From Earth to the ISS to the Moon and Mars: Development Considerations for Space Habitation and Current Efforts at NASA

University of North Dakota
Space Colloquium Series
April 28, 2014

Tracy Gill, Research and Technology Management Office - NASA/KSC

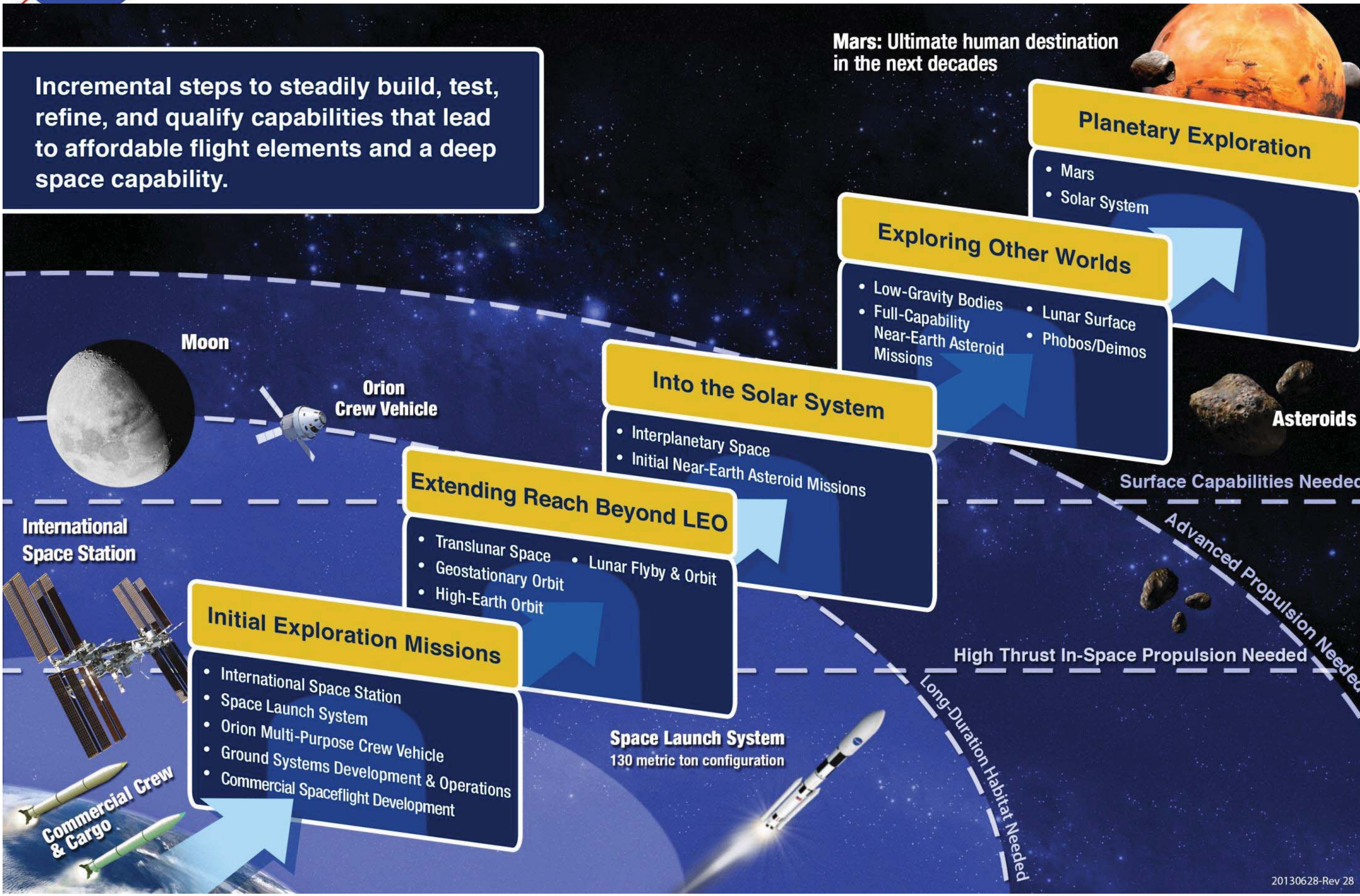
Agenda

- Capability Driven Framework
- Deep Space Habitat Concept of Operations
  - Design Reference Missions
  - Crew Activities and Functions
- Trade Studies
  - DSH Configurations
  - Modularity
  - Example Study
  - DSH Analog Concept Demonstrators
- Exploration Augmentation Module
- Technology Development

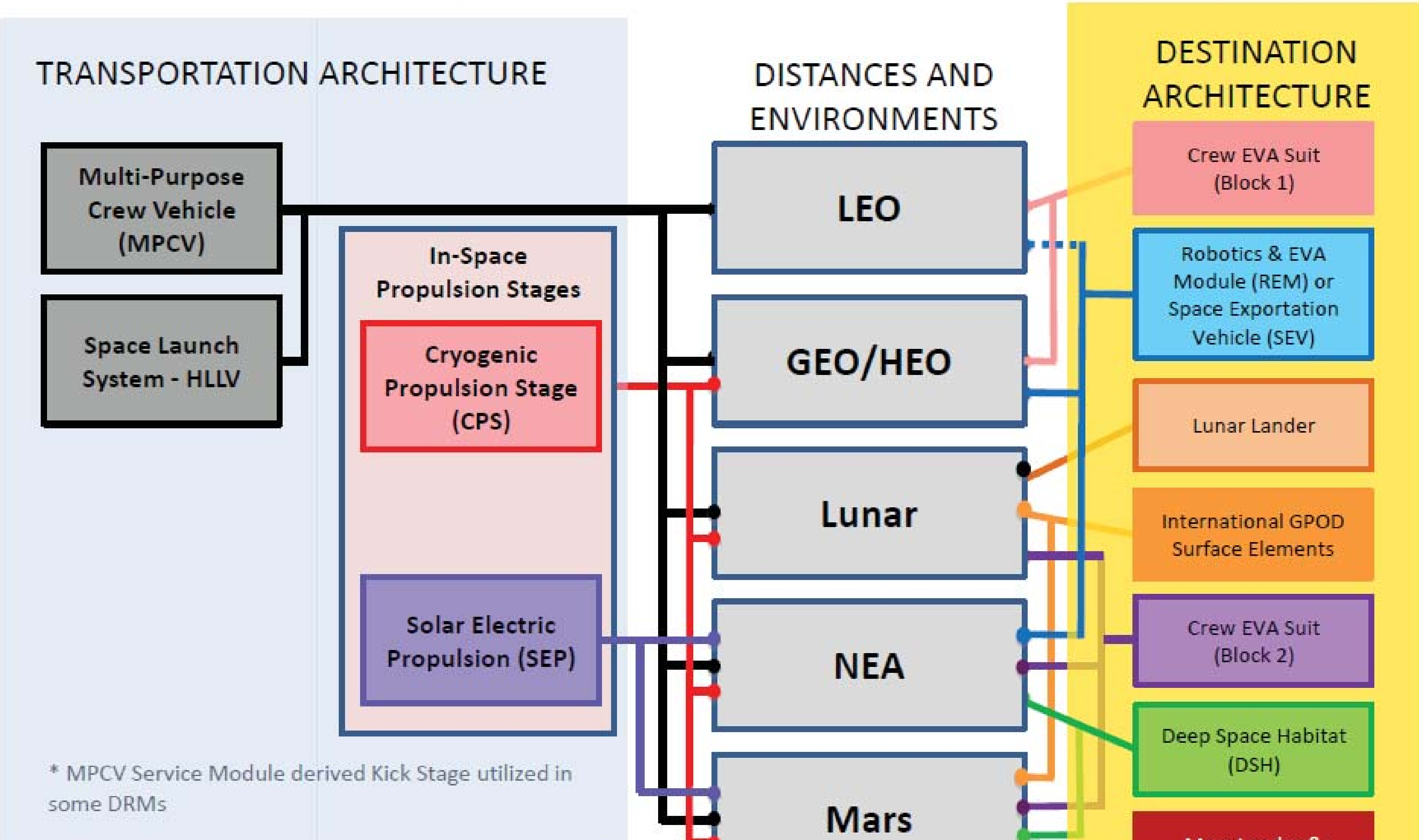
Capability Driven Framework

- Feb 2010. Constellation program canceled and NASA flew out the shuttle program to complete the International Space Station.
- NASA focus turned to deep space exploration beyond low Earth orbit, and effort made to reinvigorate research and technology work at the agency to develop new capabilities
- March 2011 – update of the Human Space Exploration Framework Summary (Ref 1)
- Established notion of Capability Driven Framework. Based on Incremental Expansion of Capabilities to achieve multiple missions

Capability Driven Framework



Transportation and Destination Architectures for Flexible Path



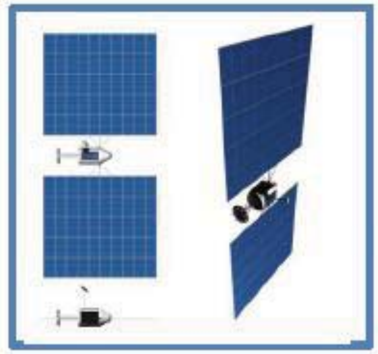
Elements based on Authorization Act and other conditions. Different constraint basis would result in different elements, but capabilities represented would be unchanged.

Notional Architecture Elements

Space Launch System (SLS)-HLLV

Multi-purpose Crew Vehicle (MPCV)

Cryogenic Propulsion Stage (CPS)



Solar Electric Propulsion (SEP)

Lander

Mars Elements

Graphics are Notional Only – Design and Analysis On-going

EVA Suit

Multi-Mission Space Exploration Vehicle (MMSEV)

Deep Space Habitat (DSH)

Robotics & EVA Module (REM)

Kick Stage

NEA Science Package

Deep Space Habitat Concept of Operations

In 2010-2011, a NASA Habitat team studied several Design Reference Missions to better understand Deep Space Habitat drivers (Ref 2)

- Geostationary Earth Orbits
- Earth-Moon Libration Points
- Lunar Surface
- Near Earth Asteroids
- Mars Orbit
- Mars Surface

	Geostationary Orbit	Earth-Moon Libration	Lunar Surface	Near-Earth Asteroids [1]	Mars Orbit (Phobos) [2]	Mars Surface
Typical Mission Design						
In-Space Delta-v (km/s)	5.9	4.8	~5.6	4.0-9.0+	~9.0-15.0	5.5-7.3
Descent/Ascent or Vicinity Delta-v (km/s)	-	-	4.2	-	1.7-3.5	6.3
Total Mission Duration (days) [3]	10	16	16-180	365	660	900
Outbound Time (days) [3]	0.5	4	5	170	250	180
Time at Destination (days) [3]	9	8	7-180	25	60	540
Return Time (days) [3]	0.5	4	4	170	350	180
Crew Mission Mode	Zero-g	Zero-g	Zero-g	Zero-g (?)	Artificial-g	Zero-g
Cargo Mode	Split	Split	Split	All-up	Split	Split
Typical Mission Opportunities	Daily	Weekly-Monthly	Weekly-Monthly	10-50+ Years	Every 26 Months	Every 26 Months
Quick Abort to Earth Availability	Anytime	Anytime	Nearly Anytime	None	None	None
Typical Systems Required						
Orion Multi Purpose Crew Vehicle	✔	✔	✔	✔	✔	✔
Heavy Lift Launch (Space Launch System)	✔	✔	✔	✔	✔	✔
In-Space Propulsion	✔	✔	✔	✔	✔	✔
Destination Exploration Systems	✔	✔	✔	✔	✔	✔
Deep-Space Habitat		✔		✔	✔	✔
Planetary Lander			✔			✔
Key Technologies						
Cryogenic Propulsion	✔	✔	✔	✔	✔	✔
Radiation Protection			✔	✔	✔	✔
Advanced Propulsion (SEP, NEP, NTR)				✔	✔	✔
Near-Zero Boil off Cryogenic Fluid Storage				✔	✔	✔
High-speed Earth Entry				✔	✔	✔
Life Support System Enhancements				✔	✔	✔
Zero-g Countermeasures				✔	✔	✔
In-Situ Resource Utilization			✔			✔
Entry, Descent and Landing			✔			✔
Nuclear Surface Power						✔
Typical Launch Parameters						
# SLS launches to send crew to destination	1	1	1	2-3+ [4]	3-7 [4]	3 [4]
# SLS launches for destination cargo	1	1	1	-	2-3 [4]	4 [4]
Approximate total mass in LEO (t)	200	200	200	200-300 [4]	500-900 [4]	800 [4]

18 Crew Activities and Functions Defined

1. Provide support systems (communications, thermal control [active and passive], power management, environmental protection, radiation protection, micro meteoroid/orbital debris, Environmental Control and Life Support System, etc.).
2. Provide on-board subsystem monitoring and control (communications and data handling, caution and warning, "crew autonomy" [e.g., equipment diagnostics/prognostics], etc.).
3. Provide on-board piloting/proximity operations/navigation.
4. Provide docking for one Multi-Purpose Crew Vehicle and up to two Space Exploration Vehicles (SEVs).
5. Provide control of external device (manipulators, robotic devices, etc.).
6. Provide external visibility (observation of target body, situational awareness during extravehicular activity (EVA) and SEV flight operations, etc.).
7. Provide EVA egress and ingress (with airlock or suitport) for suited crew members and for EVA
8. Provide stowage (food, personal hygiene, housekeeping, maintenance/tools, trash, waste, general, etc.).
9. Provide maintenance and repair (electronic, mechanical, and soft goods [e.g., EVA garment]).
10. Provide food preparation.
11. Provide multipurpose gathering space (meals, crew meetings, individual work, recreation, etc.).
12. Provide crew personal accommodations (sleep, private space, etc.).
13. Provide crew hygiene.
14. Provide crew exercise.
15. Provide crew health/medical support.
16. Provide mission-specific on-board research.
17. Provide crew safe haven (may be covered under environmental protection – under review).
18. Provide crew training.

However, depending on the specific mission chosen, there will be science objectives that drive the habitat design to accommodate the experiment facilities. These objectives will also help define meaningful work for the crew.

Trade Studies

- DSH Configurations
  - Mission Duration
    - Between 10-900 days for the 6 cases studied
    - Affects size, logistics concept, radiation protection, etc.
  - Habitat Shell
    - Hard shell, inflatable, hybrid, monolithic, modular
  - Volume
    - Data from Skylab, Shuttle, ISS, Analog concept demonstrators
  - Environmental effects….

