



Advanced Space Exploration

# ***LSSCS BAA Topic 2 Lunar Habitat: Minimum Functionality to Outpost Capability***

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- Lunar Transportation Systems
- Oceaneering
- Orion Propulsion
- SICSA
- Thin Red Line
- USA



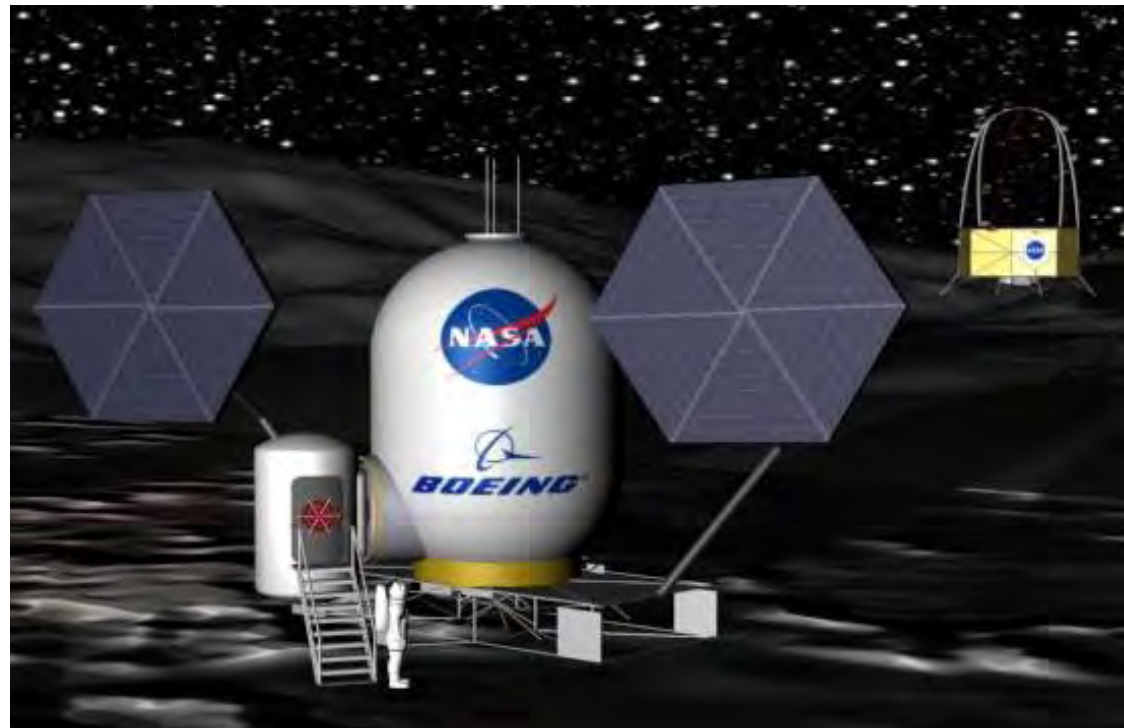
# LSSCA BAA Topic 2: MFHE Definition

- **Minimum Functionality Habitation Element**

- **Deployable Habitat**

- **DHE Update**

- **The Path to Growth**





# Requirements Definition Process

## ● Starting point - Maslow Hierarchy

- Physiological
- Safety

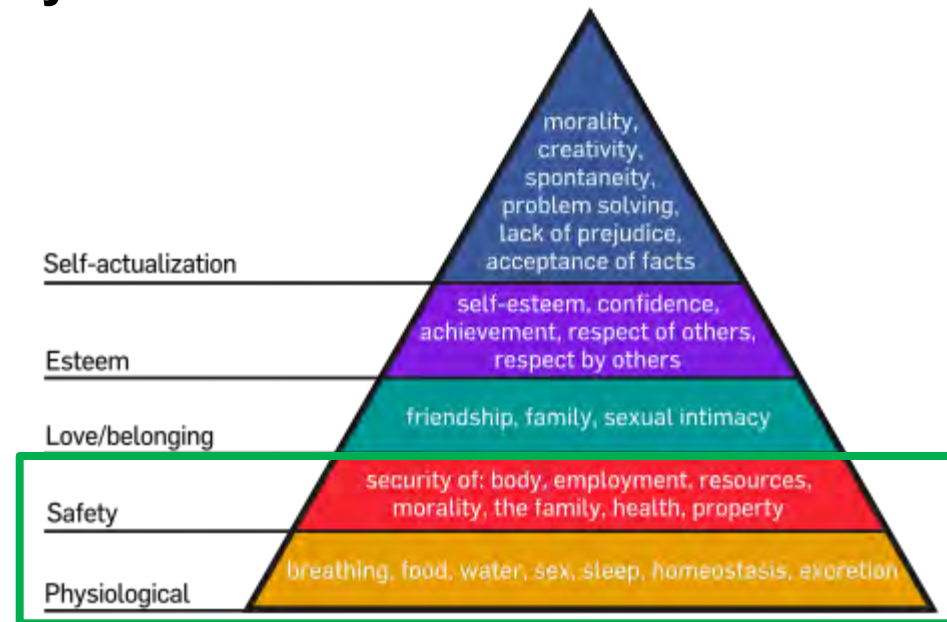
## ● Extended to meet mission

- Moon
- 4 people
- 28 days
- Exploration and Science

## ● NASA implementation needs

- Redundancy
- Fail operational / fail safe
- Operational enhancements
- Growth path

## Maslow's Hierarchy of Needs



[http://en.wikipedia.org/wiki/Maslow's\\_hierarchy\\_of\\_needs](http://en.wikipedia.org/wiki/Maslow's_hierarchy_of_needs)

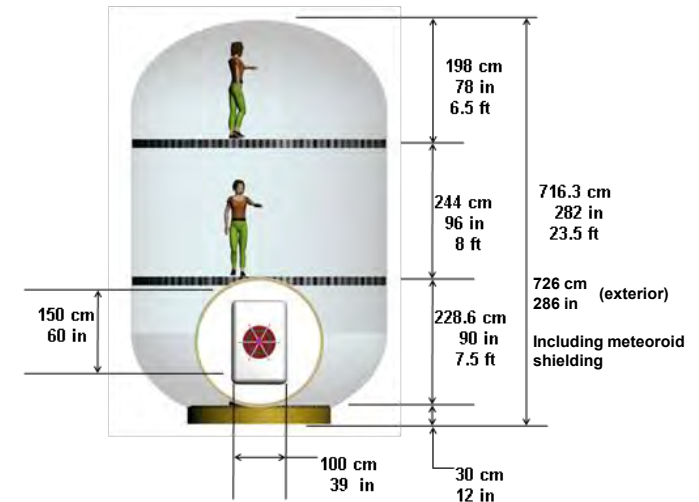
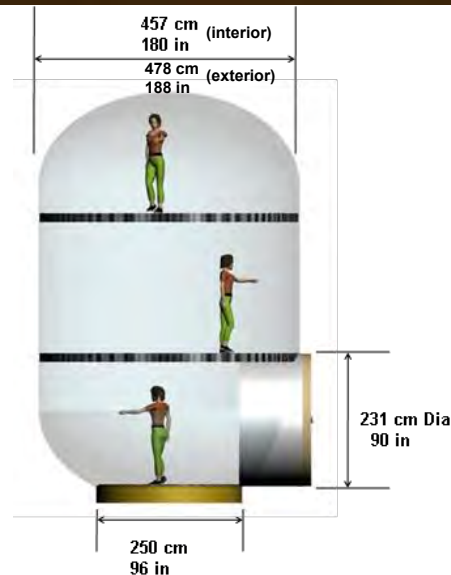
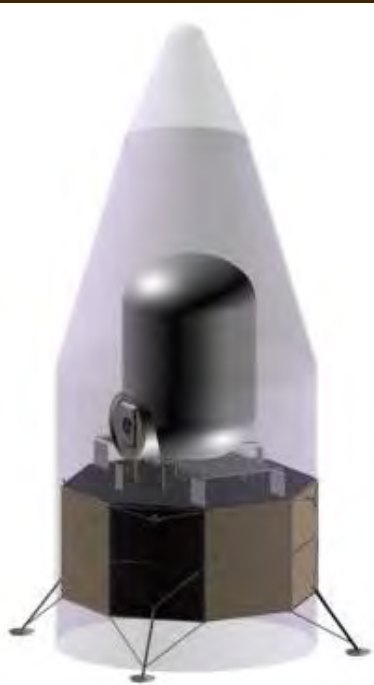
# MFHE BAA Requirements

- **Basic safety** features **without contingency** protection
- Define **minimum** required **functions for reference mission** support
- Provide conceptual design incorporating minimum functions
- Provide MFHE mass, power and volume estimates
- Define potential growth options from MFHE
- Total **mass** limited to **7000 kg**
- Support **4-person** crew for **28 days with 30-day contingency**
- Pyld Env: 8.8 m D x 11.7 m L cyl. plus 7.5 L x 4 m upper D frustum
- Provide **8 psi** atmosphere with **30% oxygen** and **70% nitrogen**
- **Provide hab health status** upon arrival and before crew launch
- **Support science and exploration objectives** with regular EVAs

# Derived MFHE Size Driving Requirements

● Ares V payload envelope constraint (m)	(cyl) 8.8 D x 11.2 L (frustum) 7.5 L x 4.0 D
● Minimum free volume (28 day, 4 people) (m <sup>3</sup> )	37.0
● Occupied volume (m <sup>3</sup> )	7.2
● Linear wall space (m)	5.4
● Floor space - unique (m <sup>2</sup> )	3.2
● Shared floor space (m <sup>2</sup> )	5.0
● Internal storage (m <sup>3</sup> )	1.0
● 30-day radiation dose limit from major SPE (cSv)	25

# Boeing Integrated MFHE Concept: Three Floors in a 4.6 m D Vertical Cylinder



- One primary and two ancillary floors
- **78 m<sup>3</sup> habitable** of 121 m<sup>3</sup> total pressurized **volume**
- **28 m<sup>2</sup> open** of 35 m<sup>2</sup> total **floor area**
- 457 cm (15 ft) diameter with 228.5 cm (7.5 ft) ceiling
- **Entry** foyer on **lowest floor**; Sleeping on upper floor

# MFHE Living Space Arrangements



## ● Four work stations

- Medical / Life Sciences
- Mission and habitat operations
- Physical sciences with glove box
- Generic work desk

