Deep Space Habitat Configurations Based On International Space Station Systems

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and

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Jacobs Engineering, Science, and Technical Services Contract, Huntsville, Alabama, USA, 35806

A Deep Space Habitat (DSH) is the crew habitation module designed for long duration missions. Although humans have lived in space for many years, there has never been a habitat beyond low-Earth-orbit. As part of the Advanced Exploration Systems (AES) Habitation Project, a study was conducted to develop weightless habitat configurations using systems based on International Space Station (ISS) designs. Two mission sizes are described for a 4-crew 60-day mission, and a 4-crew 500-day mission using standard Node, Lab, and Multi-Purpose Logistics Module (MPLM) sized elements, and ISS derived habitation systems. These durations were selected to explore the lower and upper bound for the exploration missions under consideration including a range of excursions within the Earth-Moon vicinity, near earth asteroids, and Mars orbit. Current methods for sizing the mass and volume for habitats are based on mathematical models that assume the construction of a new single volume habitat. In contrast to that approach, this study explored the use of ISS designs based on existing hardware where available and construction of new hardware based on ISS designs where appropriate. Findings included a very robust design that could be reused if the DSH were assembled and based at the ISS and a transportation system were provided for its’ return after each mission. Mass estimates were found to be higher than mathematical models due primarily to the use of multiple ISS modules instead of one new large module, but the maturity of the designs using flight qualified systems have potential for improved cost, schedule, and risk benefits.

¹ Study Lead, Advanced Concepts Office, MSFC/ED04, and AIAA Senior Member.
² Environments, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
³ Modeling, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
⁴ Avionics, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
⁵ Power, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
⁶ Configurations, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
⁷ Thermal, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
⁹ Structures and Environmental Controls, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
Deep Space Habitat Configurations
Based on International Space Station Systems

AES Habitation Project
(Update utilizing HAB and MPLM modules)

David Smitherman / Space Systems Team
Advanced Concepts Office

December 15, 2011
Space Systems Team

• Advanced Concepts Office
  – Manager – Reggie Alexander
  – Deputy Manager – Les Johnson
  – Team Leads
    • Space Systems – Jack Mulqueen
    • Launch Systems – Ed Threet
    • Jacobs Engineering Support – Tracie Bedsole

• Space Systems Team
  – Study Lead – David Smitherman
  – Configurations – Mike Baysinger
  – Mass Properties – Dauphne Maples
  – Crew Systems – Brand Griffin
  – ECLSS – Janie Miernik
  – Structures – Janie Miernik
  – Propulsion – N/A
  – Power – Leo Fabisinski
  – Avionics – Pete Capizzo
  – Thermal – Linda Hornsby
  – Environmental Protection – Tiffany Russell
Study Plan Update

- Develop Deep Space Habitat (DSH) concepts based on International Space Station Systems
  - Initial sizing range to include
    - 4 crew / 60-Day mission
    - 4 crew / 500-Day mission
    - Investigate use of ISS HAB and MPLM sized modules

- Potential Benefits
  - ISS hardware is flight qualified
  - Mass may be higher but utilization could reduce overall project cost, schedule, and risk
  - Incorporates ISS utilization into the program
  - Offers an approach to incorporating International participation

- Include HAT requirements, ground rules & assumptions for the DSH

- Products
  - General layouts, interior and exterior
  - Mass properties
  - Final documentation
Ground Rules & Assumptions

Additional Assumptions

• Design intended to meet HAT missions with modifications as required to utilize current ISS and MPCV systems and technologies

• 60-Day Missions include
  – EM L1 and EM L2 Missions
  – GEO Satellite Servicing
  – ES L2 Missions
  – Lunar orbit Missions
  – Microgravity Free-flyer

• 500-Day Missions include
  – Some near-Earth asteroid missions
  – Mars transit and orbital missions

• Sized for Existing Launch Vehicle Systems
  – DSH can be broken down into smaller modular elements for EELV launch and/or outfitted at ISS
  – SLS utilization not included but should be possible

• Assembled and serviced at ISS
• Propulsion and Control provided by CPS, MPCV, and/or SEP
60 & 500-Day Vehicle Configurations

Basic Vehicle Elements
- Cryogenic Propulsion Stage (CPS) to be sized for mission
- HAB module (same size as ISS LAB module)
- Utility Tunnel / Airlock with attached FlexCraft or MMSEV
- Multi-Purpose Crew Vehicle (MPCV)
- Multi-Purpose Logistics Module (MPLM) added for 500-Day mission
Habitable Volume per Crew Based upon Average of Historical References

Stowage volume could be reduced to increase habitable volume

Held constant at 365 day value

60-Day Habitat Configuration (65 m³)

500-Day Habitat Configuration (90 m³)

Compiled by – NASA/LaRC/E402/Matt Simon with vehicle data added by ED04/David Smitherman

Draft – work in progress
Discipline Presentations

Configurations – Mike Baysinger
Mass Properties – Dauphne Maples
Crew Systems – Brand Griffin
  ECLSS – Janie Miernik
  Structures – Janie Miernik
  Power – Leo Fabisinski
  Avionics – Pete Capizzo
  Thermal – Linda Hornsby
Environmental Protection – Tiffany Russell
Configuration

Mike Baysinger
December 15, 2011
Configurations

60-DAY

- HAB
- Docking ports
- Tunnel
- Radiators

4.5 m

11.5 m

500-DAY

- HAB
- MPLM
- Docking port
- Tunnel

4.5 m

18 m
60-Day Configuration

ECLSS and other subsystems are located primarily above ceiling and below floor.
500-Day Configuration

500-day DSH:
Pressurized volume = ~ 193 m$^3$
Habitable volume = ~ 90 m$^3$
Stowage volume = ~ 49 m$^3$

Service Tunnel / Airlock:
Pressurized volume = ~ 10 m$^3$
Habitable volume = ~ 9 m$^3$

HAB:
Pressurized volume = ~ 107 m$^3$
Habitable volume = ~ 56 m$^3$
Stowage volume = ~ 16 m$^3$

MPLM:
Pressurized volume = ~76 m$^3$
Habitable volume = ~ 25 m$^3$
Stowage volume = ~ 33 m$^3$
500-Day Configuration

- **Crew Quarters (4)**
- **Science Stations**
- **Galley**
  - Opens up to Wardroom area
- **HAB Module**
- **MPLM**
- **Hatch**
- **Tunnel / Airlock**
- **Avionics and CHECS**
- **ECLSS**
  - (below floor)
- **Storage**
- **Subsystems**
  - Subsystems racks are located primarily above ceiling and below floor
- **WMC**

**Habitat Plan View**

Storage in the MPLM includes 2 wall storage areas plus storage areas in the floor and ceiling.
Internal Secondary Structure

6 Equal Bays similar to rack bay spacing

HAB shell

Secondary Structure Support
Vehicle Configurations

60-DAY

500-DAY
Delta IV-H Launches

60-Day

500-Day
Mass Summary

Dauphne Maples
December 15, 2011
Due to high TRLs, these designs may reduce cost, production, and flight-readiness schedule.

**60 Day Case**

- Average TRL: 7.7
- TRL 9 Components: 43%
- Dry Mass MGA: 12%
- Spacecraft Length: 11.5 m
- Spacecraft Diameter: 4.5 m

**500 Day Case**

- Average TRL: 7.7
- TRL 9 Components: 43%
- Dry Mass MGA: 13.6%
- Spacecraft Length: 18 m
- Spacecraft Diameter: 4.5 m

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GR&A / Reserves

• Ground Rules & Assumptions
  – The Margin Growth Allocation (MGA) per component/subsystem will vary, depending on individual Technology Readiness Levels (TRLs)
  – Project Manager’s Reserve will be 10% of the predicted mass/total wet mass

• Reserves
  – Margin Growth Allocation
    • MGA was applied to the basic mass of all subsystems included in Dry Mass
    • Subsystem leads determined TRLs per component and applied MGA accordingly
  – Project Manager’s Reserve
    • PMR was applied to the total wet mass of the DSH
    • 10% of the predicted mass (basic mass + MGA) for each category
      • Includes DSH mass not considered Dry Mass, such as Stowed Provisions and Consumables
Crew Systems

Brand Griffin

December 15, 2011
### Habitation and Autonomy

**500-Days without resupply**

<table>
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<tr>
<th>Activity</th>
<th>DSH Accommodation</th>
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<tbody>
<tr>
<td>Privacy, personal space</td>
<td>Large crew quarters, no through traffic, quiet end of module, acoustic insulation, personal control over temperature/air flow, adjustable lighting, data/power access, private communications</td>
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<tr>
<td>Eating, group meetings</td>
<td>Open area to accommodate all 4 crew, restraints for food and crew, one meal together per day</td>
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<tr>
<td>Food Preparation</td>
<td>Open area, microwave, refrigerator</td>
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<tr>
<td>Sleeping</td>
<td>Crew quarters, weightless restraints, change of bedding, radiation protection (storm shelter)</td>
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<tr>
<td>Exercise</td>
<td>Open area, adjustable air flow, easily cleaned, scheduling should not conflict with common meal</td>
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<tr>
<td>Waste Mgt</td>
<td>Larger enclosure than ISS, adjustable airflow, easily cleaned</td>
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<tr>
<td>Personal Hygiene</td>
<td>Enclosed area for whole body cleansing, hand wash, brushing teeth, personal grooming</td>
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<tr>
<td>Recreation, off-duty time</td>
<td>Crew choice, window, exercise, crew quarters or galley wardroom</td>
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<tr>
<td>Mission Operations</td>
<td>Science and flight operation workstations</td>
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<tr>
<td><strong>Autonomy</strong></td>
<td><strong>DSH Accommodations</strong></td>
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<tr>
<td>Servicing</td>
<td>Easy access to ORUs and utilities. Service while operational.</td>
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<tr>
<td>Consumables</td>
<td>Bring all consumables for entire mission (plus margin)</td>
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<tr>
<td>Spares</td>
<td>Hot spares, stored spares, design for repair or work around</td>
</tr>
</tbody>
</table>
Longitudinal Sections

Transverse Section AA

Plan

Longitudinal Sections

Port

Starboard

MSFC/ED04 – DSH Configurations Based On ISS Systems

FINAL 12-15-2011
ISS Rack Based Layout

- Standoff (4)
- Structure and Utilities
- Rack rotates to the center

Shell/ORU Based Layout

- Open web Longeron
- Cable Tray (4)
- Easy access utility packaging (two sides)
- Flex lines allow racks to rotate and remain operational

**ISSUE:**
Same size racks do not accommodate different functions

- Crew activities package differently than subsystems
  - Enclosures
  - Multiple crew
- Subsystems have different access requirements
  - Single layer (don't have to remove a component to get to another)
  - Service while functioning
- Large aisle way
  - All rack swing against long axis
  - Designed around infrequent operation

**Designed for ORU level Interchangeability**

- Two-sided equipment pallet
- Crew activities in wall
- Subsystem to ceiling/floor
- Dedicated utility interface

**Local vertical for crew**

- Head-to-toe air flow
- Overhead lighting

**Easy access Cable Tray**
EZ Access Architecture

- Longerons/cable tray (4) (Combined structure and cable tray)
- Utilities Single layer (For direct access and efficient utility routing)
- EZ Access Pallet Rotating subsystem mounting frame (Single layer ORUs on Both sides of frame)
- Transverse Utility Beam
- Seat track or similar (top surface)
- Seat track or similar (edge)
- Floor and ceiling panels (open iso-grid provides visibility to systems and attach points for mounting work lights fans, etc.)
Utility Layout Comparison

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

Shell/ORU Based

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

<table>
<thead>
<tr>
<th>ISS Rack Based</th>
<th>Shell/ORU Based</th>
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<tbody>
<tr>
<td><strong>Racks</strong></td>
<td><strong>Cable Tray</strong></td>
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<tr>
<td><strong>Floor</strong></td>
<td><strong>Floor</strong></td>
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<tr>
<td><strong>Wall</strong></td>
<td><strong>Wall</strong></td>
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<tr>
<td><strong>Ceiling</strong></td>
<td><strong>Ceiling</strong></td>
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<tr>
<td><strong>Standoff</strong></td>
<td><strong>Standoff</strong></td>
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</table>

**X Over**

- No Utilities

**Utilities**

- Transverse Utilities
Crew Quarters

ISS (~2 m³ each)

DSH (~4 m³ each)

Radiation Protection

Crew Quarters (4)
DSH Waste Hygiene Compartment

Utility Cross Over

Aisle Hygiene Station
(Brush teeth if WHM is occupied)

Access to WHC hardware

Commode (position takes advantage of shell curvature)

Direct access to hull

Restraints

Open area for whole body cleansing)