Space Environment Considerations

- Radiation
  - Exposure to radiation especially beyond the Van Allen belt for Galactic Cosmic Rays and Solar Particle Events
  - Manage with crew selection, mission duration, shielding (materials, water walls, electromagnetic)
- Distance
  - Affects communication tools and methods. Communications time between 1-20 min for various phases of an exploration mission drive a different paradigm from the Mission Control to LEO standard
    - Affects verbal communication and telerobotics
  - Affects emergency return time and resupply and logistics considerations. Varies from hours in LEO to days in Cis-Lunar to months for Mars or asteroid missions.
  - Affects amount of water brought aboard, whether used for consumption and/or radiation protection. Improving water recovery can produce significant mass savings
- Microgravity and partial gravity considerations
  - Surface Habitats for Moon and Mars may rely on convection flow and gravity driven processes and need to be oriented with respect to gravity
  - Habitats for microgravity cannot rely on gravity driven processes but may be able to more effectively utilize volume in all directions

Modularity Effects in Habitat Design

Purpose:

- Describe considerations and demonstrate advantages of modularity in habitat concepts for future human exploration missions beyond LEO
- Modularity Defined
- Categories of Modularity
  - Pressure Vessel Modularity
  - Distributed Functions
  - Subsystems Modularity

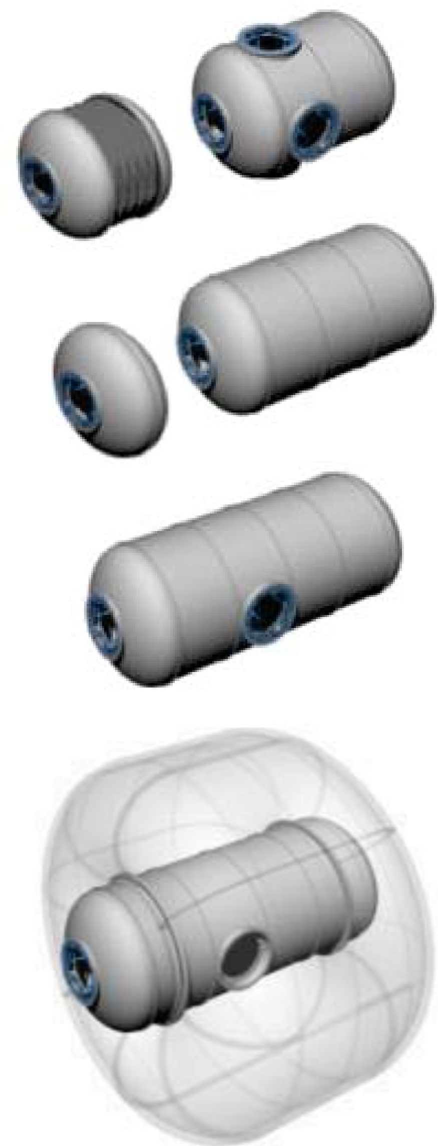
What is Habitat Modularity?

- **Habitat Modularity:**
  "…Buildup of a habitat with a complete set of required functionality through the assembly or recombination of multiple habitat modules or modular subsystems within the habitats"

- **Advantages of Modularity:**
  - Increased **flexibility** to alleviate launch constraints
  - Increased **redundancy** through common components
  - Improved propulsive **performance** through customization of habitat size (mass & volume) to mission duration

- **Disadvantage of Modularity**
  - Increased complexity, risk, or mass

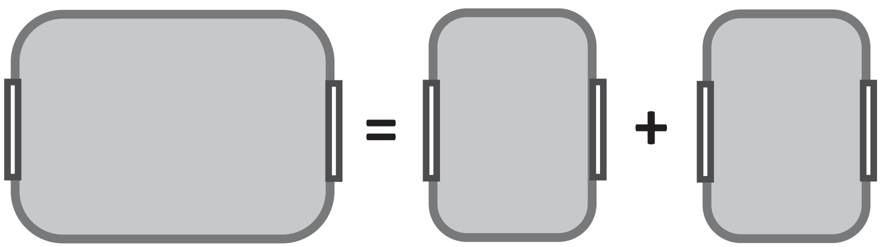
- **Modularity Drivers**
  - Monolithic habitat which exceeds launch vehicle capability (ISS)
  - Enables incremental buildup of habitat capability for longer missions (Commercial Human Exploration beyond LEO)



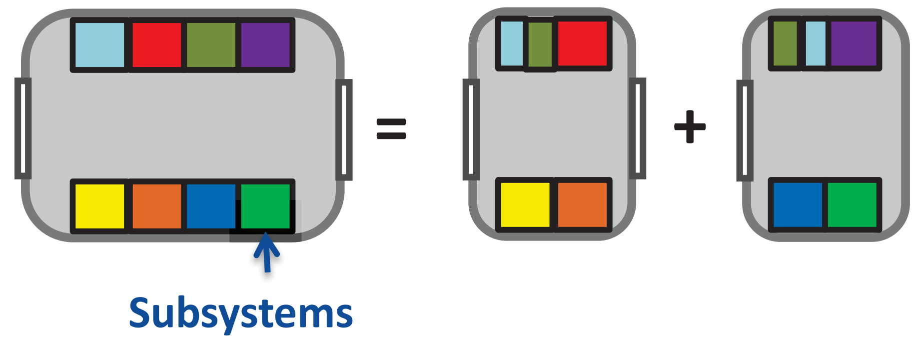
Images Courtesy of NASA

Categories of Modularity

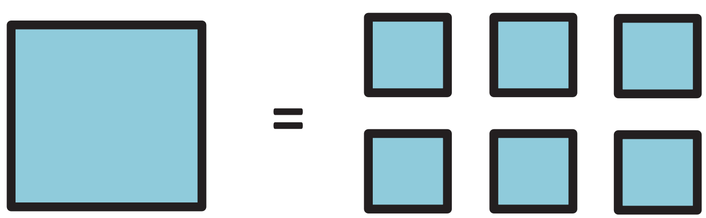
Pressure Vessel Modularity



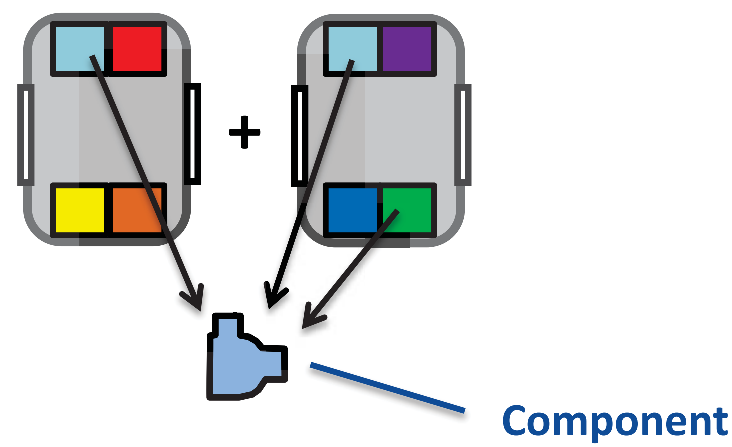
Distributed Subsystem Functionality



Subsystems Modularity



Commonality across Subsystems

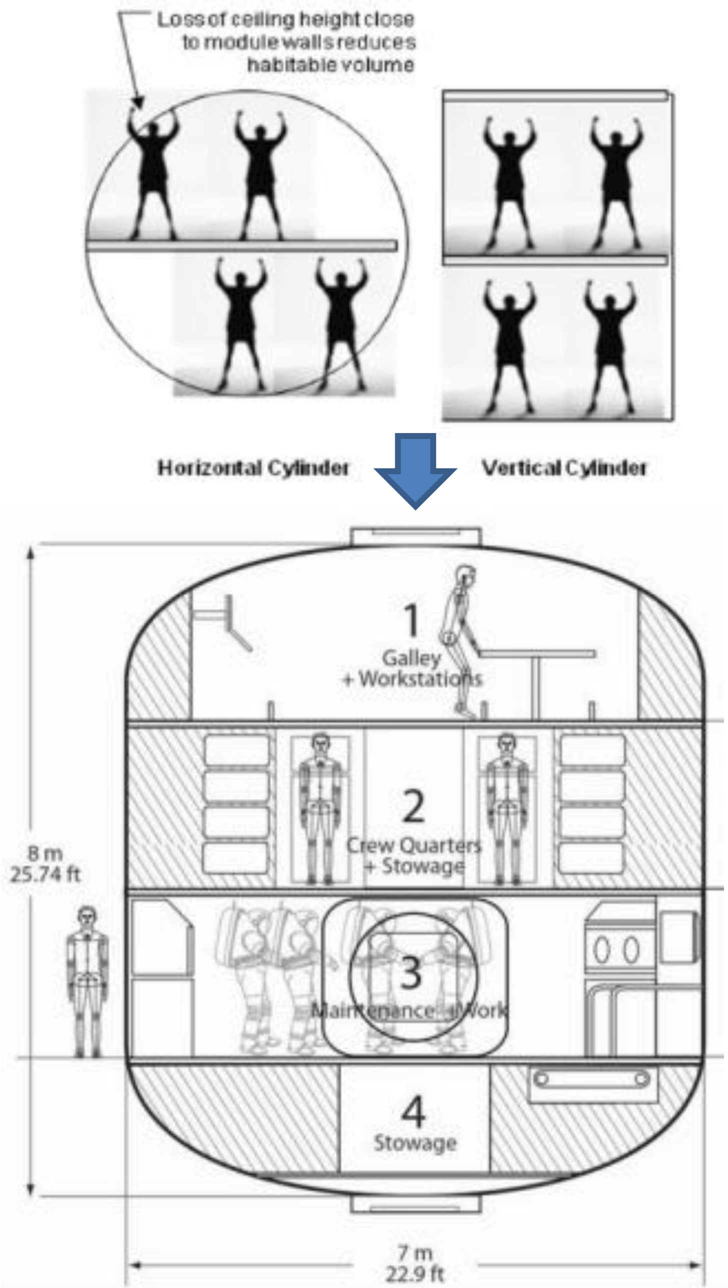


Sample DSH Study

- 4 crew, 380 day Near Earth Asteroid rendezvous mission
- Elements:
  - SEP = Solar Electric Propulsion
  - DSH = Deep Space Habitat
  - MMSEV = Multi Mission Space Exploration Vehicle
  - CPS = Cryogenic Propulsion Stage
  - Orion = Crew Exploration Vehicle

Ref 6

Deep Space Habitat Layout



Parameter	DSH	* Mir	† Skylab	‡ TransHab	§ BA 330	¶ 6-Crew ISS
Crew	4	2 – 6 (3 typ.)	3	6	6	6
Mission Duration	380 Days	Up to 437 Days	Up to 84 Days	180 Days	180 Days Per Expedition	180 Days Per Expedition
Length	8 m (26.25 ft)	14.4 m (Spektr Module) (47.2 ft)	14.66 m (Workshop Module) (48.1 ft)	11 m (36 ft)	14 m (45 ft)	8.5 m (Destiny Module) (27.9 ft)
Diameter	7.0 m (22.97 ft)	4.15 m max. (13.6 ft)	6.7 m (Workshop Module) (22 ft)	8.2 m (27 ft)	6.7 m (22 ft)	Typ. 4.2 m (13.8 ft)
Total Pressurized Volume	274.9 m^3 (9,708 ft^3)	380.1 m^3 (13 419 ft^3)	>345 m^3 (12,184ft^3)	339.8 m^3 (12,000 ft^3)	330 m^3 (11,653.8 ft^3)	Total 916 m^3 (32,348 ft^3)
Pressurized Volume per Crewmember	68.73 m^3 (2,427 ft^3)	126.7 m^3 w/3 crew (4,474 ft^3)	>115 m^3 (4,061 ft^3)	56.63 m^3 (2,000 ft^3)	55 m^3 (1,942 ft^3)	152.7 m^3 (6crew) (5,393ft^3)
Habitable Volume per Crewmember	33.12 m^3 (1,170 ft^3)	--	115 m^3 (4,061 ft^3)	--	--	64.67 m^3 (2,284 ft^3)

Table 1: Comparison of DSH pressurized volume against historical spacecraft

Note: This DSH mission shows twice the duration in half the volume as an ISS Expedition

Deep Space Habitat Concept Demonstrators

- Deep Space Habitat concepts mature under Advanced Exploration System Program, Habitat Systems Project from 2010-2013
- Project web page
  - http://www.nasa.gov/exploration/technology/deep_space_habitat/index.html
  - Includes X-Hab university projects and analog test summaries
- Concept Demonstrators Developed
  - Habitat Demonstration Unit - DSH
  - ISS-derived DSH

Human Exploration Systems

Elements

- Crew Return Vehicle
- Deep Space Habitat (DSH)
- Space Exploration Vehicle
- Propulsion Stage
- EVA Capabilities
- Power Generation & Storage
- Deep Space Communications

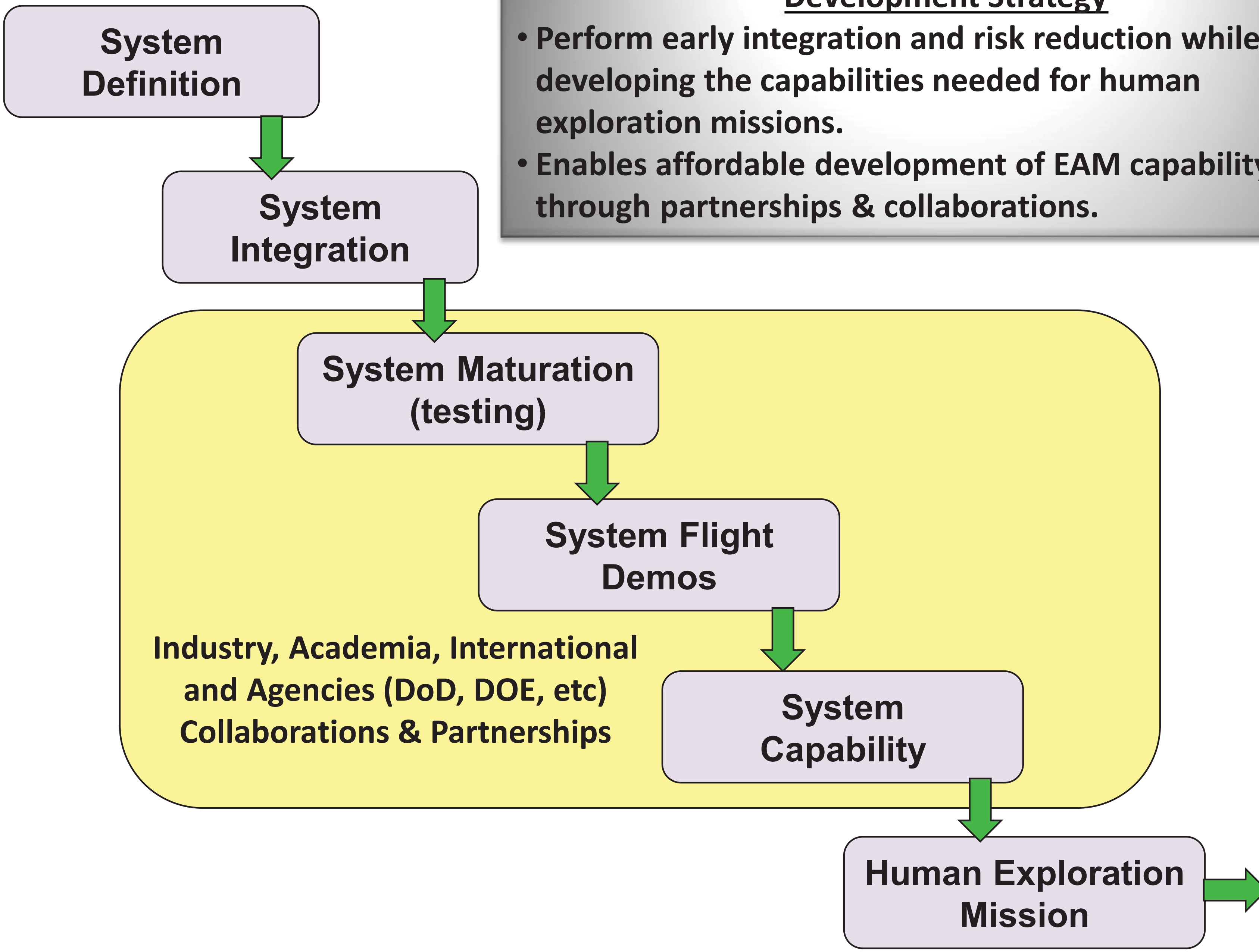
DSH Systems

- Structure
- Environmental Protection
- Life Support System
- Power Management & Distribution
- Thermal Control System
- Crew & Medical Systems
- Laboratory Systems (Geo, Tele-Robotics, Life Science)
- Logistics, Repair, & Manufacturing

Deep Space Hab Capability Development Strategy:
Integrated Work System

Development Strategy

- Perform early integration and risk reduction while developing the capabilities needed for human exploration missions.
- Enables affordable development of EAM capability through partnerships & collaborations.



