Benjamin Greaves Fall 2018 NASA Internship Final Report

Benjamin J. M. Greaves
NASA Kennedy Space Center
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Preparation of Papers for AIAA Technical Conferences (Title)

Benjamin J. M. Greaves[1]
University of Michigan, Ann Arbor, Michigan, 48109

and

Ralph Fritsche[2]
NASA Kennedy Space Center, Cape Canaveral, Florida, 32899

Nomenclature

KSC	=	Kennedy Space Center
NextSTEP	=	Next Space Technologies for Exploration Partnerships

I. Introduction

With the development of NASA's Space Launch System and the maturity of long duration space exploration mission architectures, developing the technology needed for in-space food production has become a critical step for ensuring the success of these future space exploration missions. This fall, I had the opportunity to work at NASA's Kennedy Space Center exploring what tasks need to be completed to fill the remaining technology gaps to ensure that in-space food production is a reliable system for future missions.

This work has included many different initiatives including the development of a graphic displaying the various environments of future space exploration and the respective food production goals, the definement of requirements for a food production chamber on the Gateway space station, and finally the coordination of a food production rack for the Lockheed Martin NextSTEP-2 Habitation module.

[1] NIFs Intern, Utilization & Life Sciences Office, Kennedy Space Center, University of Michigan
[2] Project Manager, Utilization & Life Sciences Office, Kennedy Space Center

II. Project Summaries

The three projects described below are not an exhaustive list of the tasks I did this fall, but rather a breakdown of the major elements that worked towards my internships original project plan. Throughout the fall, I made sure to take the initiative to assist with other projects that allowed me to work with many of the scientists and engineers in the Utilization & Life Sciences Office.

A. Development of "Feeding Exploration" Graphic

One of the major challenges with developing technology for future space exploration missions is predicting the challenges that the technology will face, especially when the technology is to be used in a foreign environment that is difficult, if not impossible, to replicate on Earth. As difficult as this prediction may be, it is very important when ensuring the technology keeps up with the pace of the exploration missions it needs to be used on. In order to help simplify this problem, this fall, I helped develop a graphic that outlined each space environment that NASA has already or has plans to explore, the respective goal for each environment, and the tasks that have been funded for each environment in order to advance in-space food production. The development of these tasks, also called hills, has been named, within the department, as the Mortain Initiative. The initiative has outlined a series of hills, with Hill 314, being able to sustainably grow food on Mars, being the most difficult to breach. Figure 1 shows the most recent update of this graphic, which is continuing to be updated.