## ● Food management and storage

## ● Hygiene module

## ● Toilet

## ● Foldable dining / conference table

## ● Access to lower & upper floors



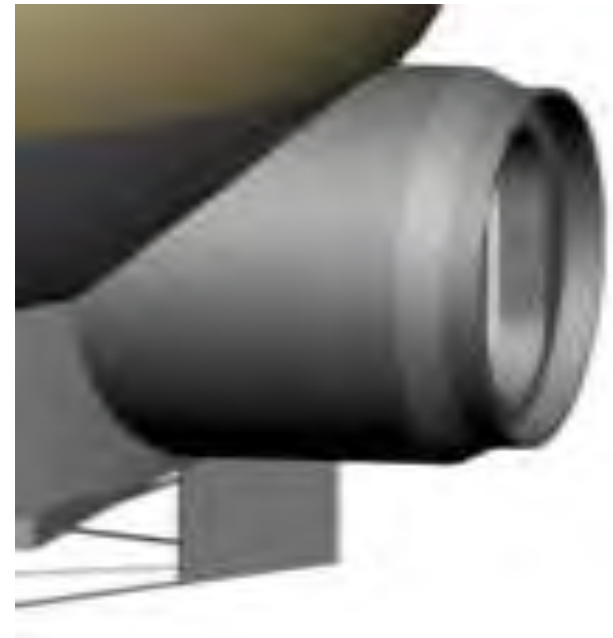


# Habitat Structure

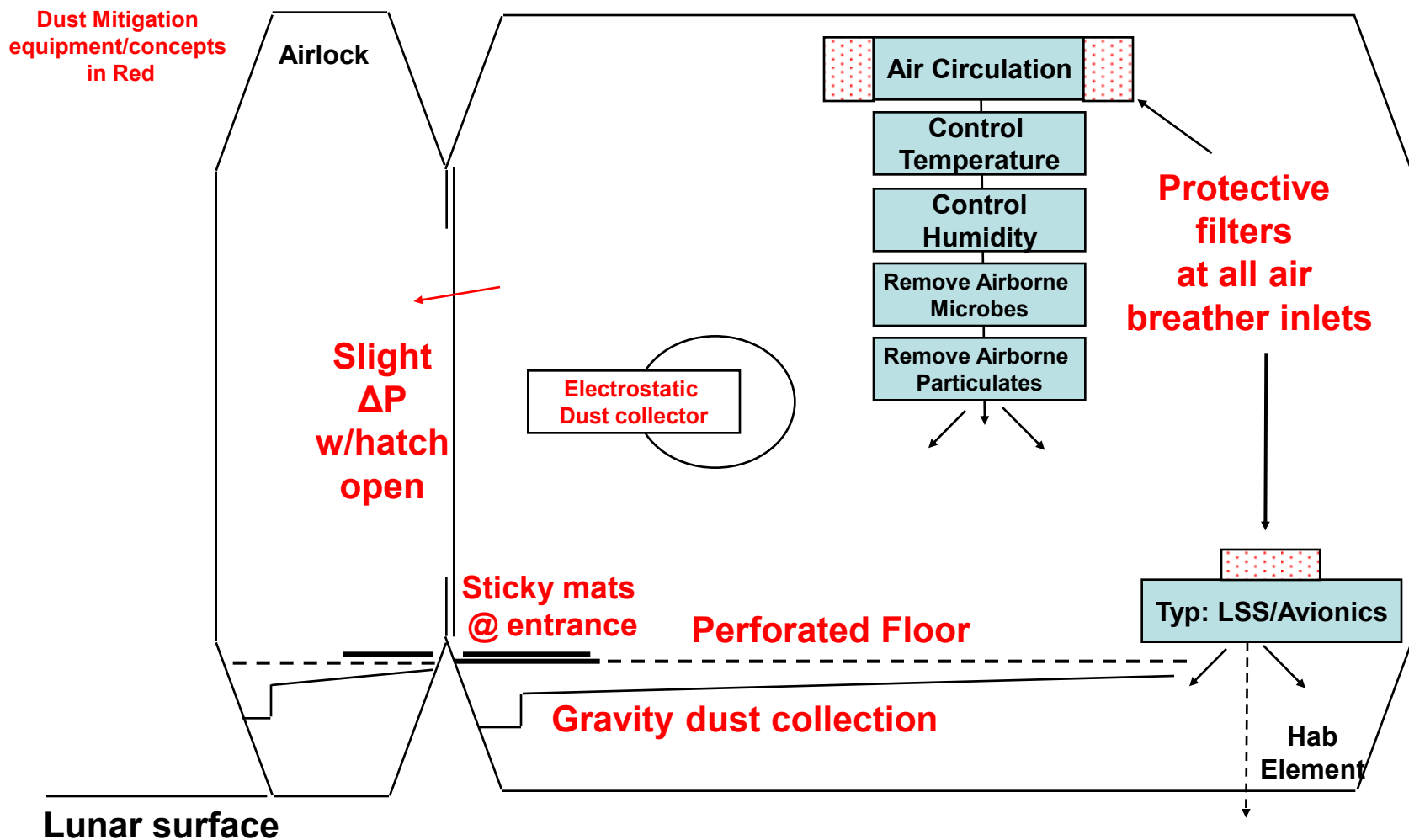
- Upright Aluminum cylinder with radical 2 domes
- 716.3 cm (23.5 ft) total internal height
- 228.6 cm (7.5 ft) hab internal radius
- 15.24 cm (6 in) floor thickness for utility runs
- Aluminum honeycomb panels for interior structure
- 228.6 cm (7.5 ft) cylindrical entryway / intermodule connector
- Hatch characteristics from ISS hatches
- Intermodule Connector based on ISS ACBM

# Intermodule Connector Assembly

- 228.6 cm (7.5 ft) cylindrical entryway / intermodule connector
- Intermodule Connector based on ISS ACBM
- Hatch characteristics from ISS hatches

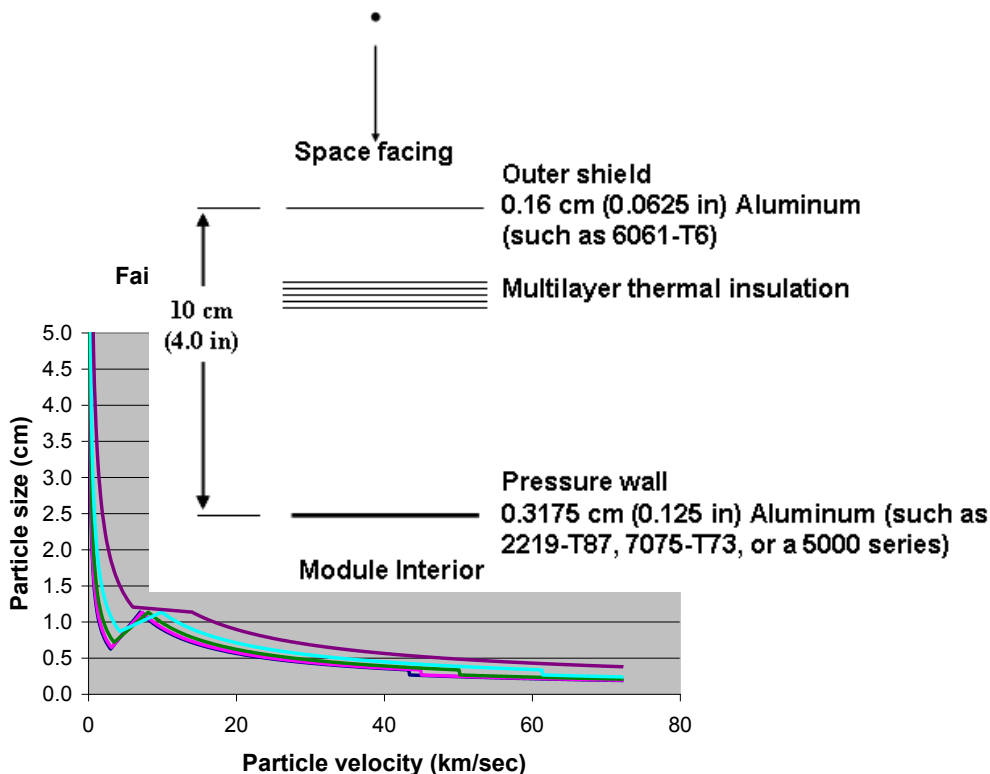


# MFHE Dust Mitigation Incorporated in ECLSS, Air Flow and Hab Layout



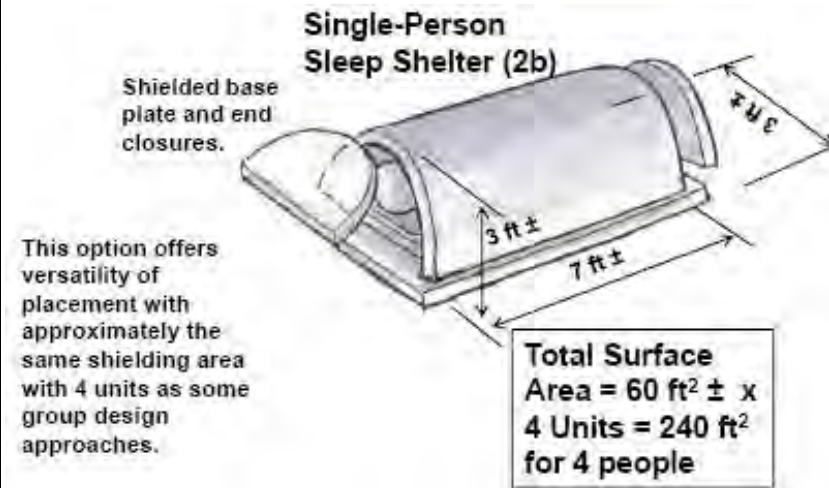
# MFHE Radiation and Meteoroid Protection

## 1.2 cm D Meteoroid Protection



**0.16 cm Al Whipple plate  
provides 0.9997 PNP/yr  
1 penetration in 3975 yrs**

## Major Solar Proton Event Protection

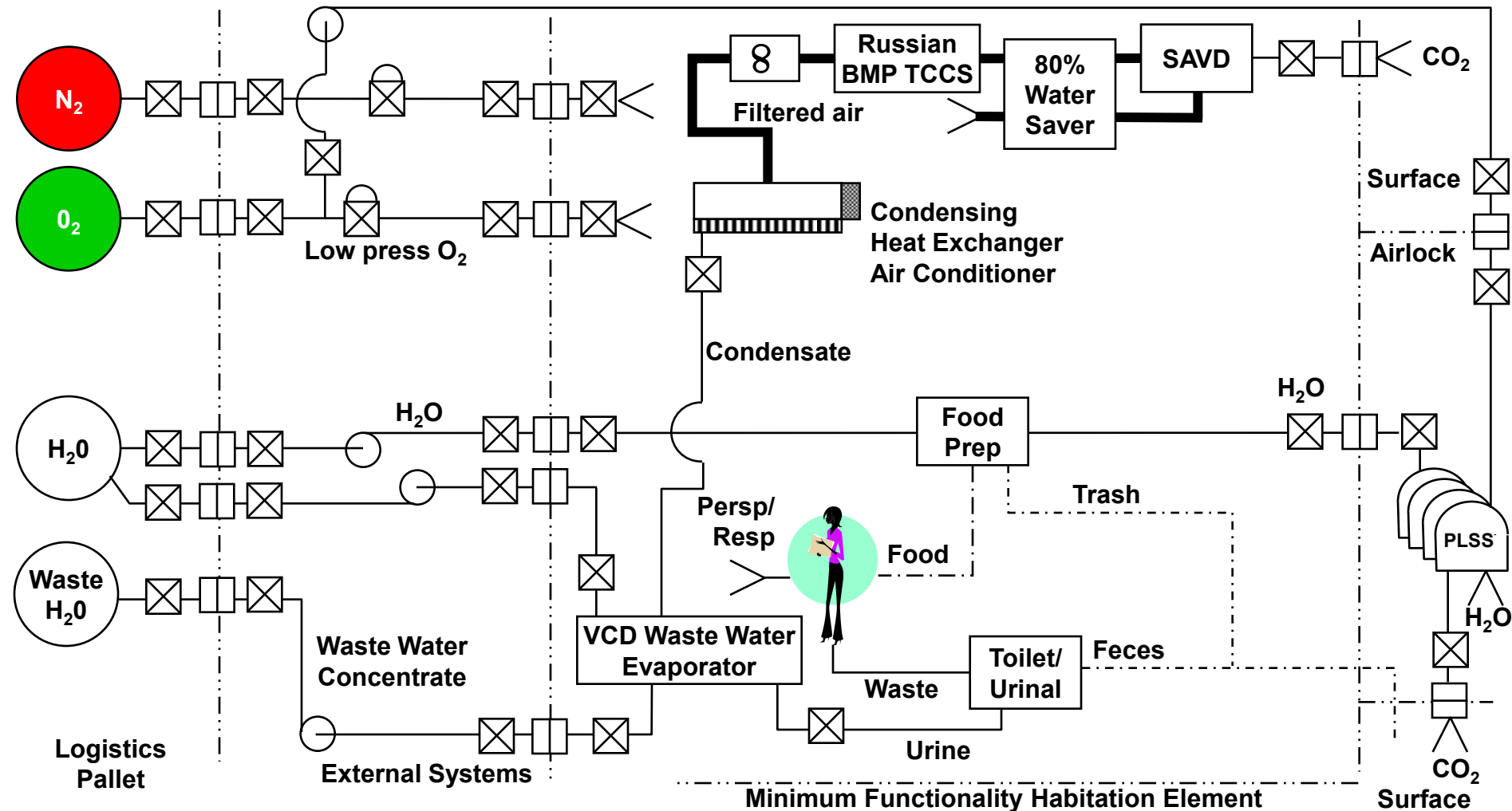


This option offers versatility of placement with approximately the same shielding area with 4 units as some group design approaches.

