Autonomy and Robotics Workshop

in support of Space Crop Production

"Feeding Exploration and Enabling Earth Independence"

August 6th and 7th 2019 Kennedy Space Center , FL

The Space Crop Production Vision

Ensure Food System Security on Long Duration Missions Beyond Low Earth Orbit*

- *Proper nutrition is critical to crew health and performance*
- **Provide safe, nutritious and acceptable fresh food**
- **Add variety to crew diet**
- **Enhance morale**

* Food security is the condition in which crew have continuous access to sufficient safe and nutritious food which meets both their dietary needs and food preferences in order to maintain peak health and performance.

Near Term Goal

Nutrient Supplementation of the Prepackaged Food System

- **Fresh produce may supplement key vitamins (B_1, K, C) and bioactive compounds that may degrade in the stored food system on multi-year exploration missions that cannot be resupplied.**

- **"Pick-and-Eat" crops that require no processing and minimal preparation will provide variety, customization, and psychological appeal without adding food security risk or high resource demand.**

- **Enable testing and demonstration of dependable crop production before reliance on system.**

- **Limiting factors are vehicle resources mass, power, volume, water, air, crew time**

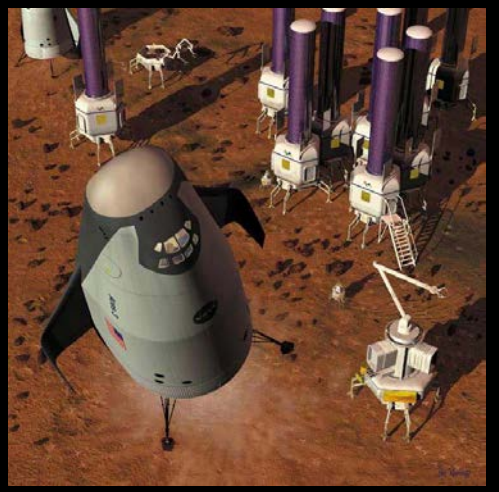
Needed for:
Deep Space Transport

Long Term Goal

Caloric Replacement to Facilitate Earth Independence

- **Reduce up-mass associated with pre-packaged food**
- **In addition to "pick and eat" crops, include staple crops that require processing and preparation**
- **Bioregenerative capability will be required for long duration surface missions**

Needed for: Long duration Surface missions on the Moon and Mars



The Underlying Question for this Week

How can Autonomy, Robotics, Automation and Mechanization Enabling Future Space Crop Production?

Operational Challenges Beyond LEO

The LEO Approach to Operations

- Hardware is designed around ORU's and spares sent from the ground
- Operations are controlled and monitored from the ground with crew Acting in the role of technicians
- Continuous presence of crew is assumed

As Distances Increase Access Decreases

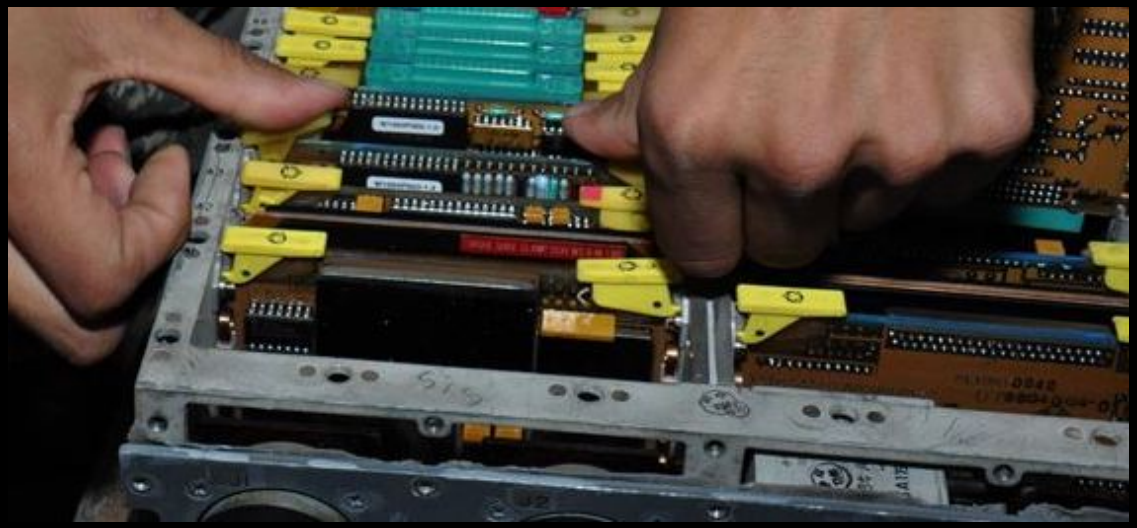
- The return journey from ISS (LEO) takes **Hours**
- From the moon **Days**
- From Mars **Years**

As Distances Increase Communications are Delayed

- LEO virtually instantaneous
- Moon **2.5 seconds** round trip
- Mars between **6 – 44 *minutes*** round trip depending on distance
- Reduce reliance on permanently staffed ground control centers

