



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



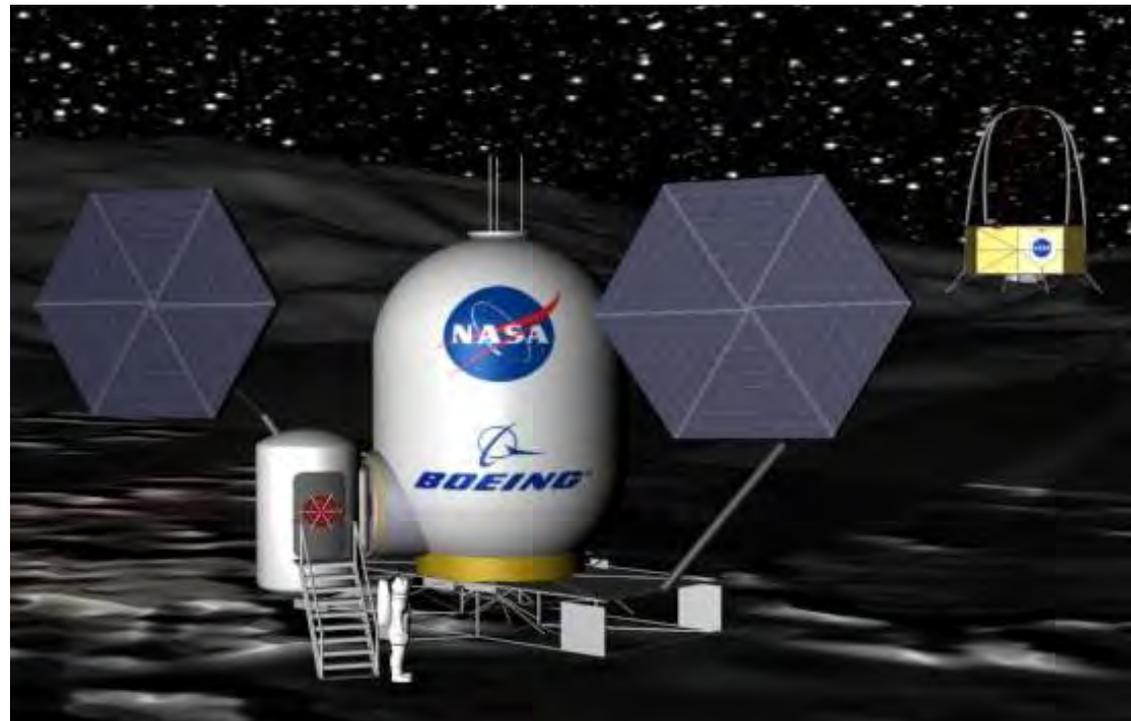
LSSCA BAA Topic 2: MFHE Definition

- **Minimum Functionality Habitation Element**

- **Deployable Habitat**

- **DHE Update**

- **The Path to Growth**



Requirements Definition Process

● Starting point - Maslow Hierarchy

- Physiological
- Safety

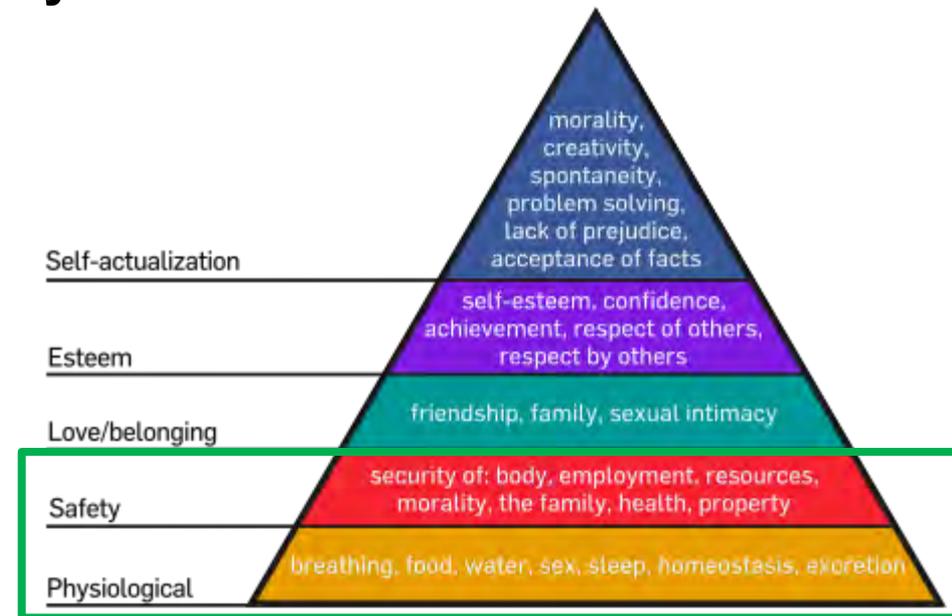
● Extended to meet mission

- 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

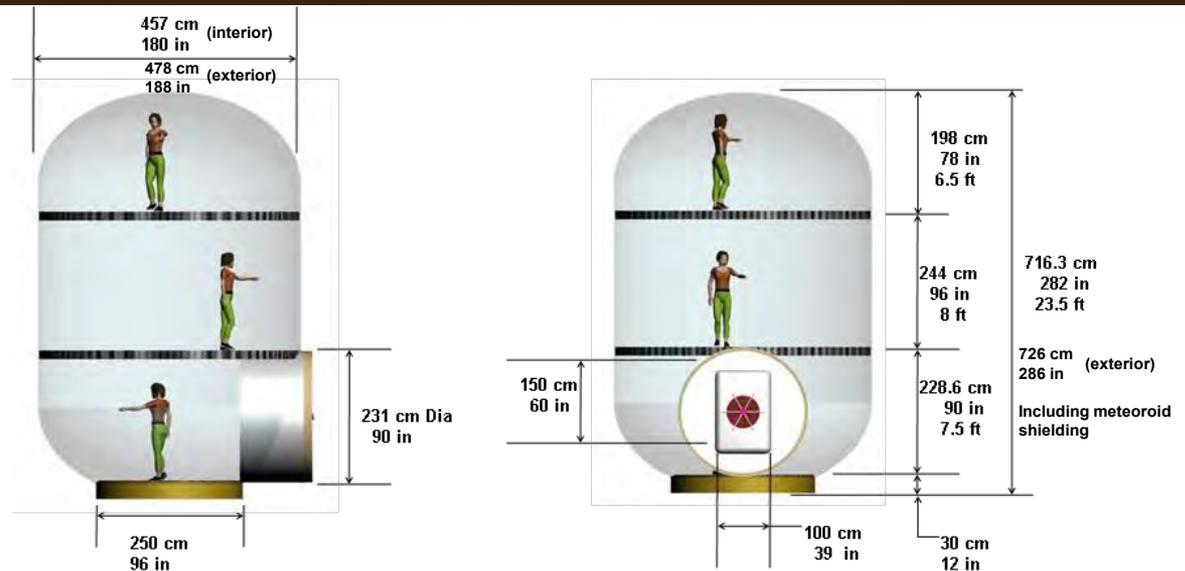
MFHE BAA Requirements

- **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 ³)	37.0
● Occupied volume (m ³)	7.2
● Linear wall space (m)	5.4
● Floor space - unique (m ²)	3.2
● Shared floor space (m ²)	5.0
● Internal storage (m ³)	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 m³ habitable** of 121 m³ total pressurized **volume**
- **28 m² open** of 35 m² 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

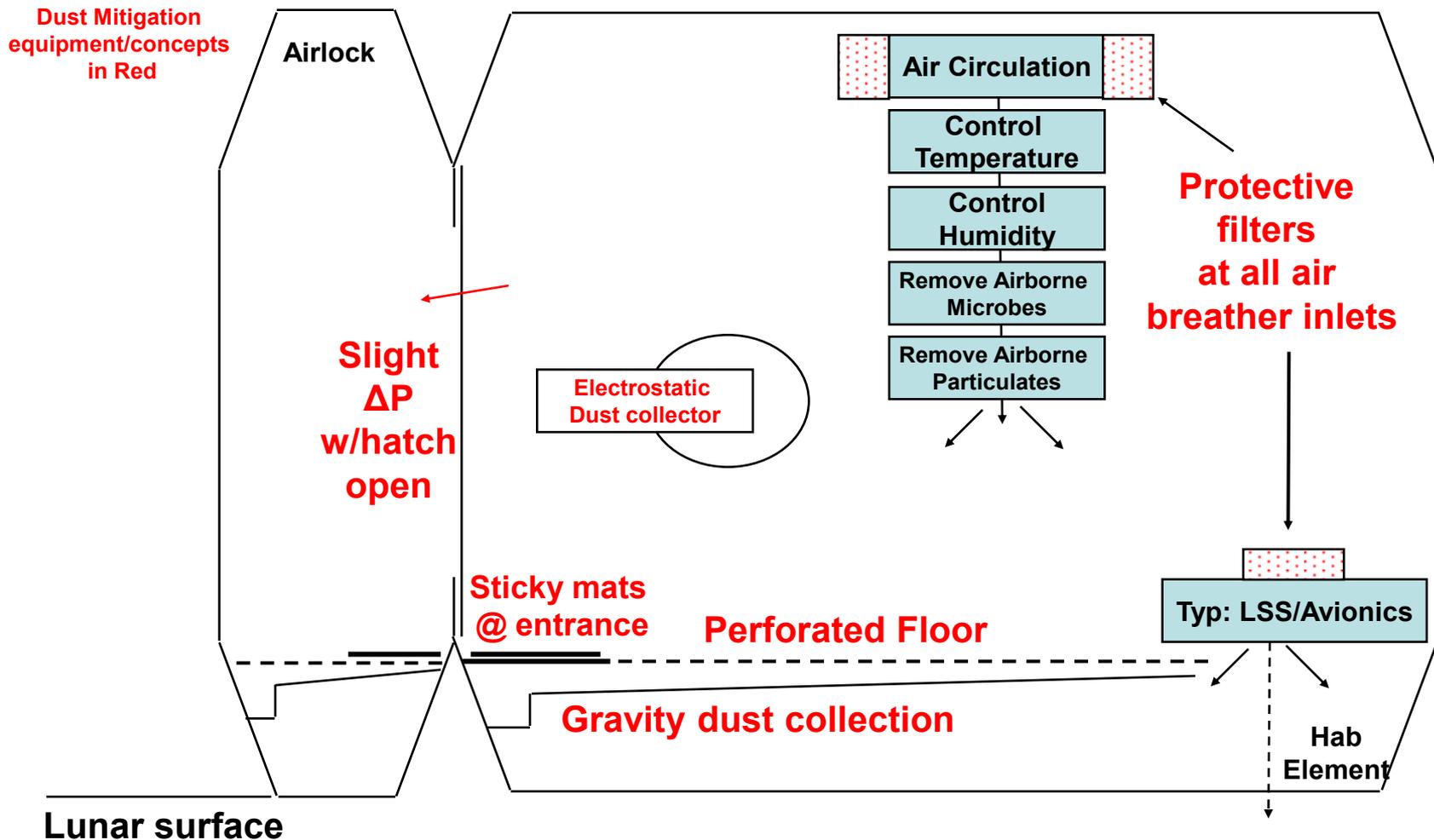
- Upright Aluminum cylinder with radical 2 domes
- 716.3 cm (23.5 ft) total internal height
- 228.6 cm (7.5 ft) hab internal radius
- 15.24 cm (6 in) floor thickness for utility runs
- Aluminum honeycomb panels for interior structure
- 228.6 cm (7.5 ft) cylindrical entryway / intermodule connector
- 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**