Edge of floor

Aisle way access to stowage

WHG access to stowage

ISS

Interior WHC

Exterior WHC

Plan

Section

DSH

Plan

Section
Accessibility Zoning

ISS Access

ISS Stowage

No immediate access to hull

- No access behind standoff
- Utilities enclosed

Shell/ORU

<table>
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<tr>
<th>Zone</th>
<th>Access</th>
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<tbody>
<tr>
<td>A</td>
<td>Immediate Physical &amp; Visual</td>
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<tr>
<td>B</td>
<td>Indirect</td>
</tr>
<tr>
<td>C</td>
<td>Infrequent</td>
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</table>

“compartment” depth less than aisle width

Cable Tray
Stowage

Subsystems

- Access to hull, Utilities exposed
Stowage Concepts

Front Access

Center Hinged Access

Refrigerator Door

Side Hinged Access

Combo

Combined Refrigerator and Hinged Access

Combo

(upper wedge access)

Combo

(two quadrant and hull access)
### Crew Systems Mass by Mission

#### 60-Day Mission

<table>
<thead>
<tr>
<th>Component</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
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<td>Wardroom</td>
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<td>16</td>
<td>16</td>
<td>3</td>
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#### 500-Day Mission

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<td><strong>103</strong></td>
<td><strong>171</strong></td>
<td>3</td>
<td><strong>180</strong></td>
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<tr>
<td>Housekeeping Expendables</td>
<td><strong>166</strong></td>
<td>3</td>
<td><strong>171</strong></td>
<td><strong>180</strong></td>
<td>3</td>
<td><strong>180</strong></td>
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<tr>
<td>Operational Spares</td>
<td><strong>175</strong></td>
<td>3</td>
<td><strong>180</strong></td>
<td><strong>180</strong></td>
<td>3</td>
<td><strong>180</strong></td>
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<tr>
<td>Maintenance Equipment</td>
<td><strong>80</strong></td>
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<td><strong>82</strong></td>
<td><strong>82</strong></td>
<td>3</td>
<td><strong>82</strong></td>
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<td>Photography</td>
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<td>3</td>
<td><strong>4</strong></td>
<td><strong>4</strong></td>
<td>3</td>
<td><strong>4</strong></td>
</tr>
<tr>
<td><strong>EVA: Provisions</strong></td>
<td><strong>60</strong></td>
<td>3</td>
<td><strong>62</strong></td>
<td><strong>62</strong></td>
<td>3</td>
<td><strong>62</strong></td>
</tr>
<tr>
<td>EVA Suits</td>
<td><strong>246</strong></td>
<td>0.0</td>
<td><strong>246</strong></td>
<td><strong>246</strong></td>
<td>0.0</td>
<td><strong>246</strong></td>
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<tr>
<td>Airlock Services</td>
<td><strong>25</strong></td>
<td>3</td>
<td><strong>25</strong></td>
<td><strong>25</strong></td>
<td>3</td>
<td><strong>25</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1243</strong></td>
<td></td>
<td></td>
<td><strong>1675</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ECLSS Summary

Janie Miernik
December 15, 2011
ECLSS – ISS Derived

- Mass of ISS subsystems, expendables, usage and failure rates are used in determining the mass allotments of ECLSS components and spares.
  - Two Water ISPR racks are included in ISS-packaged configuration and remain TRL 9.
  - The rest of the ECLSS subsystems are repackaged in DSH, believing that better configuration and lighter secondary structure can be developed; these subsystems are assigned TRL 7.

- 21 days of open-loop contingency margin on consumables (food, water, O\textsubscript{2}) is included for the 60-day mission and 60-Days contingency for the 500-day mission.
- ISS water balance is well characterized by several years of semi-open loop operation, and recently with periods of nearly closed-loop operation.
- Food mass was calculated with 35% average moisture content.
## Comparison of Mission/Mass

### 60-Day Mission vs. 500-Day Mission

<table>
<thead>
<tr>
<th>ECLSS Subsystem</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere Revitalization Sys (ARS)</td>
<td>337</td>
<td>20</td>
<td>404</td>
<td>562</td>
<td>20</td>
<td>674</td>
</tr>
<tr>
<td>Atmosphere Cont &amp; Supply System (ACSS)</td>
<td>400</td>
<td>20</td>
<td>480</td>
<td>1200</td>
<td>20</td>
<td>1440</td>
</tr>
<tr>
<td>Temp &amp; Humidity Control (THC)</td>
<td>149</td>
<td>20</td>
<td>179</td>
<td>149</td>
<td>20</td>
<td>179</td>
</tr>
<tr>
<td>Waste Hygiene Compartment (WHC)</td>
<td>455</td>
<td>20</td>
<td>546.00</td>
<td>455</td>
<td>20</td>
<td>546</td>
</tr>
<tr>
<td>Water Recovery &amp; Man (WRM)</td>
<td>1300</td>
<td>3</td>
<td>1339</td>
<td>1300</td>
<td>3</td>
<td>1314</td>
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<tr>
<td>Atmosphere Regen (OGA/ CO₂ Red Assy)</td>
<td>1000</td>
<td>20</td>
<td>1200</td>
<td>1600</td>
<td>20</td>
<td>1860</td>
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<tr>
<td>Fire Detection &amp; Suppression /module</td>
<td>35</td>
<td>30</td>
<td>46</td>
<td>70</td>
<td>30</td>
<td>91</td>
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<td>Potable Water Tanks</td>
<td>180</td>
<td>3</td>
<td>185</td>
<td>680</td>
<td>3</td>
<td>700</td>
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<td><strong>ECLSS Hardware Total</strong></td>
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<td></td>
<td>4379</td>
<td>6016</td>
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<td>6890</td>
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<td>ECLSS Expendables</td>
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<td>206</td>
<td>500</td>
<td>3</td>
<td>515</td>
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<tr>
<td>ECLSS Spares</td>
<td>730</td>
<td>3</td>
<td>752</td>
<td>1600</td>
<td>3</td>
<td>1648</td>
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<tr>
<td>H₂O</td>
<td>634</td>
<td>3</td>
<td>653</td>
<td>2520</td>
<td>3</td>
<td>2596</td>
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<tr>
<td>Food, packaged</td>
<td>337</td>
<td>10</td>
<td>371</td>
<td>2403</td>
<td>10</td>
<td>2643</td>
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<tr>
<td>Atmosphere Regen (O₂)</td>
<td>114</td>
<td>3</td>
<td>117</td>
<td>670</td>
<td>3</td>
<td>690</td>
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<tr>
<td>Atmosphere Regen (N₂) leakage</td>
<td>122</td>
<td>3</td>
<td>126</td>
<td>250</td>
<td>3</td>
<td>258</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5993</td>
<td></td>
<td>6603</td>
<td>13959</td>
<td></td>
<td>15239</td>
</tr>
</tbody>
</table>
Structures

Janie Miernik
December 15, 2011
Structures: ISS-Derived

- ISS STA Lab/HAB Module has known mass and is fabricated, not qualified, so is TRL 8.
- MPLM design is used but additional CBM docking port added, TRL drops to 7.
- The interior secondary structure is conservatively estimated at 20% of the mass that must be supported and is assigned TRL 8.
- The tunnel/contingency airlock structure mass is based on ISS airlock areal mass, is assumed to be fabricated in a similar manner, and is assigned TRL 7. External secondary structure for radiators, meteor debris shielding and power systems are estimated at 20% of the mass to be supported.
- All ports will be CBM-sized and use ISS mass for these components. A NASA Docking System (NDS) adapter will be used for MPCV interface; mass found in NDS documentation.

<table>
<thead>
<tr>
<th>STA Hab/Lab</th>
<th>MPLM</th>
<th>Tunnel</th>
<th>ISPR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td><strong>Height</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.5 m (27.4 m)</td>
<td>2 m (6.1 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindrical section length</td>
<td>6.5m (19 ft)</td>
<td>3.2 m (10.5 ft)</td>
<td></td>
</tr>
<tr>
<td>7.2 m (25.6 ft)</td>
<td>4.9 m (15 ft)</td>
<td>3.2 m (10.5 ft)</td>
<td></td>
</tr>
<tr>
<td>4.3 m (14 ft)</td>
<td>4.3 m (14 ft)</td>
<td>2.5 m (7.6 ft)</td>
<td>Max. depth .86 m (2.8 ft)</td>
</tr>
<tr>
<td>Pressurized volume</td>
<td>76.4 m^3</td>
<td>10 m^3</td>
<td>Volume 1.57 m^3</td>
</tr>
<tr>
<td>Mass of shell incl. CBMs and hatches</td>
<td>3833 kg (8450 lbs)</td>
<td>2502 kg (5516 lbs)</td>
<td>1284 kg (2204 lbs) ~25 kg/m^2 areal mass</td>
</tr>
</tbody>
</table>

- A new launch adapter must be developed for EELV launch to interface ISS elements and it is not included in stated mass.
## Comparison of Mission/Mass

<table>
<thead>
<tr>
<th>Structural Component</th>
<th>60-Day Mission</th>
<th>500-Day Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (kg)</td>
<td>MGA %</td>
</tr>
<tr>
<td>STA Lab/Hab outfitted Pressure Shell</td>
<td>3833</td>
<td>10</td>
</tr>
<tr>
<td>Hab Secondary Structure</td>
<td>2141</td>
<td>20</td>
</tr>
<tr>
<td>MPLM outfitted Pressure Shell w/2 axial CBM ports</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>MPLM Secondary Structure</td>
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<td>20</td>
</tr>
<tr>
<td>Tunnel/Ext. Secondary Structure</td>
<td>1782</td>
<td>20</td>
</tr>
<tr>
<td>20” ISS Window</td>
<td>75</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7831</strong></td>
<td></td>
</tr>
</tbody>
</table>
Power System

Leo L. Fabisinski
December 15, 2011
Power System Summary

- Power Requirement:
  - 60-Day: 14,136 W
  - 500-Day: 18,824 W
- UltraFlex Arrays with Inverted Metamorphic (IMM) Cells

- 120V MPCV-Compatible Bus
- VME Power Electronics Boards (MPCV Heritage)
- Off-The-Shelf VME Enclosure for Power Electronics
• Batteries are Off-The-Shelf High-Capacity Lithium Ion Cells in series to provide 122.4 V nominal

<table>
<thead>
<tr>
<th>Component</th>
<th>60-Day</th>
<th>500-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>Solar Arrays (with Booms, Actuators)</td>
<td>204</td>
<td>20</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>75</td>
<td>16</td>
</tr>
<tr>
<td>Secondary Batteries</td>
<td>153</td>
<td>10</td>
</tr>
<tr>
<td>Power Cabling</td>
<td>152</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>584</strong></td>
<td></td>
</tr>
</tbody>
</table>
Avionics

Pete Capizzo
December 15, 2011
The avionics for the DSH has been based on the MPCV crew vehicle avionics. This was judged to be a practical approach since the MPCV vehicle is largely a habitat vehicle with all the electronics required to operate ECLSS systems and provides a robust communications system with good ground link and local communications capabilities.

The 500-Day habitat avionics is about the same as the 60-Day configuration, but has a much larger communication dish (1.5 m vs .75 m).

