Deep Space Habitat Configurations Based On International Space Station Systems

David Smitherman[1] and Tiffany Russell[2]
NASA Marshall Space Flight Center, Huntsville, Alabama, 35812, USA

and

Mike Baysinger[3], Pete Capizzo[4], Leo Fabisinski[5], Brand Griffin[6], Linda Hornsby[7], Dauphne Maples[8], Janie Miernik[9]
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 Senior Member.
[7] Thermal, Advanced Concepts Office, MSFC/ED04, and AIAA Member.
[8] Mass Properties, 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

HAT – Human Exploration Architecture Team

Ground Rules & Assumptions

Additional Assumptions

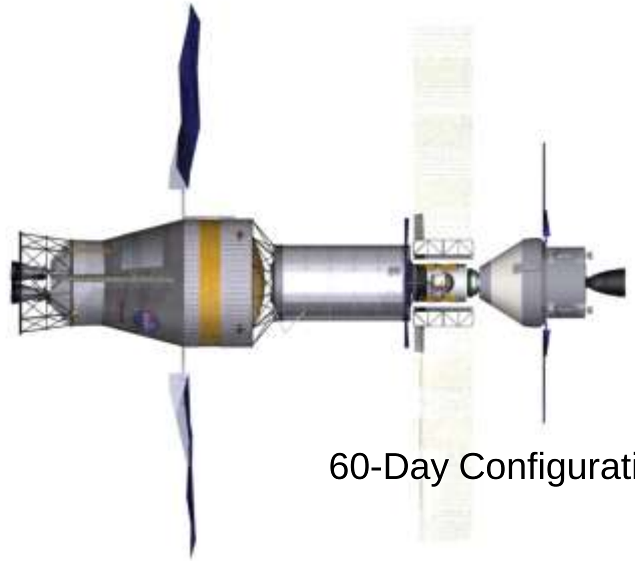
- Design intended to meet HAT missions with modifications as required to utilize current ISS and MPCV systems and technologies
- 60-Day Missions include
  - EM L1 and EM L2 Missions
  - GEO Satellite Servicing
  - ES L2 Missions
  - Lunar orbit Missions
  - Microgravity Free-flyer
- 500-Day Missions 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

