and human space activity in particular. The addition of the unique inflatable "Farm" module provides scientists and engineers with the tools they need to unlock the future of human spaceflight. With these tools they can begin to integrate the components of a closed ecological life support system to sustain permanent presence in space, allowing humanity to explore and eventually settle distant planets, while unravelling the mysteries of our universe.

IX. Acknowledgments

This paper results from a section in the final project completed at the University of Southern California in the ASTE 527 Space Exploration Architectures Concept Synthesis Studio during the fall semester of 2009. The course is all about creating new and innovative ideas for human space exploration. In the fall of 2009, the participants focused on the future of the International Space Station as their team project. Each participant chose to focus on one area of interest. The slides of the entire Team project entitled "The International Space Station:Investing in Humanity's Future may be found at http://denecs.usc.edu/hosted/ASTE/TeamProject20093/

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