External cameras are used to assist in Flexcraft/SEV mission operations, or EVAs, from a Hab flight control center.
# Avionics Mass Comparison

<table>
<thead>
<tr>
<th>Sub-System</th>
<th>60-Day</th>
<th>500-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>AR&amp;D System</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Command and Data Handling</td>
<td>220</td>
<td>18</td>
</tr>
<tr>
<td>Displays &amp; Controls</td>
<td>134</td>
<td>18</td>
</tr>
<tr>
<td>Communications System</td>
<td>159</td>
<td>18</td>
</tr>
<tr>
<td>Intercom &amp; Video</td>
<td>56</td>
<td>22</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>IHM System</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Avionics Cabling</td>
<td>290</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>965</strong></td>
<td><strong>1176</strong></td>
</tr>
</tbody>
</table>
Thermal

Linda Hornsby
December 15, 2011
Thermal Control

- Active waste heat collection – redundant internal and external pumped loops with cold plates and heat exchangers
  - DSH 60-Day mission metabolic and equipment waste heat – 11,970 W
  - DSH 500-Day mission metabolic and equipment waste heat – 12,925 W
- Active waste heat rejection
  - Radiators (with redundant loops) – deployed, non-articulating in flight
- Passive waste heat rejection
  - MPLM, HAB, tunnel pressure shell– multi-layer insulation (MLI)
- Exterior temperature control
  - MPLM, HAB, tunnel pressure shell– MLI and heaters
  - Exterior antennas, cameras, and gimbal shelf– MLI, heaters, louvers, coatings
# Thermal Mass Comparison by Mission

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>60-Day</th>
<th>500-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>Internal TCS Rack LT/MT</td>
<td>226</td>
<td>20</td>
</tr>
<tr>
<td>Internal Rack Support</td>
<td>270</td>
<td>20</td>
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<tr>
<td>Internal TCS Misc.</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>External Active TCS</td>
<td>376</td>
<td>15</td>
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<tr>
<td>External Passive TCS</td>
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<td>20</td>
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<tr>
<td>External Heat Rejection Sys.</td>
<td>1482</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2539</strong></td>
<td></td>
</tr>
</tbody>
</table>
Environments Protection

Tiffany E. Russell
December 15, 2011
Crew Quarters Protection

- Environments Protection System consists of two main components
  - External Micrometeoroid Debris Protection Shield (MDPS), MPLM-derived
  - Interior Radiation Water Wall
- Nominal 60 and 500-Day water wall:
  - 0.55 cm thick polyethylene tank
  - 9.9 cm thick water wall
  - Total protection = 11 g/cm^2
  - Mass = 2850 kg
- Water wall provides a storm shelter during a Solar Particle Event (SPE)
  - Current design does not include protection against Galactic Cosmic Radiation (GCR)
Tank Configuration

- Water Wall surrounding crew quarters comprised of several tanks

<table>
<thead>
<tr>
<th>Sub-System</th>
<th>60-Day</th>
<th>500-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>Micro-Meteoroid &amp; Debris Protection System (MPDS)</td>
<td>1121</td>
<td>10</td>
</tr>
<tr>
<td>Radiation Protection Tanks</td>
<td>332</td>
<td>5</td>
</tr>
<tr>
<td>Radiation Water</td>
<td>2518</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3971</strong></td>
<td></td>
</tr>
</tbody>
</table>
Findings & Recommendations

David Smitherman
December 15, 2011
**4 Crew / 60-Day Summary**

### Design Constraints/Parameters

- **Pressurized Volume**: ~117 m$^3$
- **Habitable Volume**: ~65 m$^3$
- **Cabin Pressure**: 70.3 kPa
- **Crew Capacity**: 4
- **Crewed Mission Duration**: 60 d
- **EOL Solar Power Generation**: 25.8 kW
- **Power Load During Battery Operation**: 15.3 kW
- **Average TRL**: 7.7
- **TRL 9 / Heritage**: 43%
- **ECLSS Closure - Water**: Closed Loop
- **ECLSS Closure - Air**: Closed Loop
- **Habitat Structure**: Rigid Cylinder
- **Habitat Length**: 11.5 m
- **Habitat Diameter**: 4.5 m
- **Mass Growth Allocation (MGA)**: 12.04%
- **Project Manager’s Reserve**: 10%

### Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures</td>
<td>9,002</td>
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<tr>
<td>Propulsion</td>
<td>-</td>
</tr>
<tr>
<td>Power</td>
<td>698</td>
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<tr>
<td>Avionics</td>
<td>1,177</td>
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<tr>
<td>Thermal</td>
<td>2,780</td>
</tr>
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<td>Environment Protection</td>
<td>4,175</td>
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<td>ECLSS</td>
<td>4,379</td>
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<tr>
<td>Crew Systems</td>
<td>690</td>
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<tr>
<td>EVA</td>
<td>272</td>
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<tr>
<td>Dry Mass</td>
<td>23,173</td>
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<tr>
<td>Stowed Provisions</td>
<td>1,240</td>
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<tr>
<td>Consumables</td>
<td>1,267</td>
</tr>
<tr>
<td>Non-Propellant Fluids</td>
<td>457</td>
</tr>
<tr>
<td>RCS Propellant</td>
<td>-</td>
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<tr>
<td><strong>DSH Wet Mass</strong></td>
<td>26,136</td>
</tr>
<tr>
<td><strong>Project Mgr’s Reserve (PMR) (10%)</strong></td>
<td>2,614</td>
</tr>
<tr>
<td><strong>Total Wet Mass w/PMR</strong></td>
<td>28,750</td>
</tr>
</tbody>
</table>

*Note: MGA for the 60 day case totaled an average of 12.04% Dry Mass due to 43% of the hardware being TRL 9.*

---

**Description**

The Deep Space Habitat based on International Space Station systems (DSH-ISS) shown in this configuration provides habitation for 4 crew members on missions up to 60 days. Possible destinations include Low-Earth-Orbit, Earth-Moon L1, Earth-Sun L2 and other destinations within the Earth-Moon system. Initial assembly and operation from ISS is assumed. The DSH-ISS has connection adapters to dock with the ISS for assembly, and the MPCV and CPS propulsion unit(s) for mission operations. Exploration and servicing vehicle attachments are also provided for the single-crew FlexCraft. The DSH-ISS includes use of a HAB module (an ISS Lab sized module that has not flown) and a new utility tunnel. The HAB provides habitable volume for the crew with life support based on ISS systems and the utility tunnel provides airlock services and supports external power and thermal systems.
4 Crew / 500-Day Summary

Design Constraints/Parameters

- Pressurized Volume: ~193 m³
- Habitable Volume: ~90 m³
- Cabin Pressure: 70.3 kPa
- Crew Capacity: 4
- Crewed Mission Duration: 500 d
- EOL Solar power generation: 34 kW
- Power load during battery operation: 20 kW
- Average TRL: 7.7
- TRL 9 / Heritage: 47%
- ECLSS Closure - Water: Closed Loop
- ECLSS Closure - Air: Closed Loop
- Habitat Structure: Rigid Cylinder
- Habitat Length: 18 m
- Habitat Diameter: 4.5 m
- Mass Growth Allocation*: 13.62%
- Project Manager’s Reserve: 10%

Description

The Deep Space Habitat based on International Space Station systems (DSH-ISS) shown in this configuration provides habitation for 4 crew members on missions up to 500 days. Possible destinations include long duration missions within the Earth-Moon system, Near-Earth Asteroid missions, and Mars orbital missions. Initial assembly and operation from ISS is assumed. The DSH-ISS has connection adapters to dock with the ISS for assembly, and the MPCV and CPS propulsion unit(s) for mission operations. Exploration and servicing vehicle attachments are also provided for the single-crew FlexCraft. The DSH-ISS includes use of a HAB module (an ISS Lab sized module that has not flown), a new utility tunnel, and a MPLM. The HAB provides habitable volume for the crew with life support based on ISS systems, the utility tunnel provides airlock services and supports external power and thermal systems, and the MPLM provides additional habitable volume and logistics to support the 500 day mission.

<table>
<thead>
<tr>
<th>Category</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures</td>
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<td>Propulsion</td>
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<tr>
<td>Power</td>
<td>924</td>
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<tr>
<td>Avionics</td>
<td>1,321</td>
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<tr>
<td>Thermal</td>
<td>2,868</td>
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<tr>
<td>Environment Protection</td>
<td>4,826</td>
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<tr>
<td>ECLSS</td>
<td>6,890</td>
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<tr>
<td>Crew Systems</td>
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<tr>
<td>EVA</td>
<td>272</td>
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<tr>
<td>Dry Mass</td>
<td>32,022</td>
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<td>Stowed Provisions</td>
<td>2,766</td>
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<tr>
<td>Consumable Fluids</td>
<td>6,187</td>
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<tr>
<td>Non-Propellant Fluids</td>
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</tr>
<tr>
<td>RCS Propellant</td>
<td>-</td>
</tr>
<tr>
<td>DSH Wet Mass</td>
<td>41,430</td>
</tr>
<tr>
<td>Project Mgrs Reserve (PMR) (10%)</td>
<td>4,143</td>
</tr>
<tr>
<td><strong>Total Wet Mass w/PMR</strong></td>
<td><strong>45,573</strong></td>
</tr>
</tbody>
</table>

*Note: MGA for the 500 day case totaled an average of 13.62% Dry Mass due to 43% of the hardware being TRL 9.
Mass Comparison

### MEL - DSH Comparison

<table>
<thead>
<tr>
<th>Mass Breakdown Structure</th>
<th>EXAMINE Tool</th>
<th>EXAMINE Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 Day</td>
<td>60 Day</td>
</tr>
<tr>
<td><strong>Mass (kg)</strong></td>
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<td>9,001.51</td>
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<td>698.06</td>
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<td>4,175.24</td>
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<td>9.0 EVA</td>
<td>635.00</td>
<td>271.75</td>
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<td><strong>Dry Mass</strong></td>
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<td><strong>32,021.75</strong></td>
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<td><strong>28,749.85</strong></td>
</tr>
</tbody>
</table>

- **DSH-ISS mass comparison to EXAMINE tool** (parametric analysis)
  - DSH-ISS utilizes flight hardware with known mass and other components at a high TRL
  - 1.0 Structures includes multiple modules with more end-cones and docking mechanisms for the 500-Day case
  - 4.0 Avionics includes a spare control station plus controls for robotics and propulsion elements
  - 5.0 Thermal is sized for the LEO environment and utilizes more massive ISS thermal systems
  - 6.0 Environmental protection includes more radiation shielding for SPE, and micrometeoroid debris shielding for the LEO environment
- Driving mass differences with EXAMINE Tool are in Structures, Avionics, Thermal, and Environmental Protection. The remaining differences are in bookkeeping methods.
Future Work Suggestions

• **Launch Vehicle Derived:**
  – SLS 2\textsuperscript{nd} Stage Hydrogen Tank (Skylab II)
  – Habitat built inside ELV shroud

• **Radiation Protection Concepts:**
  – ISS sized modules enclosed by SLS 2\textsuperscript{nd} stage hydrogen tank
  – Investigate further the combining of water for radiation protection with the contingency water for the 500-Day case

• **Artificial Gravity:**
  – Investigate artificial-gravity configurations with a vertically oriented multi-floor interior (similar to DSH D-RATS 2011 configuration) for end over end rotation of the vehicle

• **Reusability:**
  – Explore mission scenarios that incorporate the DSH into a reusable system operating from the ISS or an Earth-Moon L1 or L2 Station

• **Configuration:**
  – Look at advantages of using ISS STA Lab (HAB) and STA Node (Node 1) configuration, instead of the HAB and MPLM, for better docking arrangements with other elements.
  – Consider commercial and international modules in production or available spares
Backup Materials
Ground Rules & Requirements

David Smitherman
December 15, 2011
HAT GR&A (tentative)

- Habitat Structure & Mechanisms
  - Metallic, cylindrical habitat (4.27m diameter for ELV payload envelope dimensions)
  - 42 m$^3$ pressurized volume /crew for HAT asteroid
  - Secondary structure sized as 2.46 kg/m$^2$ of habitat structural
  - Integration structure 2% of habitat gross mass
  - ~4 x 0.5m windows, 1 exterior hatch, 4 docking mechanisms
  - Atmospheric Pressure = 70.3 kPa (10.2 psi), 1 ATM when docked to ISS

- Protection
  - 1 cm thick MLI covering external habitat surface for passive TCS
  - 5.8 cm water-wall covering crew quarters only
    - Water included

Modifications to GR&A

- Habitat Structure & Mechanisms
  - ISS module dimension, 4.5 m outside diameter
  - Structure calculated based on ISS structural system mass
  - One 20” ISS window plus the Flexcraft windows

- Protection
  - ISS micrometeoroid debris shield, thermal insulation, and pressure shell
  - 10 cm water-wall in segmented polyethylene (PE) tanks protecting crew quarters area only
Ground Rules & Assumptions

HAT GR&A (tentative)

• Power
  – 2 photovoltaic (3-junction GaAs) arrays each generating 6.5 kW EOL
  – EPCU 28 V dc PMAD (92% efficient) (120 V optional)
  – 3 Li-ion batteries sized for 2 batteries generating 10.4 kW for 1.2 hours

• Environmental Control and Life Support Systems
  – 10% mass for redundant plumbing and backup distribution hardware
  – 30 days open loop contingency consumables for critical subsystems

• Avionics
  – Provide CC&DH, GN&C and communications

Modifications to GR&A

• Power
  – 2 photovoltaic (3-junction IMM) UltraFlex Wings – construction consistent with MPCEV (2.5g max)
  – 120 V dc PMAD – cabling sized for 1% loss
  – Li-ion Secondary Battery Storage, 60% Max Depth of Discharge

• Environmental Control and Life Support Systems
  – Use ISS ECLSS hardware mass and expendables usage rates
  – 21 day open loop contingency for 60-day mission; 60-day open loop contingency for 500-day mission
  – 2-fault tolerant for air, 1-fault for water

• Avionics
  – Provides Command, Control, Data Handling and communications systems. But, no flight control.
  – 100 Mbps ground link for 60-Day DSH at lunar locations, 1 Mbps link for 500-Day DSH from Mars.
  – Attitude control of the DSH will be provided by an attached element, either a CPS, SEP, or MPCV.
Ground Rules & Assumptions

HAT GR&A (tentative)