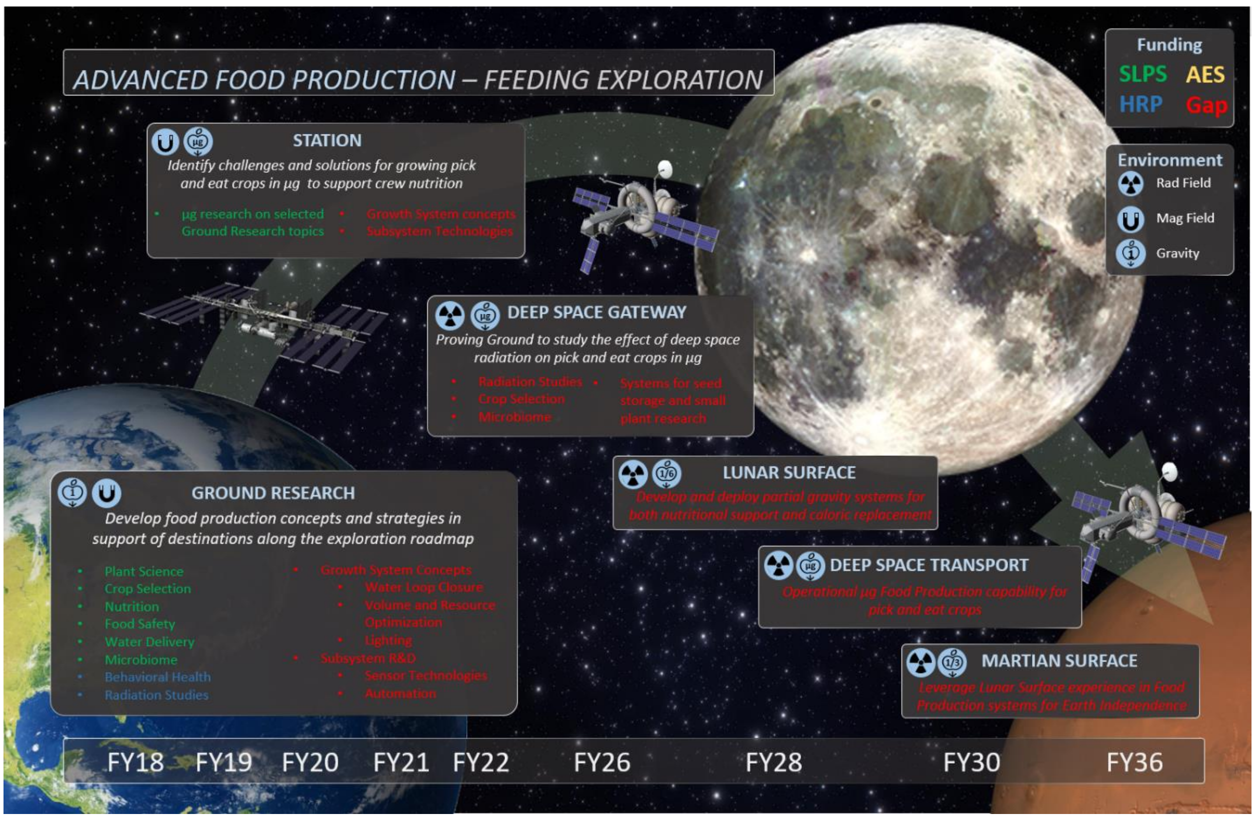

Figure 1. Advanced Food Production Environment Graphic. *This graphic describes the current and future space environments and how their goals for in-space food production*

B. Definement of Requirements for a Gateway Food Production Chamber

In addition, I investigated one of the environments in Figure 1 more closely with the definement of requirements for a food production chamber for the Deep Space Gateway space station. With this task, I began by looking to past plant growth chambers developed by the Utilization and Life Sciences Office to create a foundation for the requirements needed for this potential new food production chamber. However, as this new chamber will be attempting to produce food in the deep space environment where the Gateway will reside, it will need to be able to monitor the effect of deep space radiation. This new requirement will require something known as a Falaise Pocket, that will house sensors and electronics that will investigate the strength of the radiation that the plants are exposed to. The sensitivity and frequency of sensor readings of the sensors in this Falaise Pocket were significant points of discussion between the scientists and engineers during the meetings defining these requirements. All defined requirements, broken down in Level 1, Level 2, and Level 3, based on the parent-child relationship of the requirements, are shown in the Appendix.

C. Coordination of a Food Production Rack for the Lockheed Martin NextSTEP-2 Habitation Mockup

Finally, starting in early November, I have been the project manager of the design and build of a food production rack for the Lockheed Martin NextSTEP-2 Habitation Mockup. This rack would be housed in a carrier known as Gambier Bay in the habitation mockup and would be used to show how, when fully built, Lockheed Martin's habitation module would have the capability of plant growth research. The systems within this rack do not need to be functional, but rather simply display the systems involved, the interfaces required, and the data produced by the system.

As project manager, I am coordinating other interns and full-time employees in the Utilization and Life Sciences Office with how to outfit the box that Lockheed Martin has provided us. This coordination has allowed me to work with scientists and engineers to understand what research should take priority, the technology involved to achieve such research, and the engineering tasks that need to be completed to make the research possible.

III. Conclusion

The work I have done this fall has far exceeded my expectations for what I imagined I would be doing. Through these three projects, I have been given many opportunities to apply the systems engineering knowledge that I have learned at my university, while working on projects that I find to be pivotal for the future of human space exploration. During my final month here, I am looking forward to successfully concluding my work with the hope of returning the Kennedy Space Center in the future to continue working with this great team!

