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Plant Atrium System for Food Production in NASA's Deep Space Habitat Tests

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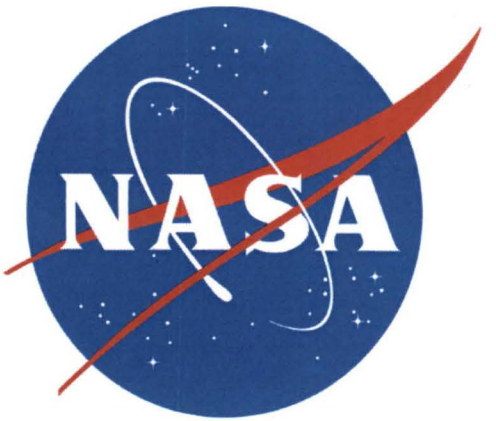

43nd ICES, 14–18 July 2013, Vail, Colorado

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Introduction

- Future human space exploration missions will need functional habitat systems.
  - Possible concepts are assessed for integration issues, power requirements, crew operations, technology, and system performance.

- A food production system concept was analyzed at NASA Desert Research and Technology Studies (DRATS) in 2011, and at NASA JSC in 2012.
  - System utilizes fresh foods (vegetables and small fruits) which are harvested on a continuous basis.
  - Designed to improve crew's diet and quality of life without interfering with other components or operations.

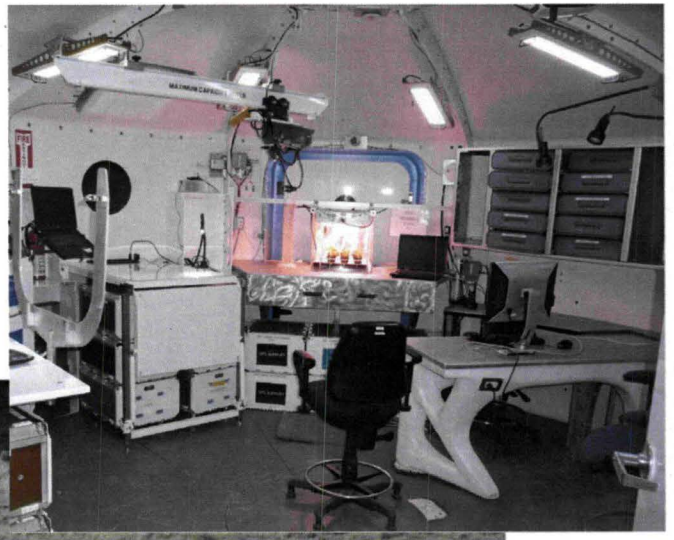
Goals and Objectives

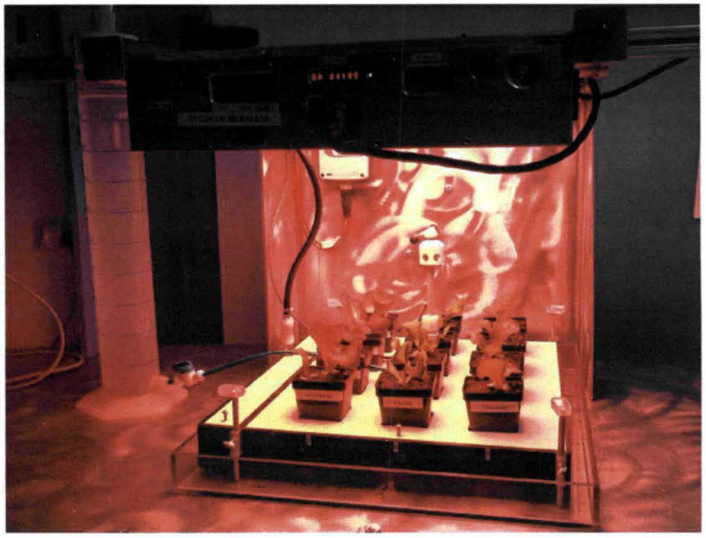
- Apply lessons learned from 2010 test to develop and validate a larger volume food production area in un-utilized space within new crew habitat architecture.

- Evaluate watering, lighting, sensors, and plant performance in an integrated test bed with crew under operational scenarios.

- Evaluate operational objectives associated with transport and maintaining live plant material.
  - Planting, watering, harvesting, sanitation, plant status monitoring, crew acceptance of selected crops, quantifying impact of crew activities on subsequent quality of crops(irregular lighting cycles, temperature changes)