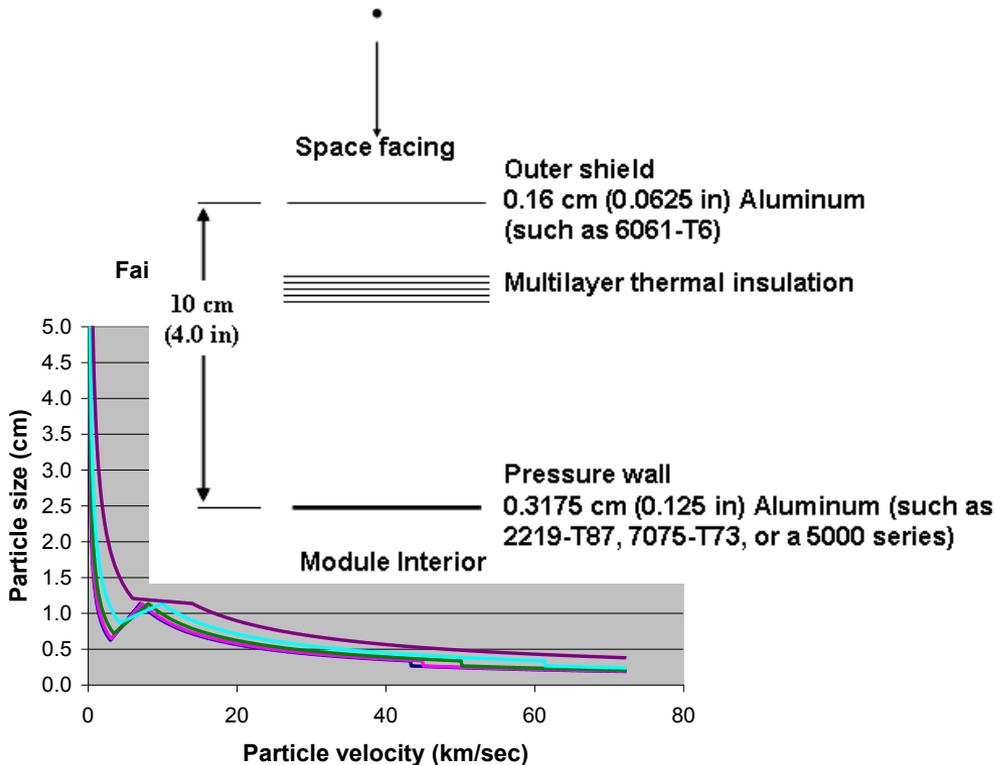


MFHE Dust Mitigation Incorporated in ECLSS, Air Flow and Hab Layout



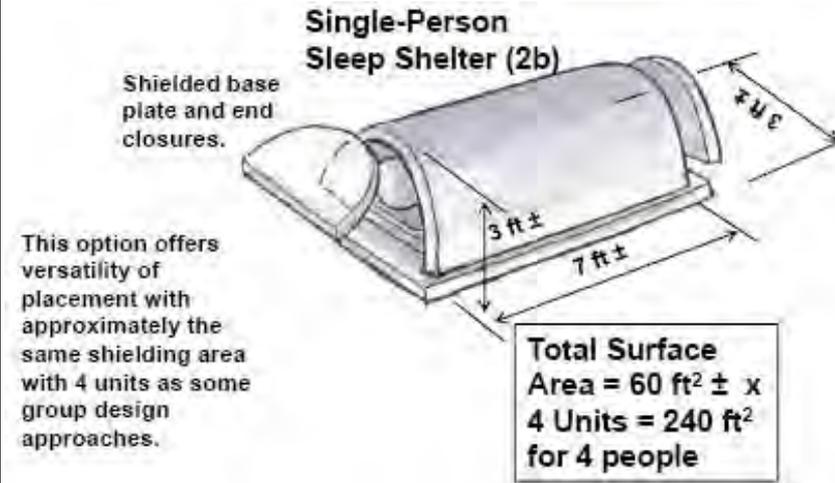
MFHE Radiation and Meteoroid Protection

1.2 cm D Meteoroid Protection



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

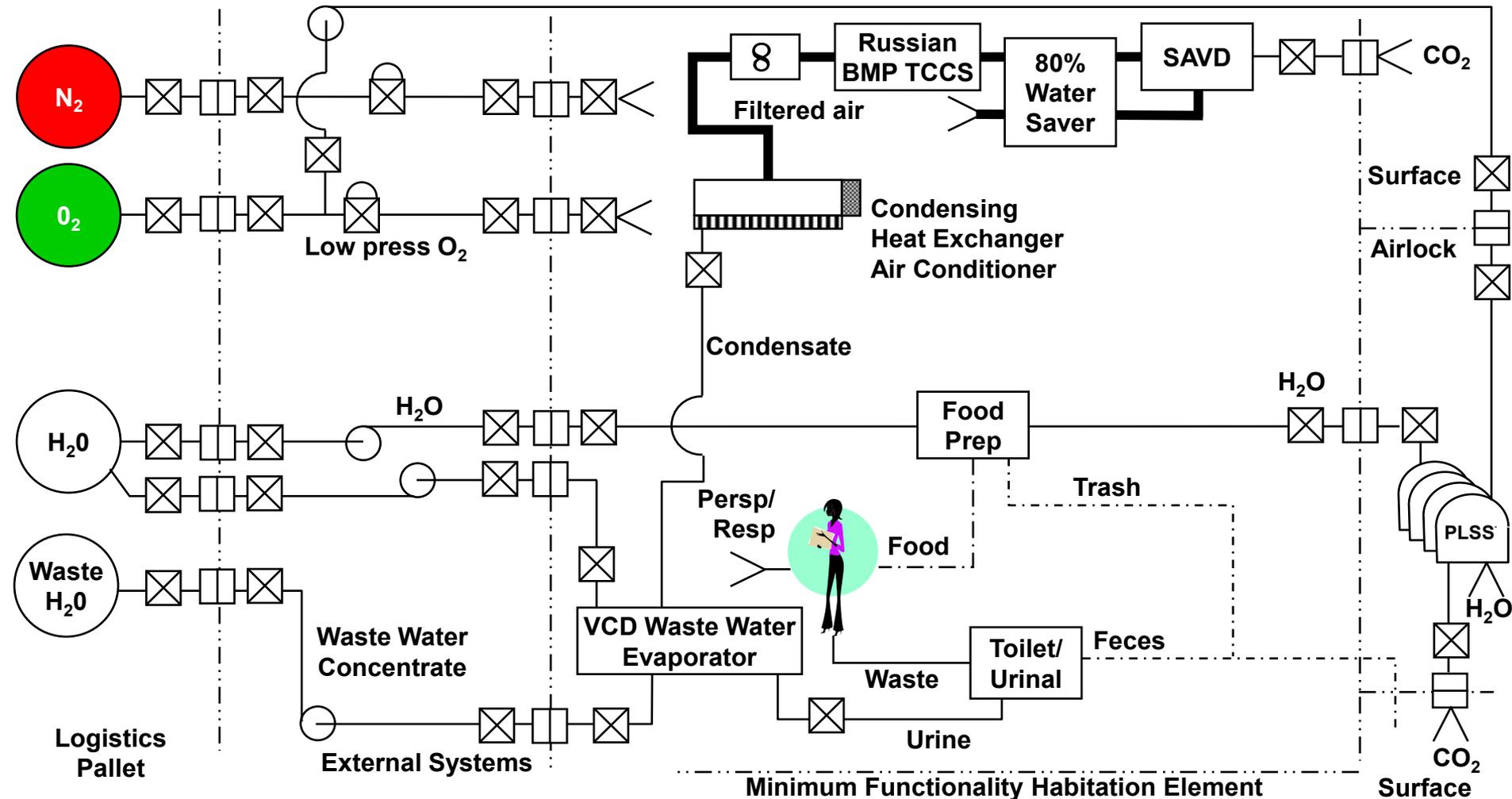
Major Solar Proton Event Protection



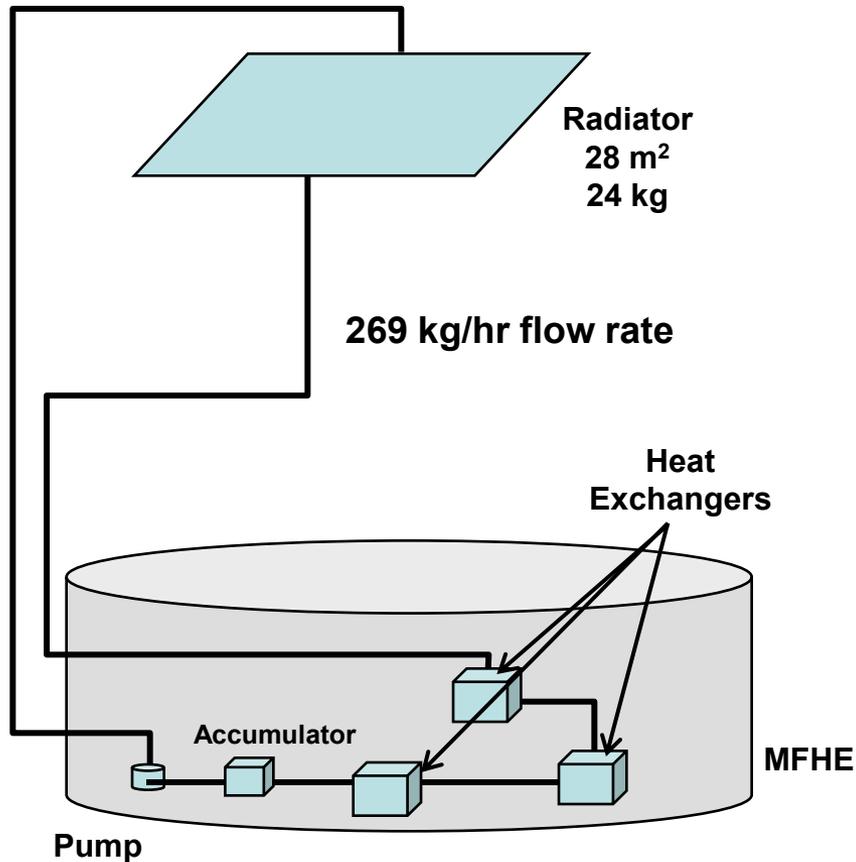
This option offers versatility of placement with approximately the same shielding area with 4 units as some group design approaches.