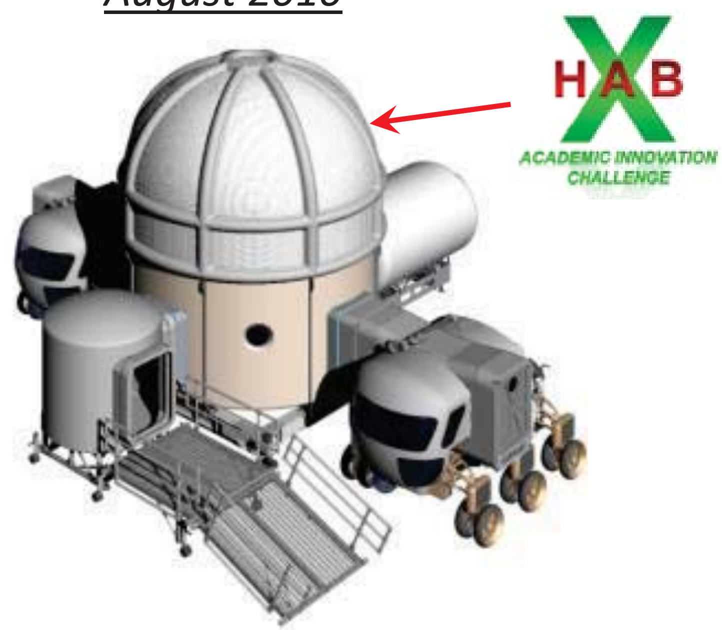
From PowerPoint to Demo Unit

Pressurized Excursion Module

June 2009

August 2010

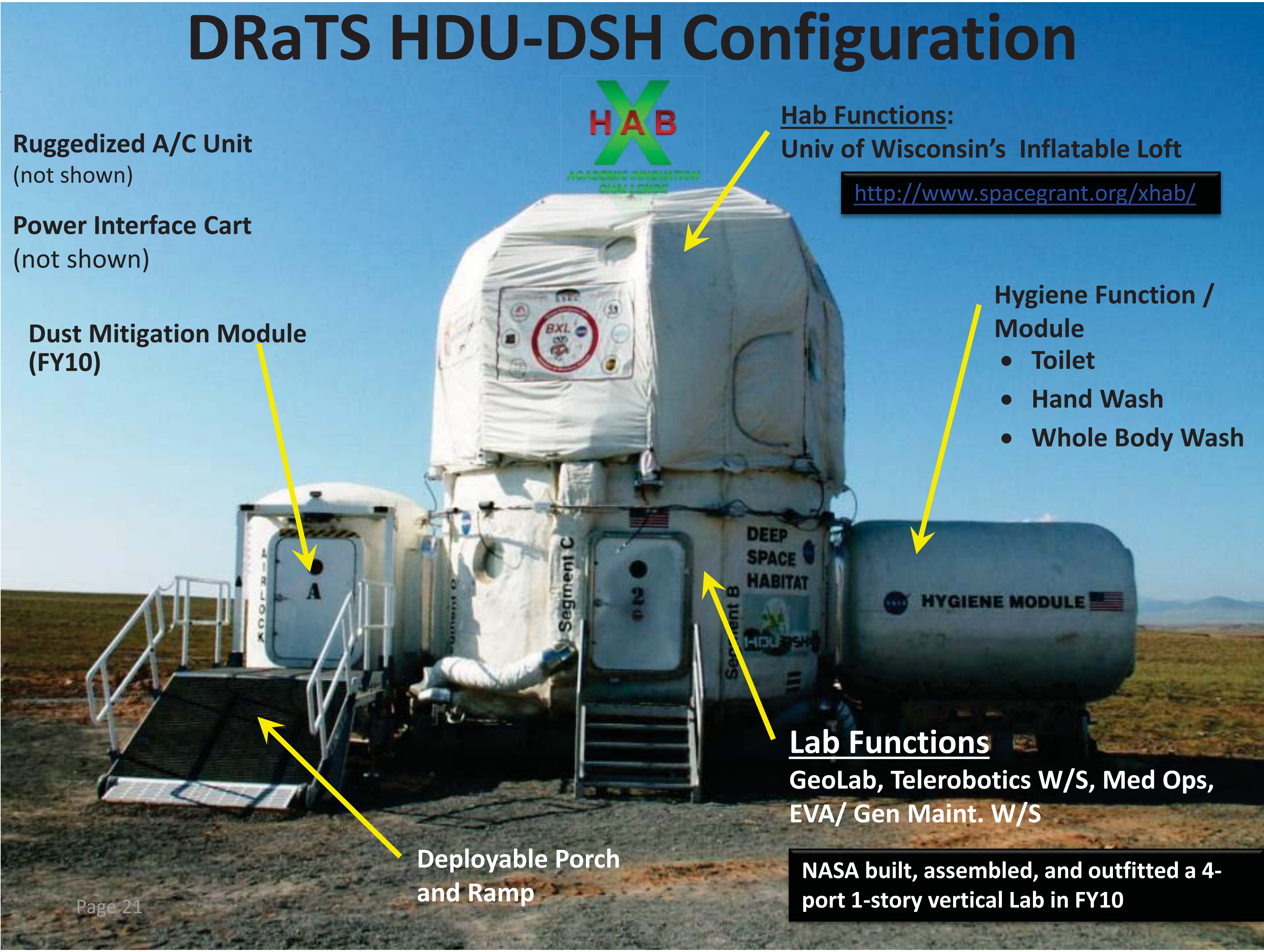
Deep Space Habitat



September 2010

~ August 2011

DRaTS HDU-DSH Configuration



Ruggedized A/C Unit
(not shown)

Power Interface Cart
(not shown)

Dust Mitigation Module (FY10)

Hab Functions:
Univ of Wisconsin's Inflatable Loft

http://www.spacegrant.org/xhab/

Hygiene Function / Module
- **Toilet**
- **Hand Wash**
- **Whole Body Wash**

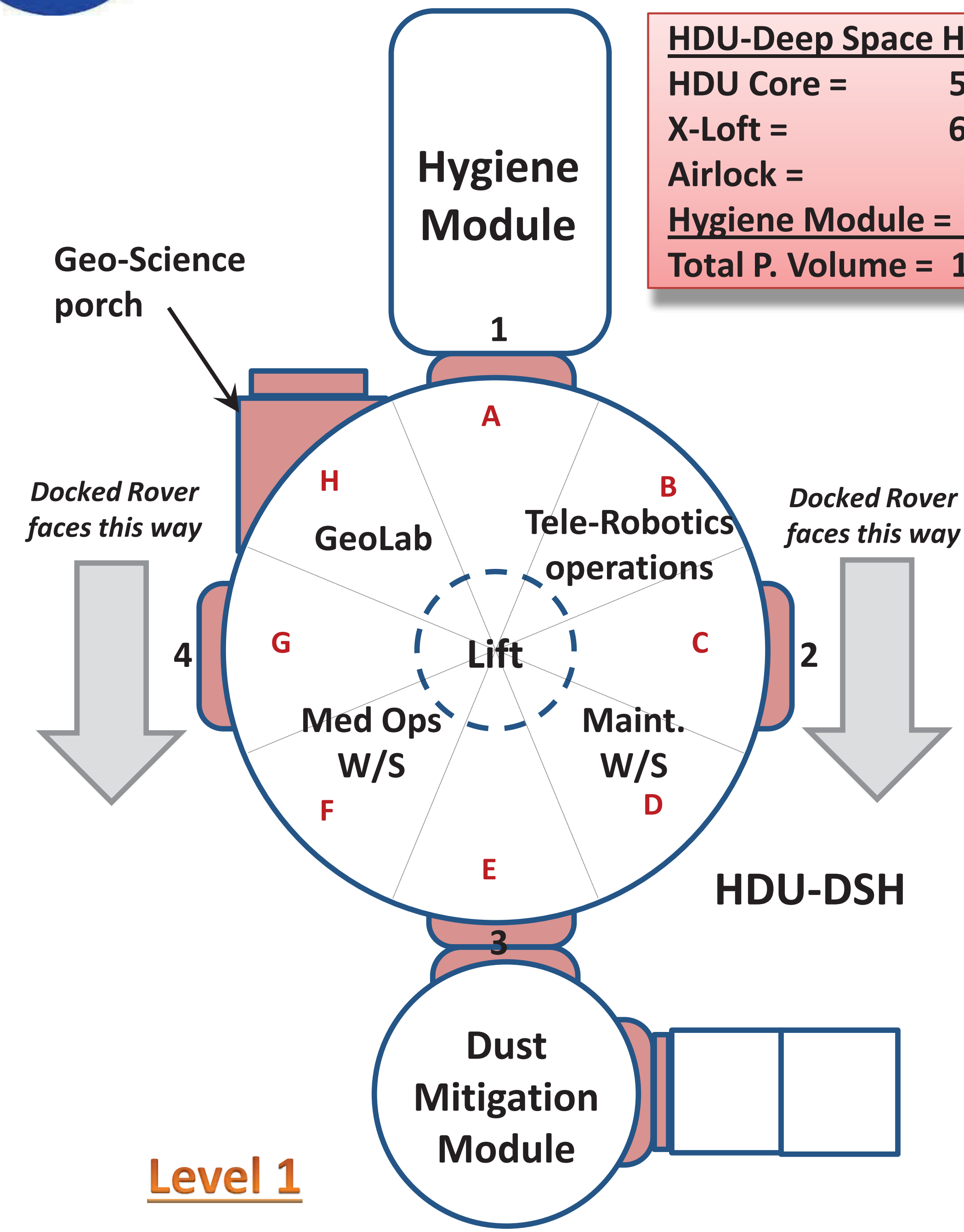
Lab Functions
GeoLab, Telerobotics W/S, Med Ops, EVA/ Gen Maint. W/S

Deployable Porch and Ramp

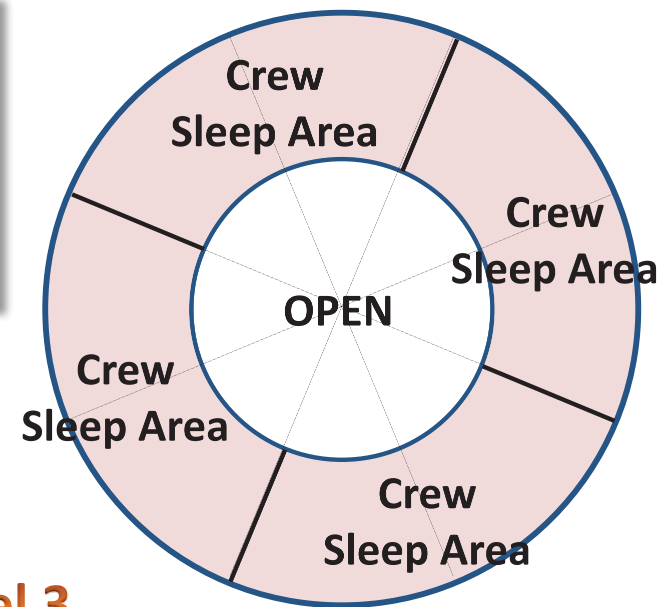
NASA built, assembled, and outfitted a 4-port 1-story vertical Lab in FY10

HDU-DSH Plan Views

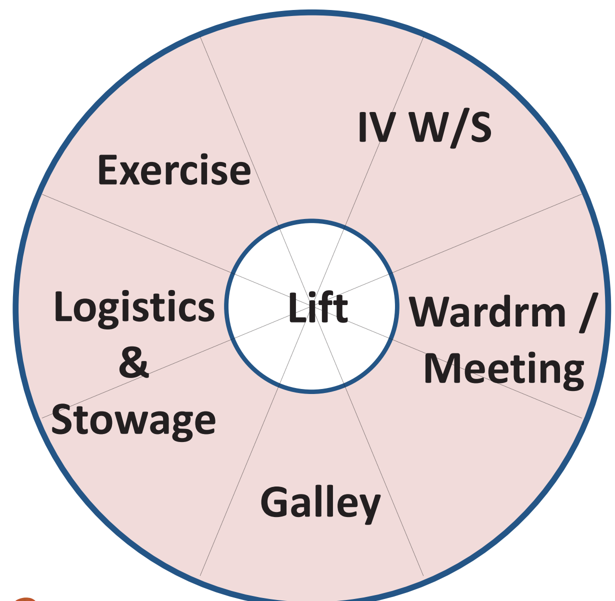
HDU-Deep Space Hab:	
HDU Core =	56.0 m^3
X-Loft =	69.9 m^3
Airlock =	8.6 m^3
Hygiene Module =	14.1 m^3
Total P. Volume =	148.1 m^3