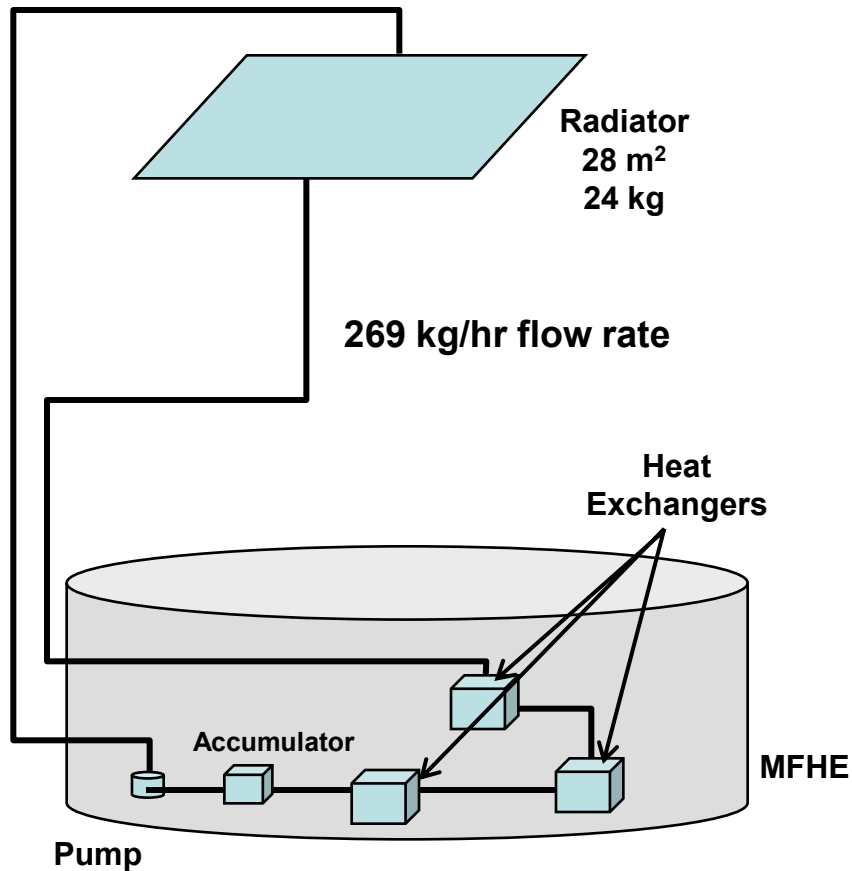
**10 cm polyethylene pup tent  
for SPE radiation protection**



# Water Recovery is a Key ECLSS Capability

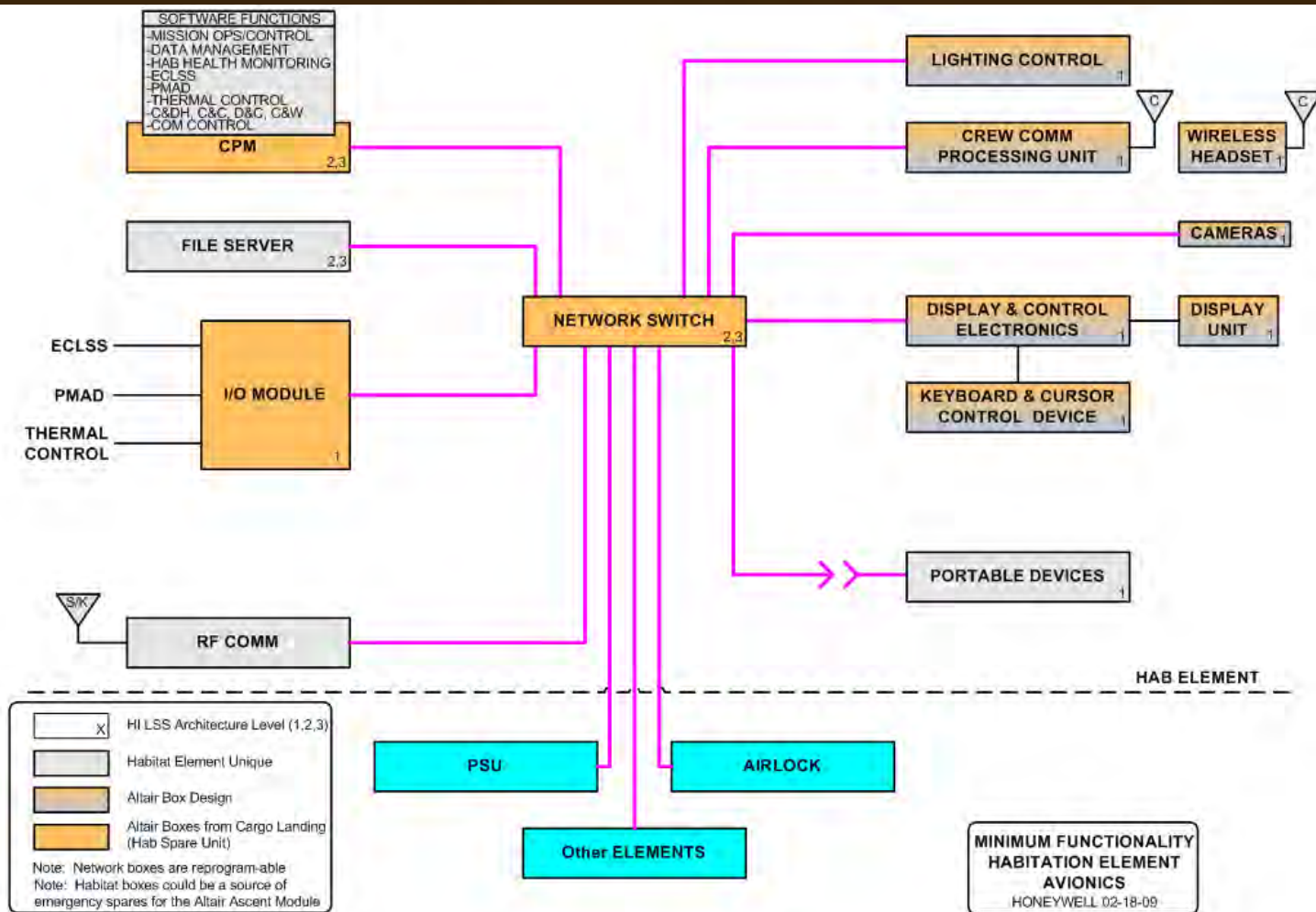


# Single-Loop Single-Fluid Thermal Control System

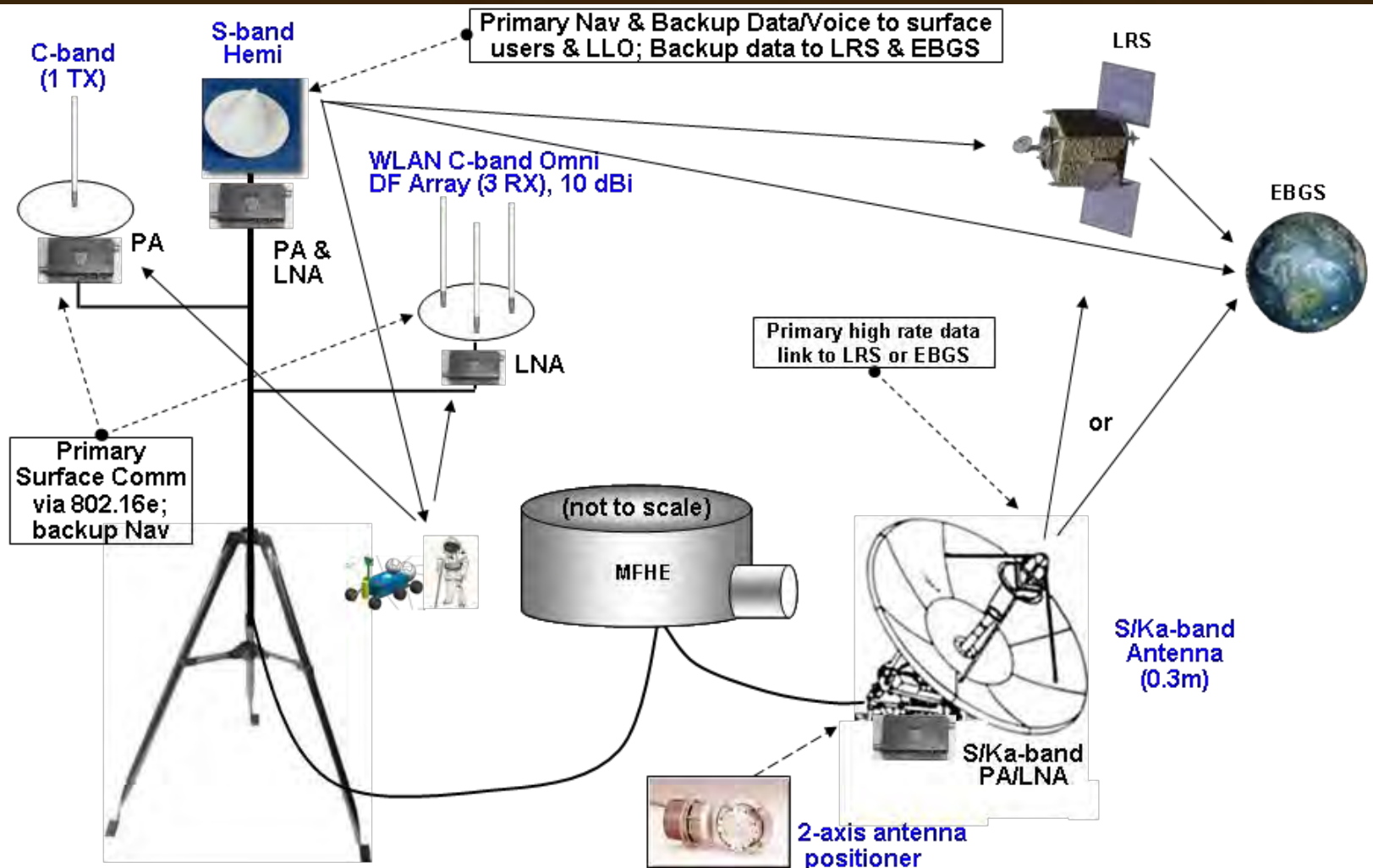


- Simple flat-plate aluminum radiator
- Assumed 20 gal coolant volume
- 3M Novec HFE-7200 coolant
- Air to coolant heat exchangers
- Cold plates for electronics
- 4554 W heat rejection capacity