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

Water Recovery is a Key ECLSS Capability

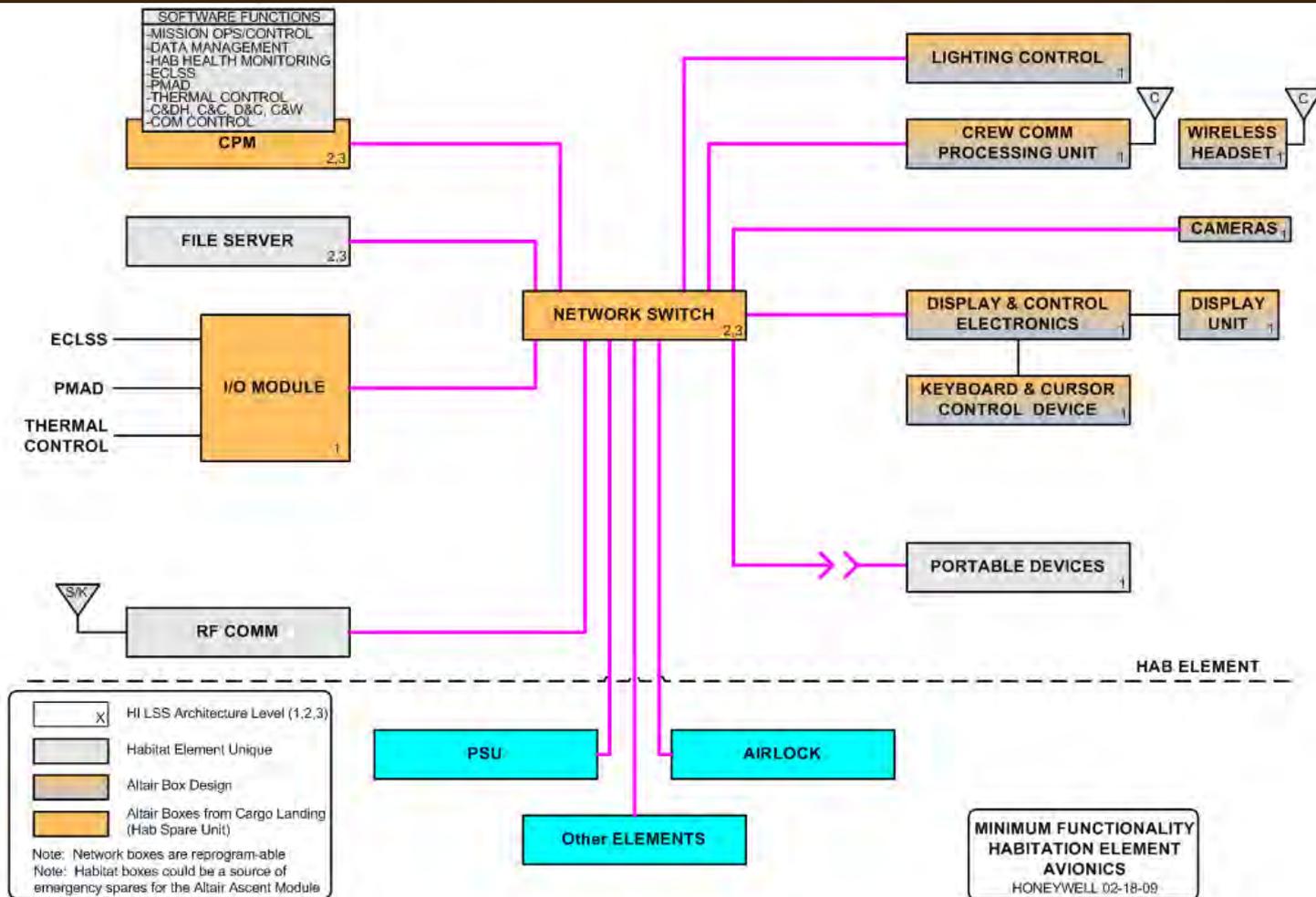


Single-Loop Single-Fluid Thermal Control System

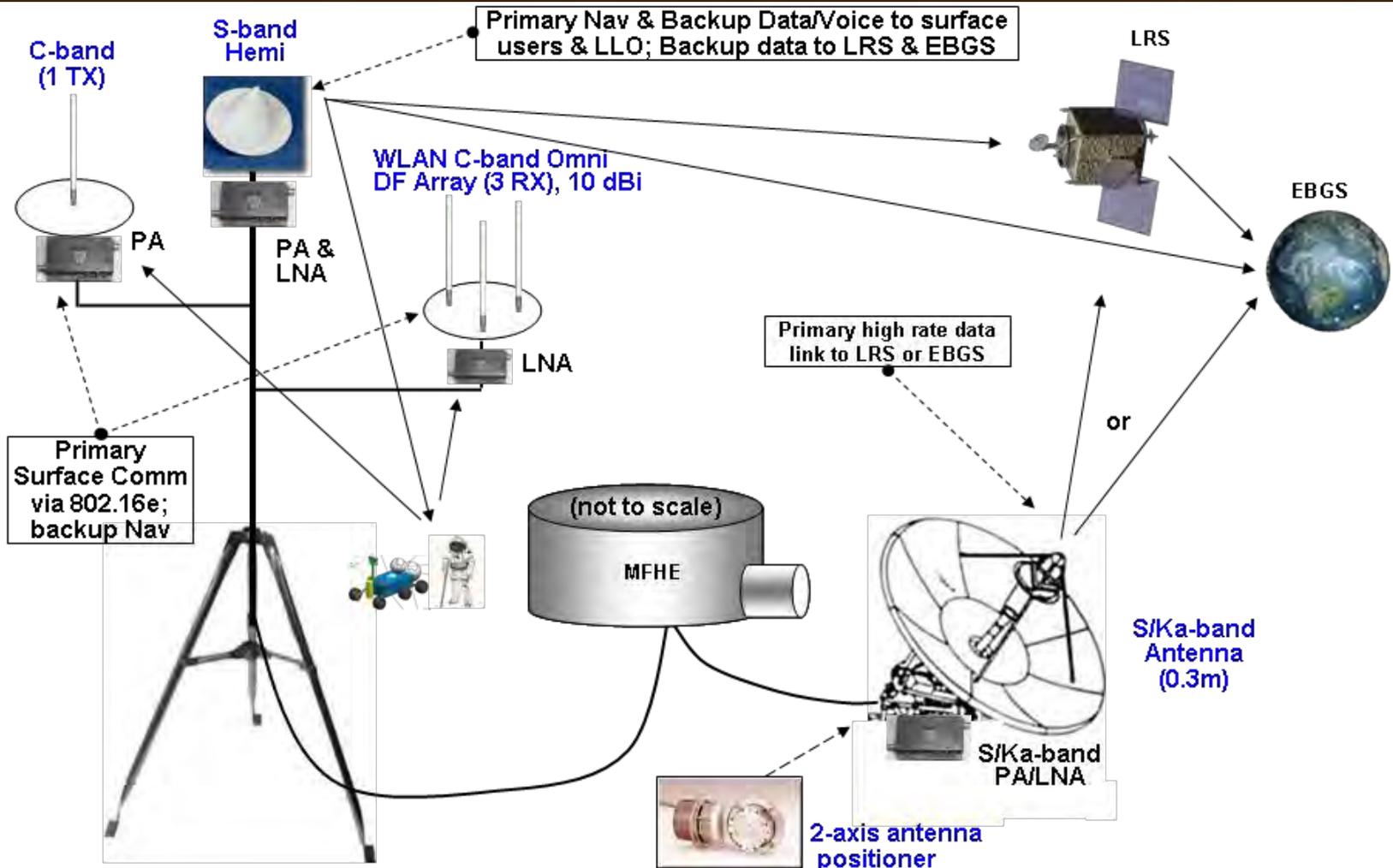


- Simple flat-plate aluminum radiator
- Assumed 20 gal coolant volume
- 3M Novec HFE-7200 coolant
- Air to coolant heat exchangers
- Cold plates for electronics
- 4554 W heat rejection capacity