Habitation Demonstration Unit (HDU) Configuration in 2010

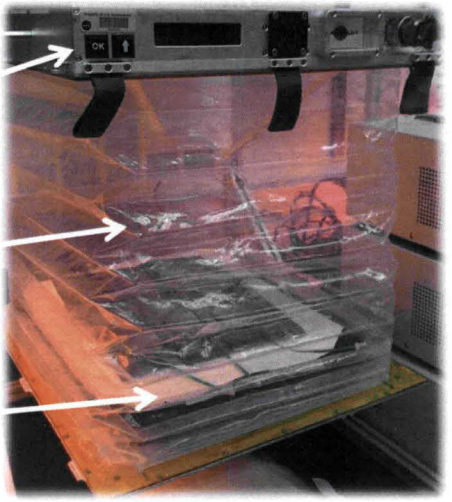




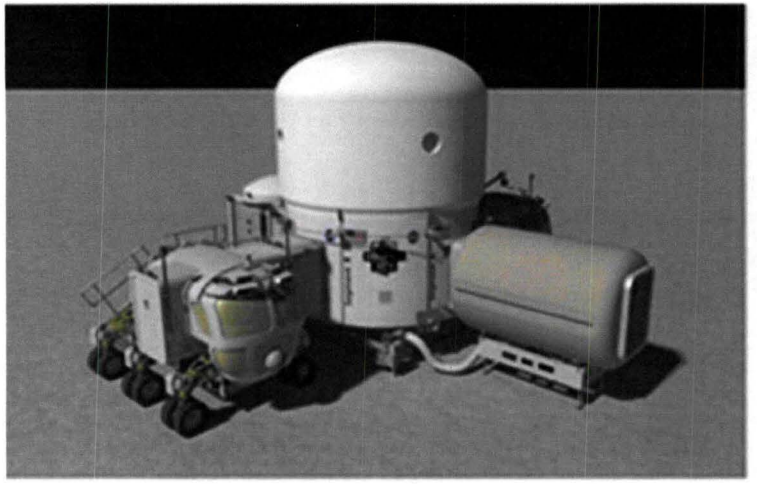
LED
Light Cap

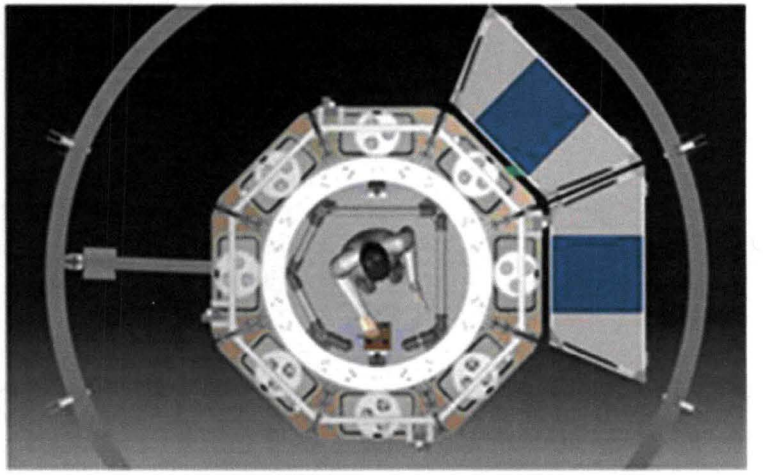
Teflon
Bellows

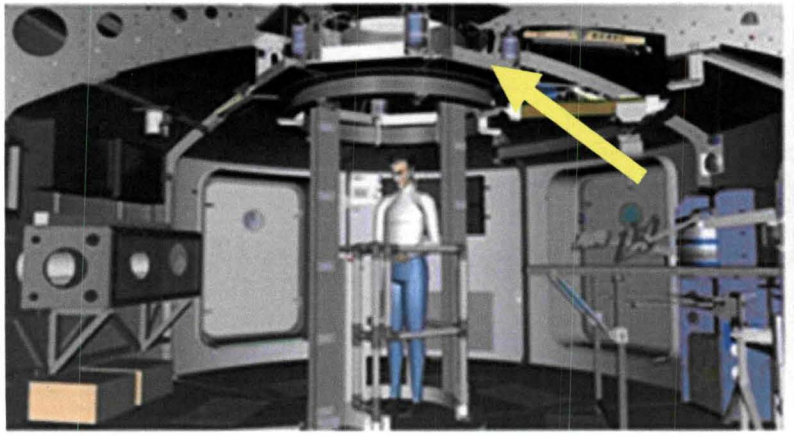
Reservoir

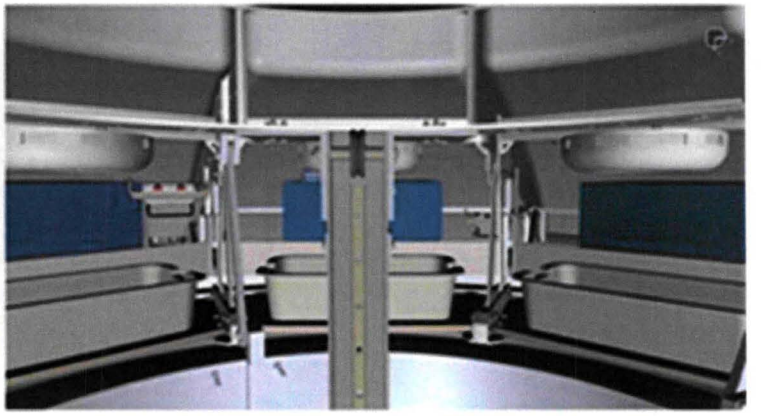


CAD View of HDU 2011- 2012



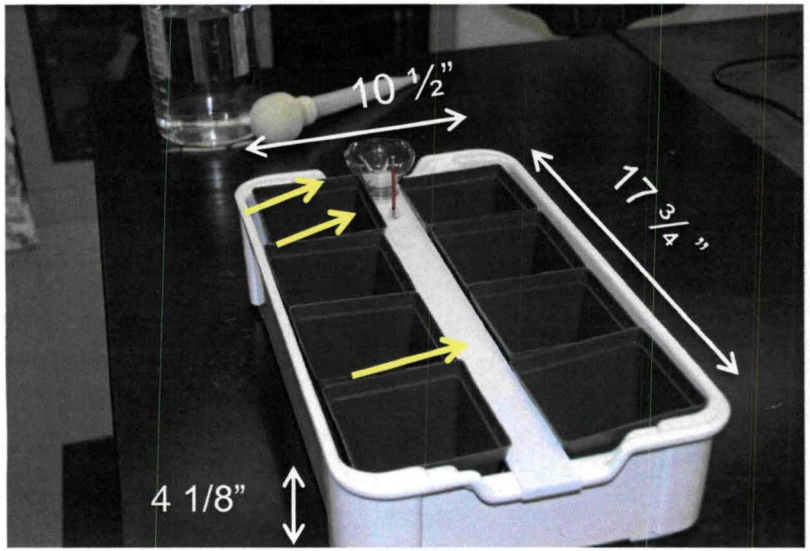




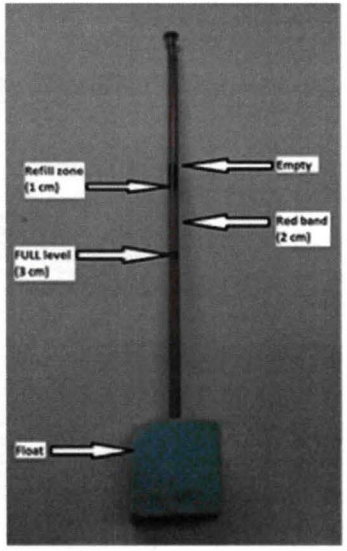


2011 Plant Atrium: Growth System Details

- Thermal and load resistant fiberglass tray.
  - Lined with capillary mat fabric
  - Direct bottom watering via a perched water table