Level 1



Level 3



Level 2


HDU Lab deck


Dust Module
3

X-Hab Inflatable Loft

Hygiene Module

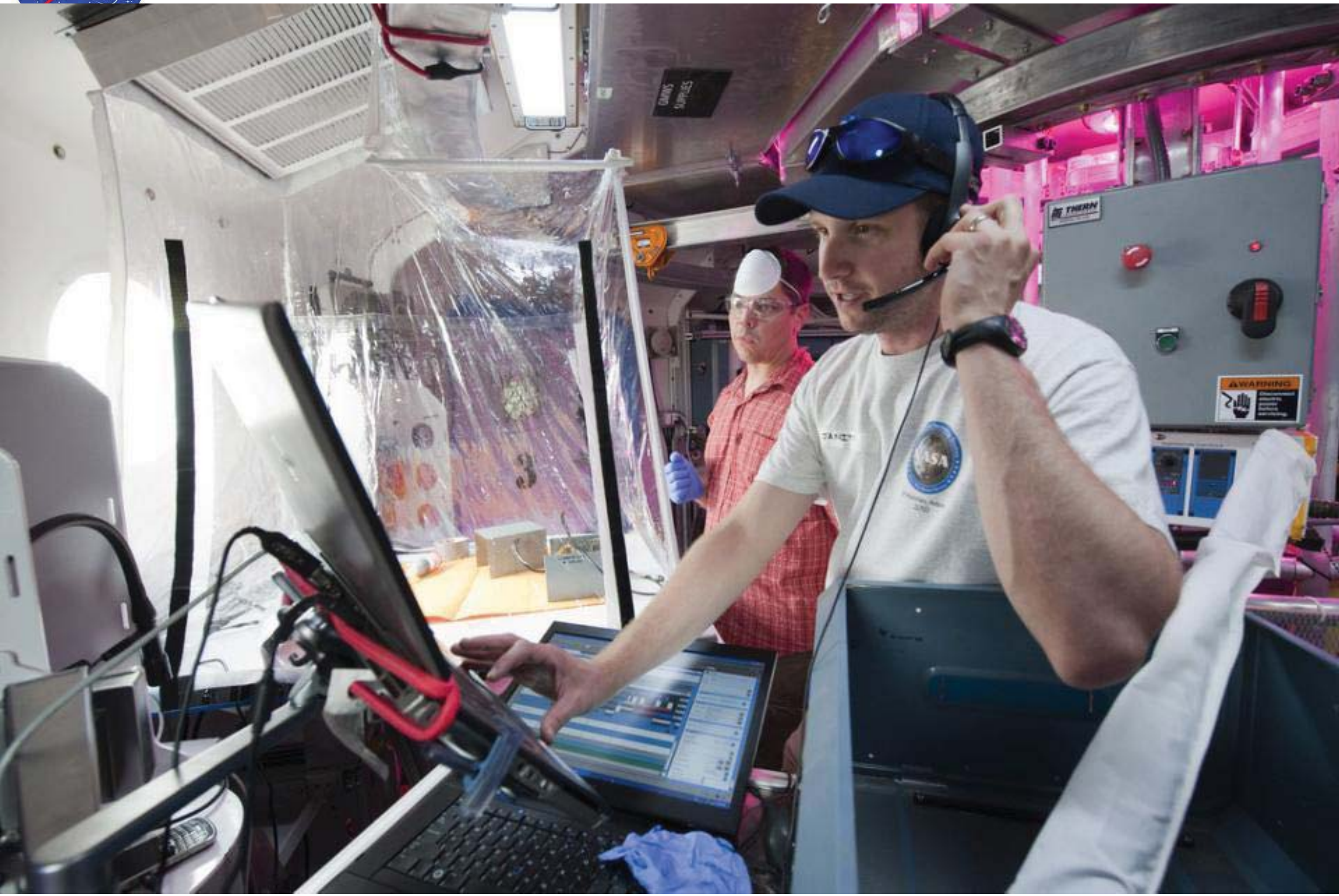
Geo-Lab Glovebox

Robotically-Assisted GeoScience Operations

Tele-Robotics Work Station

Megan at the Gen Maintenance W/S

Jake and Bob at General Maintenance W/S



Medical Operations Work Station

Waste & Hygiene Functions

X-Hab Loft Academic Innovation Challenge

Oklahoma State University
June 6-10, 2011

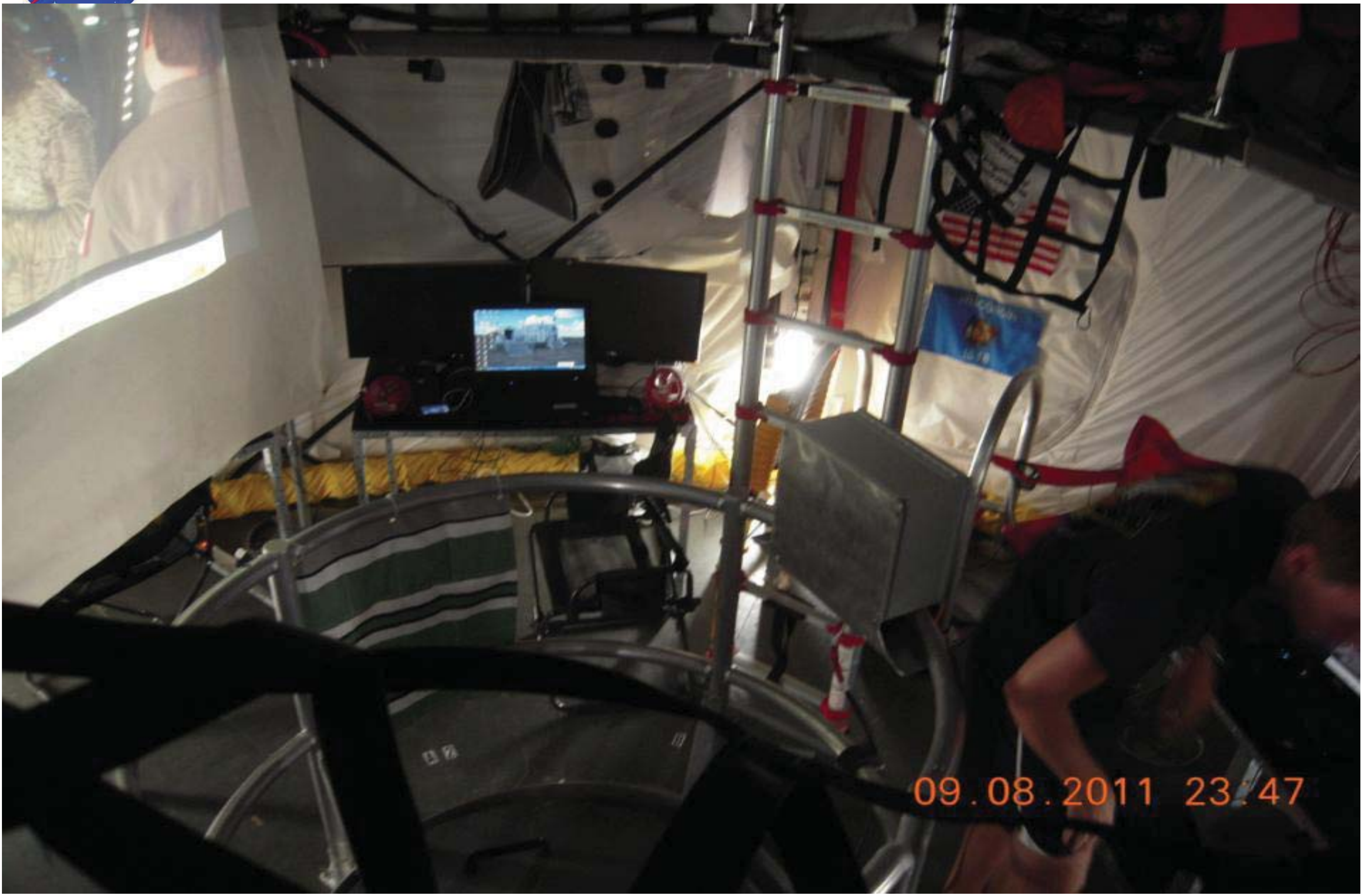
University of Maryland
June 13-17, 2011

CONGRATULATIONS to the 2011 X-Hab Academic Innovation Challenge Winners -
University of Wisconsin – June 20-24, 2011

Channels (flex duct) to Internal Air Ductwork

X-Hab Loft: Habitation Function

X-Hab Loft: Habitation Function



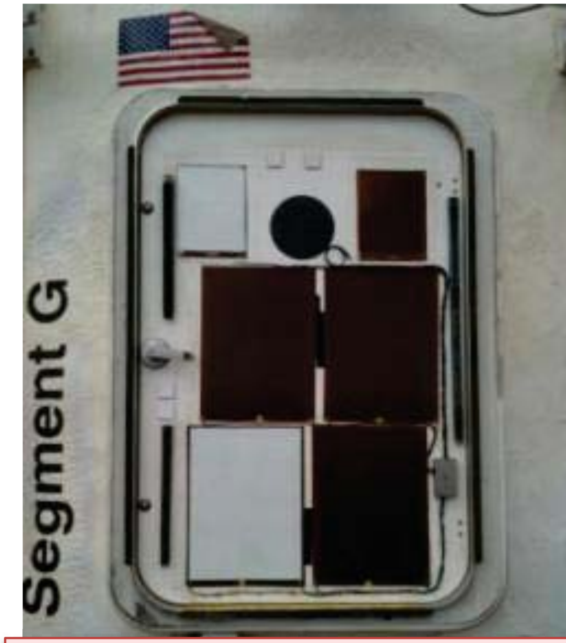
Intelligent Habitat (iHab) Operating System

2011 HDU-DSH Research and Technology Demonstrations

- "Intelligent" Hab System Management Software
- Power management systems
- Extra-Vehicular Activity (EVA) System
- HDU Core Computing, Networking and Communications Infrastructure
- Wireless Comm & RFID
- Communications Service Assembly (CSA)
- Standards-based Modular Instrumentation System
- Flat Surface Damage Detection
- Particle Impact Monitoring System
- Medical Operations (Med Ops)
- Geo-Science Lab
- LED Lighting
- Logistics to Living (L2L) demonstration and use
- Trash management - odor control
- Habitability / Habitation
- Advanced life support systems *
- Environmental Protection *
- Food Production *

Technology Demonstrations

Food Production in Atrium



Dust Mitigation: Electrodynamic Dust Shield & Lotus Coating

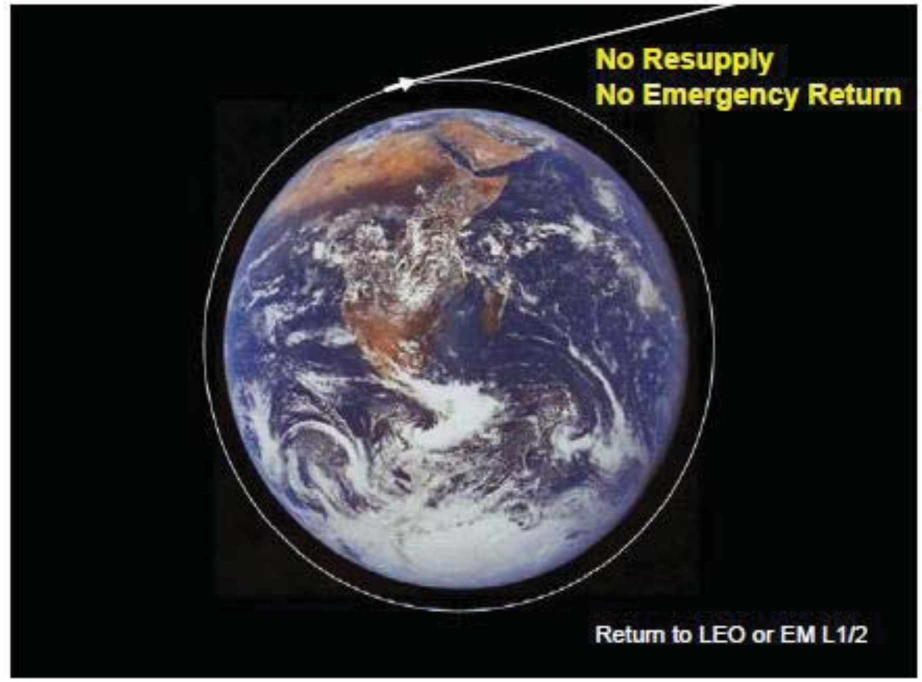
Damage Detection System

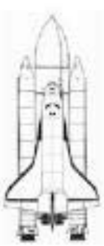
Cargo Transfer Bag Radiation Protection Water Walls

Different Missions, Different Solutions

ISS Close to Earth

DSH Distant Missions





Logistics Delivery Necessary (rack modularity

- Outfitting (launched with 5 system racks)
- Resupply consumables
- Parts for servicing and repair

No Habitat on ISS

Possible rapid (emergency) return

No Logistics Flights

- Departs LEO with all outfitting
- Carries provisions for continuous operations
- Carries provisions for servicing and repair

DSH is a Habitat (vs. Lab)

No Rapid (emergency) return

Therefore: Rack architecture not necessary; Emphasize design for habitation and provide for easy access to ORUs and utilities

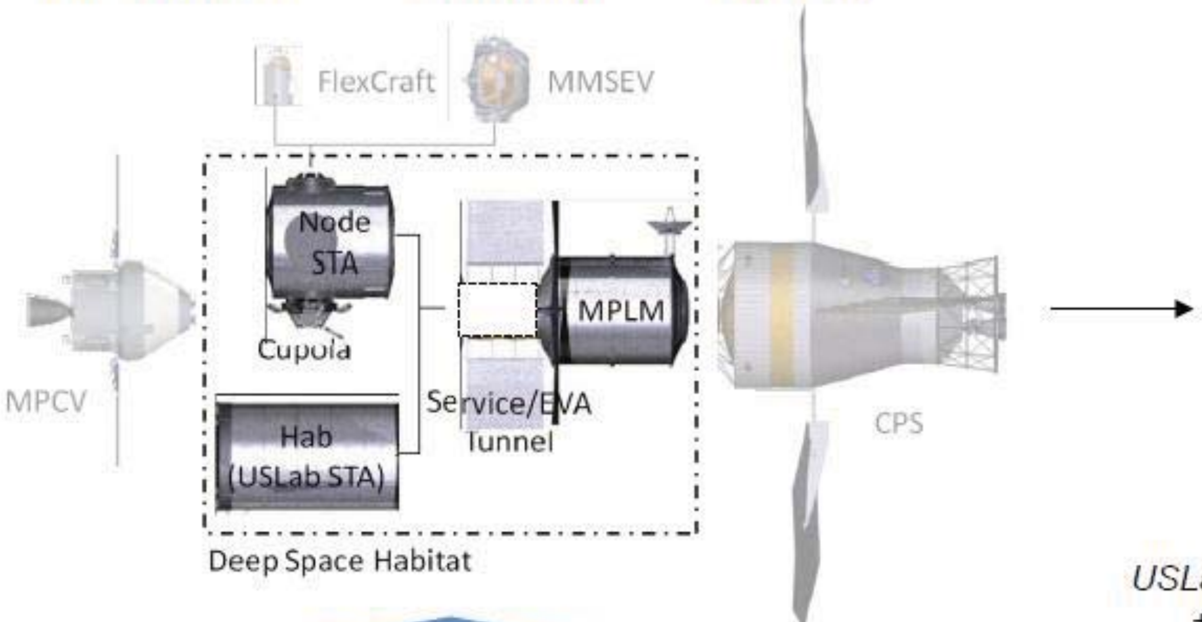
Proposed Solution

ISS Structural Shells

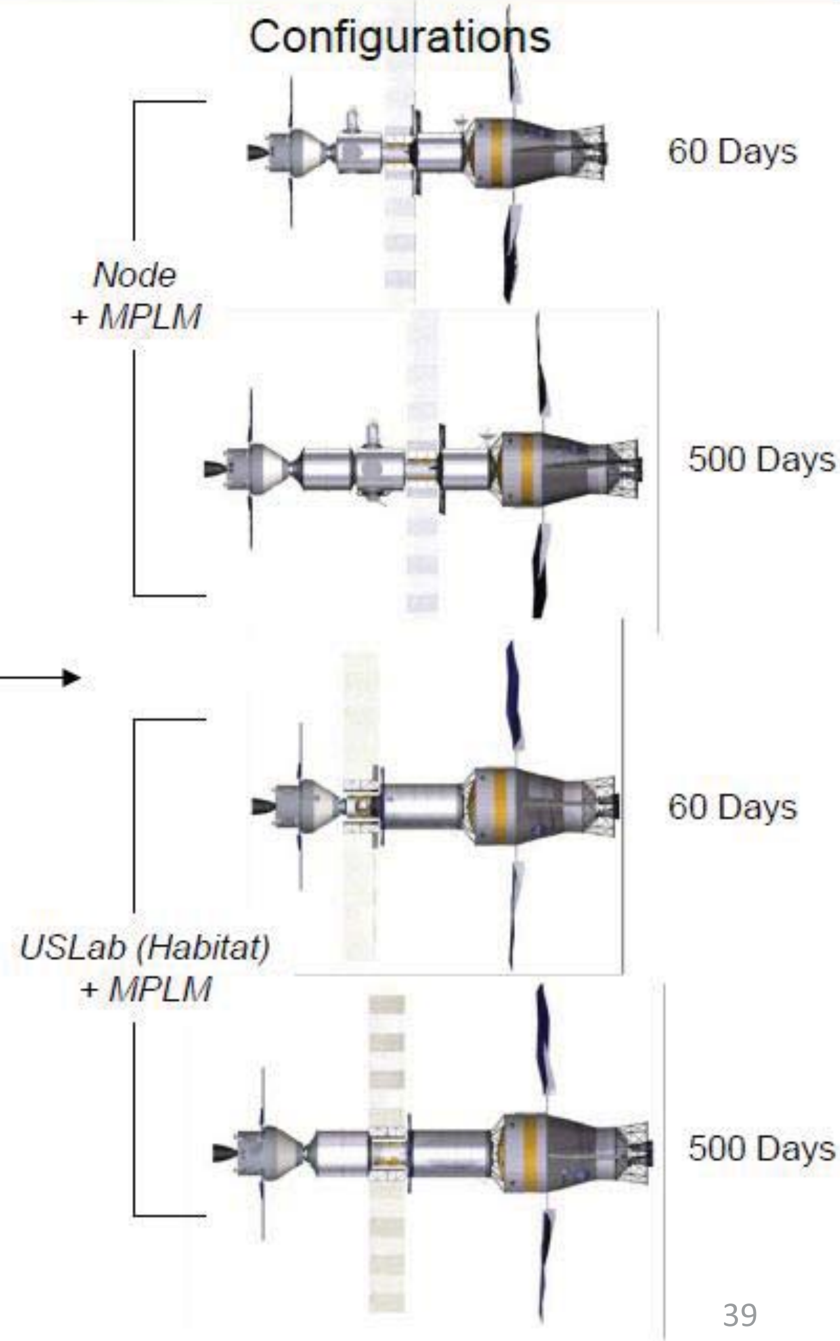

Hab Shell (MSFC)


MPLM (KSC)


Node (KSC)