Appendix

Table 1. Level 1 Requirements for a Gateway Food Production Chamber. *Also known as the parent requirements, these requirements are the foremost objectives that need to be met in order for the chamber to be successful.*

Level 1 Requirements					
Level	**Requirement**	**Traceability**	**Rationale/Details**	**Verification**	**Type of Requirement**
L1_01	The growth chamber shall be capable of growing at least 25 plants.	Oscar	25 plant is needed in order to collect statistically significant data on the germination of the plants.	Inspection / Test / Demonstration	Functional
L1_02	The growth chamber shall meet all ISS payload requirements and standards.	Scientific specification	The growth chamber has to meet ISS imposed limits.	Test	Constraint
L1_03	The growth chamber shall follow appropriate human factors requirements.	Scientific specification	We don't want to kill astronauts.	Inspection	Constraint
L1_04	The growth chamber shall be able monitor plant growth progress and environmental conditions.	Scientific specification	Environmental conditions and plant growth progress needs to be monitored for proper scientific data.	Test	Functional
L1_05	No aspect of growth chamber design shall adversely impact the plant specimens.	Scientific specification	In order to collect proper scientific data, the growth chamber design cannot negatively interfere with the plant specimens.	Test	Constraint
L1_06	The experiment length shall range from 30 to 90 days.	See Details	**Minimum 30 days** (https://www.nasa.gov/sites/default/files/atoms/files/20180327-crusan-nac-heoc-v8.pdf) **to maximum 90 days** (https://www.nasa.gov/feature/nasa-seeks-information-for-gateway-cargo-delivery-services)	Test	Constraint

Table 2. Level 2 Requirements for a Gateway Food Production Chamber. *These requirements are a breakdown of the objectives that need to be met in order for the Level 1 requirements to be met.*