- Custom-built center insert
  - Holds custom float stick to maintain water level between 2-3 cm
  - Water transfer funnel



- 8-10.2 cm square plant pots
  - Layer of Arcillite in bottom of pots
  - Nitex nylon mesh covered Arcillite



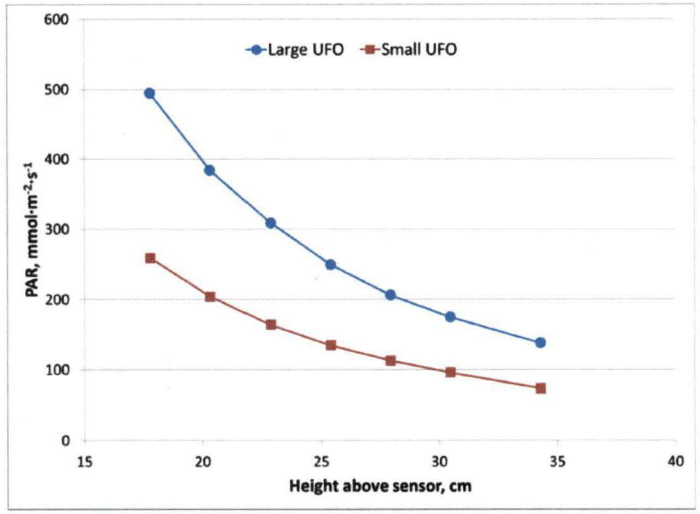
- Peat-based commercial potting media
  - With perlite and vermiculite
  - 50:50 mixture of Fafard #2 and Arcillite
- Nutricote slow release fertilizer was mixed with potting media @7.5 g/L
- Plants pre-germinated in Jiffy starter plugs then transplanted to pots
  - 2 seeds per plug
  - 2 plugs per pot (4 plants)
  - Thinned to 2 plants per pot