- **Thermal Control**
  - External fluid loop for heat acquisition using ammonia
  - Internal fluid loop for heat acquisition using 60% prop glycol/water
  - ~13 kW heat acquired from MM cabin & avionics rejected using ISS-type radiators.
  - MLI covering external habitat surface for passive TCS.
  - ~13 kW heat acquired from MM cabin & avionics rejected using ISS-type radiators w/ 10 mil Ag-teflon coating

- **Crew Accommodations**
  - Standard suite for 60 & 500-Day deep space transfers (ref. Human Spaceflight Mission Analysis & Design)
  - Sink(spigot), freezer, microwave oven, hand/mouth wash faucet, washer & dryer, 2 vacuums, laptop, trash compactor, printer, hand tools & accessories, test equipment, ergometer, photography equipment, exercise equipment, treadmill, table

Modifications to GR&A

- **Thermal Control**
  - Active waste heat collection/rejection
    - Redundant internal pumped water loop
    - Redundant external pumped ammonia loop
    - ISS LTL/MTL TCS components (pump package, filters, valves, HX, QDs, etc.)
    - ISS External TCS components (pump package, filters, valves, HX, QDs, etc.)
    - Deployed, non-articulating ISS PVR radiator.
  - Exterior shell thermal control
    - 19-layers DAK MLI, Nomex outer layer
    - Areal density estimated at .5 kg/m2
    - Shell heaters on HAB, MPLM, and tunnel

- **Crew Accommodations**
  - No freezer, shower or washer & dryer for 60-day mission
  - Add freezer for 500-day mission.
### Ground Rules & Assumptions

#### HAT GR&A (tentative)

- **Reserves**
  - Margin growth Allocation - 20% of basic mass
  - Project Manager’s Reserve - 10% of basic mass

- **Internal bulkhead with airlock services**
  - For contingent EVAs after NEO ops

- **Reusability**
  - Reusable, 10 year lifetime minimum

- **Spares**
  - 1500 kg spares mass bogey assigned by DRM team needs verification by subsystem experts related to LOC/LOM (unclear what is captured here: EVA Spares?, ECLSS Spares)

#### Modifications to GR&A

- **Reserves**
  - Margin growth allocation is variable depending on individual component TRLs (Average is 8% for 60-Day case; 6% for 500-Day case)
  - Project Manager’s Reserve - 10% of predicted total wet mass

- **Internal bulkhead with airlock services**
  - No internal bulkhead required; contingency airlock in tunnel

- **Reusability**
  - Reusable if transportation system returns to ISS for vehicle refurbishment

- **Spares**
  - Operational spares of ~100 kg estimated for all but ECLSS
  - ECLSS spares taken from ISS usage and mass for either mission length.
    - ~800 kg for 60-Day case
    - ~1800 kg for 500-Day case
Ground Rules & Assumptions

Additional Assumptions

• Habitat sized for 4 crew, 60-Day missions & 4 crew, 500-Day missions

• 60-Day Missions include
  – EM L1 and EM L2 Missions
  – GEO Satellite Servicing
  – ES L2 Missions
  – Lunar orbit Missions
  – Microgravity Free-flyer

• 500-Day Missions include
  – Some near-Earth asteroid missions
  – Mars transit missions

• Sized for Existing Launch Vehicle Systems
  – DSH exceeds mass an ELV can place in a 407km by 407km orbit (capability ~23mt)
  – DSH can be broken down into smaller modular elements for ELV launch and/or outfitted at ISS

• Assembled and serviced at ISS

• Propulsion and Control provided by CPS, MPCV, and/or SEP

• DSH will provide supporting power, utilities, & ECLSS for attached vehicles during transit mode
Configuration

Mike Baysinger
December 15, 2011
60-Day Launches

Xx kg ≤ Mass ≤ xx,000kg
60-Day Launches

Xx kg ≤ Mass ≤ xx,000kg
Habitable volume=56 m$^3$
Stowage volume= 16 m$^3$
60-Day
60-Day

MPLM

CPS

Core Habitat

MMSEV

Flexcraft

MPCV

Advanced Concepts
60-Day
500-Day Launches

$x,000 \text{kg} \leq \text{Mass} \leq x,000 \text{kg}$

HAB

MPLM, Tunnel Radiators, Solar Arrays
500-Day

Docking port

HAB

MPLM

Tunnel

18 m
STA HAB:
Pressurized volume = 107 m³
Habitable volume = 56 m³
Stowage volume = 16 m³

MPLM:
Pressurized volume = 76 m³
Habitable volume = 25 m³
Stowage volume = 33 m³
500-Day
500-Day

CPS

MMSEV

Flexcraft

Core Habitat

MPCV
500-Day
Mass

Dauphne Maples
December 15, 2011
# Mass Summary: 60 Days

## MEL - DSH 60 Day Case

<table>
<thead>
<tr>
<th>Mass Breakdown Structure</th>
<th>Basic Mass (kg)</th>
<th>MGA (%)</th>
<th>MGA (kg)</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Structures</td>
<td>7831.30</td>
<td>14.94%</td>
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<td>690.32</td>
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<tr>
<td>9.0 EVA</td>
<td>271.00</td>
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<td>0.75</td>
<td>271.75</td>
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<tr>
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<tr>
<td>13.0 RCS</td>
<td>0.00</td>
<td>0.00%</td>
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<td><strong>DSH Wet Mass</strong></td>
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<td><strong>26,136.23</strong></td>
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<tr>
<td><strong>Project Manager's Reserve (PMR)</strong></td>
<td><strong>2,613.62</strong></td>
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<tr>
<td><strong>Total Wet Mass w/PMR</strong></td>
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<td></td>
<td><strong>28,749.85</strong></td>
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# Mass Summary: 500 Days

## MEL - DSH 500 Day Case

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<th>Mass Breakdown Structure</th>
<th>Basic Mass (kg)</th>
<th>MGA (%)</th>
<th>MGA (kg)</th>
<th>Predicted Mass (kg)</th>
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</thead>
<tbody>
<tr>
<td>1.0 Structures</td>
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<td>0.00%</td>
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<tr>
<td>3.0 Power</td>
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<td>4.0 Avionics</td>
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### Dry Mass

<table>
<thead>
<tr>
<th>Description</th>
<th>Basic Mass (kg)</th>
<th>MGA (%)</th>
<th>Predicted Mass (kg)</th>
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<tbody>
<tr>
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<td>12.0 Non-Prop Fluids</td>
<td>415.00</td>
<td>10.00%</td>
<td>41.50</td>
</tr>
<tr>
<td>13.0 RCS</td>
<td>0.00</td>
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</table>

**DSH Wet Mass**

<table>
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<th>Description</th>
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<tr>
<td>DSH Wet Mass</td>
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<td>Project Manager’s Reserve (PMR)</td>
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</table>

**Total Wet Mass w/PMR**

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<td>Total Wet Mass w/PMR</td>
<td>45,573.33</td>
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</table>
## Predicted Mass Comparison: 60 Vs. 500 Days

### MEL - DSH Comparison

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<th>Mass Breakdown Structure</th>
<th>60 Day</th>
<th>60 Day</th>
<th>500 Day</th>
<th>500 Day</th>
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<tbody>
<tr>
<td>EXAMINE Tool</td>
<td>Mass (kg)</td>
<td>Mass (kg)</td>
<td>Mass (kg)</td>
<td>Mass (kg)</td>
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<td>1.0 Structures</td>
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<td>45,573.33</td>
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</table>

**EXAMINE Tool**

- Predicted Mass Comparison:
  - 60 Days: 23,172.81 kg
  - 500 Days: 32,021.75 kg

**Mass Breakdown Structure**

- Structures
- Propulson
- Power
- Avionics
- Thermal
- Environmental Protection
- ECLSS
- Crew Systems
- EVA
- Stowed Provisions
- Consumables
- Non-Prop Fluids
- RCS
- Project Manager's Reserve (PMR)
- Total Wet Mass w/PMR

**Project Manager's Reserve (PMR)**

- 60 Days: 2,613.62 kg
- 500 Days: 4,143.03 kg

**Total Wet Mass w/PMR**

- 60 Days: 18,448.00 kg
- 500 Days: 34,391.00 kg

**DSH Wet Mass**

- 60 Days: 26,136.23 kg
- 500 Days: 41,430.30 kg
Crew Systems

Brand Griffin
December 15, 2011
Deep Space Missions

ISS
Close to Earth

Logistics (rack) Delivery Necessary
- Outfitting (launched with 5 out of 24 racks)
- Resupply consumables
- Parts for servicing and repair

No Habitat on ISS
Rapid (emergency) return

DSH
Distant Missions

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

Possible Return to LEO
ISS Rack Based Layout

ISSUE:
Same size racks do not accommodate different functions

- Crew activities package differently than subsystems
  - Enclosures
  - Multiple crew
- Subsystems have different access requirements
  - Single layer (don't have to remove a component to get to another)
  - Service while functioning
- Large aisle way
  - All rack swing against long axis
  - Designed around infrequent operation

Shell/ORU Based Layout

Designed for ORU level Interchangeability
Two-sided equipment pallet
Crew activities in wall
Subsystem to ceiling/floor
Dedicated utility interface

Local vertical for crew
Head-to-toe air flow
Overhead lighting
Easy access Cable Tray
The Real ISS

Utility Connections

Waste Hygiene Compartment

US Lab (Destiny)
Difficult access to utilities and hull

Racks impede access to utilities

No access to hull behind standoff
Enclosed ducts, plumbing and cables

Difficult access to rack hardware

Confined access from inside rack
## Habitation and Autonomy

### 500-Days without resupply

<table>
<thead>
<tr>
<th>Activity</th>
<th>DSH Accommodation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Privacy, personal space</td>
<td>Large crew quarters, no through traffic, quiet end of module, acoustic insulation, personal control over temperature/air flow, adjustable lighting, data/power access, private communications</td>
</tr>
<tr>
<td>Eating, group meetings</td>
<td>Open area to accommodate all 4 crew, restraints for food and crew, one meal together per day</td>
</tr>
<tr>
<td>Food Preparation</td>
<td>Open area, microwave, refrigerator</td>
</tr>
<tr>
<td>Sleeping</td>
<td>Crew quarters, weightless restraints, change of bedding, radiation protection (storm shelter)</td>
</tr>
<tr>
<td>Exercise</td>
<td>Open area, adjustable air flow, easily cleaned, scheduling should not conflict with common meal</td>
</tr>
<tr>
<td>Waste Mgt</td>
<td>Larger enclosure than ISS, adjustable airflow, easily cleaned</td>
</tr>
<tr>
<td>Personal Hygiene</td>
<td>Enclosed area for whole body cleansing, hand wash, brushing teeth, personal grooming</td>
</tr>
<tr>
<td>Recreation, off-duty time</td>
<td>Crew choice, window, exercise, crew quarters or galley wardroom</td>
</tr>
<tr>
<td>Mission Operations</td>
<td>Science and flight operation workstations</td>
</tr>
</tbody>
</table>

### Autonomy

<table>
<thead>
<tr>
<th>Activity</th>
<th>DSH Accommodations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servicing</td>
<td>Easy access to ORUs and utilities. Service while operational.</td>
</tr>
<tr>
<td>Consumables</td>
<td>Bring all consumables for entire mission (plus margin)</td>
</tr>
<tr>
<td>Spares</td>
<td>Hot spares, stored spares, design for repair or work around</td>
</tr>
</tbody>
</table>
Weightless Posture

Zero g Projected Height

~1.74 m (68”)

~1.38 m (54”)

95 %ile US Male

5 %ile Female
**Assumed Crew Schedule**

**Guidelines:**
- Common sleep time
- Eat one meal together (dinner)
- Dinner is one hour (prep, eat, cleanup)
- Two hours exercise
- One person at a time for exercise
- Exercise does not interfere with meals
- Four hours off-duty (not exercise or dinner)
- At least one hour off-duty before sleep

| Hour of the Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|----------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| **Crew**       |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| A              |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| B              |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| C              |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| D              |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

- Sleep
- Work
- Exercise
- Dinner
- Off Duty

**Notes:**
- The schedule is designed to balance work, exercise, and rest.
- Each crew member has a dedicated time for off-duty activities.
Alternate Cross Sections

ISS-Rack
Symmetrical
2.2 m Aisle

"Small compartments
Complex utilities
Unforgiving"

Shell/ORU
Symmetrical
~1.5 m Aisle

Moderate compart.
Two person translation
Good packaging depth
Endcone crew qrtrs
Works with 50” hatch

Can be combined

Shell/ORU
Asymmetrical
1.0 m Aisle
Compartment

Generous compart.
Tight two per. Trans.
Good packaging depth
Wall crew qrtrs
May work with 50” hatch