As Distances Increase the Focus Changes from Replacement to Repair

- Systems designed with repair in mind
- Systems need to be robust and resilient
- Manage logistics by using common components and interfaces where possible
- Leverage in space manufacturing for repair
- Minimize non-reusable components
- Reduce reliance on non renewable consumable commodities
- The crew will be an active component of autonomy (from earth)



As Distances Increase Vehicle Systems and Software Controls will need to Detect, Decide and Do

- Common operations will be automated
- Allow for manual control and system overrides
- Notify crew when a detected fault is present
- Automatic failure recovery if back-up is available
- Automatic fault detection and safing

As Distances Increase Vehicle Systems will need to be Evolvable

- Initial systems capabilities must ensure core functions are provided
- Enhancements should be iterative and not require complete system replacement
- Hardware design and thinking should work backwards from final systems goals (*Start with the end in mind*)

As Distances Increase Vehicle System Dormancy will be a Design Driver

- For Early exploration missions to the Gateway and the Lunar and Martian surface there will be long durations of time when crews will not be present our systems powered
- Provides unique challenges for systems that use water and support biology
- Hardware designs need to build in this operational scenario into their concepts

SPACE CROP PRODUCTION ROADMAP FOR BEYOND LEO

MARTIAN SURFACE

Leverage Lunar Surface experience in Food Production systems to extend Earth Independence for Mars missions

Scale: Single Locker to Greenhouse Module

GATEWAY

Proving Ground to study the effect of deep space radiation on pick and eat crops in µg

Scale: Single Locker

MARS TRANSIT

Provide an operational µg Food Production capability for pick and eat crops to supplement crew diet

Scale: One to Two EXPRESS Rack Equivalents

LUNAR SURFACE

Develop and deploy operational partial gravity systems for both nutritional support and caloric replacement as both a source of food for long duration lunar missions and as a demonstration for Mars

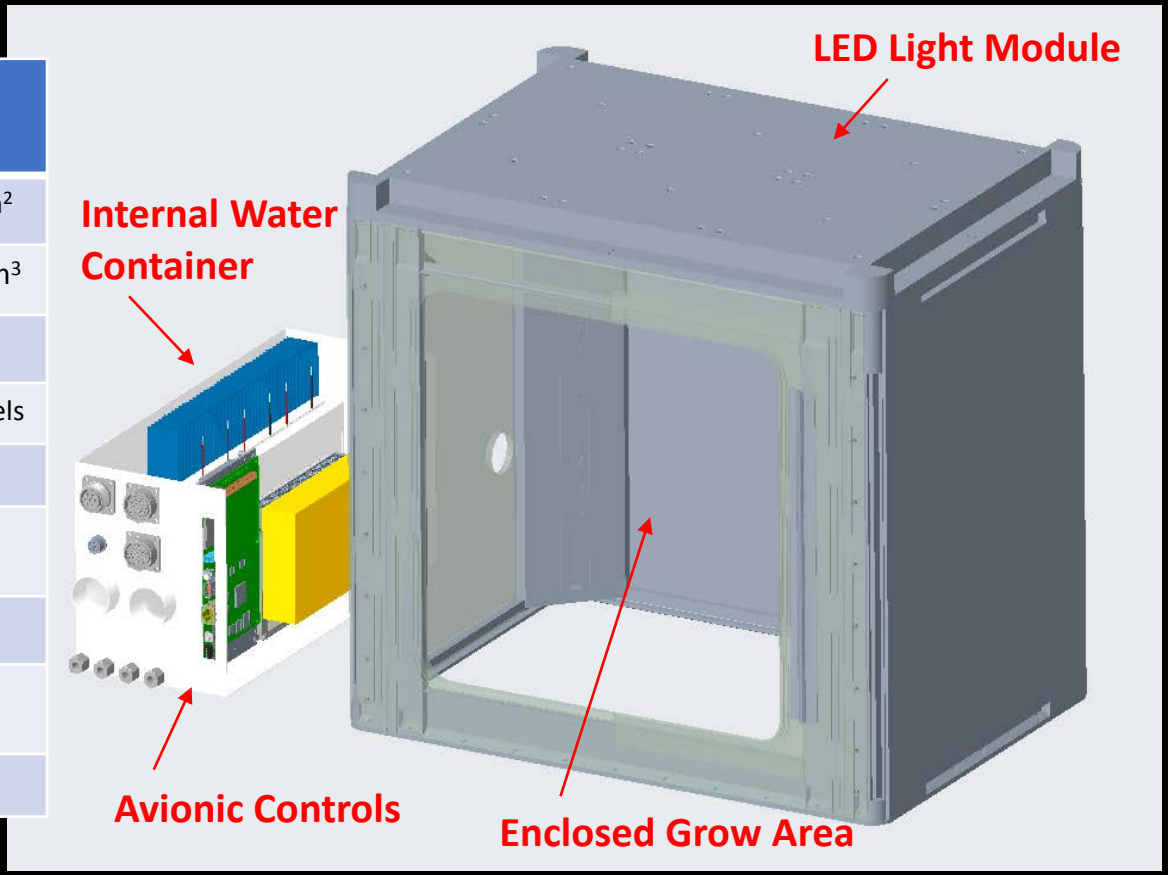
Scale: Single Locker to Greenhouse Module