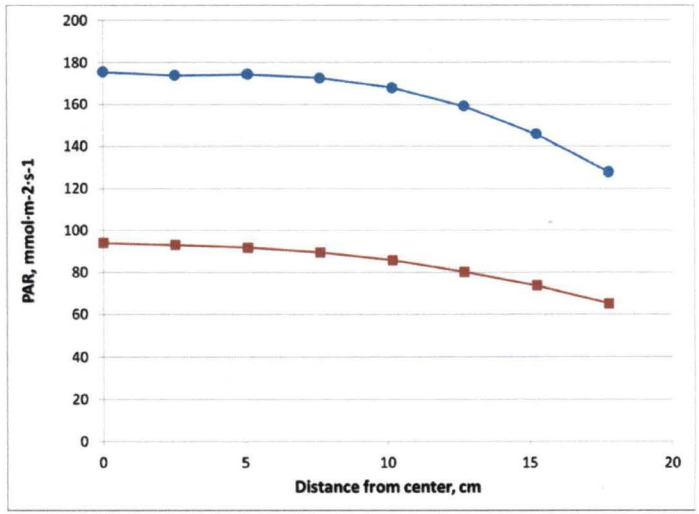
2011 Plant Atrium: Plants Grown

- Plants Used
  - *Lactuca sativa*
    - 'Outredgeous' (Lettuce)
    - Red romaine type lettuce
    - 'Flandria' (green butter head)
  - Mizuna
  - 'Cherry Bomb II' Radish
  - *Ocimum basilicum*
    - 'Spicy Globe' Basil
    - 'Genovese' Basil
  - *Ipomea batatas*
    - 'Beauregard' Sweet Potato
- Lettuces, mizuna, and radish grown from seeds in plug.
- Basil and sweet potato were transplanted as rooted cuttings
- Plant types mixed throughout atrium trays
  - Sweet Potatoes placed in end of trays to allow for vine trailing
- 2 additional control trays with lights were grown in CECs at KSC
  - Conditions set to mimic HDU

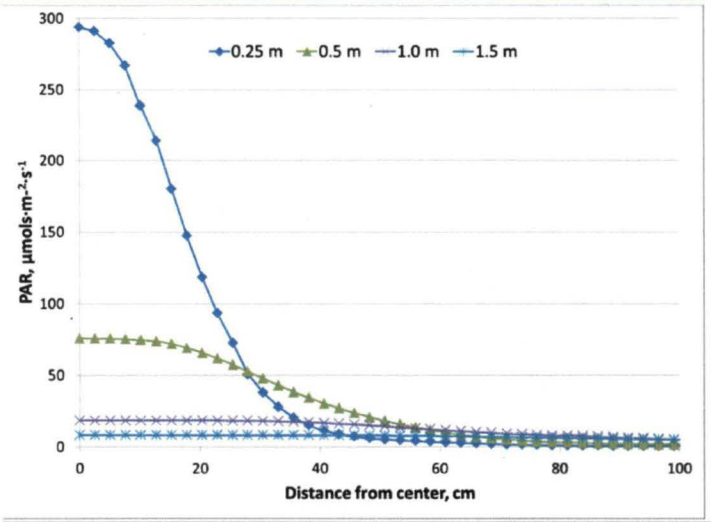
2011 Plant Atrium: Lighting

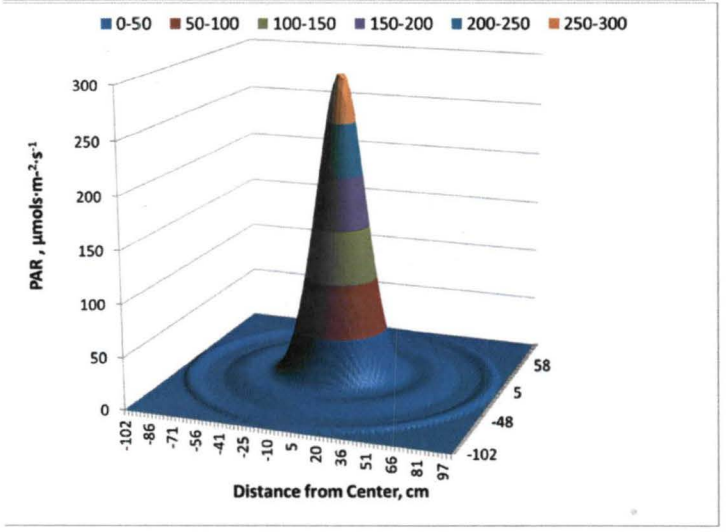
- 2 "UFO" LEDs compared for use (50 W, std. 110 VAC, no dimming).
  - Small had 50 LEDs (44 red; 6 blues)
  - Large had 48 LEDs (43 red; 5 blue)
- Larger UFO had 40% greater quantum output than smaller.
- Both units showed similar average decrease in photosynthetically active radiation (PAR) away from center
  - ~70% full level at 18 cm away and 30.5 cm below
- 11 Larger UFO LEDs purchased for HDU
  - PAR output was <4% different between units; voltage and current were uniform.
  - Housing and LED placement was altered from original test unit