# Minimum Habitat Avionics Architecture

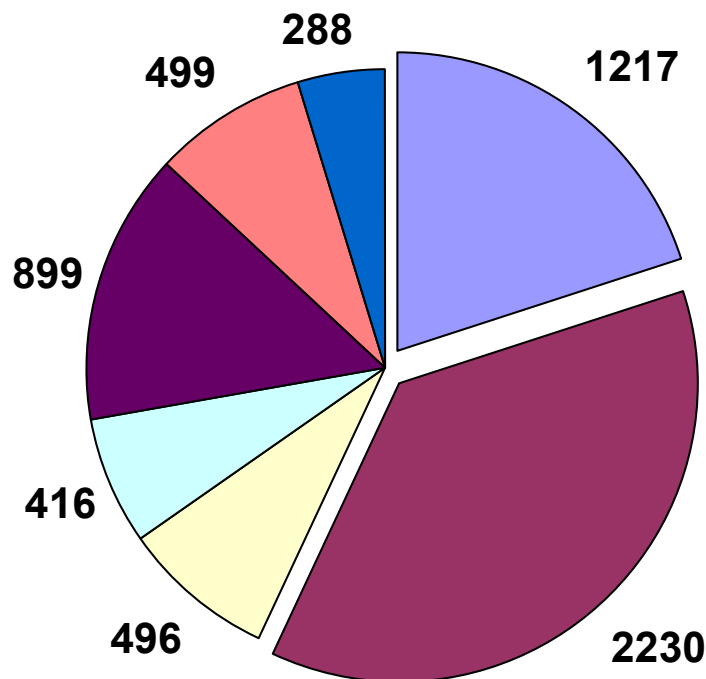


# MFHE Communications Overview





# MFHE 6044 kg Mass Estimate is 956 kg Less Than 7000 kg Limit



- **Structure and Radiation Protection 57% of total**

- **251 kg (walls, floors, ceiling) moved from Structure to Internal Outfitting**

- **Available volume and area for component mounting exceeds requirement**

- Internal volume for subsystem components

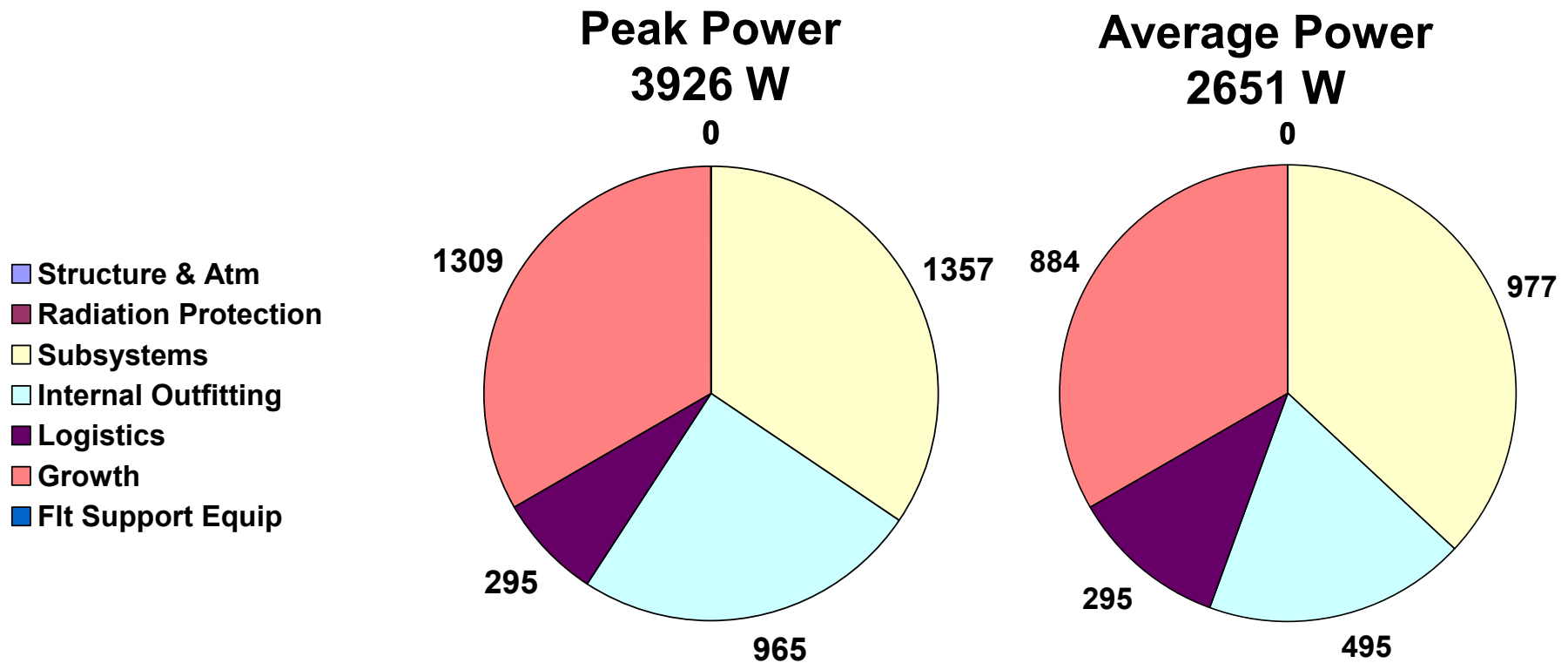
- Required, with 25% packing factor 0.8 m<sup>3</sup>
- Available in lower dome 17.1 m<sup>3</sup>

- Internal area for subsystem components

- Required, with 25% packing factor 24.5 m<sup>2</sup>
- Available in lower dome (1 layer on shell) 27.4 m<sup>2</sup>

Growth allowance: mass, structure - 15%; mass, components - 50%; power & heat rejection - 50%; packing factor - 25%

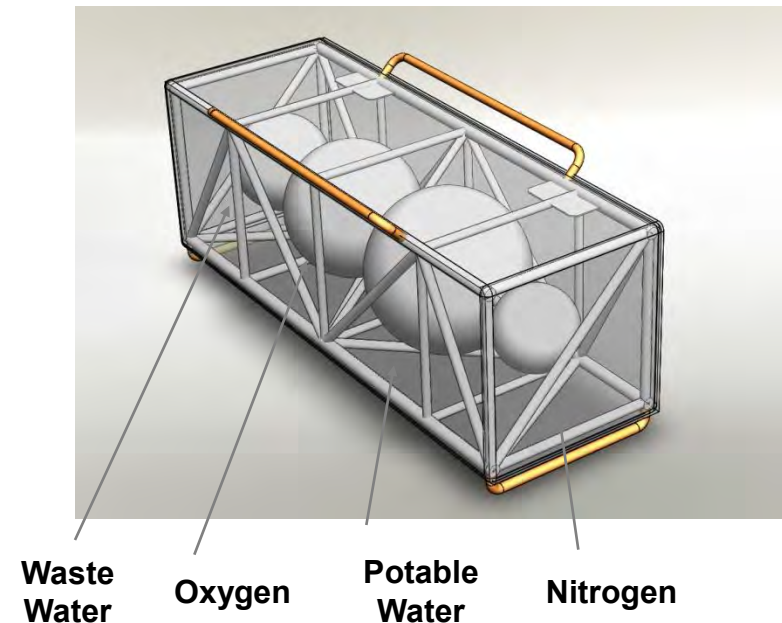
# Boeing MFHE Requires 3.9 kW Peak and 2.6 kW Average from Power Support Unit



# MFHE Logistics Support

- 28-day stay plus 30-day contingency
- Flex lines for MFHE connection
- Three Consumables (kg) **474**
  - Oxygen: 196
  - Potable Water 262
  - Nitrogen 16
  - Waste Water (capacity 69 kg) 0
- Hardware mass (kg) **296**
- New pallet required for each mission
- Food (carried separately) (kg) **129**