Shell/ORU
Asymmetrical
1.0 m Aisle
Quadrant

Generous compart.
Tight two per. Trans.
Good packaging depth
Wall crew qrtrs (stakced)
May work with 50” hatch

Favored

Ample compart.
Tight two per. Trans.
Deep packaging
Wall crew qrtrs
May work with 50” hatch
Utility Layout Comparison

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

Shell/ORU Based

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
**EZ Access Architecture**

- **Longerons/cable tray (4)**: (Combined structure and cable tray)
- **Utilities**: Single layer (For direct access and efficient utility routing)
- **EZ Access Pallet Rotating subsystem mounting frame**: (Single layer ORUs on Both sides of frame)
- **Transverse Utility Beam**
- **Seat track or similar (top surface)**
- **Seat track or similar (edge)**
- **Floor and ceiling panels**: (open iso-grid provides visibility to systems and attach points for mounting work lights fans, etc.)
Axial Modularity

ISS

ISS US Lab-6 Rack Bays (24 racks)

~ 1.05 m Repeat
Coupled with utilities
No fractional racks (large dimension impacts layout flexibility)

Shell/ORU

No Rack Bays
Linear structure (e.g., aircraft seat track)

~ 2 cm Repeat
Decoupled with utilities (small dimension allows layout flexibility)

Seat Track and Attachments
Layout Rationale
Non Rack Based (1.5 m aisle)

Crew Quarters
- Individual
- Acoustic and visual privacy
- Quiet end of module
- End cone for extra volume

Stowage
- Acoustic insulation
- Radiation protection

Maint/Science
- Workstation
- Open to aisle

Wardroom
- Open area with window
- Dining and group gathering

Suit Stowage (2)
- In stowage area
- Used for contingency

SPE Radiation Protection
- “Shelter” approach (retreat during storm and surrounds area where crew spends most time
- Potable water

Local Vertical
- Port and starboard racks for crew functions (e.g., wardroom, waste mgt)
- Floor and ceiling for subsystems (e.g., ECLSS, TCS)

Waste Mgt
- Not adjacent to Crew Qrtrs or Galley
- Adjacent to ECLSS racks in ceiling

CHECS
- Open area for exercise
- Adjacent to medical equipment

Hatches
- Hab (50 inch)
- MPCV (LIDS)
- FlexCraft docking

Service Tunnel
- Length for ISS radiators
- Diameter (Suits + translation)
- Diameter to allow external packaging of batteries, arrays, avionics and radiators

Utility Crossover
- Return air and water
- End-cone location
Crew Quarters

ISS (~2 m3 each)

DSH (~4 m3 each)

Radiation Protection
DSH Waste Hygiene Compartment

Utility Cross Over

Aisle Hygiene Station
(Brush teeth if WHM is occupied)

Access to WHC hardware

Commode (position takes advantage of shell curvature)

Direct access to hull

Restraints

Open area for whole body cleansing)

Edge of floor

Aisle way access to stowage

WHG access to stowage

ISS

Interior WHC

Exterior WHC

Plan

Section

DSH

Plan

Section
Accessibility Zoning

ISS Access

ISS Stowage

No immediate access to hull

- No access behind standoff
- Utilities enclosed

Shell/ORU

<table>
<thead>
<tr>
<th>Zone</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Immediate Physical &amp; Visual</td>
</tr>
<tr>
<td>B</td>
<td>Indirect</td>
</tr>
<tr>
<td>C</td>
<td>Infrequent</td>
</tr>
</tbody>
</table>

“compartment” depth less than aisle width

Access to hull, Utilities exposed
Stowage Concepts

Front Access

Center Hinged Access

Refrigerator Door
Side Hinged Access

Combo
Combined Refrigerator and Hinged Access

Combo
(upper wedge access)

Combo
(two quadrant and hull access)
### Crew Systems Mass by Mission

#### 60-Day Mission

<table>
<thead>
<tr>
<th>Component</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galley</td>
<td>150</td>
<td>3</td>
<td>154</td>
<td>150</td>
<td>3</td>
<td>154</td>
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<tr>
<td>Wardroom</td>
<td>50</td>
<td>3</td>
<td>52</td>
<td>50</td>
<td>3</td>
<td>52</td>
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<tr>
<td>Crew Quarters</td>
<td>248</td>
<td>5</td>
<td>260</td>
<td>248</td>
<td>5</td>
<td>260</td>
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<tr>
<td>Restraints</td>
<td>24</td>
<td>3</td>
<td>25</td>
<td>24</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Crew Health Care (Medical)</td>
<td>73</td>
<td>3</td>
<td>75</td>
<td>173</td>
<td>3</td>
<td>178</td>
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<tr>
<td>Crew Health Care (Exercise)</td>
<td>91</td>
<td>3</td>
<td>94</td>
<td>91</td>
<td>3</td>
<td>94</td>
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<tr>
<td>Personal Laptops</td>
<td>16</td>
<td>3</td>
<td>16</td>
<td>16</td>
<td>3</td>
<td>16</td>
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<tr>
<td>General Illumination</td>
<td>12</td>
<td>15</td>
<td>14</td>
<td>24</td>
<td>15</td>
<td>28</td>
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<tr>
<td>Crew Systems Total</td>
<td>664</td>
<td></td>
<td>690</td>
<td>776</td>
<td></td>
<td>802</td>
</tr>
</tbody>
</table>

#### 500-Day Mission

<table>
<thead>
<tr>
<th>Component</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stowed Provisions: Personal</td>
<td>80</td>
<td>3</td>
<td>82</td>
<td>100</td>
<td>3</td>
<td>103</td>
</tr>
<tr>
<td>Housekeeping Expendables</td>
<td>20</td>
<td>3</td>
<td>21</td>
<td>166</td>
<td>3</td>
<td>171</td>
</tr>
<tr>
<td>Operational Spares</td>
<td>100</td>
<td>3</td>
<td>103</td>
<td>175</td>
<td>3</td>
<td>180</td>
</tr>
<tr>
<td>Maintenance Equipment</td>
<td>40</td>
<td>3</td>
<td>41</td>
<td>80</td>
<td>3</td>
<td>82</td>
</tr>
<tr>
<td>Photography</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
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<td>EVA: Provisions</td>
<td>30</td>
<td>3</td>
<td>31</td>
<td>60</td>
<td>3</td>
<td>62</td>
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<td>EVA Suits</td>
<td>246</td>
<td>0.0</td>
<td>246</td>
<td>246</td>
<td>0.0</td>
<td>246</td>
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<tr>
<td>Airlock Services</td>
<td>25</td>
<td>3</td>
<td>25</td>
<td>25</td>
<td>3</td>
<td>25</td>
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<tr>
<td>Total</td>
<td>1210</td>
<td></td>
<td>1243</td>
<td>1632</td>
<td></td>
<td>1675</td>
</tr>
</tbody>
</table>
Environmental Control & Life Support Systems (ECLSS)

Janie Miernik
December 15, 2011
ECLSS Subsystems

Design Approach, Assumptions, Ground Rules

- Closed-loop ECLSS was designed and has been demonstrated for a crew of six on ISS, so application to a 4-man crew offers some extra margin. Most systems would only run in daily batches, 10 hrs/day.
- Mass of ISS subsystems, expendables, usage and failure rates are used in determining the mass allotments of ECLSS components and spares.
  - Two Water ISPR racks are included in ISS-packaged configuration and remain TRL 9.
  - The rest of the ECLSS subsystems are repackaged in DSH, believing that better configuration and lighter secondary structure can be developed; these subsystems are assigned TRL 7.
- At least single failure tolerance through spare ORUs, back-up contingency, or a second stowed subassembly is accounted for with spares and expendable mass.
- Open-loop contingency critical life support supplies are included: 21-days for the 60-day mission and 60-Days for the 500-day mission.
- Carbon dioxide removal is 2-fault tolerant for both missions with a spare CRA and LiOH back-up.
ECLSS Consumables

Design Approach

• 21 days of open-loop contingency margin on consumables (food, water, O₂) is included for the 60-day mission and 60-Days contingency for the 500-day mission.
• ISS water balance is well characterized by several years of semi-open loop operation, and recently with periods of nearly closed-loop operation.
• Food mass was calculated with 35% average moisture content for the solid food.
• A daily amount of water is calculated for hygiene, urinal flush and oxygen generation.
• Potable water for make-up and contingency will be stored in ISS qualified bellows tanks that hold/deliver about 70/65 kg of water each. Many tanks will needed for 60-Days contingency on the longer mission.
• Since oxygen generation with the ISS-sized OGA is sufficient to meet the needs of a crew of four, little more than contingency O₂ need be carried.
• N₂ will be carried for leakage and contingency EVA.
• ECLSS spares, expendables, water, food, and collected waste are “wet” and will provide radiation protection throughout mission.
  – Expended urine brine and waste management canisters will be stowed, rather than jettisoned to maintain wet radiation protection.
Description of Systems

• Air
  – Carbon Dioxide Removal Assembly (CDRA) (ISS Heritage)
    • Feeds Sabatier
    • Lithium hydroxide (LiOH) canisters are stored for backup CO₂ removal.
  – Temperature and Humidity Control (THC) (ISS Heritage)
    • Feeds WPA
  – Trace Contaminant Control System (TCCS) (ISS Heritage)
  – Atmosphere Control and Supply System (ACSS) (ISS Heritage)
  – Oxygen Generation Assembly (OGA) (ISS Heritage)
    • Creates O₂ (and H₂) from H₂O; feeds Sabatier
  – Carbon dioxide reduction – Sabatier (ISS Heritage)
    • Creates H₂O from H₂ and CO₂

• Currently no Vacuum Access on DSH
Description of Systems

- **Water**
  - Water Processor Assembly (WPA) (ISS Heritage)
  - Urine Processor Assembly (UPA) (ISS Heritage)
  Together with WPA recovers water for reuse and is called Water Recovery and Management (WRM).

- **Waste Hygiene Compartment (WHC) (ISS Heritage)**
  - Waste is collected and compacted and has a high water content.

- **Expendables and Spares**
  - Mass derived from ISS mass and usage.
  - Spares are mostly for air regeneration systems.
  - Expendables are mostly for water regeneration systems.
  - Expendables and spares are all “wet” for water regeneration hardware.
Description of Systems

• Fire Detection & Suppression (FDS)
  – Smoke detectors, portable fire extinguishers and breathing apparatus.

• Food and stowed consumables
  – 35% average moisture content in the food to maintain an optimal water balance in the nearly-closed ECLSS.
  – Over 30 tanks of water are projected for the 500-day mission. This will provide extra radiation protection.
  – $O_2$ and $N_2$ are tanked at 3000 psi and stored inside the module.
## Comparison of Mission/Mass

### 60-Day Mission vs 500-Day Mission

<table>
<thead>
<tr>
<th>ECLSS Subsystem</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere Revitalization Sys (ARS)</td>
<td>337</td>
<td>20</td>
<td>404</td>
<td>562</td>
<td>20</td>
<td>674</td>
</tr>
<tr>
<td>Atmosphere Cont &amp; Supply System (ACSS)</td>
<td>400</td>
<td>20</td>
<td>480</td>
<td>1200</td>
<td>20</td>
<td>1440</td>
</tr>
<tr>
<td>Temp &amp; Humidity Control (THC)</td>
<td>149</td>
<td>20</td>
<td>179</td>
<td>149</td>
<td>20</td>
<td>179</td>
</tr>
<tr>
<td>Waste Hygiene Compartment (WHC)</td>
<td>455</td>
<td>20</td>
<td>546.00</td>
<td>455</td>
<td>20</td>
<td>546</td>
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<tr>
<td>Water Recovery &amp; Man (WRM)</td>
<td>1300</td>
<td>3</td>
<td>1339</td>
<td>1300</td>
<td>3</td>
<td>1314</td>
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<tr>
<td>Atmosphere Regen (OGA/ CO₂ Red Assy)</td>
<td>1000</td>
<td>20</td>
<td>1200</td>
<td>1600</td>
<td>20</td>
<td>1860</td>
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<tr>
<td>Fire Detection &amp; Suppression /module</td>
<td>35</td>
<td>30</td>
<td>46</td>
<td>70</td>
<td>30</td>
<td>91</td>
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<tr>
<td>Potable Water Tanks</td>
<td>180</td>
<td>3</td>
<td>185</td>
<td>680</td>
<td>3</td>
<td>700</td>
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<tr>
<td><strong>ECLSS Hardware Total</strong></td>
<td>3856</td>
<td></td>
<td>4379</td>
<td>6016</td>
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<td>6890</td>
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<tr>
<td>ECLSS Expendables</td>
<td>200</td>
<td>3</td>
<td>206</td>
<td>500</td>
<td>3</td>
<td>515</td>
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<tr>
<td>ECLSS Spares</td>
<td>730</td>
<td>3</td>
<td>752</td>
<td>1600</td>
<td>3</td>
<td>1648</td>
</tr>
<tr>
<td>H₂O</td>
<td>634</td>
<td>3</td>
<td>653</td>
<td>2520</td>
<td>3</td>
<td>2596</td>
</tr>
<tr>
<td>Food, packaged</td>
<td>337</td>
<td>10</td>
<td>371</td>
<td>2403</td>
<td>10</td>
<td>2643</td>
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<tr>
<td>Atmosphere Regen (O₂)</td>
<td>114</td>
<td>3</td>
<td>117</td>
<td>670</td>
<td>3</td>
<td>690</td>
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<tr>
<td>Atmosphere Regen (N₂) leakage</td>
<td>122</td>
<td>3</td>
<td>126</td>
<td>250</td>
<td>3</td>
<td>258</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5993</td>
<td></td>
<td>6603</td>
<td>13959</td>
<td></td>
<td>15239</td>
</tr>
</tbody>
</table>
Structures