Minimum Habitat Avionics Architecture

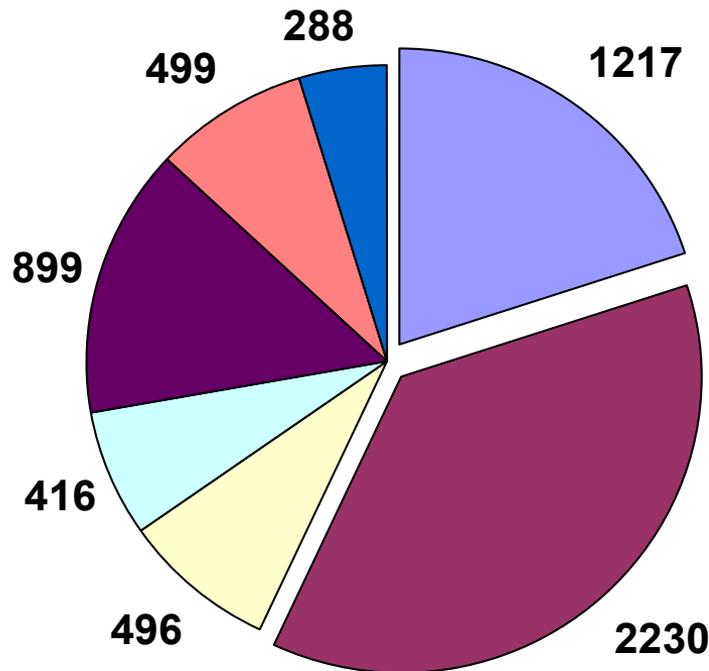


MFHE Communications Overview



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

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



- **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 m³
- **Available in lower dome** 17.1 m³

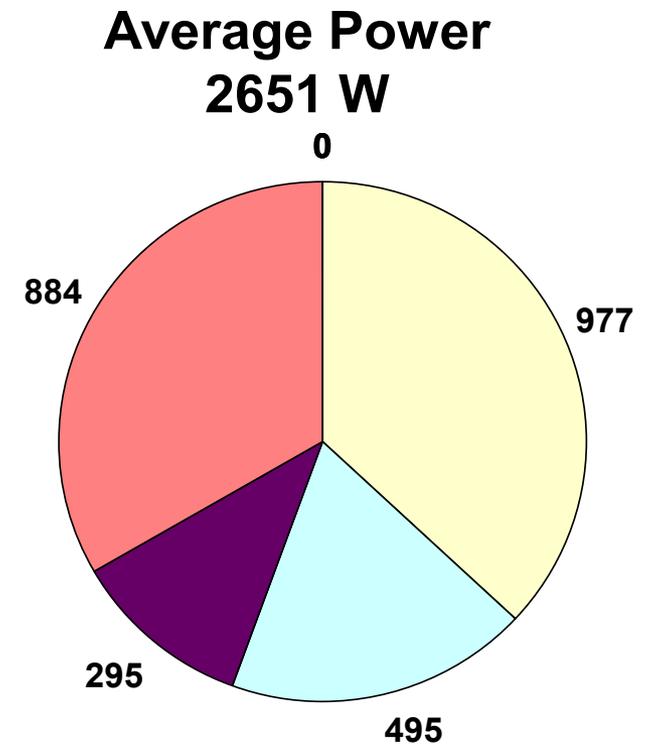
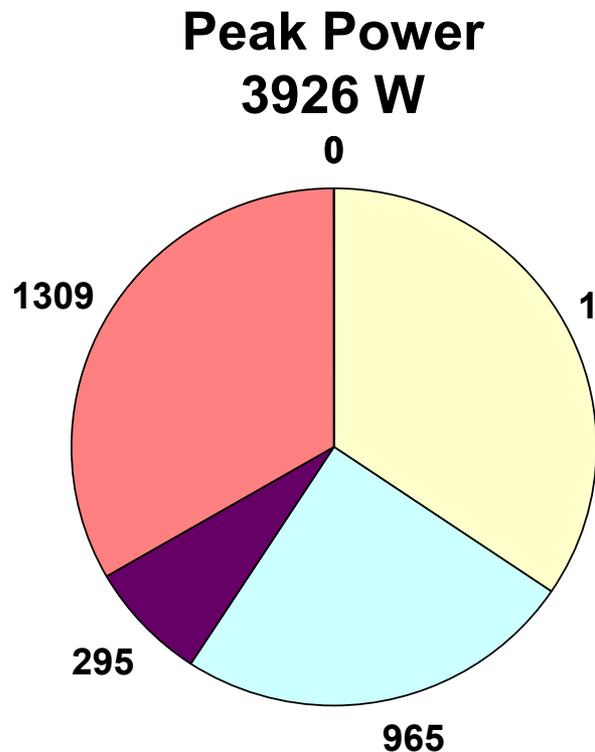
- **Internal area for subsystem components**

- **Required, with 25% packing factor** 24.5 m²
- **Available in lower dome (1 layer on shell)** 27.4 m²

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

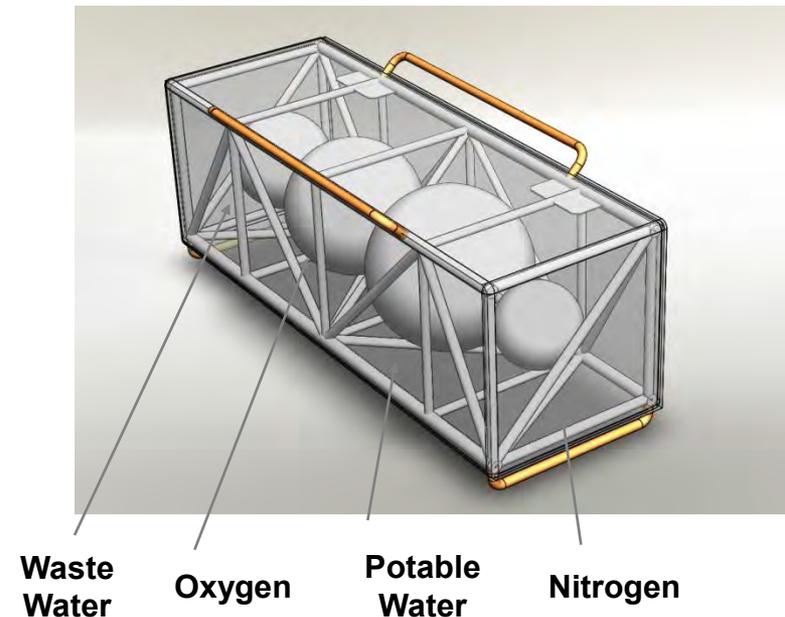
- Structure & Atm
- Radiation Protection
- Subsystems
- Internal Outfitting
- Logistics
- Growth
- Flt Support Equip