**899 kg including food in Hab**



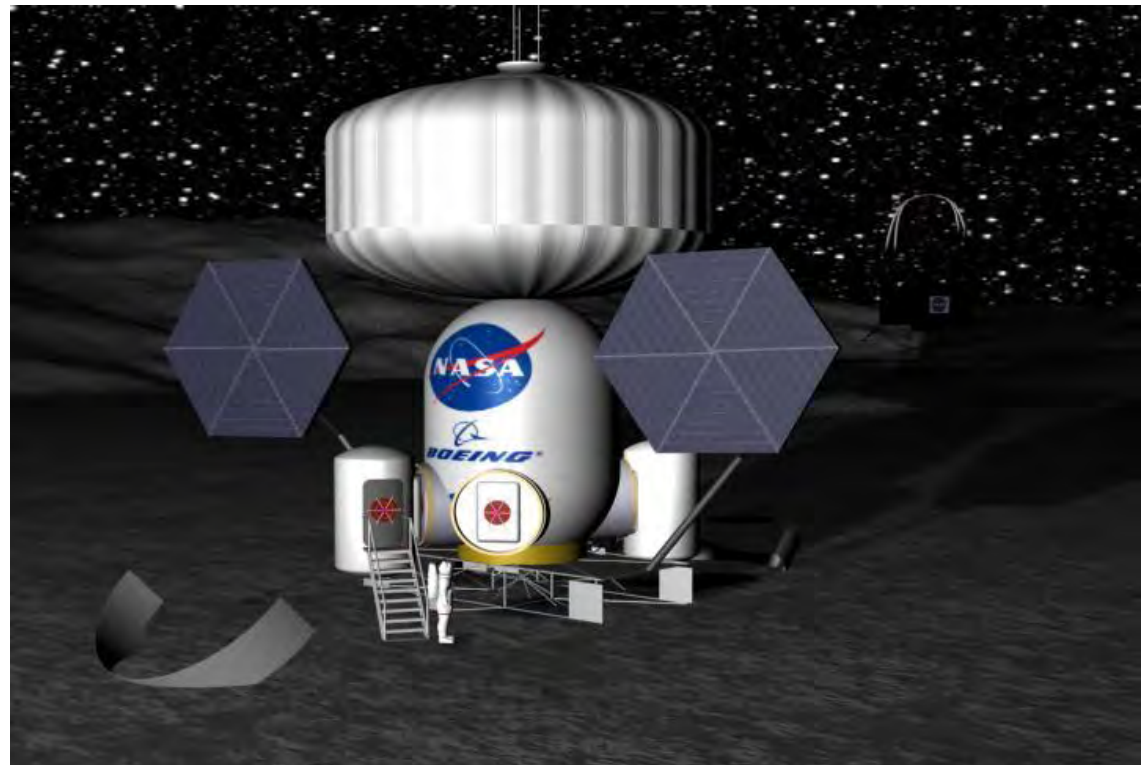
# LSSCA BAA Topic 2: MFHE Definition

- Minimum Functionality Habitation Element

- Deployable Habitat

- DHE Update

- The Path to Growth

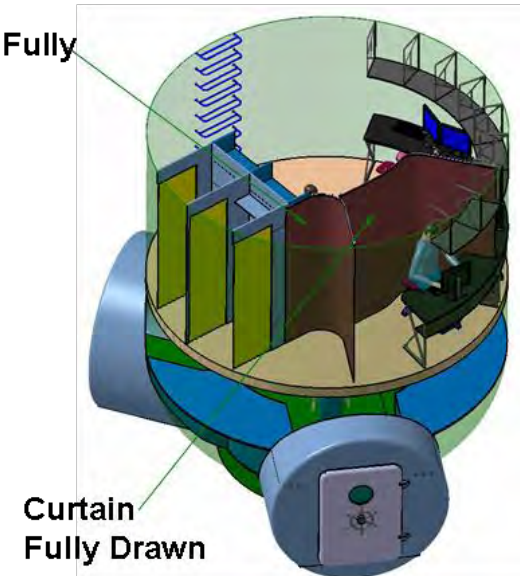
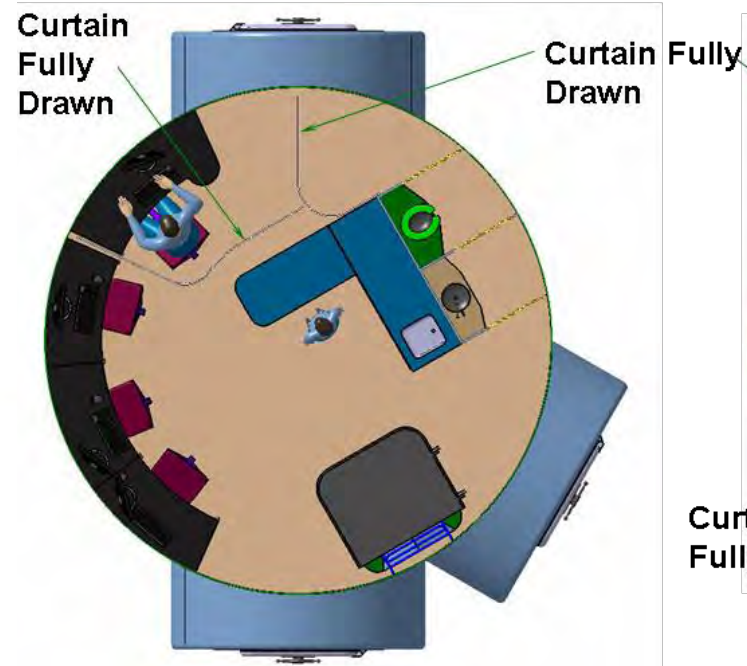
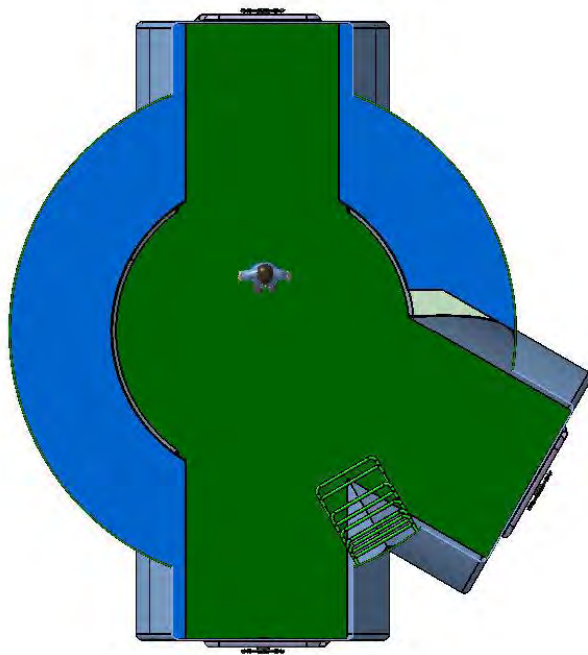




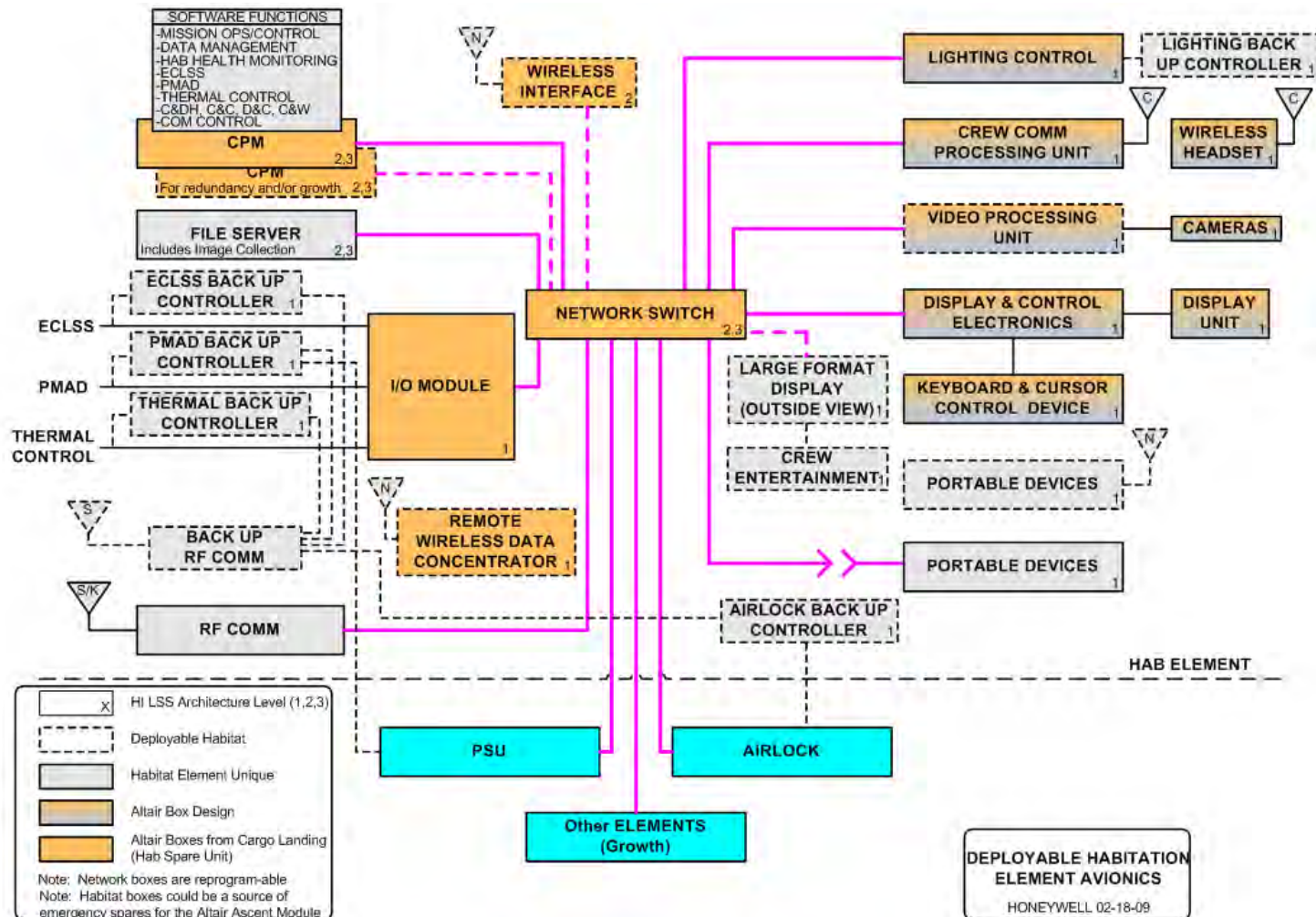
# Deployable Habitat Derived from MFHE

- Added **two access ports** and hatches to ingress floor
- **Fire detection**, suppression, and remediation
  - Hand-held fire extinguishers
  - **Atmosphere replacement** capability
- Emergency breathing apparatus; **Personal Protection Equipment**
- Identified FDIR need (software, Avionics, etc.)
- Added **redundancy and spares** to Avionics, Comm, ECLSS, & TCS
- **Increased heat rejection** capacity
- Added one **hatch to top dome** to accommodate growth
- Provided **external viewing capability** via HD cameras and monitors
- Included habitat **tool kit** for internal maintenance
- **Exercise equipment** added

# Enhancements and Detail Added to Interior



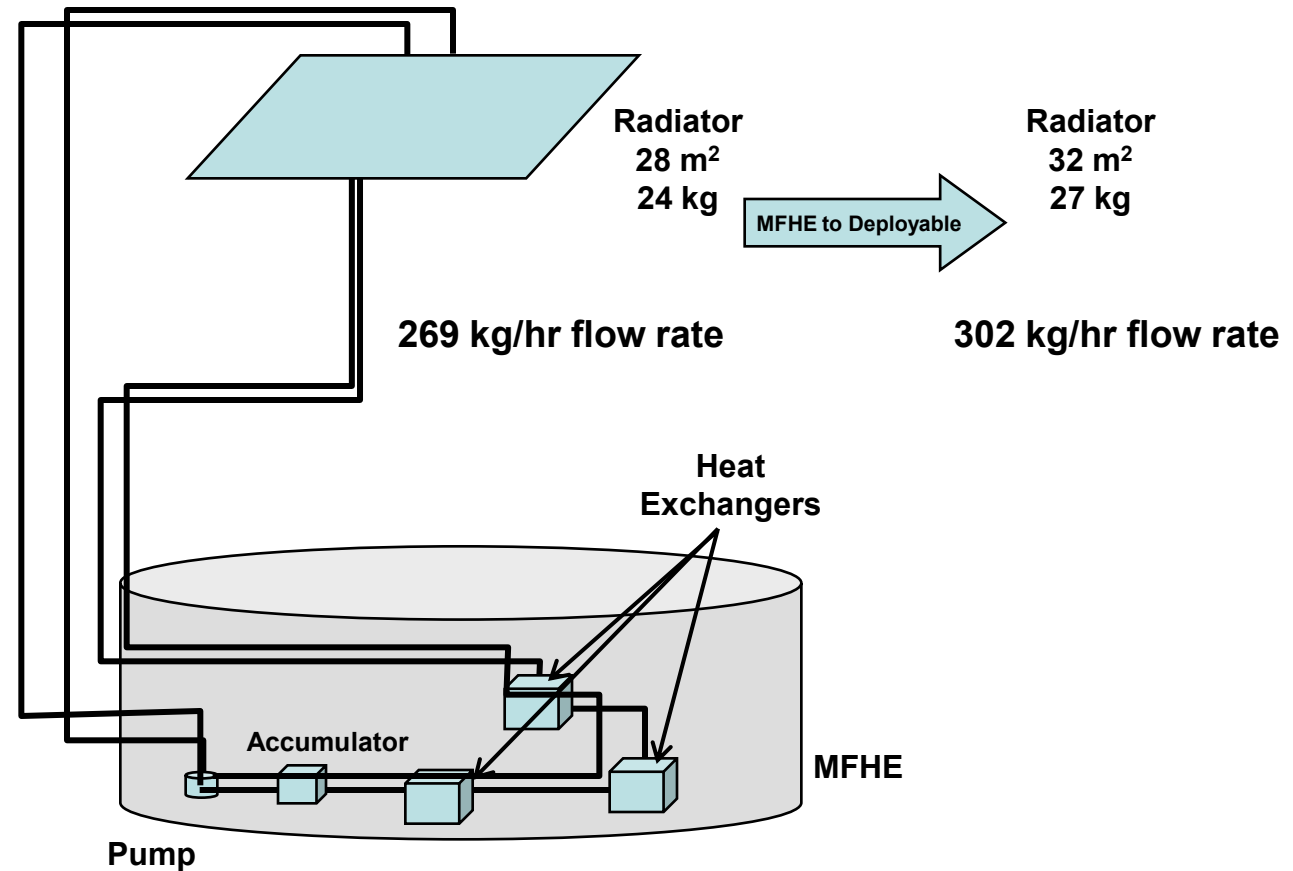
# Deployable Habitat Avionics Architecture



# Single-Fluid Dual-Loop Thermal Control Concept

Deployable goes to dual loop including internal equipment for redundancy.