Janie Miernik
December 15, 2011

Multi-Purpose Logistics Module (MPLM)
Ground Rules & Assumptions

- DSH cabin air pressure = 70.3 kPa (10.2 psi, .7 atm). 1 atm (14.7 psi, 101.3 kPa) when docked to ISS on 60-Day mission demonstrator.
- ISS STA Lab/HAB Module has known mass and is fabricated, not qualified, so is TRL 8.
- MPLM design is used but additional CBM docking port added, TRL drops to 7.
- The interior secondary structure is conservatively estimated at 20% of the mass that must be supported and is assigned TRL 8.
- The tunnel/contingency airlock structure mass is based on ISS airlock areal mass, is assumed to be fabricated in a similar manner, and is assigned TRL 7. External secondary structure for radiators, meteor debris shielding and power systems are estimated at 20% of the mass to be supported.
- All ports will be CBM-sized and use ISS mass for these components. A NASA Docking System (NDS) adapter will be used for MPCV interface; mass found in NDS documentation.
- This configuration, layout, and structural mass was not analyzed for EELV launch loads, mass or center of gravity limitations of the launch platform. A new launch adapter must be developed for EELV launch to interface ISS elements and it is not included in stated mass.
- The projected mass needed for the missions exceed the cargo launch limitation of the modules, some of the required DSH stowed mass must be launched to ISS by other means and installed at ISS.
Launch Considerations

New launch adapter is shown schematically (in teal) and launch mass limitations are given below. ISS element launch adapters would interface element trunnions. There will be mass overage and some mass must be launched by other means and installed on orbit, mostly likely at ISS.

60-day mission mass with tunnel: 28,815 kg
Launch adapter mass*: 2900 kg
Estimated STA Lab element launch mass limit: ~14,000 kg
Delta IV Heavy payload limit to ISS LEO including launch adapter: ~23,000 kg
Atlas V payload limit to ISS LEO including launch adapter: ~29,000 kg

* Launch adapter mass from Boeing Docking Hub proposal for outfitted STA Node

Dimensions: mm [in]
Same internal fairing diameter for Atlas V and Delta IV

Element diameter with MDPS = 4450; trunnions currently extend another 250 mm. There would be only 6 cm clearance around the shell with current fairing designs. Trunnions could be cut shorter and a couple more may need to be added to interface launch adapter.
Description of Modules and Components:

MPLM

- Length – 5.5m (18 ft)
- Diameter – 4.5 m (14 ft)
- Power – MPLM currently accommodates 5 powered racks
  - Two 1050 W
  - Three 598 W
  - Power, thermal and avionics will be enhanced for DSH missions.
- Pressurized Volume – 76.4 m$^3$ (2772 cu ft)
- Habitable volume – 32.3 m$^3$ (1144 cu ft)
- Mass, including 16 rack attachment blocks, MDPS, and 1 CBM for the 60-day mission: 3,767 kg (8,304 lbs) (2 CBMs for the 500-day mission)
  - Primary Structure - 2770 kg (6108 lbs)
  - MDPS - 592 kg (1305 lbs) (carried in Environmental Protection)
  - Internal Structure - 404 kg (892 lbs)
# Structures

## Description of Modules and International Payload Racks

<table>
<thead>
<tr>
<th></th>
<th>STA Lab/Hab</th>
<th>MPLM</th>
<th>Tunnel</th>
<th>ISPR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>8.5 m (27.4 m)</td>
<td>6.5 m (19 ft)</td>
<td>3.2 m (10.5 ft)</td>
<td>Height: 2 m (6.1 ft)</td>
</tr>
<tr>
<td><strong>Cylindrical section length</strong></td>
<td>7.2 m (25.6 ft)</td>
<td>4.9 m (15 ft)</td>
<td>3.2 m (10.5 ft)</td>
<td>Width: 1.05 m (3.4 ft)</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>4.3 m (14 ft)</td>
<td>4.3 m (14 ft)</td>
<td>2.5 m (7.6 ft)</td>
<td>Max. depth: .86 m (2.8 ft)</td>
</tr>
<tr>
<td><strong>Pressurized volume</strong></td>
<td>106 m³</td>
<td>76.4 m³</td>
<td>10 m³</td>
<td>Volume: 1.57 m³</td>
</tr>
<tr>
<td><strong>Mass of shell incl. CBMs and hatches</strong></td>
<td>3833 kg (8450 lbs)</td>
<td>2502 kg (5516 lbs)</td>
<td>1284 kg (2204 lbs)</td>
<td>Mass of 6-post rack: 105 kg (230 lbs)</td>
</tr>
</tbody>
</table>
## Comparison of Mission/Mass

### 60-Day Mission vs. 500-Day Mission

<table>
<thead>
<tr>
<th>Structural Component</th>
<th>Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
<th>Mass (kg)</th>
<th>MGA %</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STA Lab/Hab outfitted Pressure Shell</td>
<td>3833</td>
<td>10</td>
<td>4216</td>
<td>3833</td>
<td>10</td>
<td>4216</td>
</tr>
<tr>
<td>Hab Secondary Structure</td>
<td>2141</td>
<td>20</td>
<td>2569</td>
<td>2141</td>
<td>20</td>
<td>2569</td>
</tr>
<tr>
<td>MPLM outfitted Pressure Shell w/2 axial CBM ports</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>2502</td>
<td>20</td>
<td>3002</td>
</tr>
<tr>
<td>MPLM Secondary Structure</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>1704</td>
<td>20</td>
<td>2044</td>
</tr>
<tr>
<td>Tunnel/Ext. Secondary Structure</td>
<td>1782</td>
<td>20</td>
<td>2139</td>
<td>1815</td>
<td>20</td>
<td>2178</td>
</tr>
<tr>
<td>20” ISS Window</td>
<td>75</td>
<td>3</td>
<td>77</td>
<td>75</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7831</strong></td>
<td></td>
<td><strong>9002</strong></td>
<td><strong>12069</strong></td>
<td></td>
<td><strong>14087</strong></td>
</tr>
</tbody>
</table>
Structural Issues Not Addressed

• **Finite Element Analysis (FEA)**
  FEA will be required for element shells and secondary structure because they are being launch in a different way and used for a different application.
  – EELV launch loads and configuration with launch adapter is different from shuttle bay launch.
  – Non-rack-based secondary structure attachment to pressure shell is different in some locations.
  – Non-rack-based secondary structure attachment and access mechanisms to stowed and installed mass is different.
  – Module axial CBM docking ports are modified (added or eliminated)

• **Launch Adapter**
  Evolved Expendable Launch Vehicle (EELV) launch will require a new interface to existing module trunnions to launch these elements to space. The launch adapter mass is not considered a part of the structural module in this study.
  – A launch adapter mass/design developed for the STA Node in the 2010 Boeing Docking Hub proposal is proposed to get the DSH to ISS for mission outfitting.
  – This launch adapter may also have propulsion capability to enable docking to ISS for mission outfitting.
Power System

Leo L Fabisinski
December 15, 2011
• Since ISS is 150V and has a distributed power architecture not suitable to DSH, Use MPCV components instead.

• MPCV Power Electronics were adapted from ISS components.

• UltraFlex Arrays and Drive Actuators Scaled from MPCV are suitable for free-flying craft.
Array Wing is Populated with Multi-Junction Inverted Metamorphic (IMM) Solar Cells currently in development. These offer Higher Conversion Efficiency and Lighter Weight than SOA Cells.
Since the Hab is in the middle of the complete stack, shadowing is a problem for some flight attitudes with respect to the sun, as shown below.

If shadowing presents a problem, deployment of MPCV arrays may be delayed and MPCV will require keep-alive power from Hab or CPS. Alternatively, MPCV arrays may be turned edge-on to the sun to minimize shadow.
• Solar Array Switch Module (SASM) – derived from ISS Array Regulation Unit (ARU)

• 120V Power Switch Card – Derived from ISS Remote Power Control Module (RPCM)

• 120V Umbilical Switch Card – Derived from ISS RPCM

• 28V Power Switch Card - derived from ISS 28V converters

• Battery Controller – Derived from Mars Reconnaissance Orbiter
Deep Space Hab

Power Electronics
(Enclosure)

- Scaled from existing space-qualified enclosures
- Includes Backplane, redundant Power Supply and Connectors
• Each battery String consists of 34 SAFT VES 180 Cells in series to achieve 122.4 V nominal potential.

• Mass Packing Factor of 1.35 used to size cell-balance electronics and Enclosure
## Deep Space Hab Mass Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>60-Day</th>
<th>500-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>Solar Arrays (with Booms, Actuators)</td>
<td>204</td>
<td>2</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>75</td>
<td>16</td>
</tr>
<tr>
<td>Secondary Batteries</td>
<td>153</td>
<td>10</td>
</tr>
<tr>
<td>Power Cabling</td>
<td>152</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>584</td>
<td></td>
</tr>
</tbody>
</table>
Avionics

Pete Capizzo
December 15, 2011
• **Avionics Approach**
  – The avionics system provides all command, control, data handling, and communications systems for the habitat.

  – The avionics for this DSH has been based on the MPCV crew vehicle avionics. This was judged to be a practical approach since the MPCV vehicle is largely a habitat vehicle with all the electronics required to operate ECLSS systems and provides a robust communications system with good ground link and local comm capabilities.
    • None of the MPCV propulsion or GN&C capabilities are included in the habitat.

  – Much of the MPCV avionics is already under development and has higher levels of TRL. This approach is then lower risk and coast than new development, and can compliment a short development schedule.

  – Using MPCV avionics as a baseline establishes good DSH commonality of avionics hardware with MPCV avionics. Spare parts stored in the habitat can be used in MPCV also.
    • Commonality further reduces cost and risk

  – It is basically a single hardware redundant system with some dual and triple fault tolerance provided by complementary systems.
    • For example, the S-band system can provide the same communication functions as the Ka-band with some reduced performance.
    • The two main computers are each a self checking pair system, making each one single fault tolerant itself, providing triple fault tolerances for the complete system.

  – Using ISS avionics would mean using old/obsolete technology. ISS avionics was designed for ISS control. The DSH avionics needs to communicate with and control vastly different elements (MPCV, SEP, CPS, MMSEV, etc.)
    • The MPCV avionics is better suited to interface with these different elements, and to communicate with ground from great distances.
• **Avionics Approach** (cont.)
  
  – Primary avionics is packaged into one avionics compartment in the floor.

  – Redundant avionics is located in a ceiling compartment to physically separate components.
    - It is desirable to have some remote data acquisition and management boxes to reduce cabling and congestion at the main avionics locations.

  – It is desirable to have an avionics control center on a wall to maintain a local vertical environment.
    - This area is will be the primary habitat control center.

  – It’s expected that laptop computers will be used by the crew to interface with habitat functions.
    - The laptops will communicate commands and receive status data from the VMCs.
    - With this capability, for example, a crew member could monitor ECLSS health and status form any location within the habitat, or pan an external camera around while laying in the crew quarters.

  – The 500-Day habitat avionics is the same as the 60-Day configuration.
    - A couple of extra intercom units are included in the MPLM.

  – It’s expected that the PDUs in the Hab have enough spare capability to handle power and data loads of the MPLM.
    - Large refrigeration systems in the MPLM may require additional power and data management units.
• Avionics Approach (cont.)
  – The main avionics components external to the habitat are the antennas and cameras.

  – For the 60-Day habitat, a 0.75 meter dish easily provides 100 Mbps ground link to the deep space network from lunar locations.

  – A 1.5 meter dish is provided on the 500-Day habitat to maintain 1 Mbps from Mars locations.

  – Real-time video will not be possible from these great distances, with up to 20 minutes signal travel time delays.
    • However, most Mars reference missions include a communication satellite orbiting Mars which will greatly improve data rate capabilities from Mars.

  – The habitat dish is 180 degrees phased from the MPCV dish to provide complimentary viewing angles.