Configurations

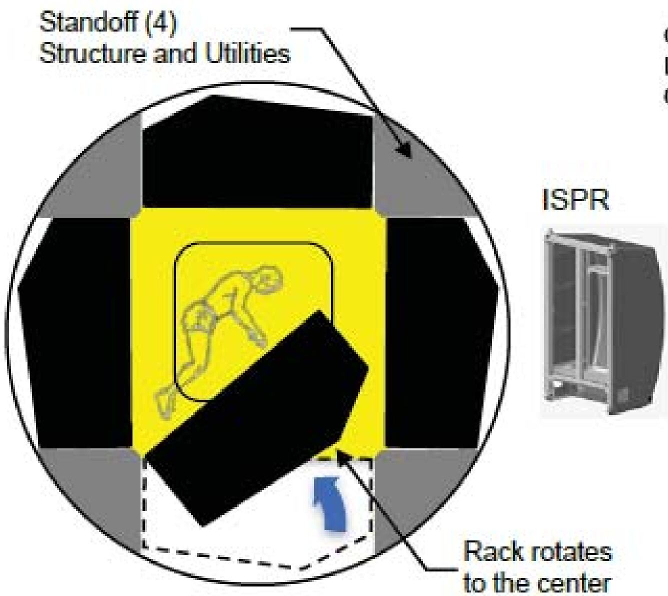


Subsystems

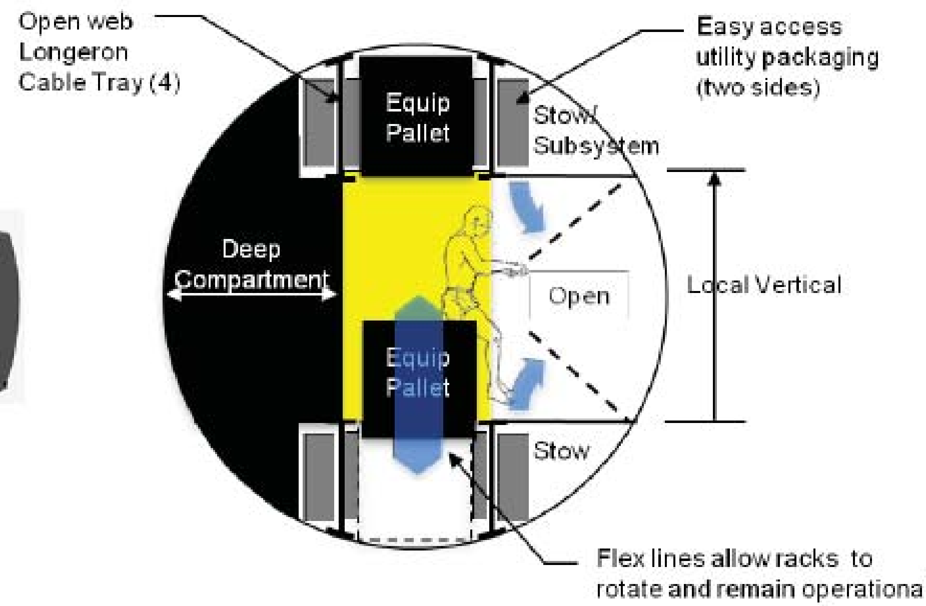
Structures	Thermal Control
Mechanisms	Electrical Power
Crew Systems	Avionics
ECLSS	Protection

Improved Internal Layout

ISS Rack Based Layout



ORU-Tailored Layout



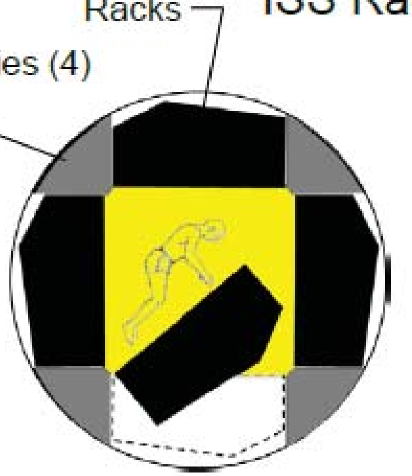
ISSUES:
Rack packaging, complex utilities, access to ORUs and hull

- Crew activities package differently than subsystems
- Subsystems have different access requirements
- Combined Aisle way and Lab work space

- Designed for ORU level Interchangeability
- Local vertical for crew
- Easy access Cable Tray and Hull

Utility Distribution

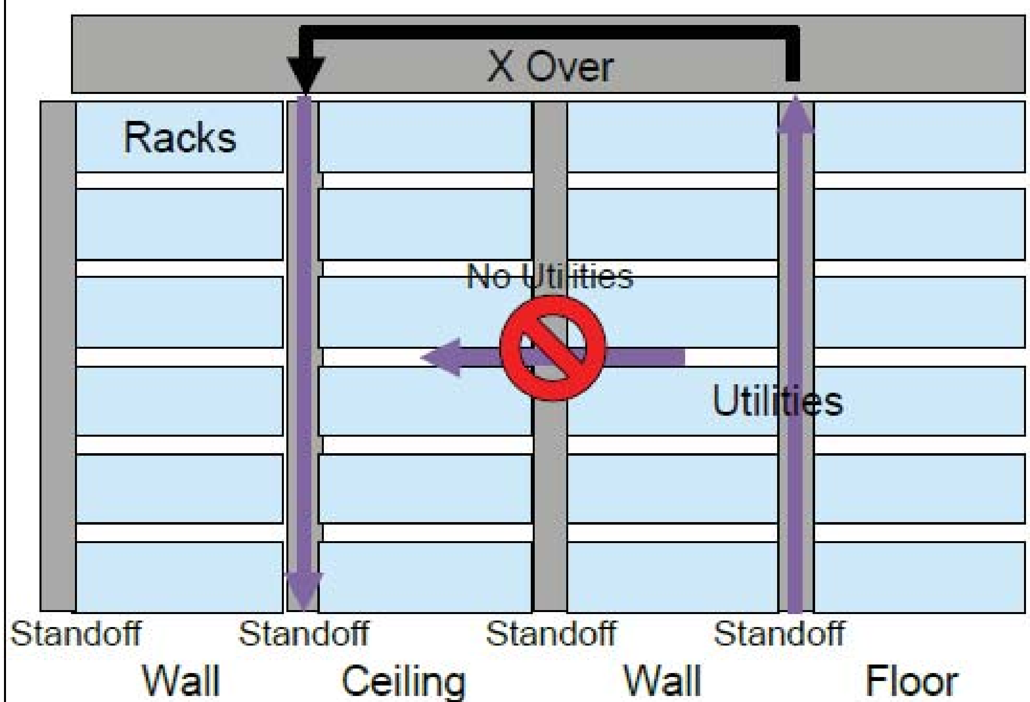
ISS Rack Based



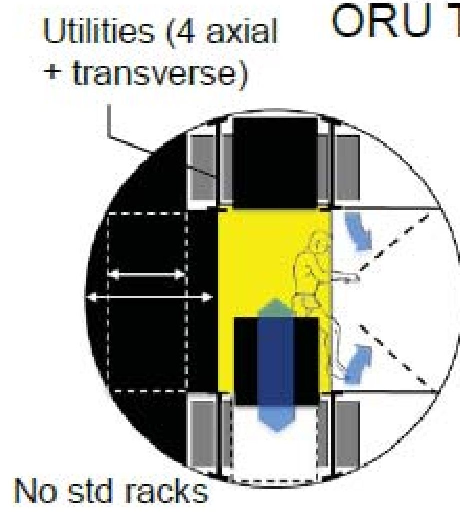
End X-Over
- Long utility runs
- Larger dia ducts
- Noise

Standoff Lighting
- Two sides
- Easily obscured

•Standoff Air Supply
- Two sides
- Easily obscured



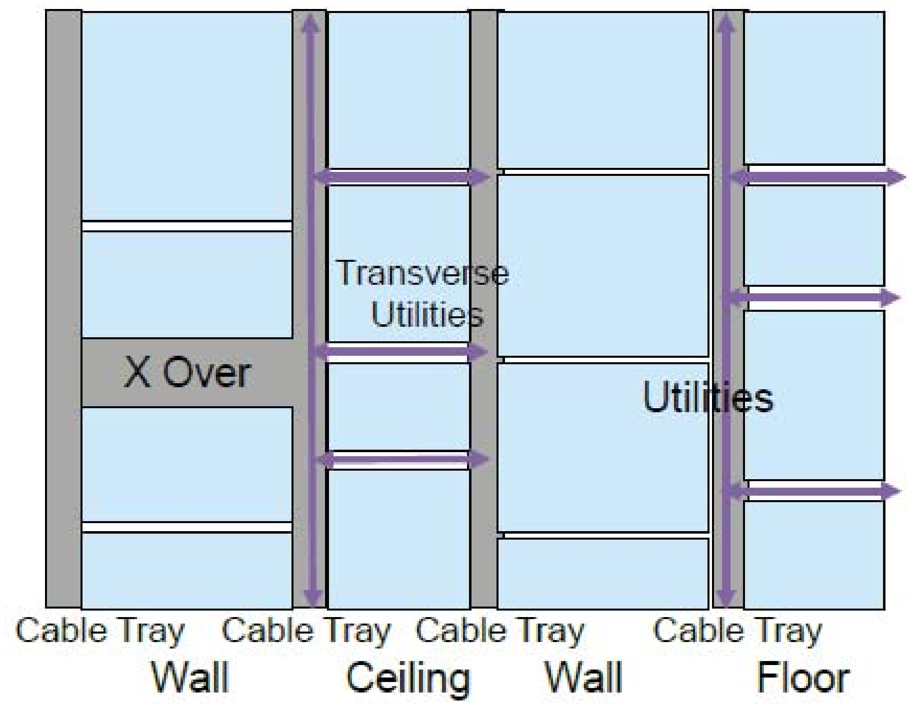
ORU Tailored



Middle X-Over
- Short utility runs
- Smaller dia ducts
- Less Noise
- More usable length

Central Lighting
- One light
- Good illumination

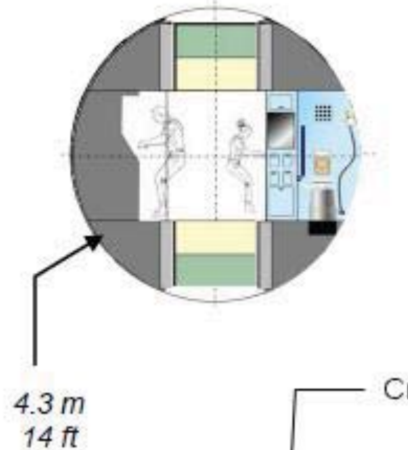
•Central Air Supply
- One diffuser
- Good distribution