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



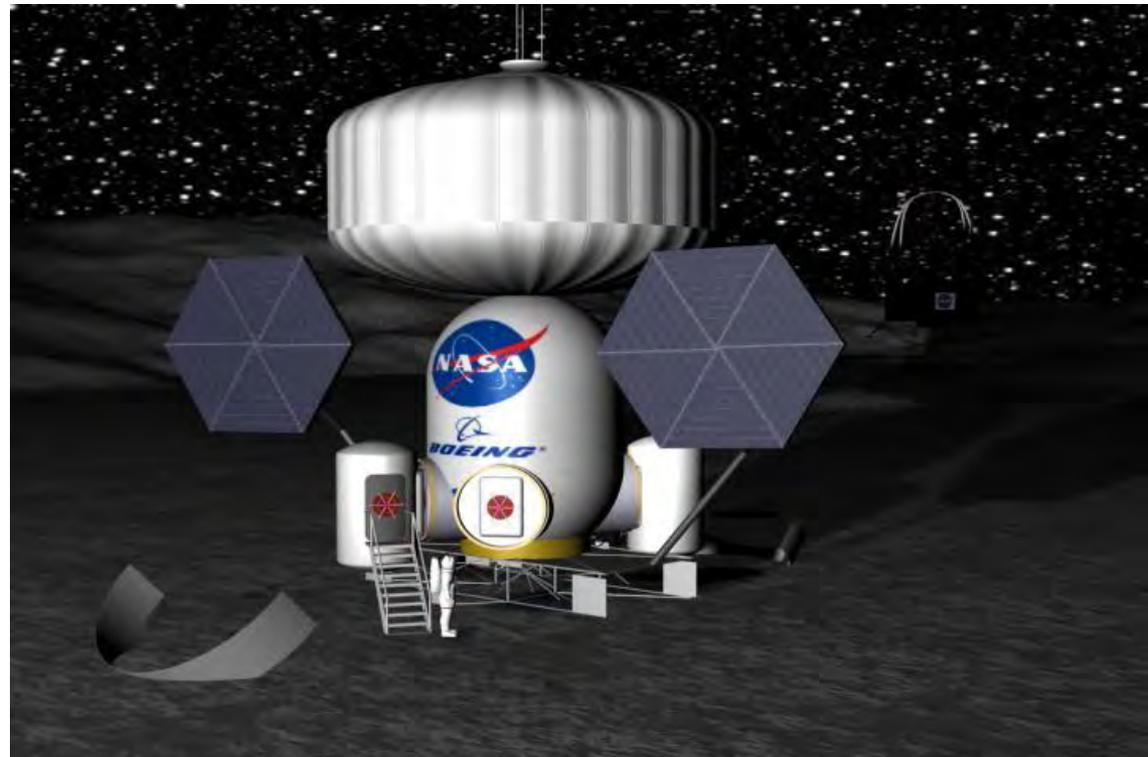
LSSCA BAA Topic 2: MFHE Definition

- **Minimum Functionality Habitation Element**

- **Deployable Habitat**

- **DHE Update**

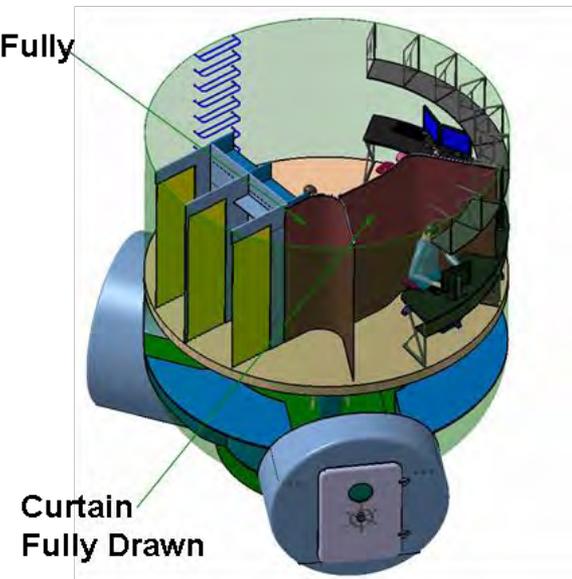
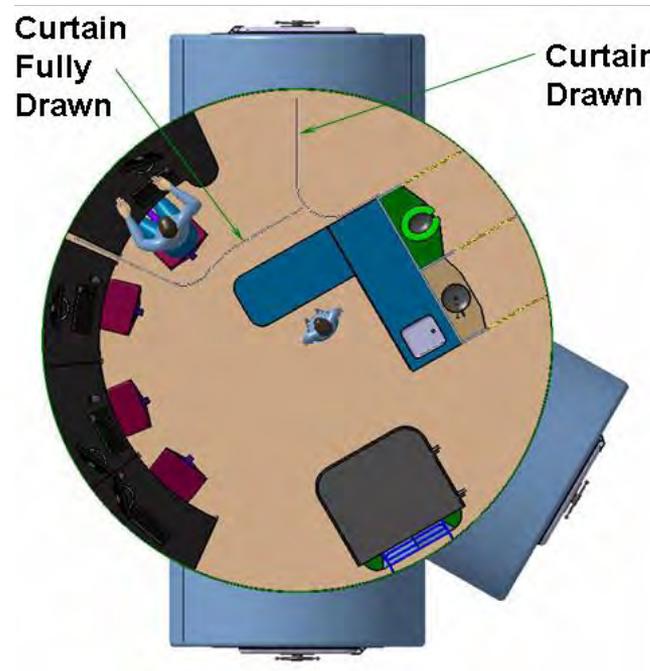
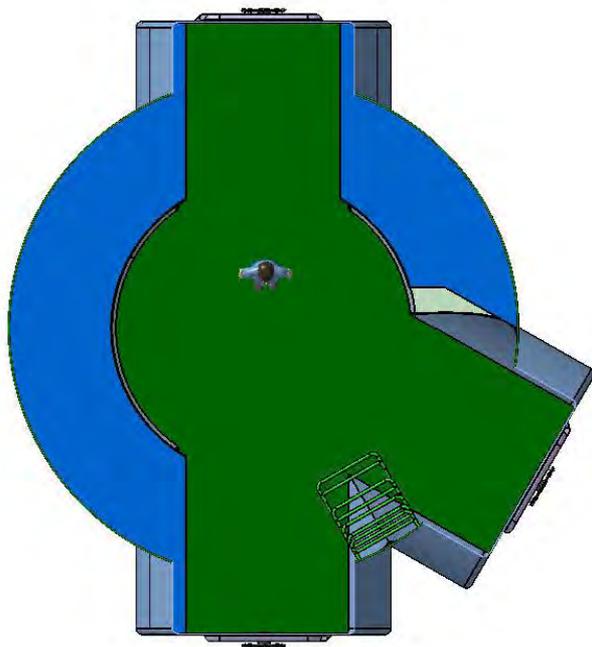
- **The Path to Growth**