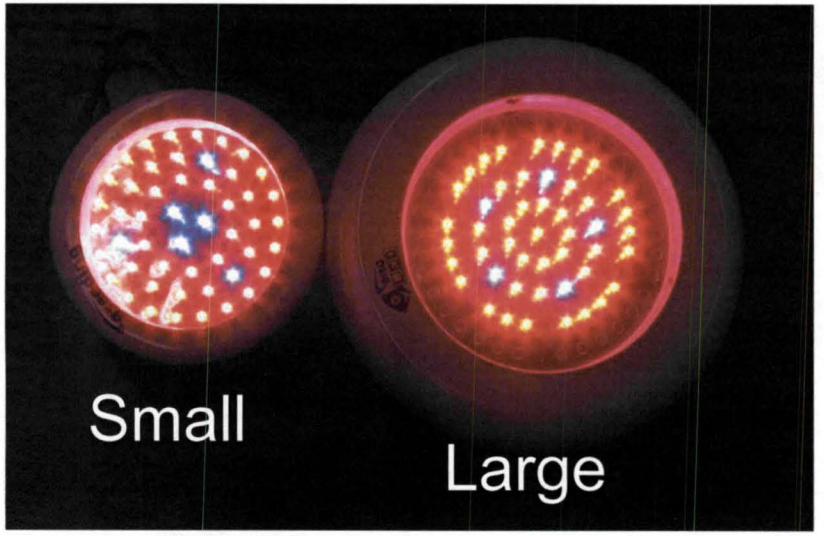
2011 Plant Atrium: Lighting

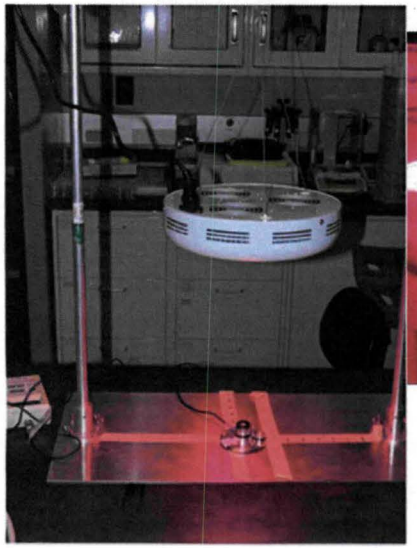


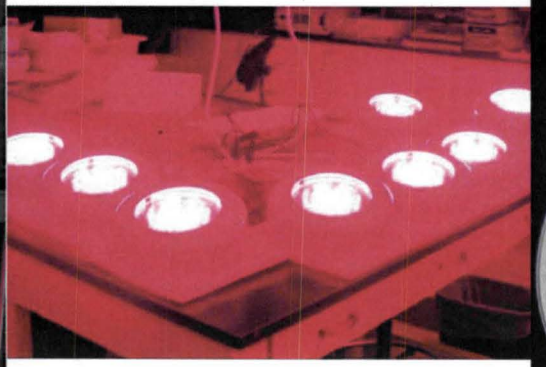


- 8 UFO LEDs closest to average PAR used
- After installation, lights perceived as problem in HDU environment
  - Disc of black window screen covering the lamp surface used to reduce light intensity and flatten cone of irradiance
- Mapping of light distribution at various heights in growth chamber was completed
  - Black matte fabric was used to eliminate light reflection