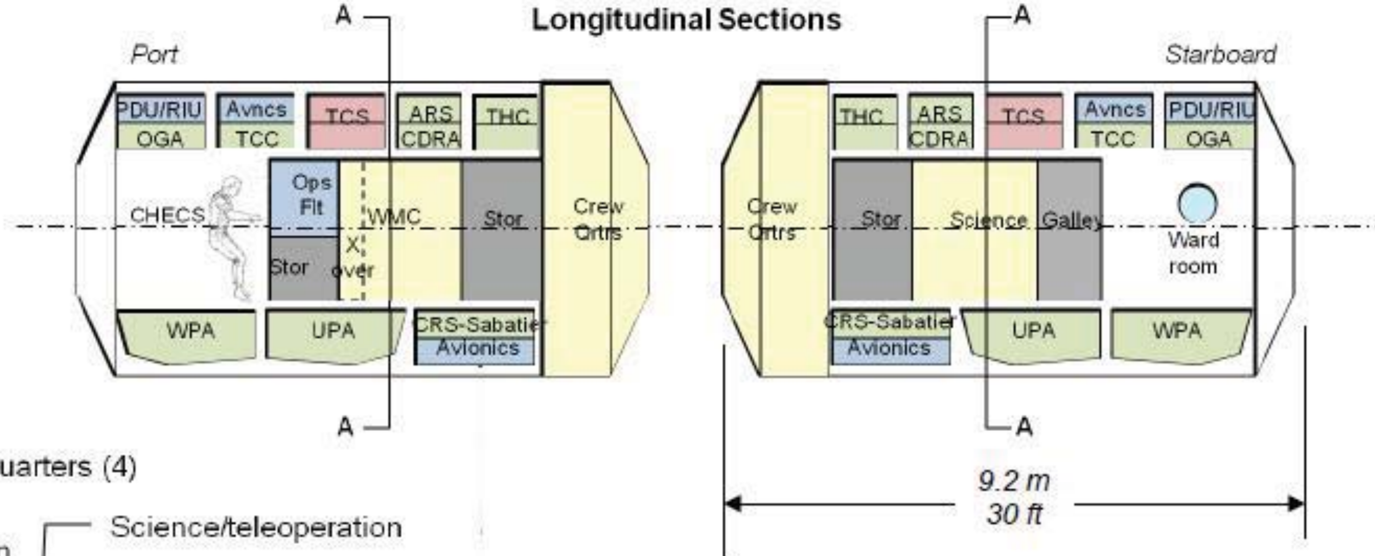
Baseline Configuration

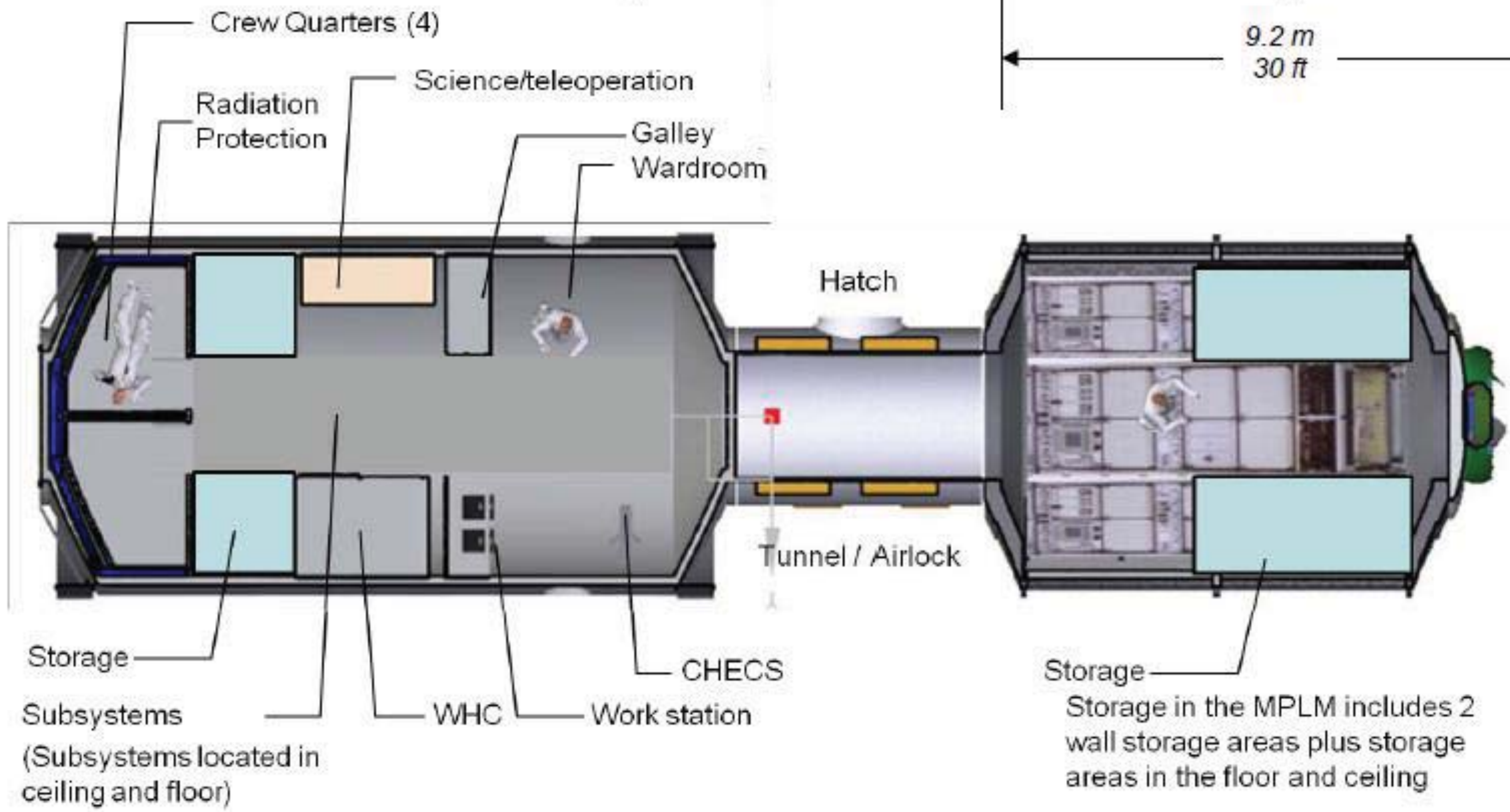
500 Day Mission

Transverse Section AA



Longitudinal Sections

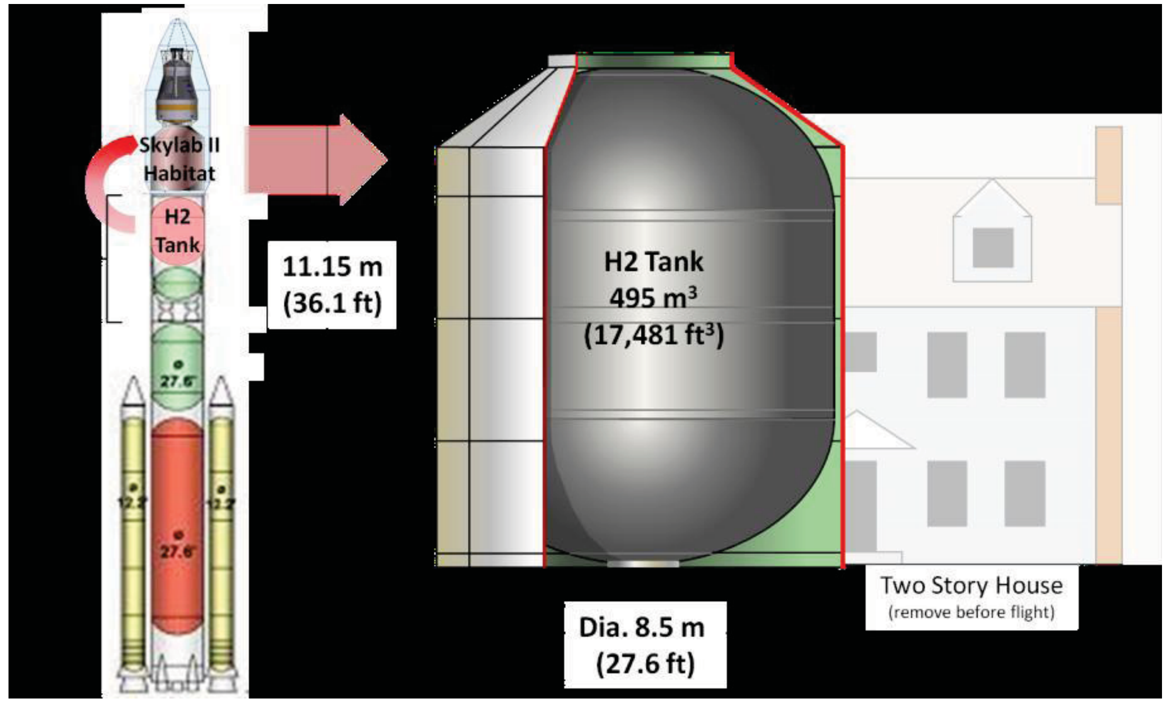


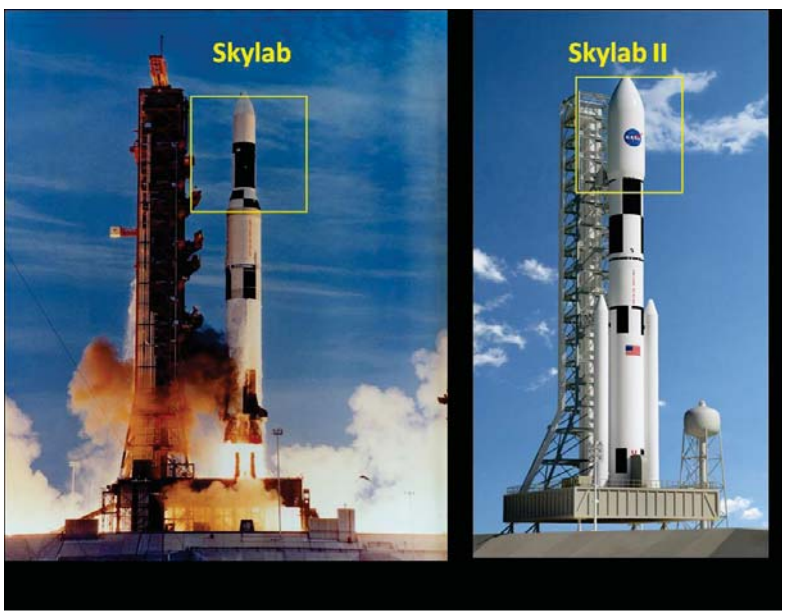


ISS-Derived Deep Space Habitat Evaluation

ISS-derived Deep Space Habitat concept demonstrator at MSFC using combination of mockups, hardware, and digital representations for human factors evaluation

Space Launch System-Derived Habitat





SLS Hydrogen Tank Provides Flight Qualified Structure with Ample Volume for Planned Deep Space Missions.

A team at MSFC currently planning to build a demonstrator for this concept

Exploration Augmentation Module

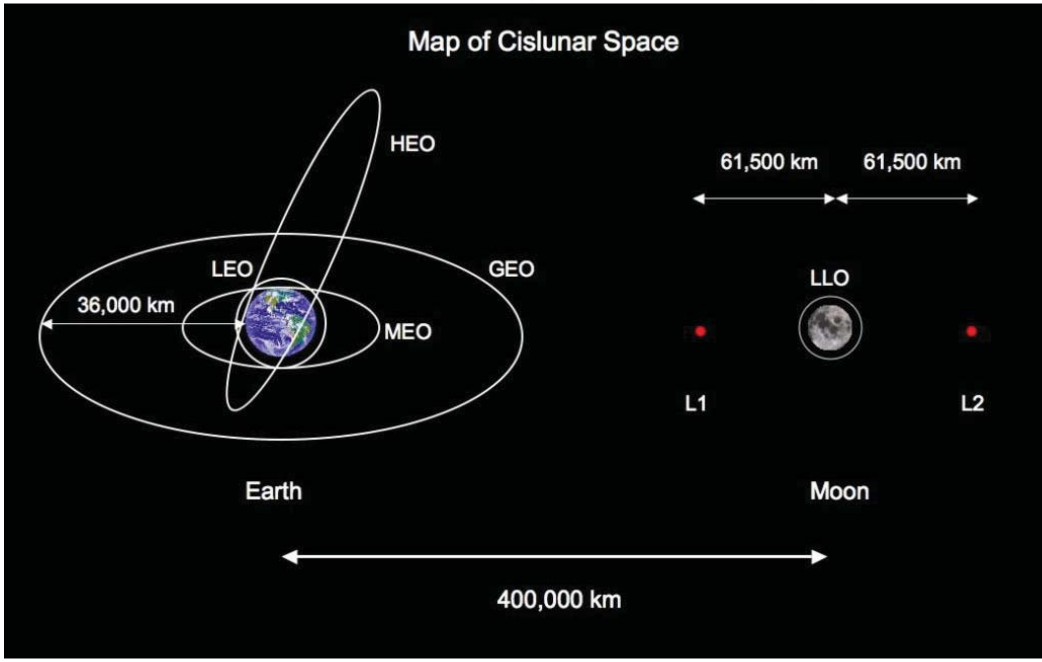
- The Exploration Augmentation Module is a new agency project for Fiscal Year 2014 under the Advanced Exploration Systems (AES) Program of the Human Exploration and Operations Mission Directorate.
- The EAM project will consolidate several existing activities into a prototype system to augment Orion's habitation and extra-vehicular activity capabilities for extended deep space missions.
- Project definition underway and may include international and/or commercial space industry participation.
- Coordinating efforts with Orion to provide synergy and potential advances for Exploration Systems.
- Continuing X-Hab Academic Innovation Challenge for University Teams
  - http://www.spacegrant.org/xhab/

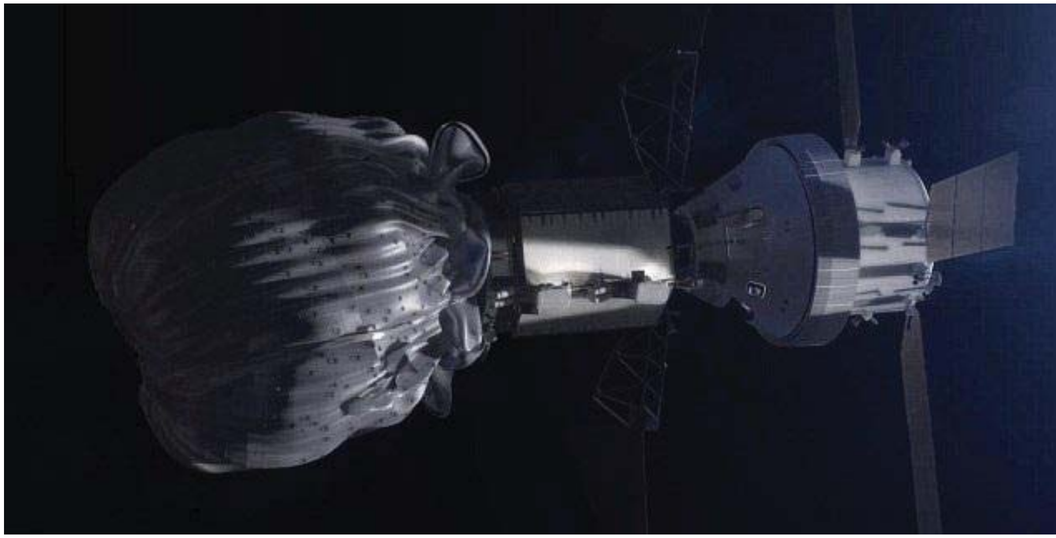
Other NASA Efforts to Further Exploration

- NASA
  - International Space Station extended to at least 2024
  - Space Launch System/Orion
    - Exploration Flight Test 1 (Delta IV) – 2014
    - Exploration Mission 1 (uncrewed) – 2017
    - Exploration Mission 2 (crewed) - 2021 – target for ARM?
  - Commercial Space Transportation for crew and cargo
    - Space X and Orbital currently for ISS Cargo
    - Boeing, Sierra Nevada, and Space X are three funded finalists for Commercial Crew
  - Lunar Catalyst RFI - http://www.nasa.gov/lunarcatalyst
    - Following model of ISS cargo for lunar cargo

Asteroid Redirect Mission (ARM)

- Solar Electric Propulsion driven robotic spacecraft redirects asteroid to lunar Distant Retrograde Orbit (DRO)
- EM-2 mission takes crew to meet asteroid in lunar DRO for EVA and sample collection





Other Efforts to Further Exploration

- Google Lunar X-prize- http://www.googlelunarxprize.org/
  - Milestones to be completed Dec 31, 2015
- Mars One - https://www.mars-one.com/
  - Privately funded venture to send people to Mars – reality TV show (~2023)
- Inspiration Mars - http://www.inspirationmars.org/
  - Potential public/private partnership for Mars flyby (~2021)
- Chinese Lunar Exploration Program
  - Chang'e 3 lander and Yutu rover landed 12/14/13
- International Space Exploration Coordination Group (ISECG) - http://www.globalspaceexploration.org/wordpress/
  - Global Exploration Roadmap and other papers/publications - http://www.globalspaceexploration.org/wordpress/?cat=3

QUESTIONS?

BACKUP CONTENT

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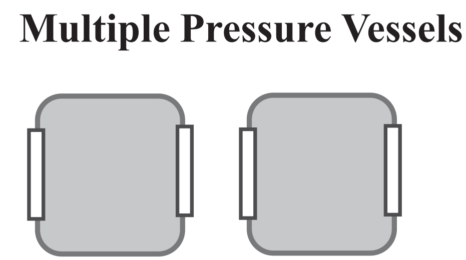
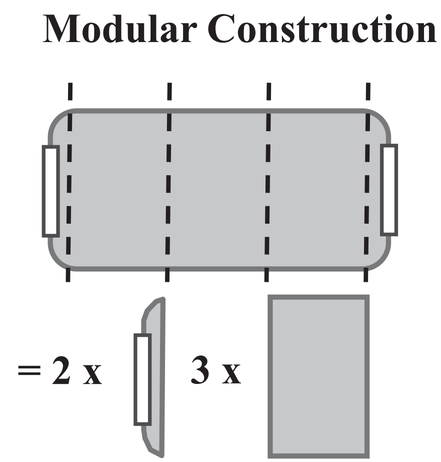
Pressure Vessel Modularity

- **Separation of habitat pressure vessel into multiple pressure vessels or a modular construction approach**

- **Two variations**
  - <u>**Multiple Pressure Vessels**</u>
    - Enables smaller launch vehicles and buildup of capability on-orbit
    - Additional mass required by docking ports, endcaps, and subsystems necessary on each vehicle (e.g. air circulation, power distribution)

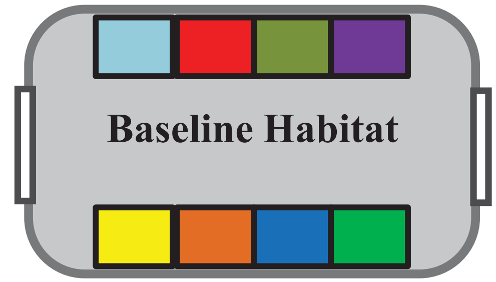


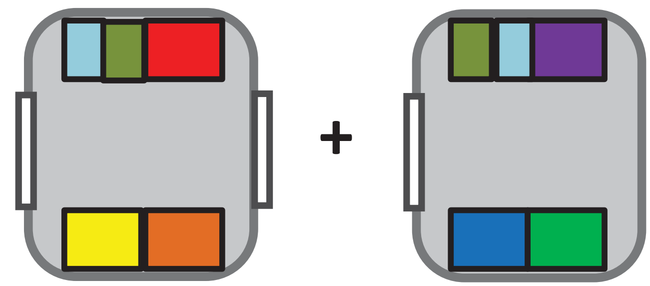
  - <u>**Modular Construction Approach**</u>
    - “Kit of parts” approach to pressure vessel construction (Cylindrical ring segments, customized endcaps)
    - Potential customization of habitat size through number of segments
    - Manufacturing cost savings through standard set of parts across all habitable elements (rovers, airlocks, landers, etc.)