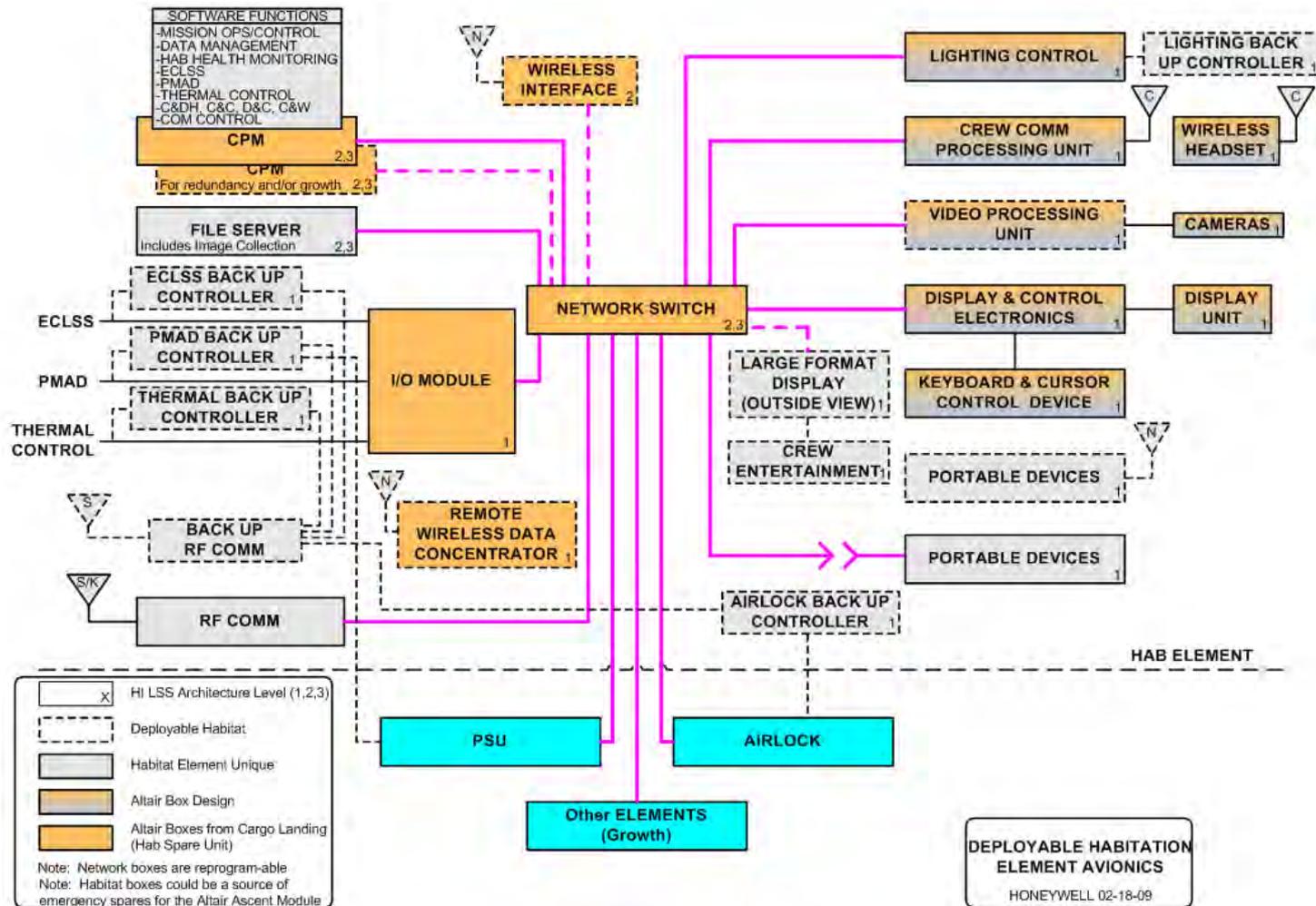
Deployable Habitat Derived from MFHE

- 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



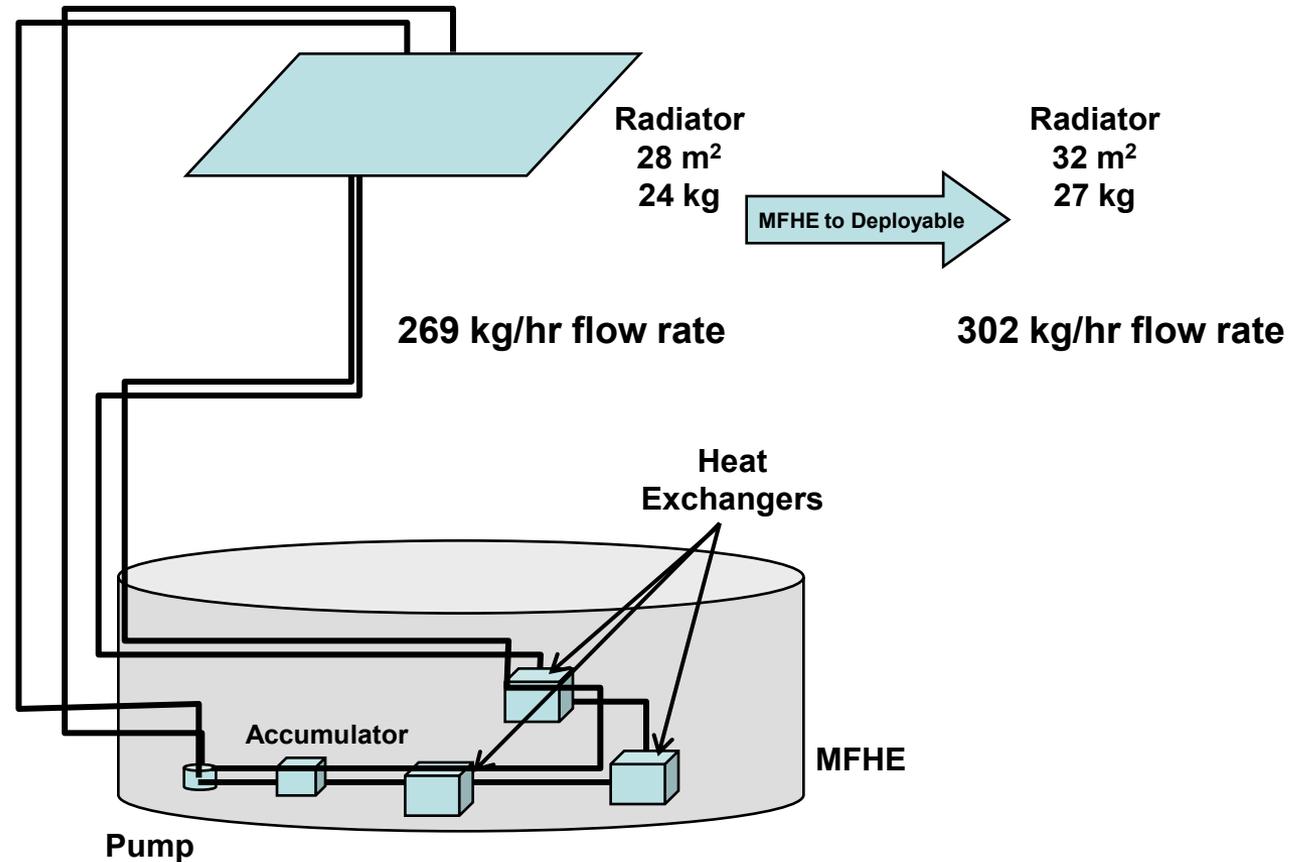
Deployable Habitat Avionics Architecture



Single-Fluid Dual-Loop Thermal Control Concept

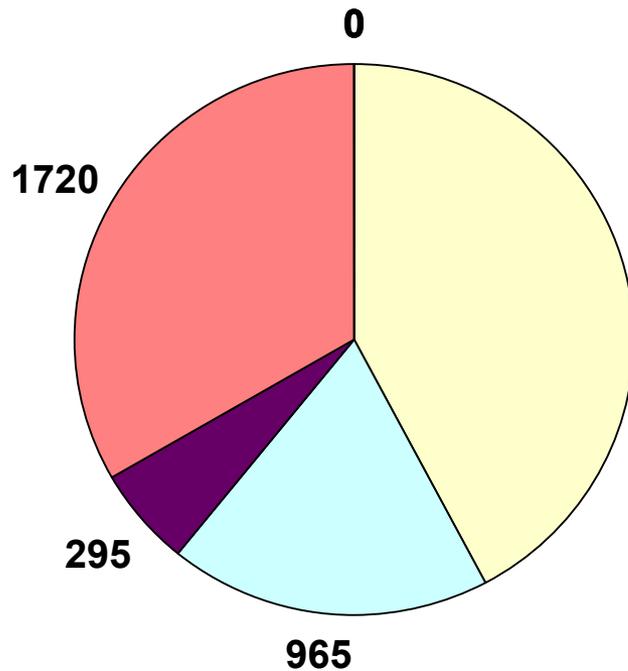
Deployable goes to dual loop including internal equipment for redundancy.

5124 w heat rejection capability

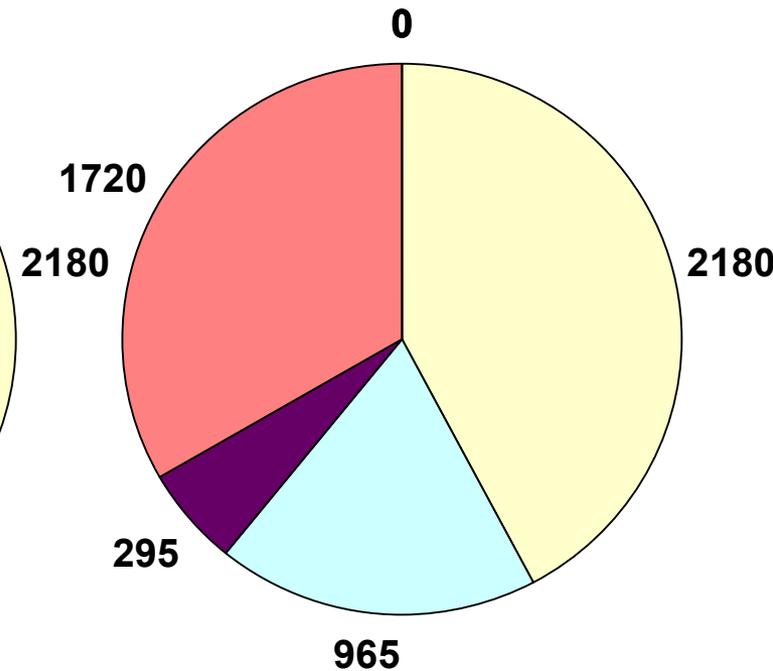


Boeing MFHE Requires 5.2 kW Peak and 3.7 kW Average from Power Support Unit

Peak Power 5160 W

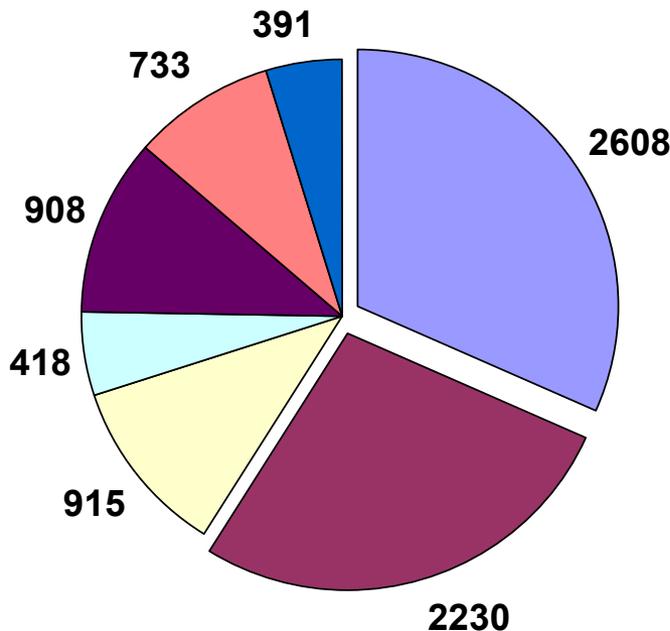


Average Power 3710 W



- 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**

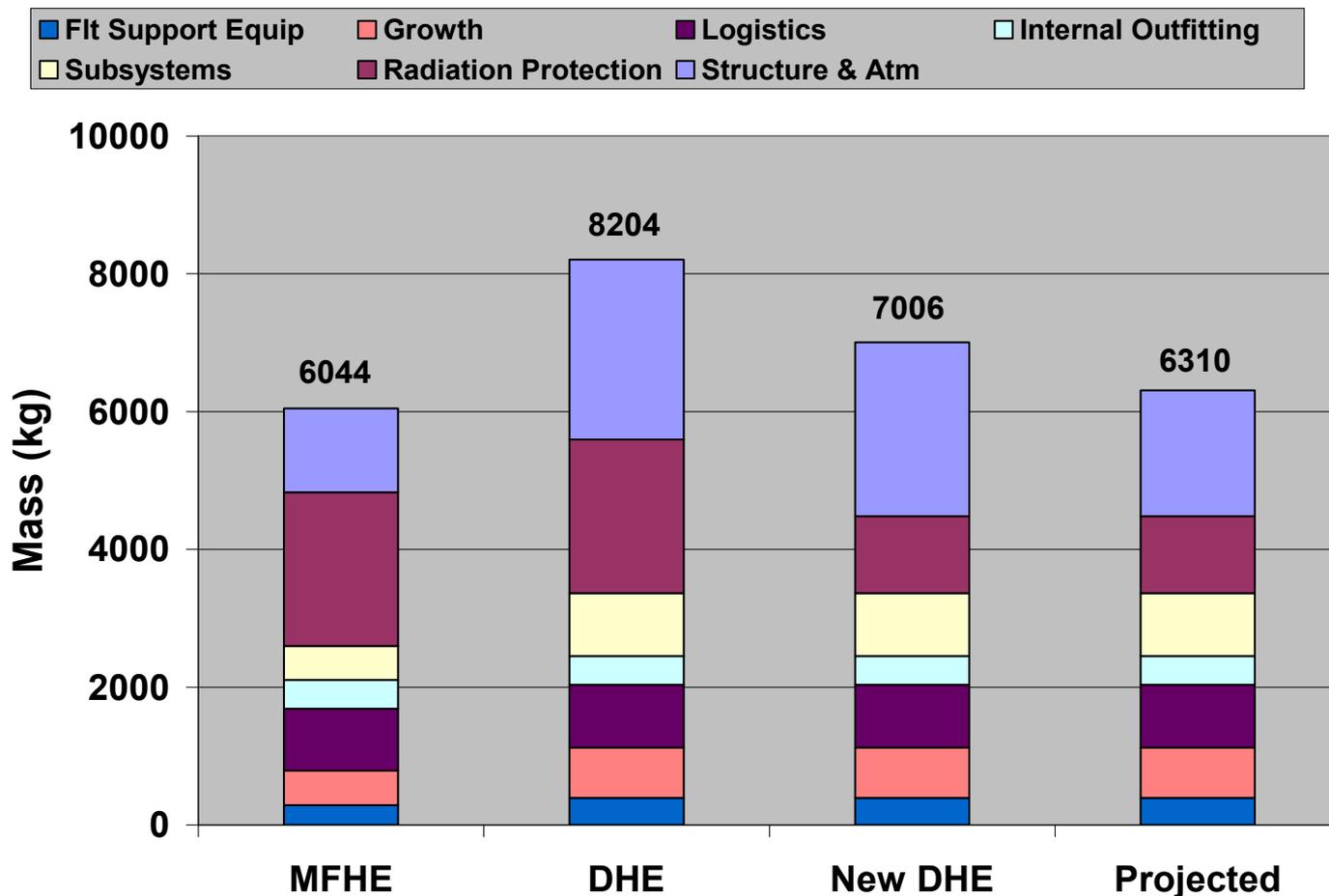
- Internal volume for subsystem components
 - Required, with 25% packing factor 1.6 m³
 - Available in lower dome 17.1 m³