Level	Requirement	Traceability	Rationale/Reference	Verification	Type of Requirement
L2_01	The growth chamber shall have at least ____ sq in of plant growth area.	L1_01	In order to effectively germinate 25 plants, this amount of space is requried.	Inspection	Constraint
L2_02	The growth chamber temperature shall be maintained within ±3°C of ambient cabin temperature.	L1_01	In order to avoid temperature extremes, the growth chamber temperature shall be maintained by forced air-cooling.	Test	Functional
L2_03	The growth chamber shall be able to provide up to 48 μmole $m^{-2} s^{-1}$ ± 5 μmole $m^{-2} s^{-1}$ of 630nm ± 10nm (red) light to the plants.	L1_01	Based on the lighting treatments of BRIC-LED and VEGGIE, projects with similar science objectives.	Test	Functional
L2_04	The growth chamber shall be able to provide up to 12 μmole $m^{-2} s^{-1}$ ± 1 μmole $m^{-2} s^{-1}$ of 455nm ± 10nm (blue) light to the plants.	L1_01	Based on the lighting treatments of BRIC-LED and VEGGIE, projects with similar science objectives.	Test	Functional
L2_05	The growth chamber shall be able to provide up to 4 μmole $m^{-2} s^{-1}$ ± 0.5 μmole $m^{-2} s^{-1}$ of 530 nm ± 10 nm (green) light to the plants.	L1_01	This will allow truer color viewing of the sytem. Amount of green light needed based on ratios found in the VEGGIE system.	Test	Functional
L2_06	The growth chamber shall provide a total uniform photon flux light within ±50% of light intensities less than 100 μmoles at a vertical distance of __ cm ± __ cm from the light cap.	L1_01	This requirement is needed to promote uniform plant growth.	Test	Functional
L2_07	The growth chamber shall provide a user-selectable lighting conditions that allows for the tuning of 5 lighting conditions (number of lighting intervals per cycle, duration of lighting intervals, red light level at each interval, blue light level of each interval, and green light level of each interval)	L1_01	This requirement will allow for the automation of unique, customizable growth cycles.	Demonstration	Functional
L2_08	The growth chamber's lighting durations shall have the resolution of one second.	L1_01	This allows precise lighting experiments.	Test	Functional
L2_09	The growth chaber shall contain a minimum of 50 mL reservoir for storage water or nutrient solution.	L1_01	This allows for no need to refill the water reservoir during an entire growth cycle.	Demonstration	Constraint
L2_10	The growth chamber shall be refilled by...??? (Reuseable?)	L1_01			
L2_11	The growth chamber shall meet limits listed in SSP 30237 Rev ___ for electromagnetic interference, specifically CE01, CE03, CE07, CS01, CS02, CS06, RE02, RS02, RS03.	L1_02	Electromagnetic interference from the growth chamber has to meet limits as stated. *SSP 30237 Rev ___*	Test	Operational
L2_12	The growth chamber shall meet all payload-generated acoustic noise requirements as listed in Section 4.7.2 of SSP 52000-IDD-ERP Rev ____.	L1_02	The growth chamber has to meet ISS imposed acoustic limits. *SSP 52000-IDD-ERP Rev ___*	Test	Operational
L2_13	The growth chamber shall contain a maximum water volume of 3.7 liters.	L1_02	The growth chamber has to meet ISS maximum volume limits. *SSP 52000-IDD-ERP Rev ____*	Test	Constraint
L2_14	The growth chamber shall have no visible leaks when it is filled with water up to the maximum capacity.	L1_02	Water must be contained. *SSP 52000-IDD-ERP Rev ___*	Test	Operational
L2_15	The growth chamber shall meet the point source light restrictions per 5.7.3.2.1 of SSP 50005.	L1_02	Point sources of light can be a hazard. *SSP 50005*	Test	Operational
L2_16	The growth chamber shall meet vibration standards per Section 4.1.2.1 of SSP 52000.	L1_02	The growth chamber has to meet the vibration limits stated. *SSP 52000*	Test	Operational
L2_17	The growth chamber shall comply to the materials requirements per NASA-STD 6001B and SSP 30233, Space Station Requirements for Materials and Processes.	L1_02	Only approved materials for use in space are to be utilized. The growth chamber will also undergo out-gas testing. *NASA-STD 6001B* and *SSP 30233*	Inspection, Test, Analysis	Constraint
L2_18	The growth chamber shall not produce stray magnetic fields per Section 7.4.3.2. of SSP 52000-IDD-ERP-Rev ___.	L1_02	This is an IDD requirement. *SSP 52000-IDD-ERP-Rev ___*	Test	Operational
L2_19	The growth chamber shall meet the payload mounting surface requirements per Section 5.3.1.4.9 of the SSP 52000-IDD-ERP Rev ___.	L1_02	This requirement is used to minimize avionics air leakage to cabin air. *SSP 52000-IDD-ERP Rev __*.	Inspection, Test	Constraint
L2_20	The growth chamber shall be designed to be launched in a pressurized volume using a Cargo Transfer Bag (CTB) in a stowed configuration.	L1_02	*JSC39207*	Inspection, Test	Constraint
L2_21	The growth chamber shall be capable of maintaining containment of a toxicity Level 2 hazardous material in accordance with SSP 51700.	L1_02	*SSP 51700*	Demonstration	Constraint
L2_22	The growth chamber shall be composed of materials that can withstand a minimum of 10 autoclave cycles at 120°C and are compatible with biology and fluids (minimum RNALater and aldehydes).	L1_02	*???*	Test	Constraint
Level	**Requirement**	**Traceability**	**Rationale/Reference**	**Verification**	**Type of Requirement**
L2_23	The growth chamber shall be labeled in accordance with Section 12.5 and Appendix E of SSP 52000-IDD-ERP Rev __.	L1_03	*SSP 52000-IDD-ERP Rev __*	Inspection	Constraint
L2_24	The growth chamber shall follow the positioning of controls and switches in accordance with Section 12.6 of SSP 52000-IDD-ERP Rev __.	L1_03	*SSP 52000-IDD-ERP Rev __*	Inspection	Constraint
L2_25	The growth chamber shall not exceed 60 lbm (not including water).	L1_03	*JSC39207 and SSP 52000-IDD-ERP Rev __*	Test	Constraint
L2_26	The growth chamber shall not draw more than 20 amps at a time.	L1_03	The growth chamber needs to adhere to the EXPRESS Rack standards. *SSP 52000-IDD-ERP*	Test	Operational
L2_27	The growth chamber shall fit within one EXPRESS rack double locker.	L1_03	The EXPRESS Rack is the desired secondary structure of the growth chamber. *Scientific specifications*	Inspection	Constraint
L2_28	The growth chamber shall be capable of stowing into a volume of an M02 bag with standard foam requirements.	L1_03	The growth chamber will be stowed in a MO2 Cargo Transfer Bag (CTB). *JSC39207G & NASA foam requirements*	Inspection	Constraint
L2_29	The growth chamber shall comply with Human Factors specifications and guidelines per Section 12.0 of SSP 52000-IDD-ERP.	L1_03	The growth chamber has to meet human factors guidelines of the ISS. *SSP 52000-IDD-ERP*	Inspection	Constraint
L2_30	The growth chamber shall meet the Class-D Reliability and Maintainability requirements as defined in SSP 50431 Rev __, Space Station Program Requirements for Payloads.	L1_03	The growth chamber will be designed to have a minimum reliability classification of subrack payload. The growth chamber will be designed to accommodate on orbit maintenance. *SSP 50431 Rev __*	Analysis	Operational
L2_31	The growth chamber shall have an camera capable of resolving 1 mm of vertical growth and leaf dimension of 1 mm and to document growth up to 1 cm.	L1_04	This will allow for proper documentation of plant growth. Same focus requirements as MPX camera system.	Demonstration	Functional
L2_32	The growth chamber shall be capable of measuring the CO_2 in the chamber between 0-10,000 ppm with a resolution no more than 30 ppm)	L1_04	This will allow for proper documentation of plant growth. Same range and resolution requirements as MPX system.	Demonstration	Functional
L2_33	The growth chamber shall be capable of collecting CO_2 readings in the chamber once every 5 minutes for a minimum of 84 days.	L1_04	Based on a 42 day Deep Space Gateway mission length with a safety margin of 2.	Demonstration	Functional
L2_34	The growth chamber shall be capable of measuring the temperature in the chamber between 0°C and 40°C with a resolution no more than 0.2°C.	L1_04	This will allow for proper documentation of plant growth. Same range and resolution requirements as MPX system.	Demonstration	Functional
L2_35	The growth chamber shall be capable of collecting temperature readings in the chamber once every 5 minutes for a minimum of 84 days.	L1_04	Based on a 42 day Deep Space Gateway mission length with a safety margin of 2.	Demonstration	Functional