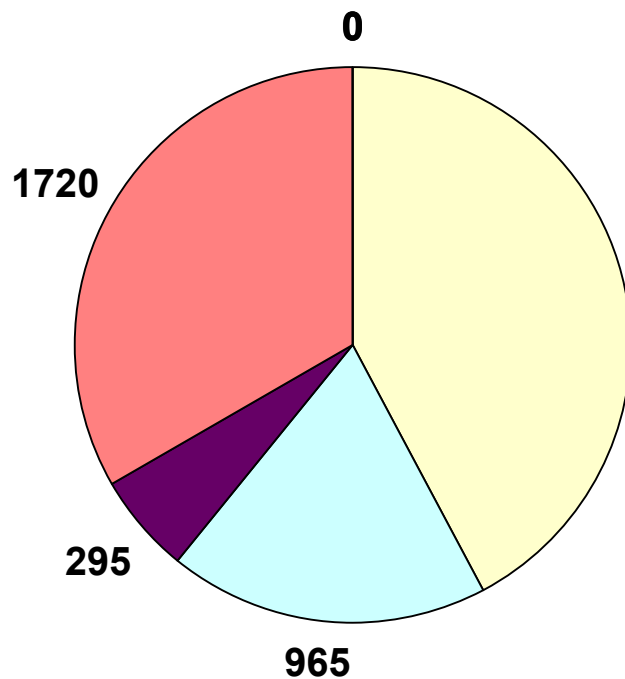
5124 w heat rejection capability



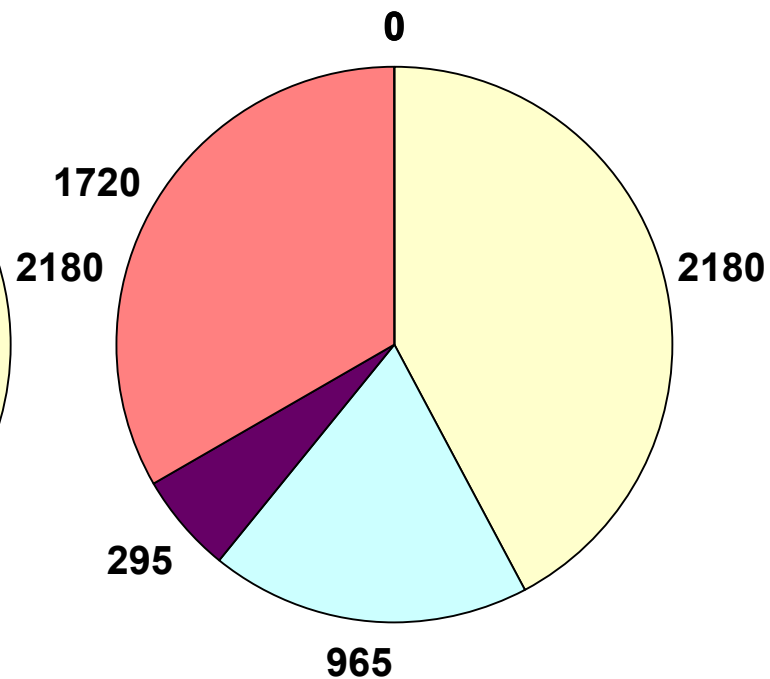


# Boeing MFHE Requires 5.2 kW Peak and 3.7 kW Average from Power Support Unit

**Peak Power  
5160 W**

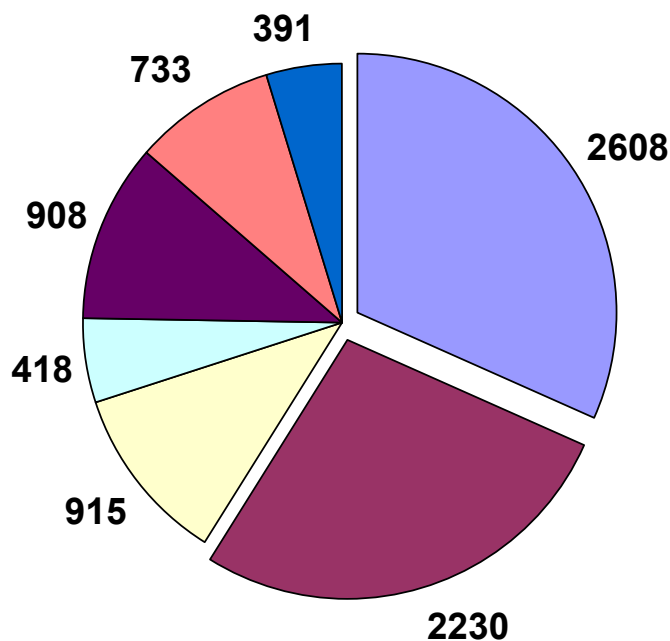


**Average Power  
3710 W**



- Structure & Atm
- Radiation Protection
- Subsystems
- Internal Outfitting
- Logistics
- Growth
- Flt Support Equip

# DHE 8204 kg Mass Estimate Exceeds 7000 kg Limit by 1204 kg



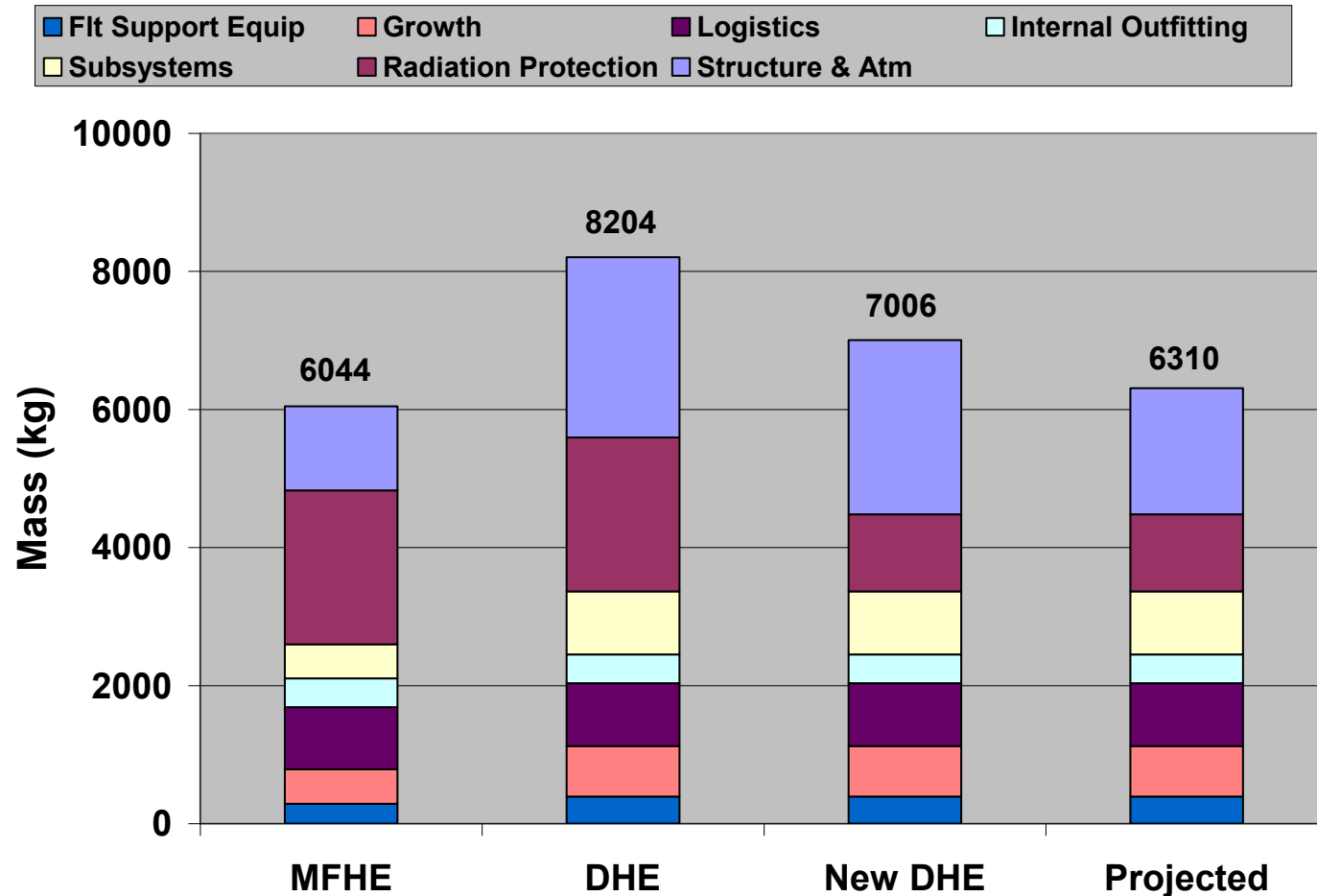
- **Structure and Radiation Protection 59% of total**
- 251 kg (walls, floors, ceiling) moved to Internal Outfitting from Structure
- Available volume for component mounting exceeds requirement
- **Two tiers required for component installation**

- Internal volume for subsystem components
  - Required, with 25% packing factor 1.6 m<sup>3</sup>
  - Available in lower dome 17.1 m<sup>3</sup>
- Internal area for subsystem components
  - Required, with 25% packing factor 49.0 m<sup>2</sup>
  - Available in lower dome (1 layer on shell) 27.4 m<sup>2</sup>

Growth: mass, structure - 15%; mass, components - 50%; power & heat rejection - 50%; packing factor - 25%

# Continued Analysis May Provide 10% Mass Margin on 7000 kg Limit

- **Conservative mass estimates in MFHE and DHE**
- **1198 kg mass reduction from Initial structure and radiation protection analysis**
- **~700 kg reduction expected from Intermodule Connectivity design analysis**



# The Boeing MFHE to Lunar Outpost Concept

## ● MFHE

- A vertical cylinder with three floors to aid in dust mitigation
- Single airlock scavenged from previous sortie missions
- 18 functions allocated to 9 subsystems
- One access port
- 6 t; 4.0 kWe peak; 2.7 kWe avg; 4.6 kWt
- 78 m<sup>3</sup> habitable volume and 28 m<sup>2</sup> open floor space

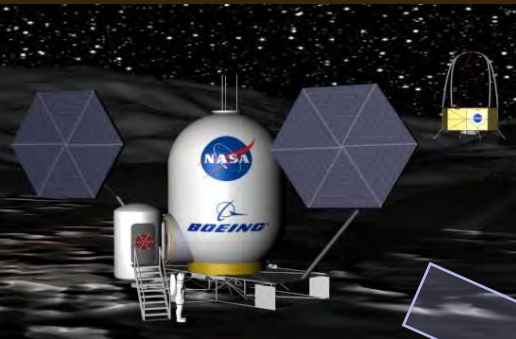
## ● DHE

- Three access ports and two airlocks
- 6.3 t, 5.2 kWe peak; 3.7 kWe avg; 5.1 kWt
- 78 m<sup>3</sup> habitable volume and 28 m<sup>2</sup> open floor space

## ● Outpost

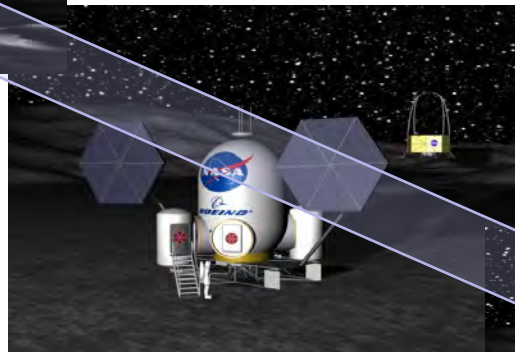
- 517 m<sup>3</sup> habitable volume; 148 m<sup>2</sup> open floor space
- Recommended capabilities for RPLMs, DPLM and bioregen ECLSS