  – Four external video cameras are provided for health and status monitoring of the habitat and attached elements.
    • The cameras can be used to assist in Flexcraft/SEV mission operations or EVAs.
    • The cameras are also phased from each other to provide complete viewing capability of the habitat.
DSH AES – Avionics Layout

Communication components

Vehicle Management Computer (VMC)

Power & Data Unit (PDU)
Remote Interface Unit (RIU)

Vehicle Management Computer (VMC)

CHECS
Ops Flt
Stor
WMC
Stor
CRS-Sabatier
Main Avionics
WPA
UPA

MSS/AV-1 with RWS

Port

MSFC/ED04 – DSH Configurations Based On ISS Systems
FINAL 12-15-2011
4 Video cameras: for monitoring EVAs, Flexcraft, and SEV operations, along with vehicle H&S

MPCV RCS provides station keeping for the stack, can be manually control from the Flight Control Center

Ka and S-band HGA 180deg from MPCV HGA
## DSH AES – Avionics Mass Summary

<table>
<thead>
<tr>
<th>Sub-System</th>
<th>Basic Mass (kg)</th>
<th>MGA (%)</th>
<th>Predicted Mass (kg)</th>
<th>Basic Mass (kg)</th>
<th>MGA (%)</th>
<th>Predicted Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR&amp;D System</td>
<td>10.8</td>
<td>3.0%</td>
<td>11.2</td>
<td>10.8</td>
<td>3.0%</td>
<td>11.2</td>
</tr>
<tr>
<td>Command and Data Handling</td>
<td>219.9</td>
<td>18.3%</td>
<td>260.2</td>
<td>219.9</td>
<td>18.3%</td>
<td>260.2</td>
</tr>
<tr>
<td>Displays &amp; Controls</td>
<td>134.0</td>
<td>18.3%</td>
<td>158.5</td>
<td>134.0</td>
<td>18.3%</td>
<td>158.5</td>
</tr>
<tr>
<td>Communications System</td>
<td>159.4</td>
<td>18.6%</td>
<td>189.0</td>
<td>187.4</td>
<td>18.1%</td>
<td>221.3</td>
</tr>
<tr>
<td>Intercom &amp; Video</td>
<td>55.5</td>
<td>22.2%</td>
<td>67.8</td>
<td>56.4</td>
<td>22.2%</td>
<td>68.9</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>45.4</td>
<td>30.0%</td>
<td>58.9</td>
<td>54.4</td>
<td>30.0%</td>
<td>70.7</td>
</tr>
<tr>
<td>IHM System</td>
<td>50</td>
<td>10.0%</td>
<td>55.0</td>
<td>70.0</td>
<td>10.0%</td>
<td>77.0</td>
</tr>
<tr>
<td>Avionics Cabling</td>
<td>289.7</td>
<td>30.0%</td>
<td>376.6</td>
<td>348.2</td>
<td>30.0%</td>
<td>542.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>964.7</strong></td>
<td></td>
<td><strong>1177.3</strong></td>
<td><strong>1081.2</strong></td>
<td></td>
<td><strong>1320.6</strong></td>
</tr>
</tbody>
</table>
Thermal

Linda Hornsby
December 15, 2011
# Ground Rules & Assumptions

## HAT GR&A (tentative)

- **Thermal Control**
  - External fluid loop for heat acquisition using ammonia
  - Internal fluid loop for heat acquisition using 60% prop glycol/water
  - ~13 kW heat acquired from MM cabin & avionics rejected using ISS-type radiators.
  - MLI covering external habitat surface for passive TCS.
  - ~13 kW heat acquired from MM cabin & avionics rejected using ISS-type radiators w/ 10 mil Ag-teflon coating

## Modifications to GR&A

- **Thermal Control**
  - Active waste heat collection/rejection
    - Redundant internal pumped water loop
    - Redundant external pumped ammonia loop
    - ISS LTL/MTL TCS components (pump package, filters, valves, HX, QDs, etc.)
    - ISS External TCS components (pump package, filters, valves, HX, QDs, etc.)
    - Deployed, non-articulating ISS PVR radiator.
  - Exterior shell thermal control
    - 19-layers DAK MLI, Nomex outer layer
    - Areal density estimated at .5 kg/m2
    - Shell heaters on HAB, MPLM, and tunnel
DSH Thermal Control System Design Approach

- External TCS System based on ISS design and flight proven through successful mission operations (TRL 9).
- Internal TCS System using ISS flight proven components, removed from racks and redistributed (TRL 8)
- Active waste heat collection – redundant internal and external pumped loops with cold plates and heat exchangers
  - DSH 60-Day mission metabolic and equipment waste heat – 11,970 W
  - DSH 500-Day mission metabolic and equipment waste heat – 12,925 W
- Active waste heat rejection
  - Radiators (with redundant loops) – deployed, non-articulating in flight
- Passive waste heat rejection
  - MPLM, HAB, tunnel pressure shell—multi-layer insulation (MLI)
- Exterior temperature control
  - MPLM, HAB, tunnel pressure shell—MLI and heaters
  - Exterior antennas, cameras, and gimbal shelf—MLI, heaters, louvers, coatings
An effective TCS is designed to insure that pressurized modules and electronics temperatures are maintained within acceptable range during all mission phases.
Active Thermal Control Schematic

Active Thermal Control

[Diagram showing the schematic of active thermal control systems, including LTL Loop and MTL Loop, with components such as System Flow Control Assembly, Pump Package Assembly, Three Way Valve, Interface HX, and Deployable Radiator (PVR).]
Internal Active Thermal Control

- Components
  - Pump Package Assembly (PPA)
  - Coldplates
  - Flow Control Valves (FCVs)
  - Three-Way Mixing Valves (TWMV)
  - Loop Cross-Over Assembly
  - Temperature Sensors

- Low Temperature Loop (LTL)
  - Typically support ECLSS requirements
  - Insulated lines, operate below dewpoint

- Moderate Temperature Loop (MTL)
  - Typically support C&DH, Comm, etc.
  - Un-insulated lines, operate above dewpoint

TCS centrally located in HAB to facilitate line access to both forward and aft sections
DSH Thermal Control Heat Rejection

Heritage – ISS EEATCS/PVR ORU
Weight - 741 kg each

EEATCS/PVR Radiator ORU Heat Rejection Capability 7kW -14kW each

Sizing is highly dependent on environmental heating and radiative interactions with other spacecraft surfaces.

<table>
<thead>
<tr>
<th>Item</th>
<th>Total Heat Dissipation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;DH, Instrumentation</td>
<td>1024</td>
</tr>
<tr>
<td>Displays &amp; Controls</td>
<td>452</td>
</tr>
<tr>
<td>Communications</td>
<td>525/625</td>
</tr>
<tr>
<td>Intercom / Video</td>
<td>292</td>
</tr>
<tr>
<td>Cabin Lighting</td>
<td>200/240</td>
</tr>
<tr>
<td>Circulation Fans</td>
<td>350/450</td>
</tr>
<tr>
<td>Heat Transport Pumps</td>
<td>700</td>
</tr>
<tr>
<td>Refrigerator/Freezer</td>
<td>540/1080</td>
</tr>
<tr>
<td>ECLSS</td>
<td>6373</td>
</tr>
<tr>
<td>Metabolic (4 crew)</td>
<td>544</td>
</tr>
<tr>
<td>Power Systems</td>
<td>970/1145</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>11,970/12,925</strong></td>
</tr>
</tbody>
</table>
External Passive Thermal Control

- MLI Blankets between MDPS & Pressure Shell
  - Double Aluminized Foil
  - Dacron net separators
  - Beta cloth or Nomex for outer layer
- Foam Insulation on ATCS lines
- Thermal Isolators
- Electrical Heaters
  - Shell, Window
  - Antennas, Cameras
  - Batteries
  - Gimbal Platform
  - External Ammonia Loop
- Heater Power
  - 400 Watts budgeted for 60-Day Mission (near ISS location)
  - 3000 Watts budgeted for 500-Day Mission (near Mars location)
## Thermal Mass Comparison by Mission

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>60-Day</th>
<th>500-Day</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
<td>Predicted Mass (kg)</td>
<td>Basic Mass (kg)</td>
</tr>
<tr>
<td>Internal TCS Rack LT/MT</td>
<td>226</td>
<td>20</td>
<td>271</td>
<td>226</td>
</tr>
<tr>
<td>Internal Rack Support</td>
<td>270</td>
<td>20</td>
<td>324</td>
<td>300</td>
</tr>
<tr>
<td>Internal TCS Misc.</td>
<td>30</td>
<td>30</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>External Active TCS</td>
<td>376</td>
<td>15</td>
<td>432</td>
<td>376</td>
</tr>
<tr>
<td>External Passive TCS</td>
<td>155</td>
<td>20</td>
<td>187</td>
<td>199</td>
</tr>
<tr>
<td>External Heat Rejection Sys.</td>
<td>1482</td>
<td>3</td>
<td>1526</td>
<td>1482</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2539</strong></td>
<td><strong>2780</strong></td>
<td><strong>2613</strong></td>
<td><strong>2868</strong></td>
</tr>
</tbody>
</table>
Future Work/Mass Saving Options

• ORU radiators were designed for ISS space environment and will operate more efficiently in deep space environment than in a ISS type environment. An external spacecraft thermal model is required to assess radiator performance due to environmental loads and blockage from other spacecraft elements. Possibility of using a single ISS radiator for the DSH design, mass savings 750 kg (high TRL).

• Lightweight composite materials radiator system, mass savings 1000 kg (low TRL).

• Consider a single internal fluid loop and/or external fluid loop and carry spare pump package and flow control valve. Preliminary fluid flow analysis is required to determine if heat loads can possibly be accommodated using a single loop and ISS size pumps, mass savings 200 kg.

• Spacecraft thermal model can also be used to size shell heaters for different DSH locations. Potential reduction of estimated heater power would save mass for power subsystem, mass savings 50 kg.
DSH Thermal Control Components

Interface Heat Exchanger
Heritage – ISS EEATCS
Weight - 41 kg
63 cm x 53 cm x 20 cm

Radiator
Heritage – ISS EEATCS/PVR ORU
Weight - 741 kg each
Heat Dissipation – 7kW to 14kW each
Dependent on environmental loading

Two Way Mixing Valve

TCS Rack
Heritage – ISS US Lab Rack
Pumps, flow control, valves, sensors for IATCS.

Manual Flow Control Valve

Regen HX

Heritage – ISS EEATCS/PVR ORU
Weight - 741 kg each
Heat Dissipation – 7kW to 14kW each
Dependent on environmental loading

Two Way Mixing Valve

TCS Rack
Heritage – ISS US Lab Rack
Pumps, flow control, valves, sensors for IATCS.
Environments Protection

Tiffany E. Russell
December 15, 2011
System Overview

- Environments protection system consists of two main components
  - External Micrometeoroid Debris Protection Shield (MDPS), MPLM derived
  - Interior Radiation Water Wall
Crew Quarters Protection

- Nominal 60 and 500 day case, water wall
  - 0.55 cm thick polyethylene tank
  - 9.9 cm thick water wall
  - Total protection = 11 g/cm²
  - Mass = 2850 kg

- Water wall provides a storm shelter during a Solar Particle Event (SPE)
  - Current design does not include protection against Galactic Cosmic Radiation (GCR)
Tank Configuration

- Tank surrounding crew quarters
Tank Configuration

- End Cap Segments

- Crew Quarters Segments
Mass Savings

- Dual functioning water tanks
  - Water transported on DSH can be used for radiation protection and ECLSS
    - ECLSS H$_2$O will bring 504 kg for 60 day and 1440 kg for 500 day
    - 60 day mission requires 9.9 cm water wall of protection
    - Use food and storage as a shield
    - Design storage bags with radiation shielding materials (e.g. polyethylene)
    - Replace depleted water tanks with waste water and brine
      - Brine available every 30 days
      - Refill storage with generated refuse

<table>
<thead>
<tr>
<th></th>
<th>60 day (kg)</th>
<th>500 day (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDPS</td>
<td>1121</td>
<td>1713</td>
</tr>
<tr>
<td>ECLSS</td>
<td>504</td>
<td>1440</td>
</tr>
<tr>
<td>Radiation Water Wall</td>
<td>2850</td>
<td>2850</td>
</tr>
<tr>
<td>Dual Water Storage System</td>
<td>2346*</td>
<td>1410*</td>
</tr>
</tbody>
</table>

*These numbers do not include the amount of water produced by ECLSS through out the duration of the mission.
# Mass Summary