Table 3. Level 3 Requirements for a Gateway Food Production Chamber. *These requirements are a breakdown of the objectives that need to be met in order for the Level 2 requirements to be met*.

Level 3 Requirements					
Level	**Requirement**	**Traceability**	**Rationale/Reference**	**Verification**	**Type of Requirement**
L3_01	The growth chamber shall receive power from...	L2_04, L2_05, L2_06	Power is required to the system in order to provide lighting and collect data	Demonstration	Operational
L3_02	The growth chamber shall include a visual indicator that illuminates when power is applied to the canister. The visual indicator must be easily observable by a crewmember when in use.	L2_04, L2_05, L2_06	Power is required to the system in order to provide lighting and collect data	Demonstration	Operational
L3_03	The growth chamber shall be capable of monitoring and recording operablity of each LED circuit.	L2_04, L2_05, L2_06	This will allow users to ensure the LED system is functioning properly.	Demonstration	Functional
L3_04	The growth chamber shall be capable of preventing light from the cabin entering the growth chamber.	L2_06	This will preserve integrity of experiments.	Demonstration	Constraint
L3_05	The growth chamber shall provide an "accepted" setting to user immediately after a setting is changed.	L2_07	This will allow the user to confirm that a change has been made	Demonstration	Functional
L3_06	The growth chamber shall be able to keep track of photoperiod cycle timing.	L2_07	This is required in order to have an autonomous photocycle system.	Demonstration	Functional
L3_07	The growth chamber shall maintain memory of settings when unpowered and can allow for experiment profiles to be programmed prior to launch.	L2_08	This allows for preprogrammed photocycle runs that help to decrease required crew time.	Demonstration	Functional
L3_08	Software source code shall include documentation necessary to fully describe code functionality.	L2_08	This allows future users to understand the code.	Inspection	Operational

Acknowledgments

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