# Direct Path From MFHE to Outpost Capability



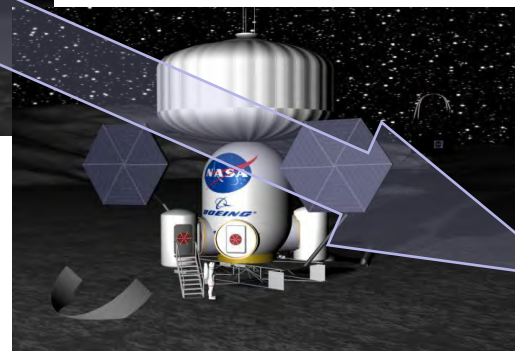
**MFHE Study**

**Mission 5**



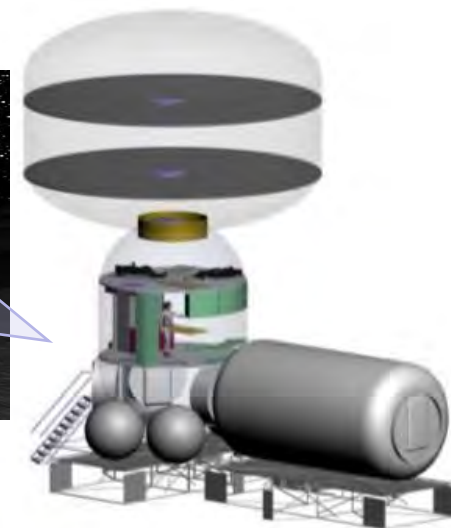
**Initial Configuration**

**Mission 7**



**First Growth Step**

**Mission 10**

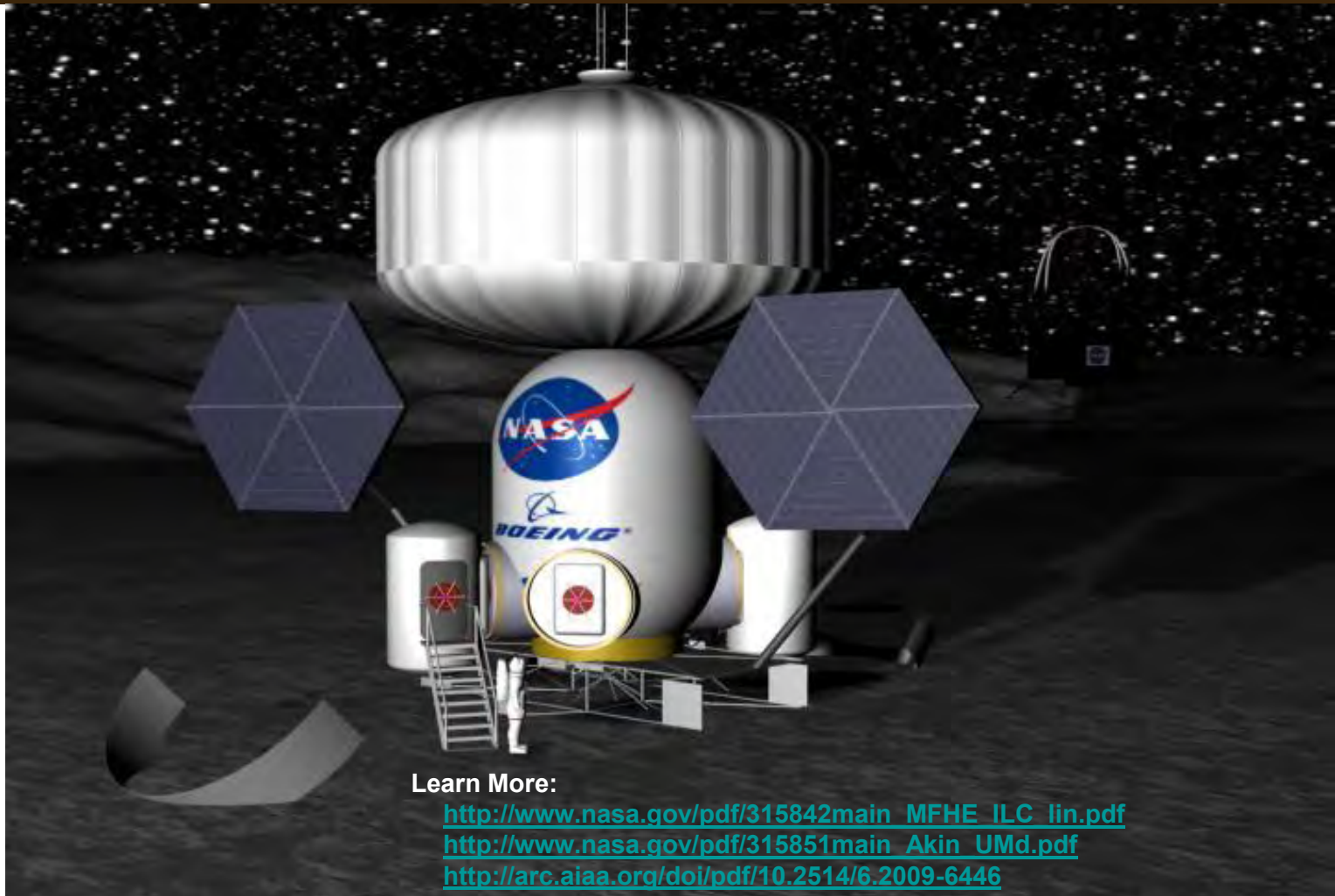


**Outpost Capability**



# Thank You!

## Questions?



# 18 Functions Identified and Allocated to MFHE

- Atmosphere Management
- Communications
- Crew Accommodations
- Data Management / C&DH
- Dust Mitigation
- Electricity Distribution
- Food Management
- Hab Health Monitoring
- Health Mgmt (First Aid Kit)
- Hygiene Management
- Intermodule Connectivity
- Meteoroid Protection
- Radiation Protection
- Stowage
- Thermal Management
- Waste Management
- Water Management
- Work Accommodations

# 4 Minimum Functions Allocated to Other Surface Systems

● **EVA Support / Surface Access**

**Descent Module Airlock**

● **Housekeeping**

**Crew members**

● **Relocatability**

**Lunar Surface Manipulator  
Power Support Unit  
Mobility Chassis**

● **Leveling**

**Power Support Unit**

# 18 MFHE Functions Allocated to 9 Subsystems

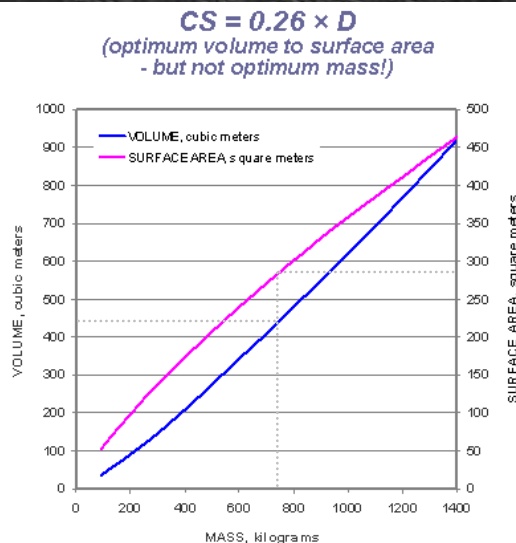
- **Avionics**
- **Dust Mitigation**
- **ECLSS**
- **Flight Crew Systems**
- **Mission Payloads**
- **Electrical Distribution System**
- **Structure & Mechanisms**
- **Thermal Control System**
- **Trash Management**

# Deployable Concept with Inflatable Upper Room



- Delivered deflated and protected
- Additional atmosphere on logistics pallet
- Can be delivered with Hab or Cargo
- Can be expanded during any crew mission
- Inflatable element characteristics

• Structure (kg):	1158
• Atmosphere (kg):	312
• Volume (m <sup>3</sup> ):	439
• Floor area (m <sup>2</sup> ):	120
• Surface area (m <sup>2</sup> ):	290
• Diameter (cm):	914
• Constant diameter height (cm):	238



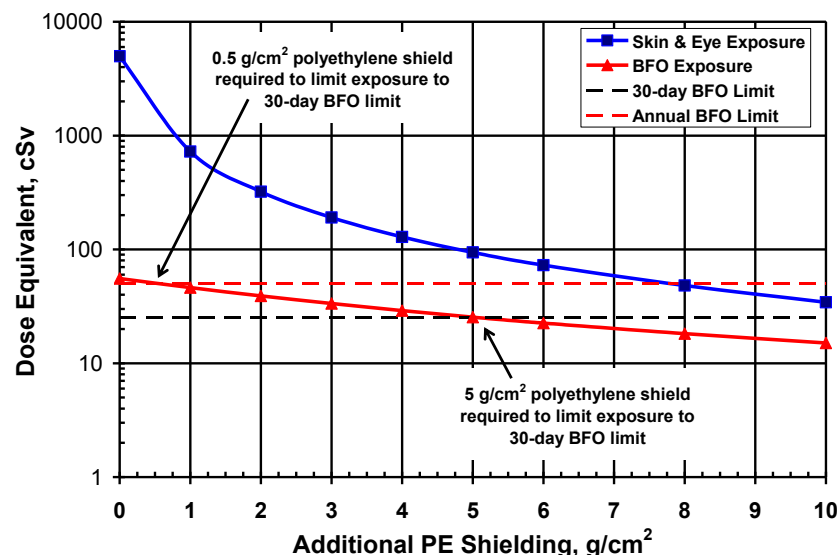
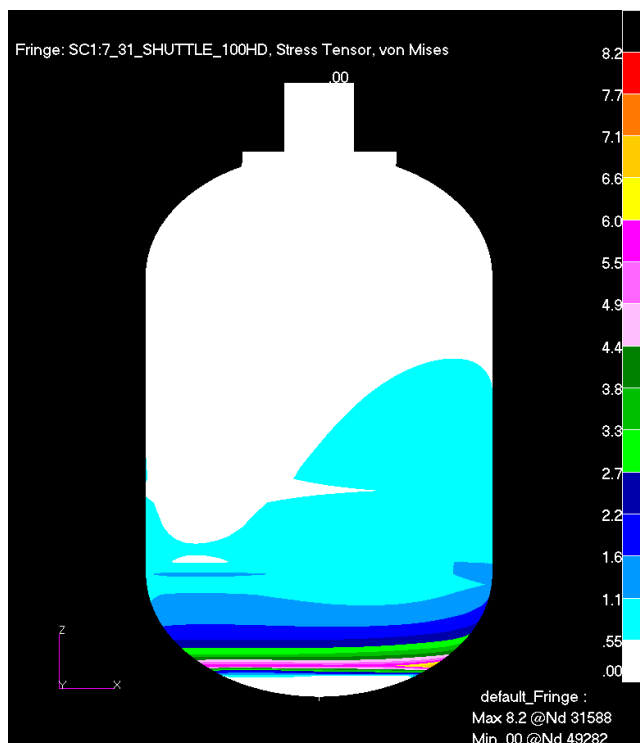


# Opportunities to Meet 7000 kg Constraint for Deployable Habitation Element

- **741 kg Growth Allowance reassessment** (247)
- **1003 kg Logistics Pallet resized for 14-day mission** (600)
- **2230 kg radiation protection mass reduction opportunities** (1115)
  - Resize for 14-day missions per Scenario 4.0.0
  - Include structure and internal outfitting for radiation protection
  - Use Entry Foyer instead of Sleep Loft to eliminate “pup tent” floor
  - Install regolith layer around lower dome
- **1632 kg CBM and hatch reduction opportunities** (544)
  - Redesign ISS ACBM and hatch for 8 psi operating pressure vs 14.7
  - Redesign ISS ACBM for expected lunar surface loads environment
- **Potential reduction (1450 target)** (2306)