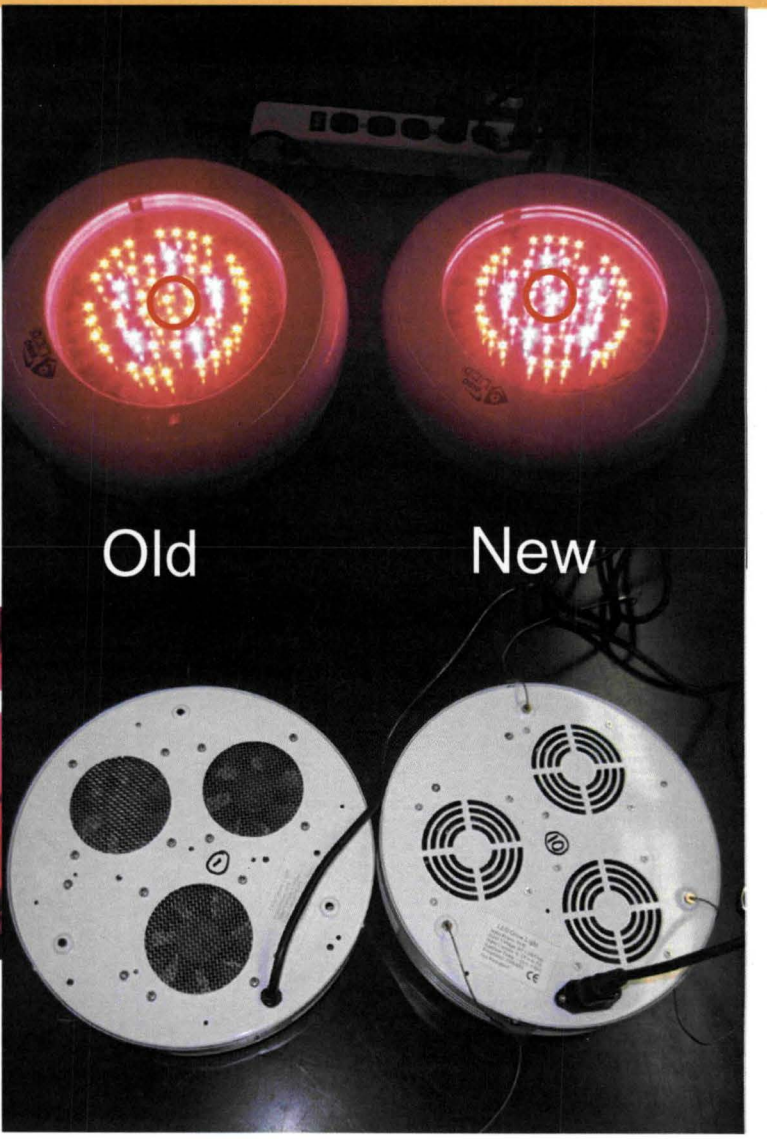
2011 Plant Atrium: Lighting





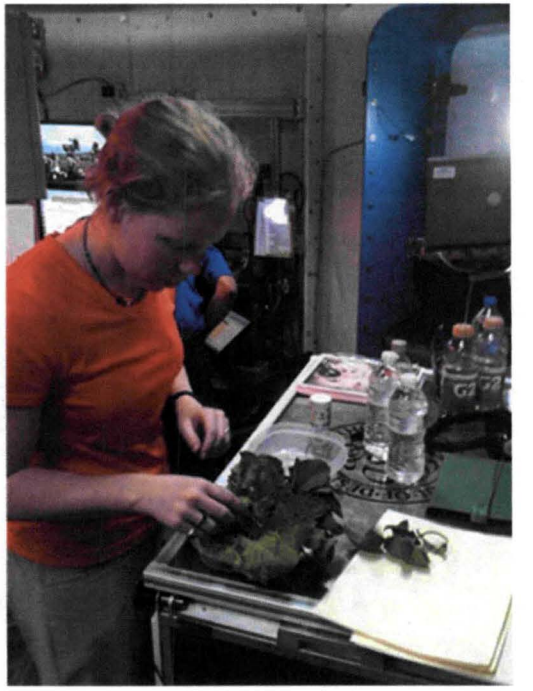


Testing

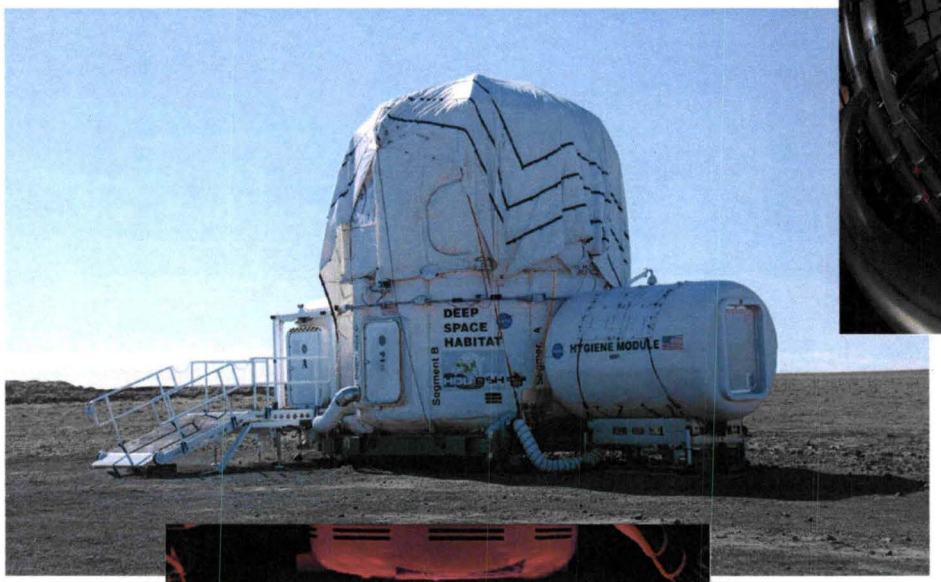


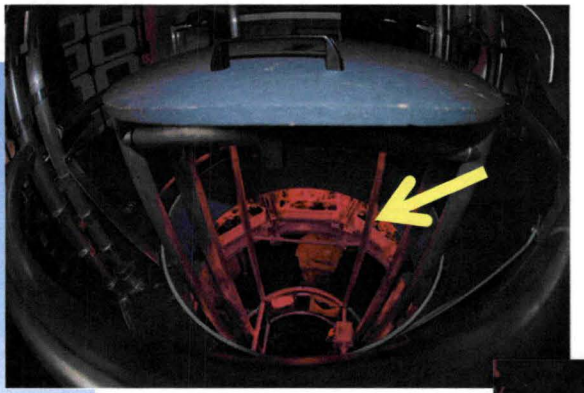
2011 Plant Atrium: Crew Activities

- Crew activities were kept to a minimum because of limited duration of the test
- An iPad application was developed for crew members to keep track of plant atrium data
- Crew were responsible for taking pictures of plant trays and tracking manual water additions.
  - Via a small flow meter
- Crew also completed evaluation surveys
  - Included questions about plants, lights, activities, and other aspects of interaction
- Crew also decided to harvest and consume a salad from plant atrium (unplanned task).