Distributed Functions

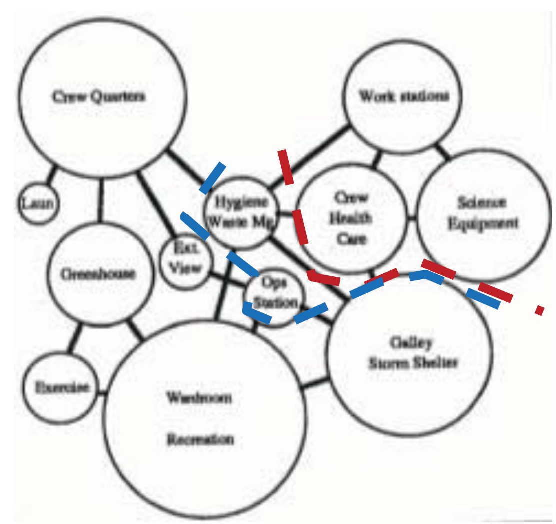
- **The distribution of functions (and corresponding subsystems) across various modules is important in a pressure vessel modularity approach**





- **Some functions are present in each separate module**
  - Atmosphere Pressurization and Circulation
  - Thermal Control
  - Power Generation and Distribution
  - Fire Detection/Suppression

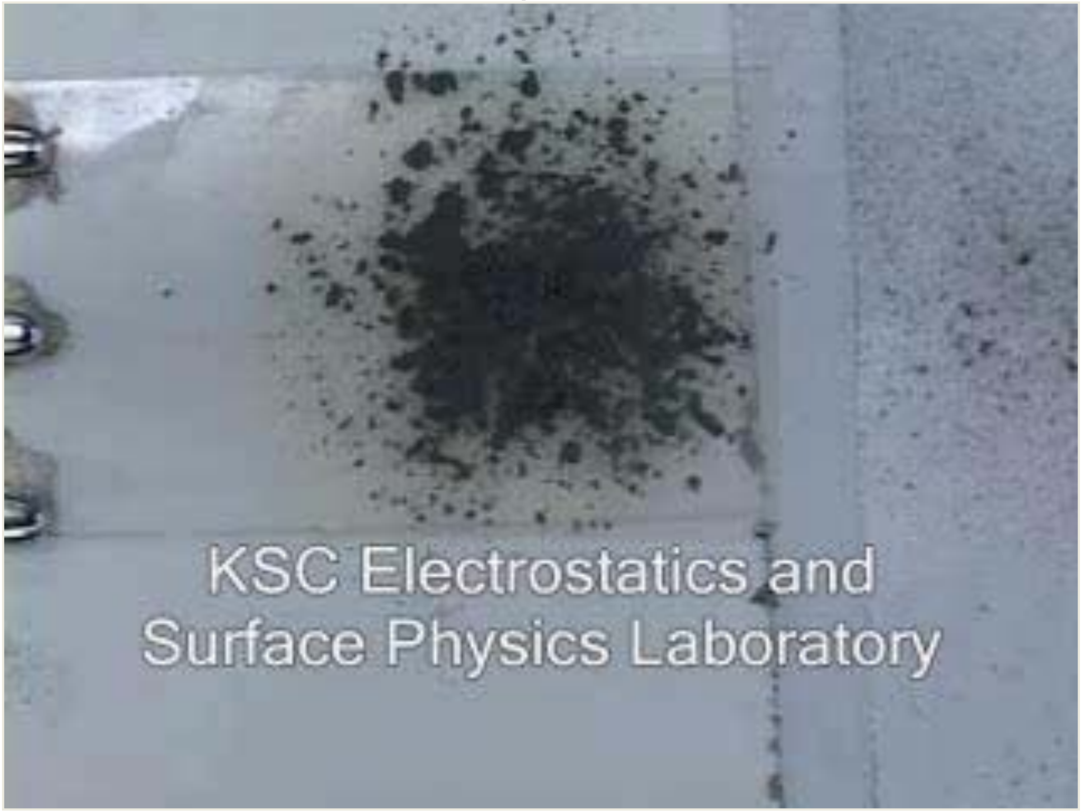
- **Four considerations for distribution of functions**
  - <u>**Interrelationships between the functions**</u>
    - e.g. Separation of work and recreation spaces, shared equipment, separation of noisy and quiet areas
  - <u>**Layout concerns addressing use of volume**</u>
    - e.g. Prevention of crowding, adequate space for tasks,
  - <u>**Historical placement of subsystems**</u>
    - e.g. Collocate Galley and Wardroom, acceptable separations
  - <u>**Emergency Response Scenarios**</u> (i.e. Safe haven)

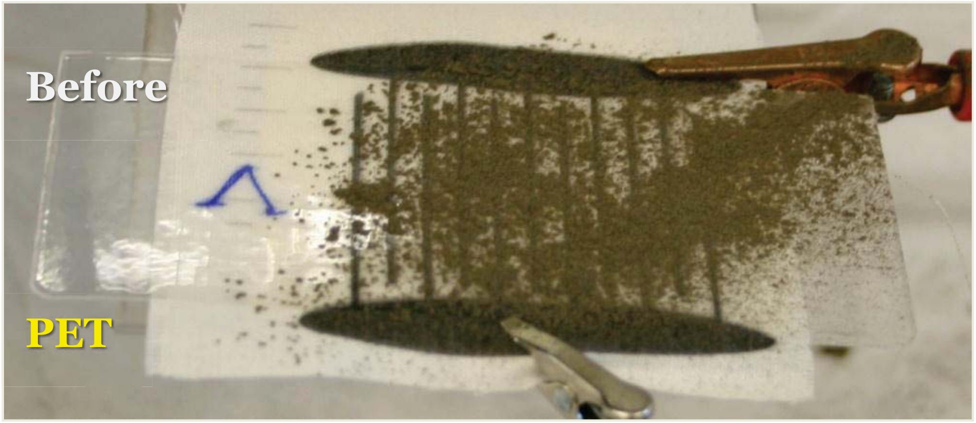


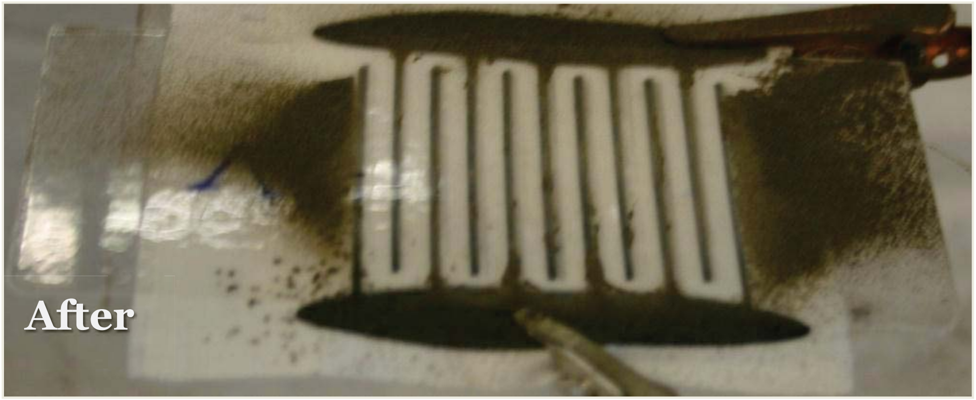
Modularity Conclusions and Future Work

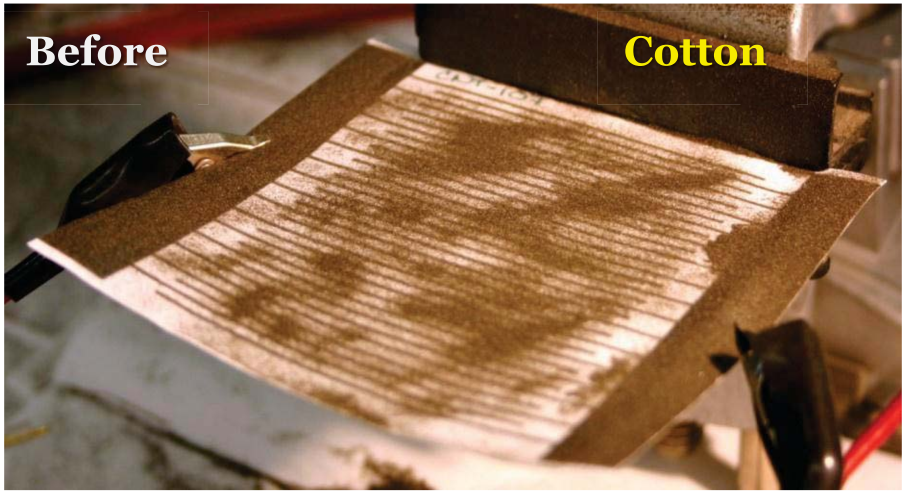
- **Slight changes to the design approach for habitats can improve launch vehicle performance, in-space propulsion performance, cost, and complexity of the overall campaign to enable human exploration missions, particularly in the context of a campaign of missions**
- **An integrated assessment of risk needs to be considered**
- **More substantial improvements are possible through the application of more distributed functions, modular subsystems and common components**
- **Development of a modular trade toolset for modular habitat design space exploration and optimization**
- **Investigation of other approaches to modularity including:**
  - Use of mixed inflatable and rigid pressure shells to improve packaging efficiency
  - Module disposal to improve propulsion performance
  - Reclamation of space through reconfigurable interior layouts
  - Assessment of performance of modularized subsystems and their impact on habitat designs
  - Non-segment module modular construction methods
  - Application of modularity principles across all habitable vehicles in an architecture including: rovers, habitats, entry vehicles, landers, etc.

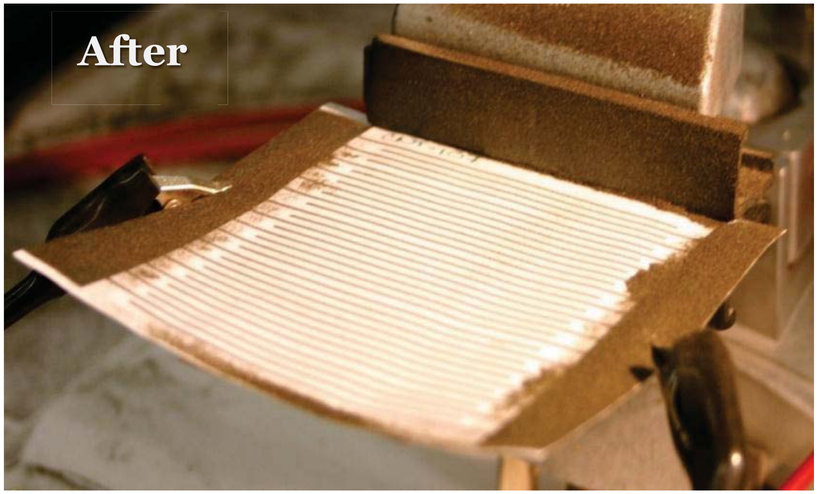
EVA Dust Shields for Space Suits and Habitats





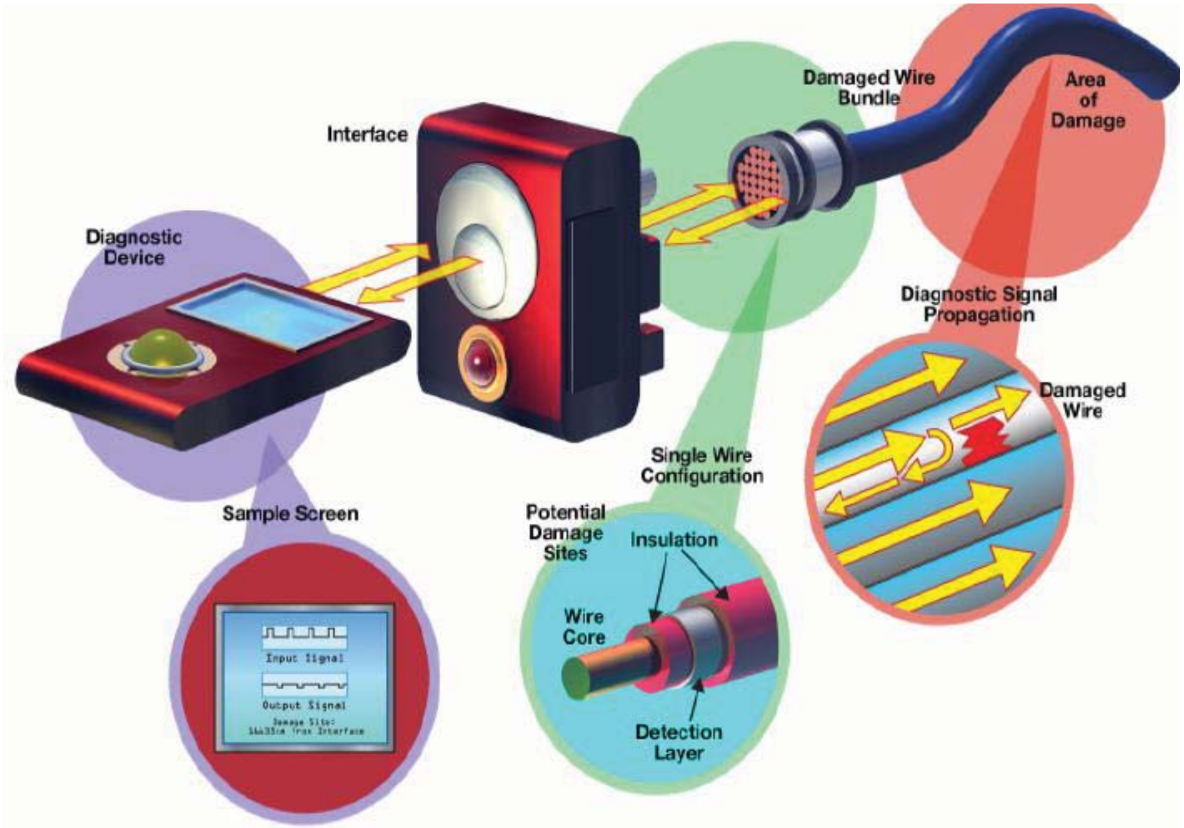


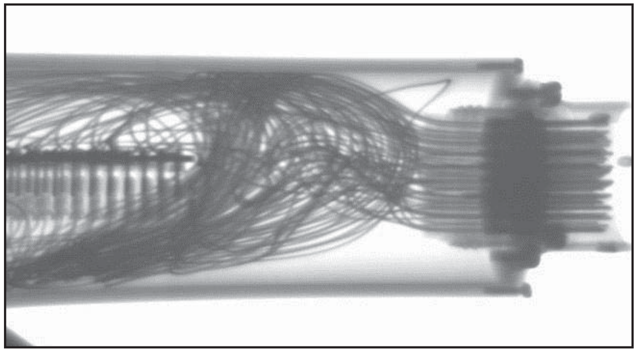




Wire Detection and Monitoring

- In-situ wire damage detection system
  - Capable of wire damage detection "on-the-fly"
- Smart Connectors
  - Small, lightweight, ultra reliable
- Integrated vehicle health monitoring (IVHM)
  - System-of-systems level, providing high level of reliability