# 1198 kg Estimate Reduction from Structural and Radiation Exposure Analyses

- Assumed thickness twice needed
- 985 kg error in initial estimate
- 83 kg net reduction
- 1-yr dose limit against 1960 SPE by protection mass only
- 30-day limit with pressure vessel for October 1989 SPE
- 5 cm vs 10 cm thick PE shields
- 50% (1115 kg) mass reduction



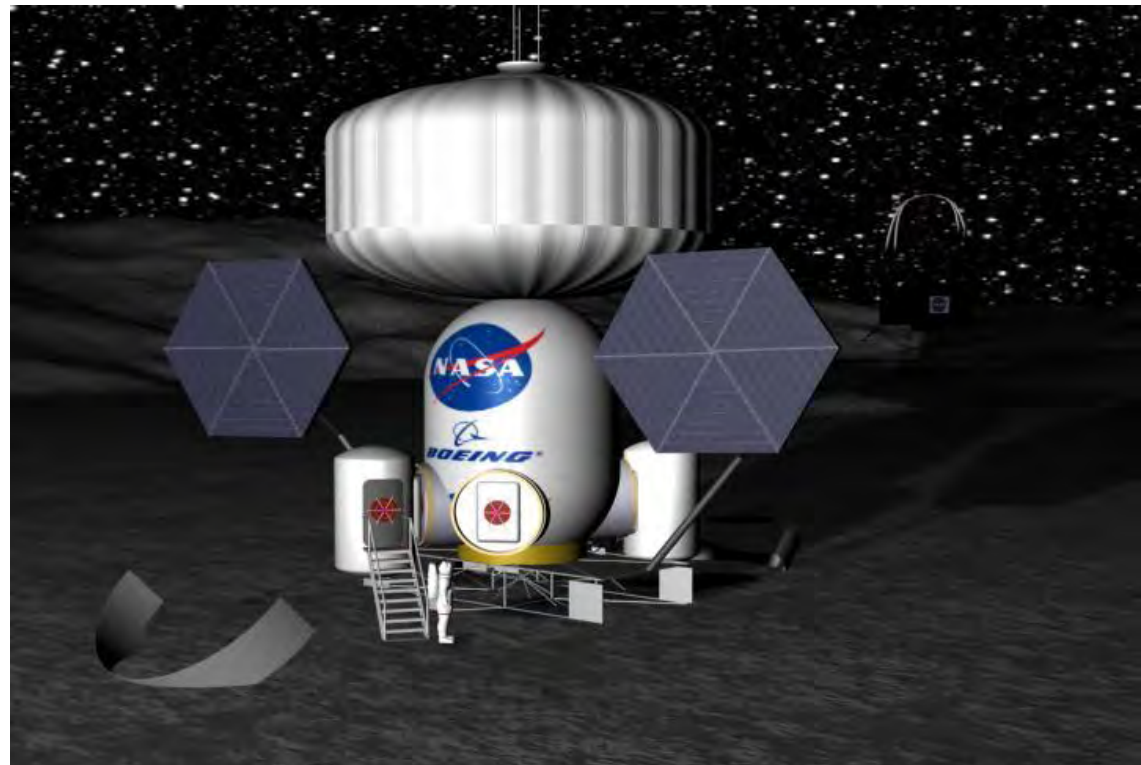
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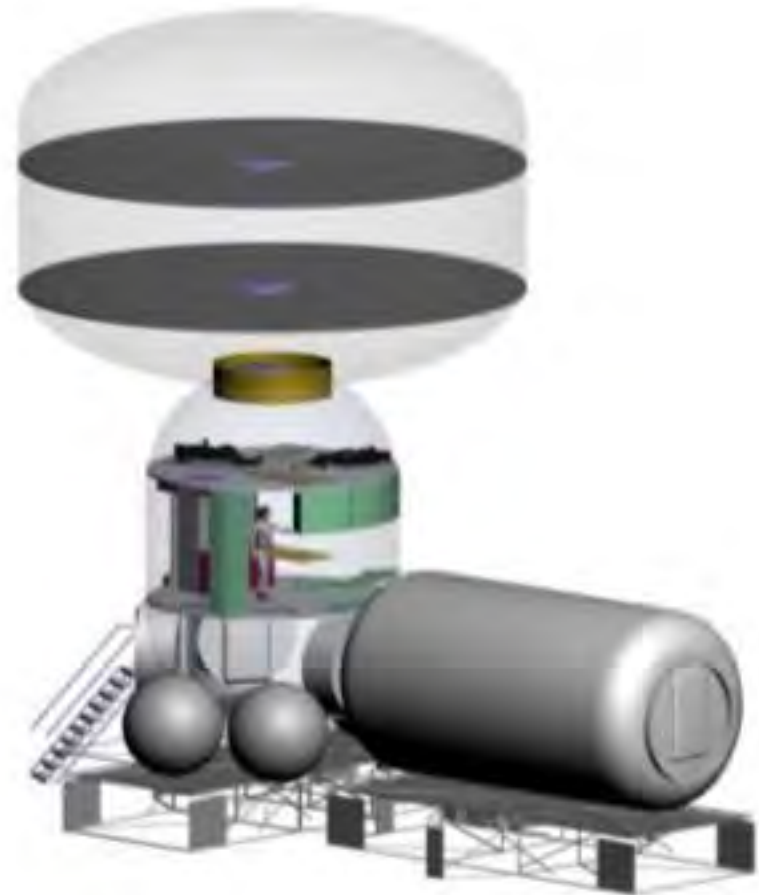
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- **The Path to Growth**



# Habitation Growth Path - 1

## ● Mission 6 - Cargo (Unpressurized Payload)

- |   |         |
|---|---------|
| • Inflatable Module + connector & hatch   | 1158 kg |
| • Atmosphere Pallet for Inflatable Module | ~800 kg |

Boeing  
Additional  
Growth  
Items

## ● Mission 9 - Cargo (RPLM-1)

- |   |                   |
|---|-------------------|
| • Additional volume attached to Deployable Hab port #3            | 55 m <sup>3</sup> |
| • Four private sleep stations                                     |                   |
| • Urgent Care capability with minor dental hygiene (Telemedicine) |                   |
| • ECLSS, TCS, electrical power distribution                       |                   |
| • CO <sub>2</sub> reduction to carbon using methane pyrolysis     |                   |
| • Water electrolysis  |                   |
| • Hydrogen production for CO <sub>2</sub> reduction               |                   |
| • Oxygen production   |                   |
| • Wet food, freezer, refrigerator                                 |                   |
| • Full galley   |                   |
| • Trash compactor   |                   |

Matches  
Scenario  
4.0.0

Boeing  
Additional  
Growth  
Items



# Habitation Growth Path - 2

## ● Mission 12 - Cargo (RPLM-2)

- |   |                   |
|---|-------------------|
| • Additional volume attached to Deployable Hab port #1                | 55 m <sup>3</sup> |
| • ECLSS, TCS, electrical power distribution                           |                   |
| • <b>Surgical and dental capability</b>                               |                   |
| • <b>Expanded scientific capabilities (includes 4.0.0 bioscience)</b> |                   |
| • <b>Shower</b>   |                   |

**Matches  
Scenario  
4.0.0**

**Boeing  
Additional  
Growth  
Items**

## ● Mission 15 - Cargo (DPLM-1)

- |  |                   |
|--|-------------------|
| • Additional volume attached to Deployable Hab port #2 | 55 m <sup>3</sup> |
| • TCS, electrical power distribution                   |                   |
| • <b>ECLSS</b>   |                   |
| • <b>Clothes washer</b>                                |                   |
| • <b>Dishwasher</b>                                    |                   |

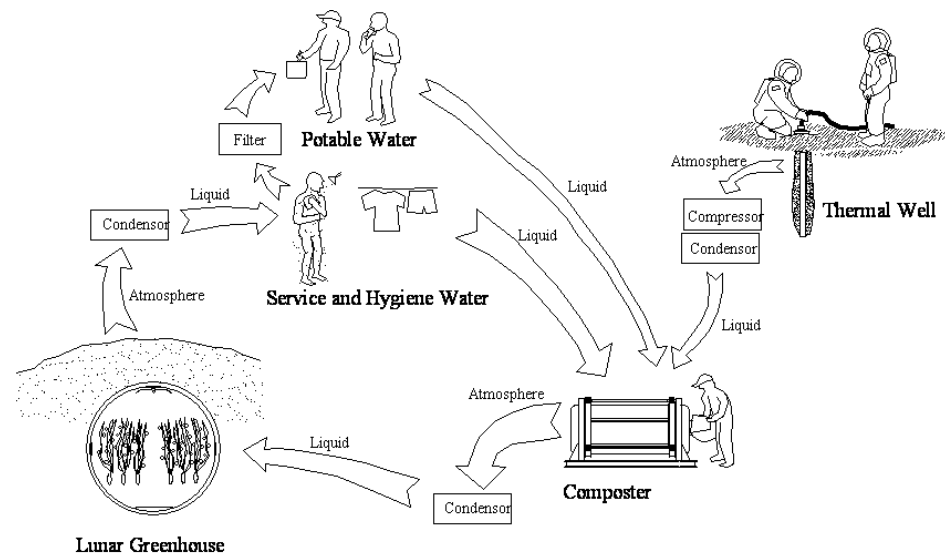
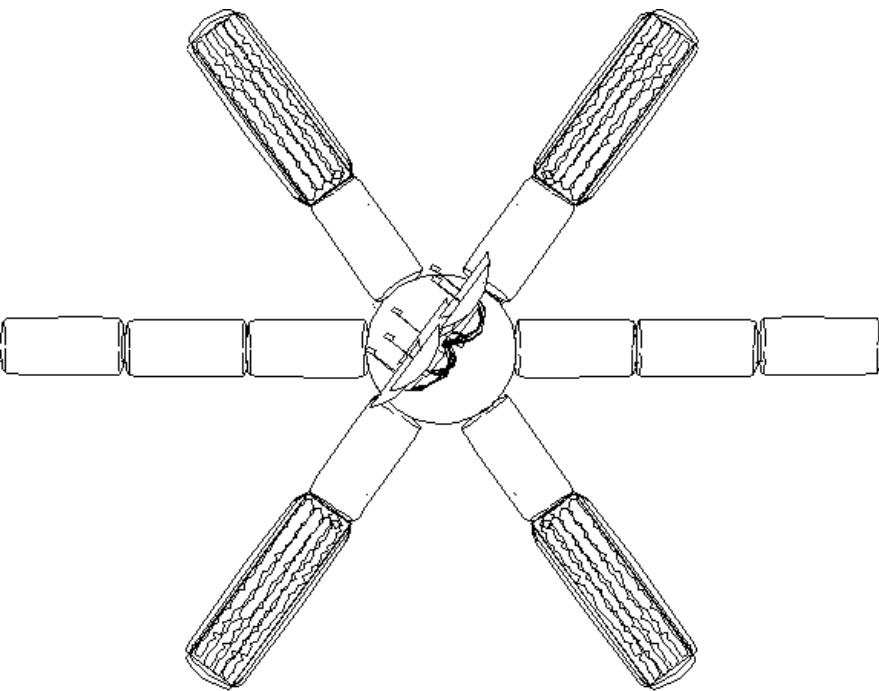
**Matches  
Scenario  
4.0.0**

**Boeing  
Additional  
Growth  
Items**

## ● Beyond Mission 16

- **Vegetable garden unit with bioregenerative life support system**
- **Composting toilet**

# Hydroponics and Bioregenerative Life Support for Permanent Continuous Human Presence



Phil Sadler (Sadler Machine Company) and Gene Giacomelli, et al (University of Arizona)