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

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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.
Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
Transportation and Destination Architectures for Flexible Path

TRANSPORTATION ARCHITECTURE

- Multi-Purpose Crew Vehicle (MPCV)
- Space Launch System - HLLV
- In-Space Propulsion Stages
  - Cryogenic Propulsion Stage (CPS)
  - Solar Electric Propulsion (SEP)

In-Space Propulsion Stages

DISTANCES AND ENVIRONMENTS

- LEO
- GEO/HEO
- Lunar
- NEA
- Mars

DESTINATION ARCHITECTURE

- Crew EVA Suit (Block 1)
- Robotics & EVA Module (REM) or Space Exportation Vehicle (SEV)
- Lunar Lander
- International GPOD Surface Elements
- Crew EVA Suit (Block 2)
- Deep Space Habitat (DSH)
- Mars Lander & Additional Elements

* MPCV Service Module derived Kick Stage utilized in some DRMs

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
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
<table>
<thead>
<tr>
<th>Typical Mission Design</th>
<th>Geostationary Orbit</th>
<th>Earth-Moon Libration</th>
<th>Lunar Surface</th>
<th>Near-Earth Asteroids</th>
<th>Mars Orbit (Phobos)</th>
<th>Mars Surface</th>
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</thead>
<tbody>
<tr>
<td>In-Space Delta-v (km/s)</td>
<td>5.9</td>
<td>4.8</td>
<td>~5.6</td>
<td>4.0-9.0+</td>
<td>~9.0-15.0</td>
<td>5.5-7.3</td>
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<td>Descent/Ascent or Vicinity Delta-v (km/s)</td>
<td>-</td>
<td>-</td>
<td>4.2</td>
<td>-</td>
<td>1.7-3.5</td>
<td>6.3</td>
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<td>Total Mission Duration (days) [2]</td>
<td>10</td>
<td>16</td>
<td>16-180</td>
<td>365</td>
<td>660</td>
<td>900</td>
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<td>Outbound Time (days) [2]</td>
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<td>5</td>
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<td>250</td>
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<td>Time at Destination (days) [2]</td>
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<td>8</td>
<td>7-180</td>
<td>25</td>
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<td>Zero-g</td>
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<td>Zero-g (?)?</td>
<td>Artificial-g</td>
<td>Zero-g</td>
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<td>Cargo Mode</td>
<td>Split</td>
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<td>All-up</td>
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<td>Typical Mission Opportunities</td>
<td>Daily</td>
<td>Weekly-Monthly</td>
<td>Weekly-Monthly</td>
<td>10-50+ Years</td>
<td>Every 26 Months</td>
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<td>Nearly Anytime</td>
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<td>Radiation Protection</td>
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<td>Advanced Propulsion (SEP, NEP, NTR)</td>
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<td>✓</td>
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<td>Near-Zero Boil off Cryogenic Fluid Storage</td>
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<td>High-speed Earth Entry</td>
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<td>In-Situ Resource Utilization</td>
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<td>✓</td>
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<td>Entry, Descent and Landing</td>
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<td>✓</td>
<td>✓</td>
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<td>Nuclear Surface Power</td>
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<table>
<thead>
<tr>
<th>Typical Launch Parameters</th>
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<tr>
<td># SLS launches to send crew to destination</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2-3+ [3]</td>
<td>3-7 [4]</td>
<td>3 [4]</td>
</tr>
<tr>
<td># SLS launches for destination cargo</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>2-3 [4]</td>
<td>4 [4]</td>
</tr>
<tr>
<td>Approximate total mass in LEO (t)</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200-300 [4]</td>
<td>500-900 [4]</td>
<td>800 [4]</td>
</tr>
</tbody>
</table>
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]).


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.


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 dayNear 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
Deep Space Habitat Layout

Table 1: Comparison of DSH pressurized volume against historical spacecraft

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DSH</th>
<th>*Mir</th>
<th>*Skylab</th>
<th>*TransHab</th>
<th>*BA 330</th>
<th>*6-Crew ISS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew</td>
<td>4</td>
<td>2 – 6 (3 typ.)</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Mission Duration</td>
<td>380 Days</td>
<td>Up to 437 Days</td>
<td>Up to 84 Days</td>
<td>180 Days</td>
<td>180 Days Per Expedition</td>
<td>180 Days Per Expedition</td>
</tr>
<tr>
<td>Length</td>
<td>8 m (26.25 ft)</td>
<td>14.4 m (Spektr Module) (47.2 ft)</td>
<td>14.66 m (Workshop Module) (48.1 ft)</td>
<td>11 m (36 ft)</td>
<td>14 m (45 ft)</td>
<td>8.5 m (Destiny Module) (27.9 ft)</td>
</tr>
<tr>
<td>Diameter</td>
<td>7.0 m (22.97 ft)</td>
<td>4.15 m max. (13.6 ft)</td>
<td>6.7 m (Workshop Module) (22 ft)</td>
<td>8.2 m (27 ft)</td>
<td>6.7 m (22 ft)</td>
<td>Typ. 4.2 m (13.8 ft)</td>
</tr>
<tr>
<td>Total Pressurized Volume</td>
<td>274.9 m³ (9,708 ft³)</td>
<td>380.1 m³ (13,419 ft³)</td>
<td>&gt;345 m³ (12,184 ft³)</td>
<td>339.8 m³ (12,000 ft³)</td>
<td>330 m³ (11,653.8 ft³)</td>
<td>Total 916 m³ (32,348 ft³)</td>
</tr>
<tr>
<td>Pressurized Volume per Crewmember</td>
<td>68.73 m³ (2,427 ft³)</td>
<td>126.7 m³ w/3 crew (4,474 ft³)</td>
<td>&gt;115 m³ (4,061 ft³)</td>
<td>56.63 m³ (2,000 ft³)</td>
<td>55 m³ (1,942 ft³)</td>
<td>152.7 m³ (6crew) (5,393 ft³)</td>
</tr>
<tr>
<td>Habitable Volume per Crewmember</td>
<td>33.12 m³ (1,170 ft³)</td>
<td>--</td>
<td>115 m³ (4,061 ft³)</td>
<td>--</td>
<td>--</td>
<td>64.67 m³ (2,284 ft³)</td>
</tr>
</tbody>
</table>