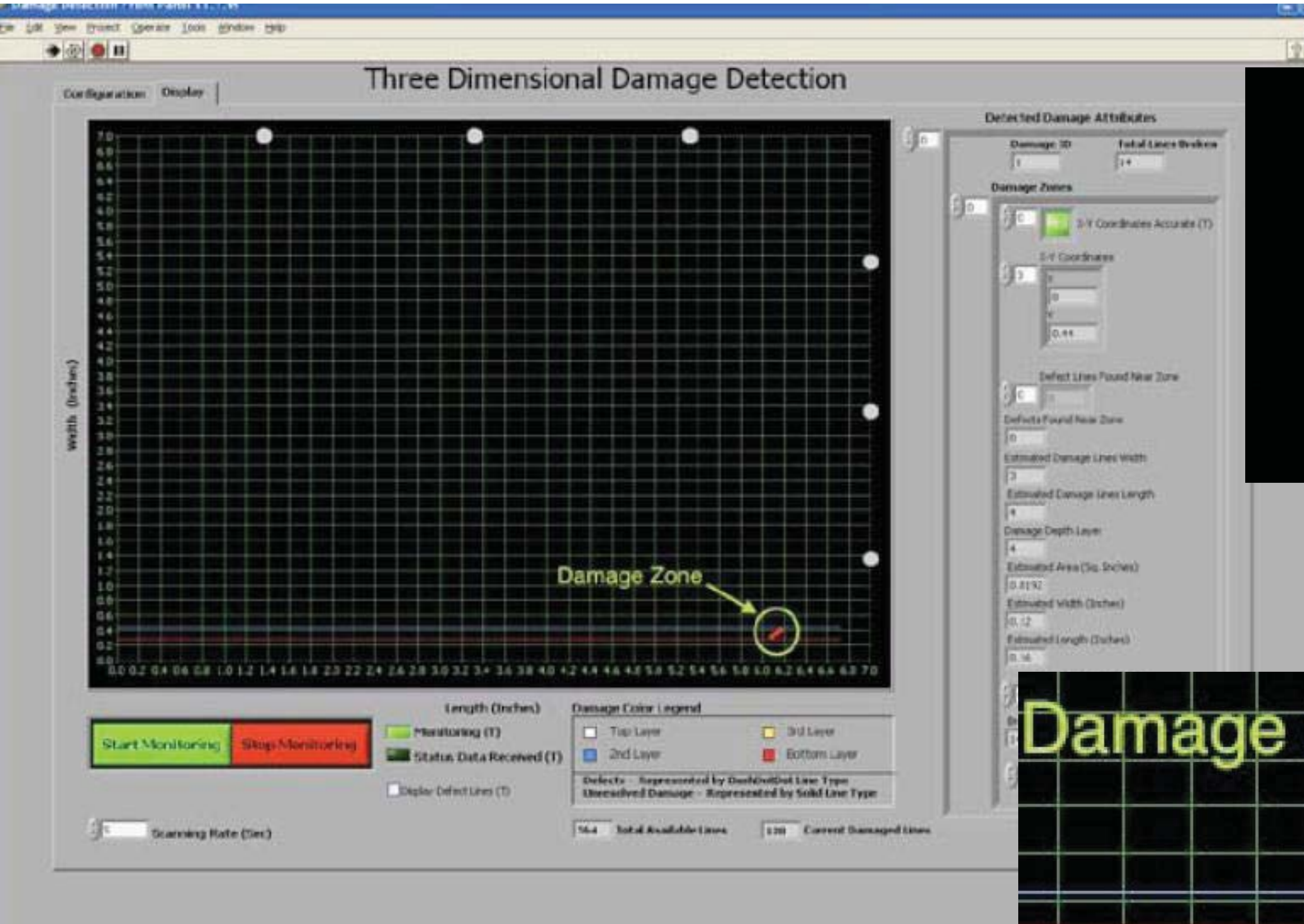


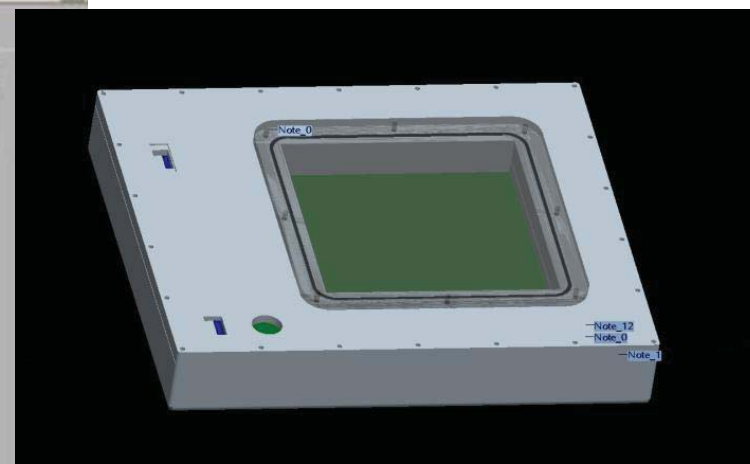
X-ray image of miniaturized TDR connector

Flat Surface Damage Detection

The Flat Surface Damage Detection system uses a series of two-dimensional detection systems and printed conductive circuitry to demonstrate a detection system for real time damage diagnosis (location and percent damage). This system will provide the ability to monitor the integrity of an inflatable habitat during in situ system health monitoring.

Flat Surface
Damage Detection





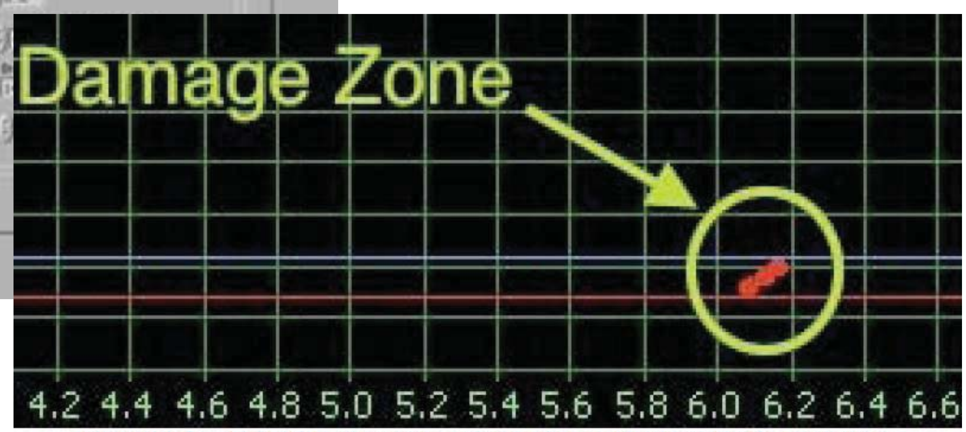
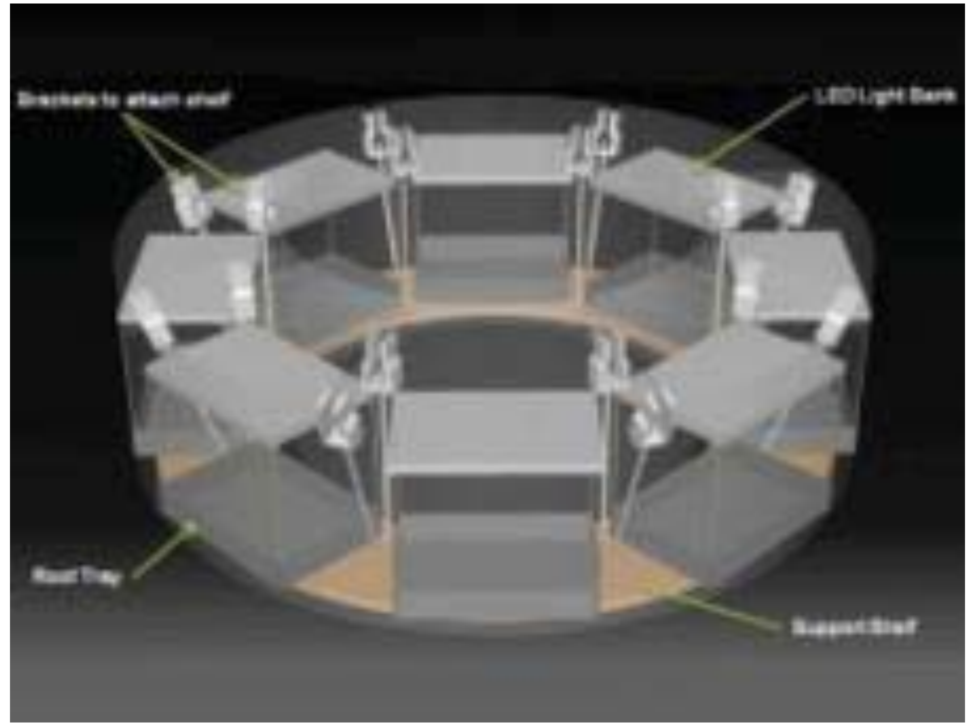
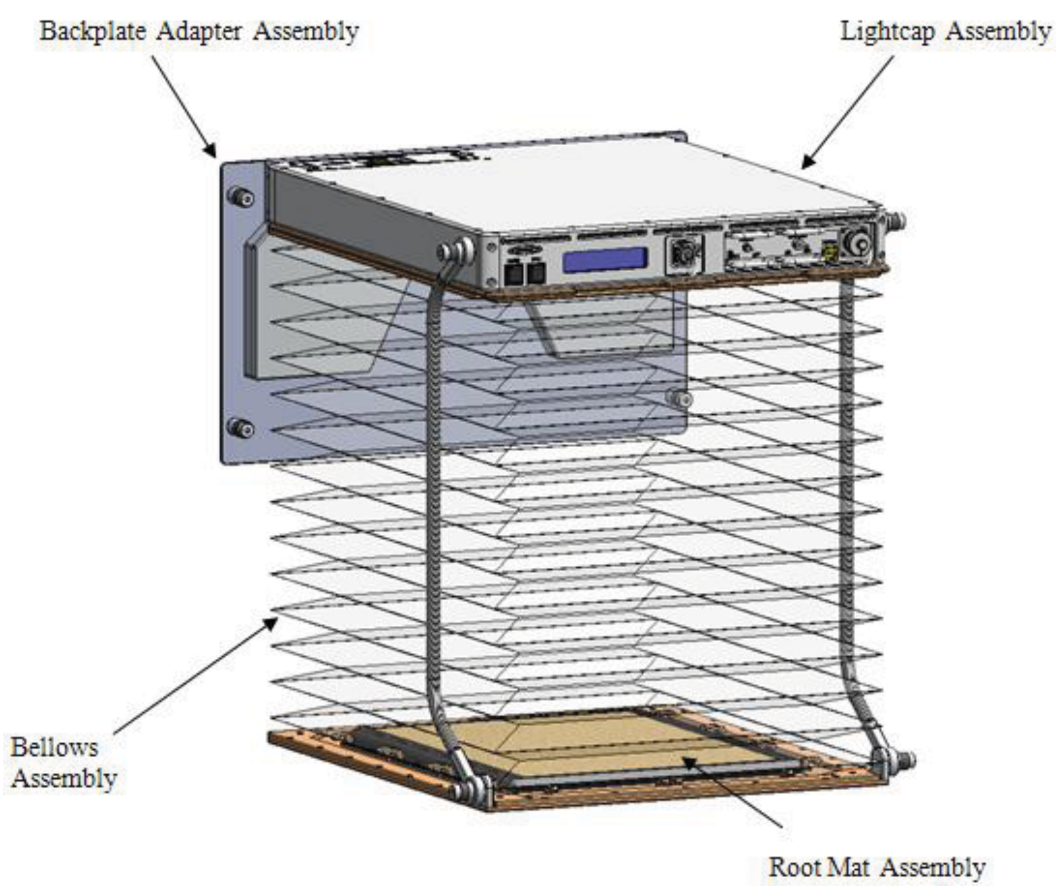


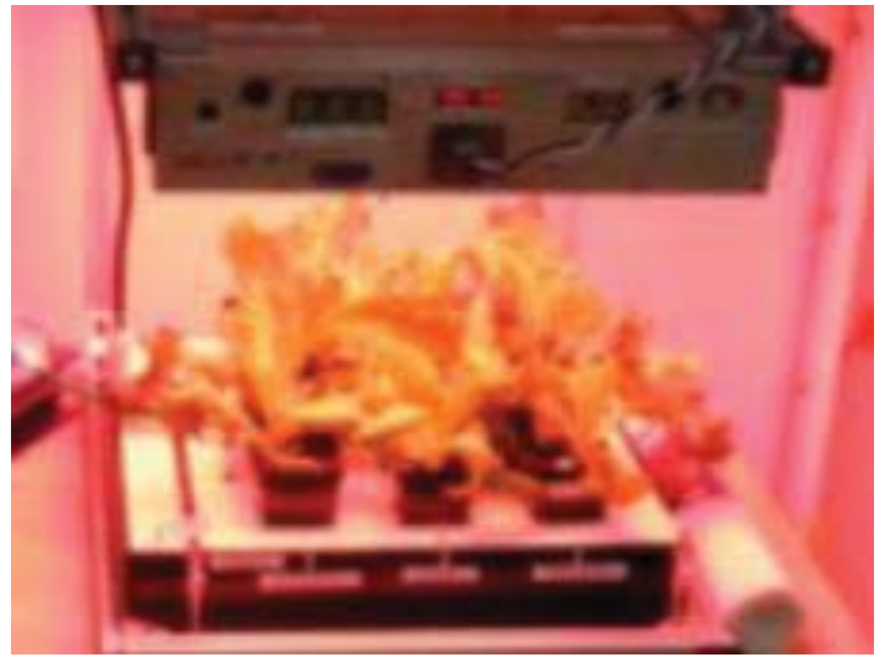
Figure 3 – FSDDS Damage Zone from Desert Rats Testing

Food Production
DSH Atrium



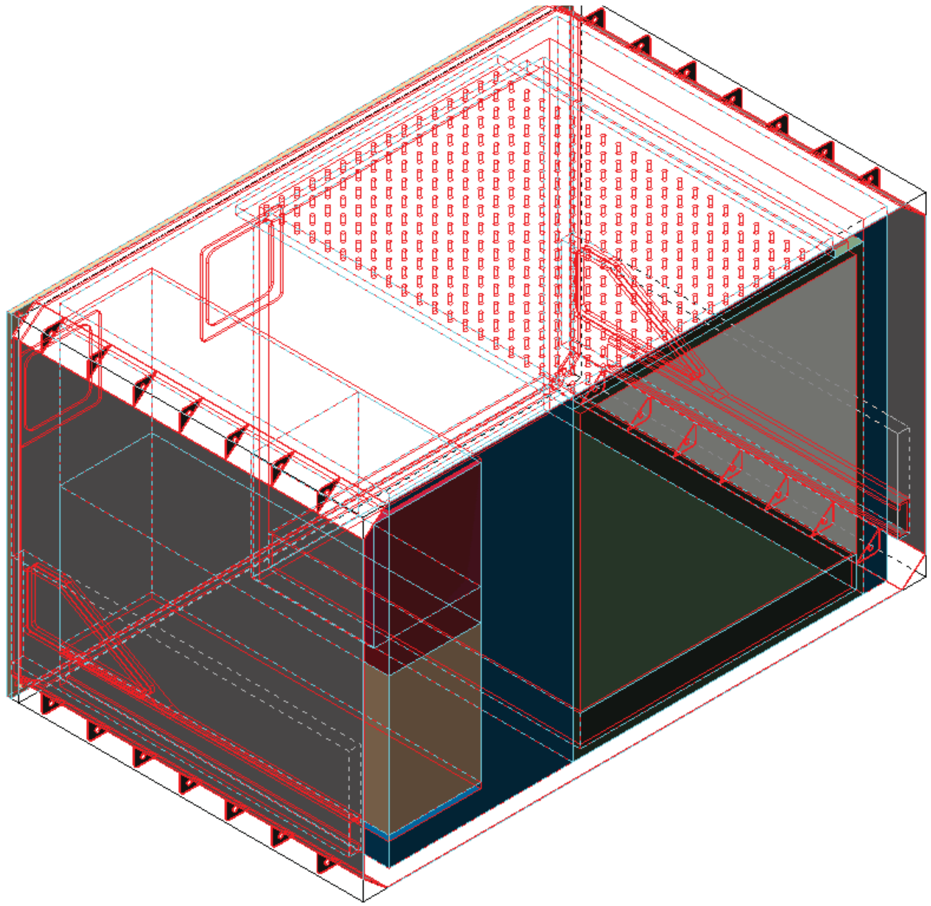
Food Production Units
VEGGIE





This demonstration will use a plant atrium in the mezzanine level between the main Habitation Unit and the inflatable X-Hab. The concept is to use under-utilized space for plant growth to supplement the crew's diet with fresh, perishable foods and herbs while on exploration campaigns.

Food Production Units
Advanced Plant Habitat



- Quad-locker EXPRESS rack payload for growing plants.
- Environmental control of humidity, temperature, lighting, CO_2, and ethylene
- Intended to be a plant growth facility for scientific customers to develop experiments.

LED Lighting

Flight hardware quality Solid State Lighting Modules, originally developed and flight tested as a prototype for the ISS, operating on 120VDC with avionics control and manual dimmer switches for each lighting module. LED lighting is also used for the food growth system and external lighting.