HDU 2011





2011 Plant Atrium: Plant Growth Results

Plant type	Height (mm)		Chlorophyll (SPAD)		Fresh Mass (g)		Dry Mass (g)	
	Field Test	Control	Field Test	Control	Field Test	Control	Field Test	Control
'Beauregard' sweetpotato	212	160	40.9	38.0	10.7	9.1	0.6	0.5
'Cherry Bomb II' radish	91	95	37.9	44.1	51.5	34.9	1.9	1.7
'Flandria' lettuce	80	60	23.3	22.2	14.4	12.8	0.4	0.4
'Genovese' basil	215	230	35.5	33.2	12.8	12.5	1.0	1.1
Mizuna	138	170	35.1	39.3	14.2	12.9	0.7	0.9
'Outredgeous' lettuce	130	123	18.4	16.4	12.6	12.2	0.4	0.4
'Spicy globe' basil	106	110	40.2	38.0	9.2	8.2	0.4	0.2

- A significant number of plants were harvested by the crew
- Plenty remained for analysis
- Height and SPAD values were similar between atrium and control
- Fresh mass was slightly higher in atrium
- Dry weights were identical between atrium and control
  - Radishes and 'Genovese' basil had highest dry masses
  - 'Spicy globe' basil and two lettuce varieties had lowest dry matter accumulation
- 'Genovese' basil plants grew into the UFO light barrier and some leaf scorching occurred.

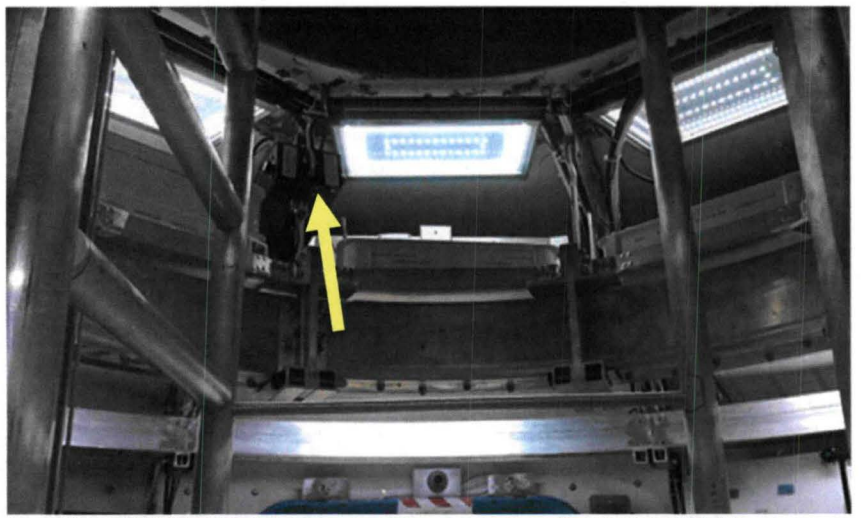
2011 Plant Atrium: Additional Results

- Crew evaluations showed satisfaction with plants and dissatisfaction with the red and blue LED plant growth lighting system
- Significant light leakage from atrium into the lab area
- Plant status was difficult to assess under red and blue wavelengths
- Strong conical light distribution was not suitable for rectangular trays
- Even with diffuser screens corner plants had very low light levels = non-uniform growth

2012 Plant Atrium: Growth System Upgrades & Plants Grown

- Plumbing was added
  - 10 gallon reservoir (exterior to habitat) used to provide water to atrium and hygiene module
  - Water lines feeding pressurized water (45 psig mac; 310 kPa) to atrium with shutoff valves
  - 2 systems for testing
    - Automated irrigation system coupled to sensor and control suite to 1 plant tray (OSUxHAB)
    - Remaining plant trays had manual irrigation controlled by a push button dispenser valve
- Manually irrigated trays also had flow meters with digital displays
- Growth medium changed
  - New media-Miracle-Gro® Expand 'n Gro- was used on top of perched water table of Arcillite
- Jiffy plugs still used to pre-germinate seeds
- Each tray in atrium contained only a single crop type.
- Lettuces, mizuna and radish from 2011 were used.
- Additional plants used
  - 'Wladmann's Green' lettuce
  - 'Sparkler White Tip' Radish
- Only salad crops used because of additional crew interaction

2012 Plant Atrium: Lighting Upgrades



- Custom white LED lights were used (AIBC's super-slim whiteEx70Dim)
  - 216 cool white LEDs
  - 24 V DC input with 110 V AAC wall plug
  - ≤75 W power
  - Dimmer-ability between 5% and 100%
  - No fans = increased plant growth space
- OSUxHAB team installed semi-transparent pull-down shades to block excess light leakage