<table>
<thead>
<tr>
<th>Sub-System</th>
<th>60 Day</th>
<th>500 Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Mass (kg)</td>
<td>MGA (%)</td>
</tr>
<tr>
<td>Micro-Meteoroid &amp; Debris Protection System (MPDS)</td>
<td>1121</td>
<td>10</td>
</tr>
<tr>
<td>Radiation Protection Tank</td>
<td>332</td>
<td>5</td>
</tr>
<tr>
<td>Radiation Water</td>
<td>2518</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3971</td>
<td></td>
</tr>
</tbody>
</table>
Mass Savings

- Reconfigure the internal layout for 500 day mission
  - Fill end-cap with wet storage and 4 ECLSS water racks to provide a 25% water mass reduction
  - An additional water wall will need to be added to the wall adjacent to the ward room
Attached Vehicles

David Smitherman
December 15, 2011
Notional MPCV* Element Description

**Assumed Design Parameters**

<table>
<thead>
<tr>
<th>Category</th>
<th>MPCV-CM</th>
<th>MPCV-SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>1700</td>
<td>1250</td>
</tr>
<tr>
<td>Protection</td>
<td>2200</td>
<td>90</td>
</tr>
<tr>
<td>Propulsion</td>
<td>220</td>
<td>1260</td>
</tr>
<tr>
<td>Control/Other</td>
<td>1750</td>
<td>450</td>
</tr>
<tr>
<td>Power</td>
<td>520</td>
<td>300</td>
</tr>
<tr>
<td>Avionics</td>
<td>690</td>
<td>270</td>
</tr>
<tr>
<td>Thermal/CLSS</td>
<td>1500</td>
<td>870</td>
</tr>
<tr>
<td>Growth</td>
<td>450</td>
<td>160</td>
</tr>
<tr>
<td><strong>DRIY MASS SUBTOTAL</strong></td>
<td>9030</td>
<td>4650</td>
</tr>
<tr>
<td><strong>TOTAL WET MASS</strong></td>
<td>9740</td>
<td>13600</td>
</tr>
</tbody>
</table>

**Description**

The MPCV provides crew ascent, entry, and on-orbit support including aborts. It is based on an Orion crew module, service module, and launch abort system. The MPCV carries the crew to LEO, providing ascent abort coverage. It is the active crewed element during the trip from LEO to Earth-Moon L1. It has sufficient delta V to return the crew from L1 in an abort scenario. The MPCV is in a quiescent mode during the trip from L1 to a NEO and during most of the return trip. The MPCV provides EDL to a water landing.

*Analysis anchored to above data with small variances to accommodate differences in consumables and crew*
FlexCraft is a single-person spacecraft designed for servicing/exploration of ISS, NEOs and satellites. It can be piloted or tele-operated. Using the same atmosphere as the host vehicle provides immediate access to space without pre-breathing or airlock. Integral propulsion enables rapid translation to the work site. It is sized for all crew working shirt sleeve operating conventional displays and controls.

### Design Constraints/Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized Vol.</td>
<td>0.62 m³</td>
</tr>
<tr>
<td>Crew Size</td>
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<tr>
<td>Excursion time</td>
<td>&lt; 8hrs</td>
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<tr>
<td>Atmosphere</td>
<td>O₂/N₂ same as host</td>
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<tr>
<td>Pre-breathe</td>
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<tr>
<td>Operations</td>
<td>Shirt sleeve</td>
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<tr>
<td>Design Population</td>
<td>One size fits all</td>
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<tr>
<td>Control</td>
<td>Piloted or tele-op</td>
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<tr>
<td>Equip/sample bin</td>
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<tr>
<td>Propellant</td>
<td>GN₂ (rechargeable)</td>
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<tr>
<td>Delta-v</td>
<td>21 m/s</td>
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<tr>
<td>Battery energy stor</td>
<td>2700 W-h</td>
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<td>ECLSS</td>
<td>Repackaged PLSS</td>
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<td>Thermal Control</td>
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<tr>
<td>Radiation Protection</td>
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<td>Category</td>
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<td>Structures</td>
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<td>Propulsion</td>
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<td>Power</td>
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<td>Docking Mechanism</td>
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<td>GROWTH</td>
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<td>DRY MASS</td>
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<td>Non-Prop Fluids</td>
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<td>TOTAL GROSS MASS</td>
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</table>

* FlexCraft POC is Brand Griffin/ED04 Advanced Concepts Office

08-29-2011
Vehicle Sizing References

David Smitherman
December 15, 2011
### ISS Module Internal Volumes

<table>
<thead>
<tr>
<th>Module/Element</th>
<th>Volume (ft^3)</th>
<th>Volume (m^3)</th>
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<tbody>
<tr>
<td></td>
<td>Habitable</td>
<td>Pressurized</td>
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<tr>
<td>USOS</td>
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<td>13230</td>
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<tr>
<td>US Lab</td>
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<td>3938</td>
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<tr>
<td>Node 1</td>
<td>1030</td>
<td>2016</td>
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<tr>
<td>Node 2</td>
<td>1230</td>
<td>2666</td>
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<tr>
<td>Node 3</td>
<td>1190</td>
<td>2666</td>
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<tr>
<td>Airlock</td>
<td>589</td>
<td>1192</td>
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<tr>
<td>PMA - 1</td>
<td>187</td>
<td>205</td>
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<tr>
<td>PMA - 2</td>
<td>157</td>
<td>185</td>
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<tr>
<td>PMA - 3</td>
<td>157</td>
<td>185</td>
</tr>
<tr>
<td>Z1 Dome</td>
<td>53</td>
<td>59</td>
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<tr>
<td>Cupola</td>
<td></td>
<td>118</td>
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<td>TeSS</td>
<td>78</td>
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<td>Crew Quarters (x3)</td>
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<td>6.63</td>
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<td>ESA</td>
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<td>2772</td>
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<td>Columbus</td>
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<td>614</td>
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<tr>
<td>MRM2</td>
<td>380</td>
<td>523</td>
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<td>Soyuz</td>
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<td>412</td>
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<tr>
<td>Progress</td>
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<td></td>
</tr>
</tbody>
</table>

*HAB volume (similar to US Lab)*
- Pressurized: 111.51 m³
- Habitable: 34.77 m³

*MPLM volume (similar to Columbus module and Nodes 2 & 3)*
- Pressurized: 76.4 m³
- Habitable: 32.3 m³

*MRLM information based off calculations done from images, results are considered estimates.*

**Information obtained through ECLSS Team, International Partners, and IVC Team analysis.**
Vehicle Habitable Volume Summary

4 Crew / 60-Day Configuration

- **DSH-ISS Element Summary**
  - **HAB (same size as US Lab)**
    - Pressurized Volume: $\sim 107 \text{ m}^3$
    - Habitable Volume: $\sim 56 \text{ m}^3$
  - **Tunnel**
    - Pressurized Volume: $\sim 10 \text{ m}^3$
    - Habitable Volume: $\sim 9 \text{ m}^3$

- **Sub-Total**
  - Pressurized Volume: $\sim 117 \text{ m}^3$
  - Habitable Volume: $\sim 65 \text{ m}^3$

- **MPCV**
  - Pressurized Volume: $\sim 20 \text{ m}^3$
  - Habitable Volume: $\sim 9 \text{ m}^3$

- **Total**
  - Pressurized Volume: $\sim 137 \text{ m}^3$
  - Habitable Volume: $\sim 74 \text{ m}^3$

4 Crew / 500-Day Configuration

- **DSH-ISS Element Summary**
  - **HAB (same size as US Lab)**
    - Pressurized Volume: $\sim 107 \text{ m}^3$
    - Habitable Volume: $\sim 56 \text{ m}^3$
  - **Tunnel**
    - Pressurized Volume: $\sim 10 \text{ m}^3$
    - Habitable Volume: $\sim 9 \text{ m}^3$

- **MPLM**
  - Pressurized Volume: $\sim 76 \text{ m}^3$
  - Habitable Volume: $\sim 25 \text{ m}^3$

- **Sub-Total**
  - Pressurized Volume: $\sim 193 \text{ m}^3$
  - Habitable Volume: $\sim 90 \text{ m}^3$

- **MPCV**
  - Pressurized Volume: $20 \text{ m}^3$
  - Habitable Volume: $9 \text{ m}^3$

- **Total**
  - Pressurized Volume: $213 \text{ m}^3$
  - Habitable Volume: $99 \text{ m}^3$
**4 Crew / 60-Day case**

**EXAMINE Tool**

---

**Design Constraints/Parameters**

- **Pressurized Vol.** 92.1 m³
- **Habitable Vol.** 56.0 m³
- **Atmospheric Pressure** 70.3 kPa
- **Crew Capacity** 4
- **Crewed Mission Duration** 60 d
- **EOL Solar power generation** 12 kW
- **Total battery energy storage** 19 kW-h
- **Number of Batteries** 3
- **Depth of Discharge** 80 %
- **Power load during battery operati** 7.9 kW

- **ECLSS Closure - Water** Partially Closed
- **ECLSS Closure - Air** Partially Closed
- **Habitat Structure** Rigid Cylinder
- **Habitat Height** 6.09 m
- **Habitat Diameter** 4.57 m

**Mass Growth Allocation**

- **Project Manager’s Reserve** 10%

---

**Category** | **Mass, kg**
---|---
**Structure** | 3,820
**Protection** | 158
**Propulsion** | 0
**Power** | 937
**Control** | 0
**Avionics** | 453
**Environ./Active Therm** | 4,563
- **ECLSS** | 2,599
- **Air Subsys** | 901
- **Water Subsys** | 675
- **Food** | 468
- **Human Accommodations** | 231
- **Other** | 325
- **EVA systems** | 635
- **Thermal Control System** | 539
- **Crew Accommodations** | 790

**Growth** | 2,979

**DRY MASS SUBTOTAL** | 12,910

**Non-cargo** | 2,890
- **Recreational Equipment** | 100
- **Crew Health Care** | 657
- **Personal Hygiene** | 33
- **Housekeeping Supplies** | 188
- **Operational Supplies** | 131
- **Maintenance Equip. & Spares** | 1,625
- **Photography Supplies** | 120
- **Sleep Accommodations** | 36
- **Cargo - Radiation Protection (waterwe** | 2,055

**INERT MASS SUBTOTAL** | 17,855

**Non-propellant** | 212

**Propellant** | 0

**TOTAL WET MASS** | 18,066

---

**Description**

The Deep Space Habitat provides habitation for crew members for long duration missions. The habitat has connection adapters in order to dock with the SEV, CTV and the propulsion unit(s). There is an internal bulkhead 2m from the aft dome with airlock services to act as a contingent airlock. The habitable volume per crew was assumed to be ~14 m³/crew with a habitat diameter of 4.57 m. The power load during battery operations is assumed to be 7.9 kW →~2.4 hrs.

---

Reference sizing from the EXAMINE tool by LaRC/Matt Simon

MSFC/ED04 – DSH Configurations Based On ISS Systems  
**FINAL 12-15-2011**
**4 Crew / 500-Day case**

**EXAMINE Tool**

---

**Design Constraints/Parameters**

<table>
<thead>
<tr>
<th>Category</th>
<th>Mass, kg</th>
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<tbody>
<tr>
<td>Structure</td>
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<tr>
<td>Protection</td>
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<td>Control</td>
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<td>Avionics</td>
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<td>Environ./Active Therm</td>
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<td>Other</td>
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<td>EVA systems</td>
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<td>Thermal Control System</td>
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<tr>
<td>Crew Accommodations</td>
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<tr>
<td>Growth</td>
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<tr>
<td><strong>DRY MASS SUBTOTAL</strong></td>
<td><strong>25,739</strong></td>
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</tbody>
</table>

**Non-cargo**

| Description                  | 5,131 |
| Recreational Equipment       | 200   |
| Crew Health Care             | 1,782 |
| Personal Hygiene             | 165   |
| Housekeeping Supplies        | 276   |
| Operational Supplies         | 252   |
| Maintenance Equip. & Spares  | 2,300  |
| Photography Supplies         | 120   |
| Sleep Accommodations         | 36    |
| Cargo - Radiation Protection (water) | 2,055 |
| **INERT MASS SUBTOTAL**      | **32,925** |
| **Non-propellant**           | **1,084** |
| **Propellant**               | 0      |
| **TOTAL WET MASS**           | **34,009** |

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**Graphic not to scale**

**Description**

The Deep Space Habitat provides habitation for crew members for long duration missions. The habitat has connection adapters in order to dock with the SEV, CTV and the propulsion unit(s). There is an internal bulkhead 2m from the aft dome with airlock services to act as a contingent airlock. The habitable volume per crew was assumed to be ~25.5 m³/crew with a habitat diameter of 5 m. The power load during battery operations is assumed to be 11 kW → 2.4 hrs.

Reference sizing from the EXAMINE tool by LaRC/Matt Simon

MSFC/ED04 – DSH Configurations Based On ISS Systems

FINAL 12-15-2011