- Internal area for subsystem components
 - Required, with 25% packing factor 49.0 m²
 - Available in lower dome (1 layer on shell) 27.4 m²

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 m³ habitable volume and 28 m² open floor space

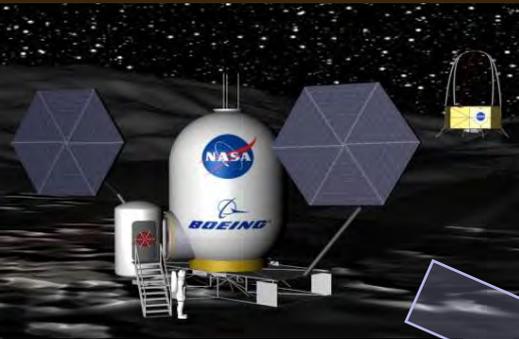
● DHE

- Three access ports and two airlocks
- 6.3 t, 5.2 kWe peak; 3.7 kWe avg; 5.1 kWt
- 78 m³ habitable volume and 28 m² open floor space

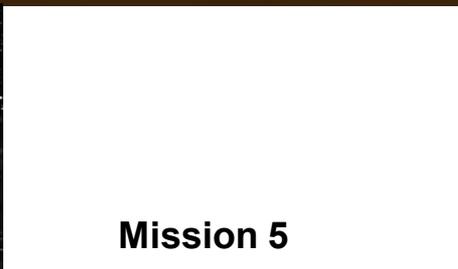
● Outpost

- 517 m³ habitable volume; 148 m² open floor space
- Recommended capabilities for RPLMs, DPLM and bioregen ECLSS

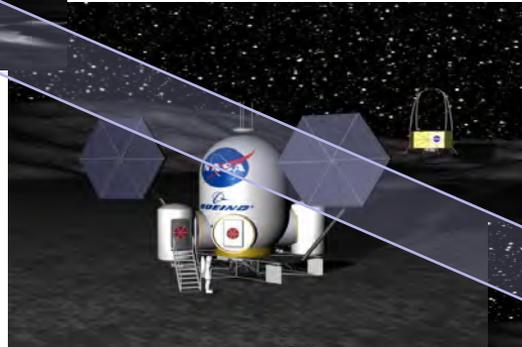
Direct Path From MFHE to Outpost Capability



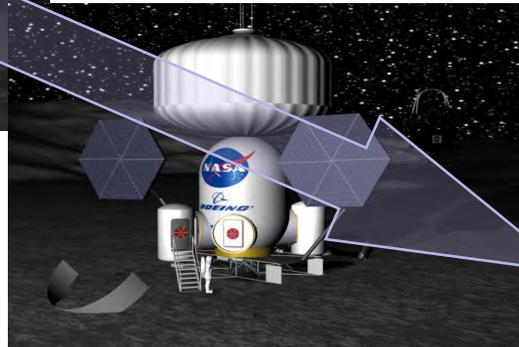
MFHE Study



Mission 5

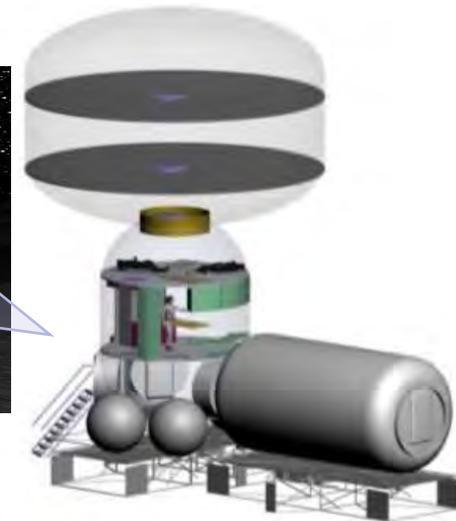


Initial Configuration



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**

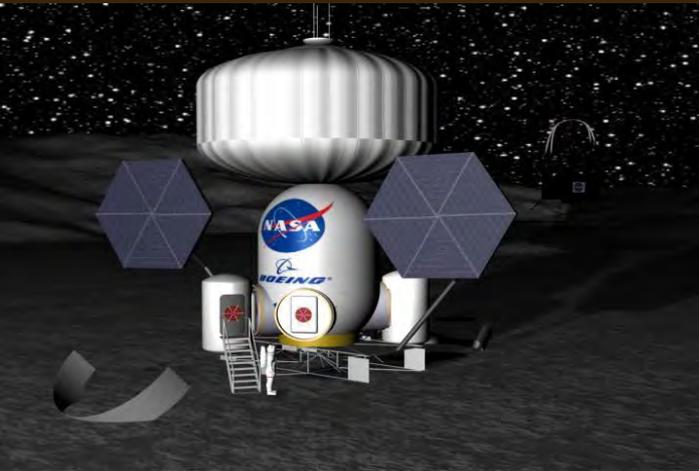
● **Leveling**

Power Support Unit

18 MFHE Functions Allocated to 9 Subsystems

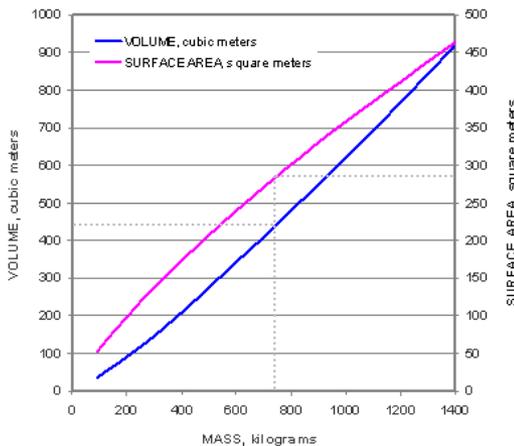
- **Avionics**
- **Dust Mitigation**
- **ECLSS**
- **Flight Crew Systems**
- **Mission Payloads**
- **Electrical Distribution System**
- **Structure & Mechanisms**
- **Thermal Control System**
- **Trash Management**

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

$CS = 0.26 \times D$
 (optimum volume to surface area
 - but not optimum mass!)



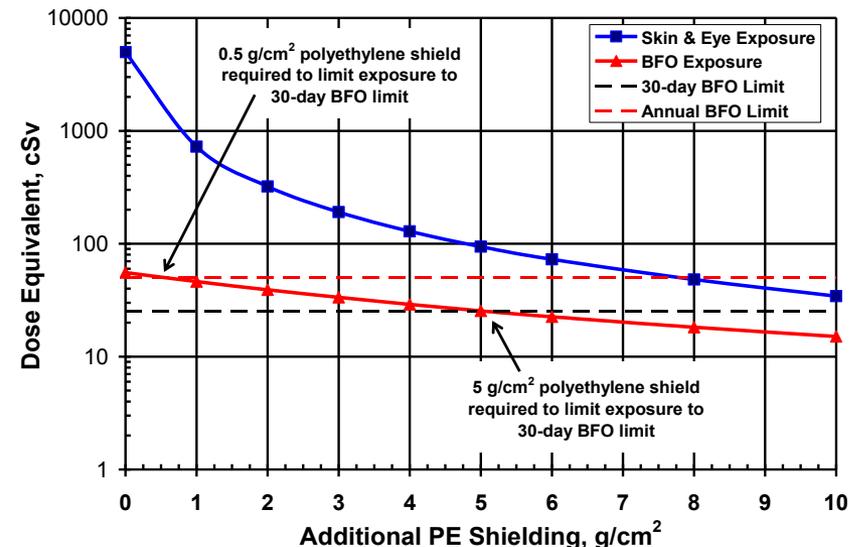
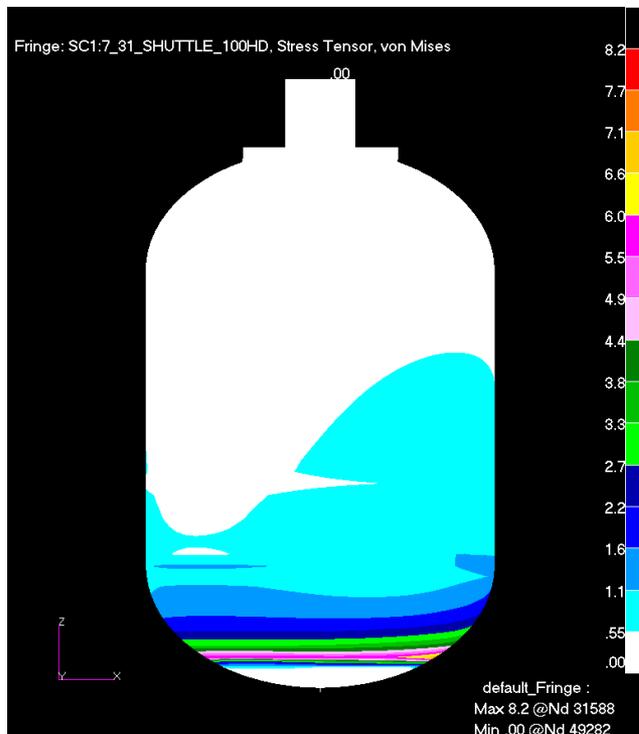
- Structure (kg): 1158
- Atmosphere (kg): 312
- Volume (m³): 439
- Floor area (m²): 120
- Surface area (m²): 290
- Diameter (cm): 914
- Constant diameter height (cm): 238