Systems Scale Will Drive Options

Notional Single Locker Sized Growth Chamber

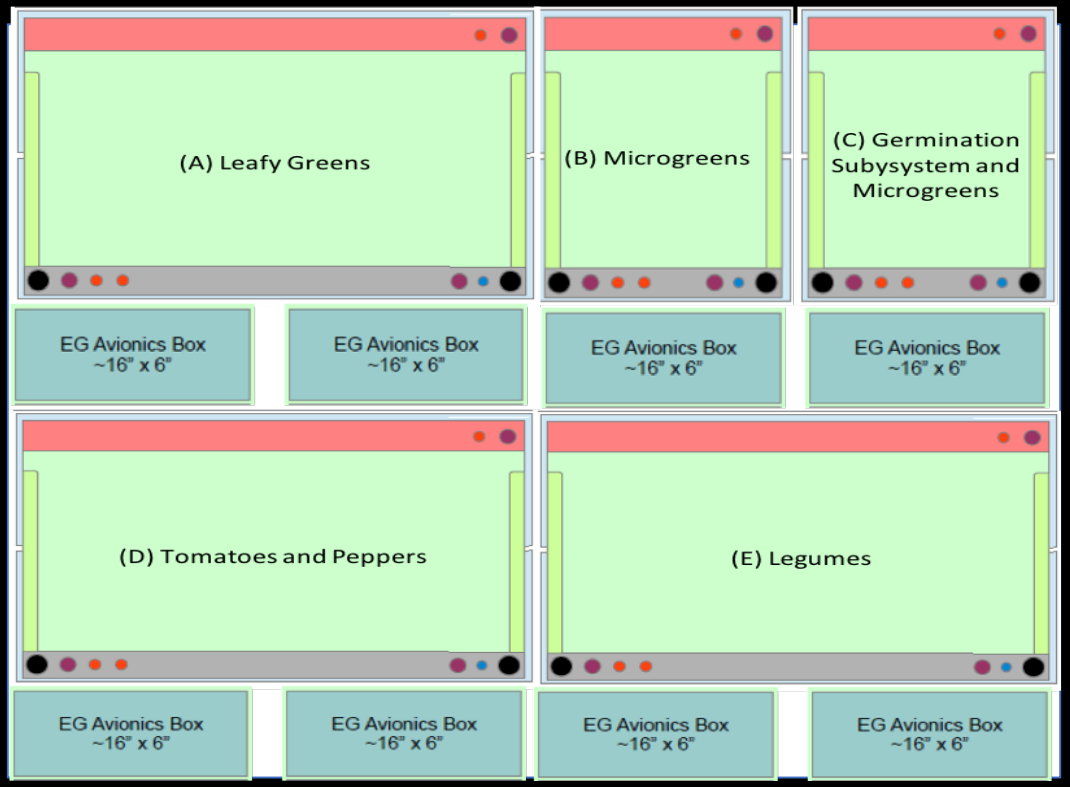
- Plant Research System for CIS Lunar/Gateway or Partial Gravity Environment
- Can Serve as a Component of a Larger Space Crop Production System

NOTIONAL FACILITY SPECIFICATIONS	
Grow Area	0.150 m^2
Avionics H/W Volume	0.125 m^3
Water Volume	1L
LED Colors	6 Channels
Light Intensity (PAR)	450
Power Requirements (Peak)	700 W
Controlled Environment	Yes
Temp and Humidity Control	Yes
Water Recovery	Yes



Notional Deeps Space Transport Crop Production System

- Scaled to the Volume of Two ISS EXPRESS Racks (equivalent to 16 middeck lockers)
- Plant Chamber Configuration designed to accommodate a variety of Pick-and-Eat Crops
- Hydroponic based Growth Systems
- In this example multiple Control Units would Provide Fault Tolerance
- 2.5 to 3 year mission



Notional Lunar and Martian Surface System

- Initial food production capability may be an adaptation of the microgravity hydroponic system from the DST
- Eventually envision Dedicated Module(s) to Produce a Range of Both Pick-and-Eat and Staple Crops
- Will there be a Role for Processed ISRU Regolith?

Workshop Focus Topics

A note on the topics

- Topics were prioritized based on survey responses
- Additional topics may be added if time is available
- A facilitator and a record keeper will lead and document each topic

Wednesday Afternoon Topics

Growth Technologies Discussion(light, water, airflow, crop scheduling, multi-cropping, etc.)

Monitoring Discussion (plant health, food safety)

Thursday Topics

Initiation Discussion (planting, transplanting)

Turnover Discussion (harvest, cleanup, re-plant)

Operations Discussion (repair, maintenance, interoperability)

Thank you for your participation and let's have a great workshop!