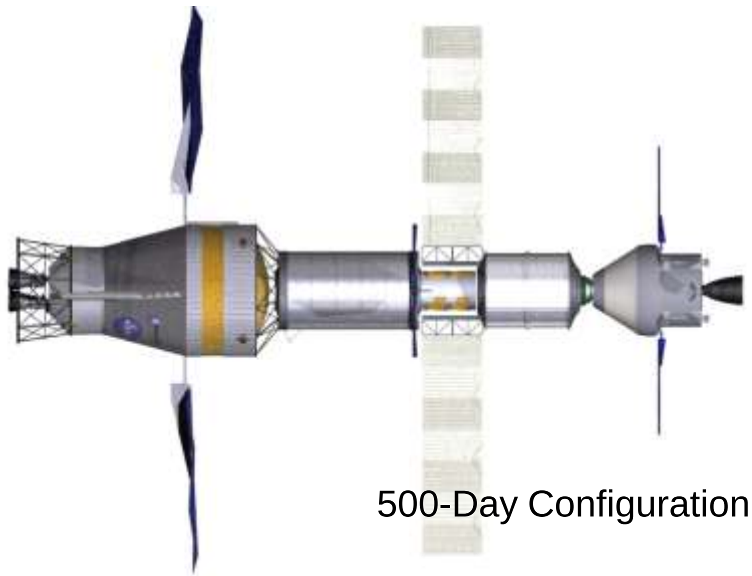
Basic Vehicle Elements

- 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

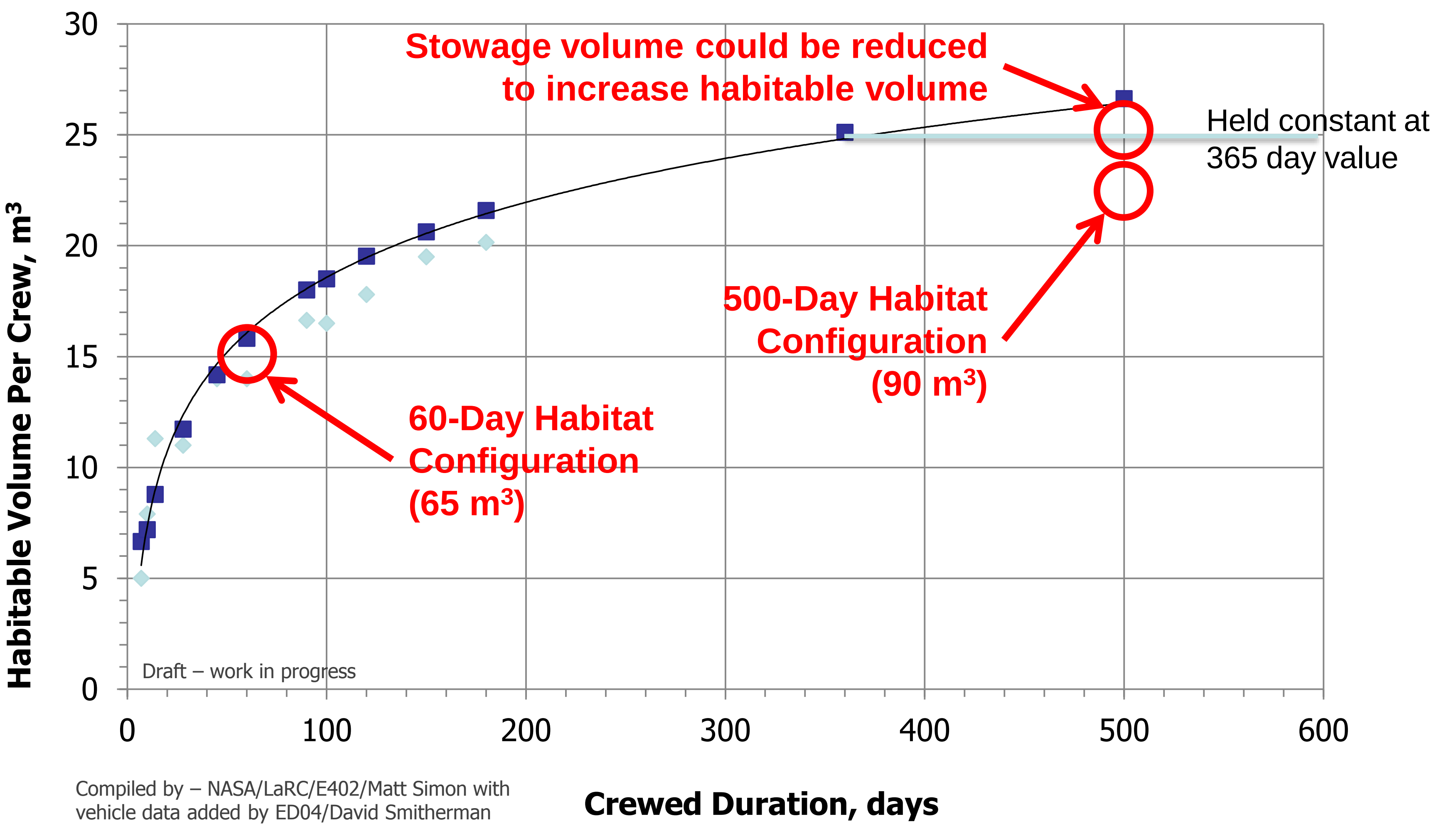


60-Day Configuration



500-Day Configuration

Habitable Volume per Crew Based upon Average of Historical References



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