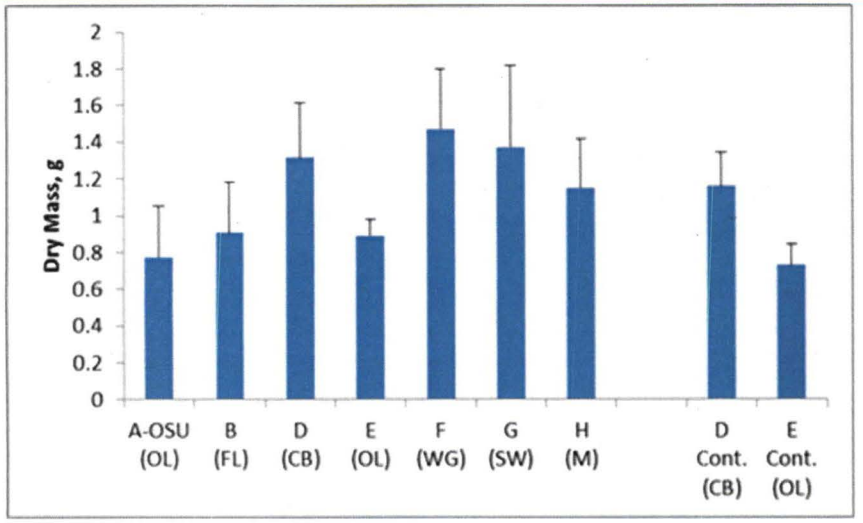
2012 Plant Atrium: Crew Activity Changes

- Due to 2011 request for more human-plant interaction crew activities increased
- Plant watering and daily checks using updated iPad app
- Plant thinning and harvesting
- Produce sanitizing and Salad Consumption
  - Analogous consumption by ground (control) crew
- Updated Crew Questionnaire

2012 Plant Atrium: Crew Activity Methods

- Plants checked and watered by crew daily (accept for OSUxHAB automated tray)
  - Photographed, status and water added recorded
- Plants thinned after 14 days and harvested after 20 days
- Crew sanitized with 2% PRO_SAN™
  - Leaves and radish roots
  - Radish scrubbed and soaked (15 min) , Lettuce submerged for (2 min)
  - Rinsed and Spun dry in salad spinner
  - Consumed by crew
- Anomaly event involved plastic insect being placed in tray
  - Crew responded by isolating and contacting ground for countermeasures
- Rest of plants harvested by crew at day 24
- 11 Question Crew Survey

2012 Plant Atrium: Plant Growth Results



OL= 'Outredgeous' lettuce, FL='Flandria' lettuce, CB='Cherry Bomb II' radish, WG='Waldmann's Green' lettuce, SW='Sparkler white tip' radish and M=mizuna. Cont. = control

- Radishes had highest dry mass due to large storage root
- 'Waldmann's Green' lettuce plants were large and grew very well
- Control plants were slightly smaller than atrium plants
  - Possibly because of slightly lower average light levels (285 $\mu mol \cdot m^{-2} \cdot s^{-1}$ vs. 367$\mu mol \cdot m^{-2} \cdot s^{-1}$)
- OSUxHAB tray plants were also smaller than manually watered plants
  - Less watering due to low setting on automated system
- All trays had 1-1.5 L of water remaining except OSUxHAB tray
  - After harvesting OSUxHAB tray pots had differential water status

2012 Plant Atrium: Additional Results

- More than one water sensor is needed per tray to better assess plant water needs.
- Crew enjoyed plant tasks, presence of plants, and eating plants
- Crew did not like the sanitation method given resources and equipment
- Crew approved of white LEDs and also liked their contribution to lab lighting
  - Did NOT use pull down shades once, and didn't like them
- Crew was positive or neutral on future plant involvement with DSH
- Crew opinions were mixed on having less, ore or same interaction with plants
- All Crew enjoyed consumption and appreciated plant flavors added to meals

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2011/2012 Plant Atrium Conclusions

- Plant atrium was successfully tested in 2011 and improved upon in 2012 tests.
- Un-utilized space was used and had a positive impact on crew.
- Overall the 2012 crew enjoyed watching plant growth and doing maintenance.
- Automation and remote telepresence devices show promise in reducing required crew time and knowledge to maintain crops
- Dietary supplementation, atmosphere revitalization and additional light were appreciated during 2012 test
- Presence of growing green plants, recreational gardening, and fresh produce were hard to quantify, but were appreciated even in short duration test.

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Acknowledgements

The authors wish to thank the 2011 2012 crews of the DSH tests, Ken Mellott, Mary Hummerick, Tracy Gill, Ken Hollifield for CAD support, Anthony Nguyen, Cedrick Flemming, and the many individuals supporting the DSH including Amanda Lynch, Chris Chapman, Ronnie Gambrell, Ed Walsyh, Danny Carrejo, Lui Wang, Kristina Rojdev, Melissa Borrego, and many others who helped contribute to the success of the plant atrium.

We are grateful to the OSUxHAB student team and their advisor Dr. Peter Ling for their efforts to support the 2012 test.

We are grateful to NASA for funding this research as part of the Advanced Exploration Systems Deep Space Habitat program.

Questions?

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