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](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
**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.

**System Capability**

**System Flight Demos**

**System Maturation (testing)**

**System Integration**

**System Definition**

Industry, Academia, International and Agencies (DoD, DOE, etc) Collaborations & Partnerships
From PowerPoint to Demo Unit

June 2009

Pressurized Excursion Module

August 2010

Deep Space Habitat

September 2010

~ August 2011
DRaTS HDU-DSH Configuration

Hab Functions:
- Univ of Wisconsin’s Inflatable Loft

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

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

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

Deployable Porch and Ramp

Dust Mitigation Module (FY10)

Power Interface Cart (not shown)

Ruggedized A/C Unit (not shown)

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
- Geo-Science porch
- Docked Rover faces this way
- GeoLab
- Med Ops W/S
- Maint. W/S
- Tele-Robotics operations
- Dust Mitigation Module

Level 2
- Lift
- Wardrm / Meeting
- Logistics & Stowage
- IV W/S

Level 3
- Crew Sleep Area
- Crew Sleep Area
- Crew Sleep Area
- OPEN
Robotically-Assisted GeoScience Operations
Waste & Hygiene Functions
CONGRATULATIONS to the 2011 X-Hab Academic Innovation Challenge Winners -
University of Wisconsin – June 20-24, 2011

Oklahoma State University
June 6-10, 2011

University of Maryland
June 13-17, 2011
Intelligent Habitat (iHab) Operating System

Autonomous Mission Ops & Planning

SHIELD & Adv C&W
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: Electrodynastic Dust Shield & Lotus Coating

Damage Detection System

Cargo Transfer Bag Radiation Protection Water Walls
Different Missions, Different Solutions

ISS Close to Earth
- Resupply
- Emergency Return

DSH Distant Missions
- No Resupply
- No Emergency Return

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

Node + MPLM

MPCV

Deep Space Habitat

Subsystems

Structures  Thermal Control
Mechanisms  Electrical Power
Crew Systems  Avionics
ECLSS  Protection

Node STA

Cupola

Service/EVA Tunnel

MPLM

CPS

USLab (Habitat) + MPLM

60 Days

500 Days

60 Days

500 Days

GLEX-2012.01.1.8x12219 – DSH Configurations Based On ISS Systems
ISS Rack Based 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

No std racks

GLEX-2012.01.1.8x12219 – DSH Configurations Based On ISS Systems
Baseline Configuration
500 Day Mission

Transverse Section AA

Longitudinal Sections

Crew Quarters (4)

Radiation Protection

Science/teleoperation

Galley Wardroom

Hatch

Tunnel / Airlock

Storage

Subsystems
(Subsystems located in ceiling and floor)

WHC

Work station

Storage in the MPLM includes 2 wall storage areas plus storage areas in the floor and ceiling
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.
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/](http://www.googlelunarxprize.org/)
  – Milestones to be completed Dec 31, 2015

• Mars One - [https://www.mars-one.com/](https://www.mars-one.com/)
  – Privately funded venture to send people to Mars – reality TV show (~2023)

  – 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/](http://www.globalspaceexploration.org/wordpress/)
  – Global Exploration Roadmap and other papers/publications - [http://www.globalspaceexploration.org/wordpress/?cat=3](http://www.globalspaceexploration.org/wordpress/?cat=3)
QUESTIONS?
References

1. Anon. *Human Exploration Framework Summary*, NASA, 
   http://www.nasa.gov/pdf/525162main_HEFT_Final_Brief_508_20110309.pdf


Pressure Vessel Modularity

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

- Two variations
  - **Multiple Pressure Vessels**
    - 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)
  - **Modular Construction Approach**
    - “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:
  - Interrelationships between the functions
    - e.g. Separation of work and recreation spaces, shared equipment, separation of noisy and quiet areas
  - Layout concerns addressing use of volume
    - e.g. Prevention of crowding, adequate space for tasks,
  - Historical placement of subsystems
    - e.g. Collocate Galley and Wardroom, acceptable separations
  - Emergency Response Scenarios (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

KSC Electrostatics and Surface Physics Laboratory
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
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
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.
• 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.
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.