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



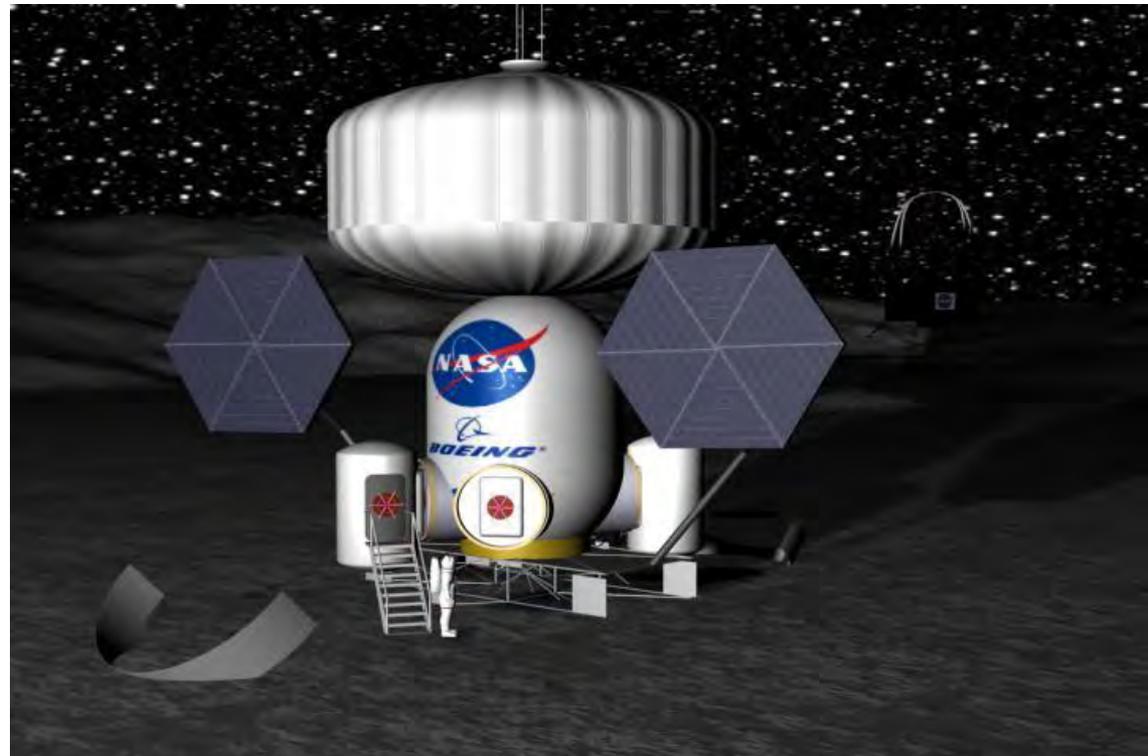
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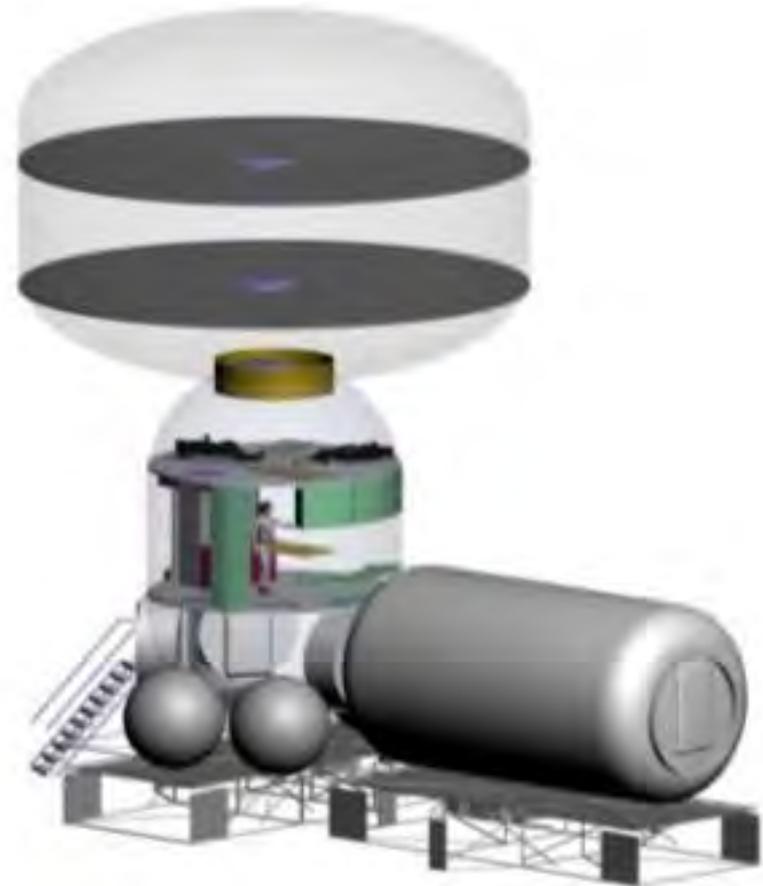
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Habitation Growth Path - 1

● 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 m³
- Four private sleep stations
- Urgent Care capability with minor dental hygiene (Telemedicine)
- ECLSS, TCS, electrical power distribution

**Matches
Scenario
4.0.0**

- **CO₂ reduction to carbon using methane pyrolysis**
- **Water electrolysis**
 - Hydrogen production for CO₂ reduction
 - Oxygen production
- **Wet food, freezer, refrigerator**
- **Full galley**
- **Trash compactor**

**Boeing
Additional
Growth
Items**

Habitation Growth Path - 2

● Mission 12 - Cargo (RPLM-2)

- Additional volume attached to Deployable Hab port #1 55 m³
- ECLSS, TCS, electrical power distribution
- **Surgical and dental capability**
- **Expanded scientific capabilities (includes 4.0.0 bioscience)**
- **Shower**

Matches
Scenario
4.0.0

**Boeing
Additional
Growth
Items**

● Mission 15 - Cargo (DPLM-1)

- Additional volume attached to Deployable Hab port #2 55 m³
- TCS, electrical power distribution
- **ECLSS**
- **Clothes washer**
- **Dishwasher**

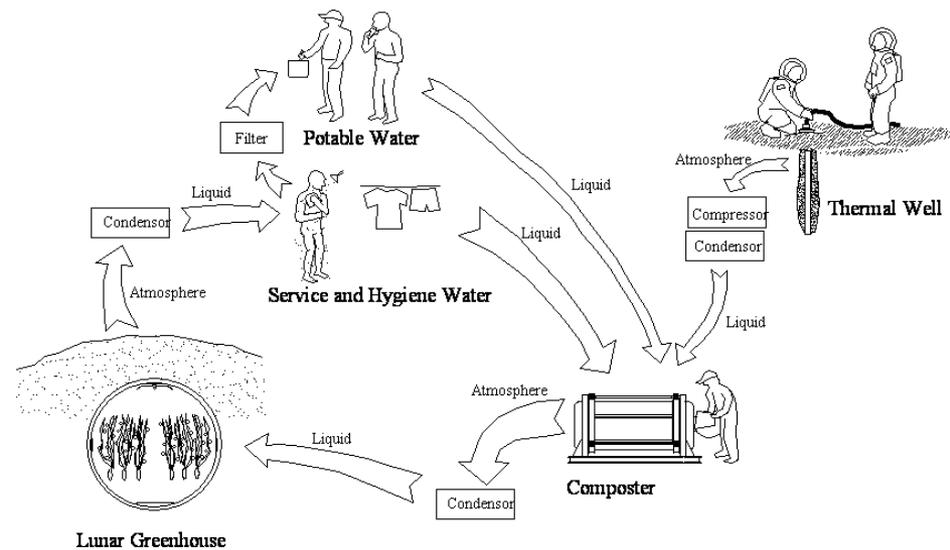
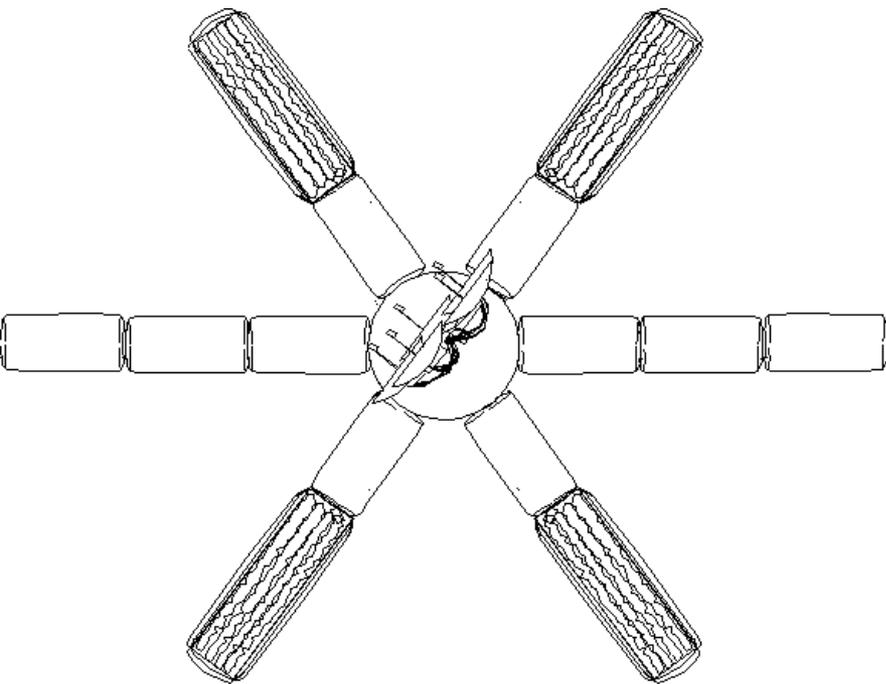
Matches
Scenario
4.0.0

**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)