Discipline Presentations

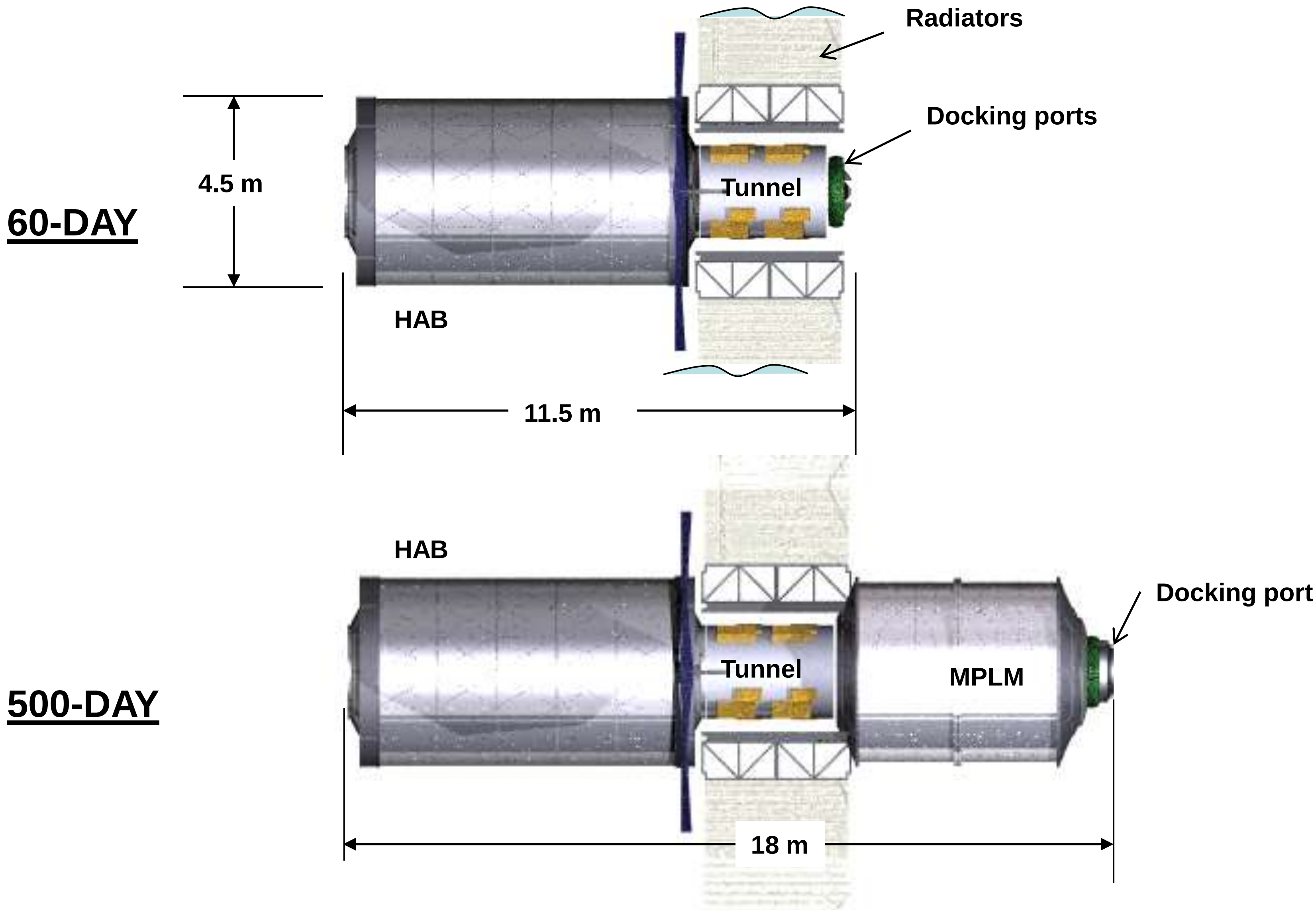
Configurations – Mike Baysinger
Mass Properties – Dauphne Maples
Crew Systems – Brand Griffin
ECLSS – Janie Miernik
Structures – Janie Miernik
Power – Leo Fabisinski
Avionics – Pete Capizzo
Thermal – Linda Hornsby
Environmental Protection – Tiffany Russell

Configuration

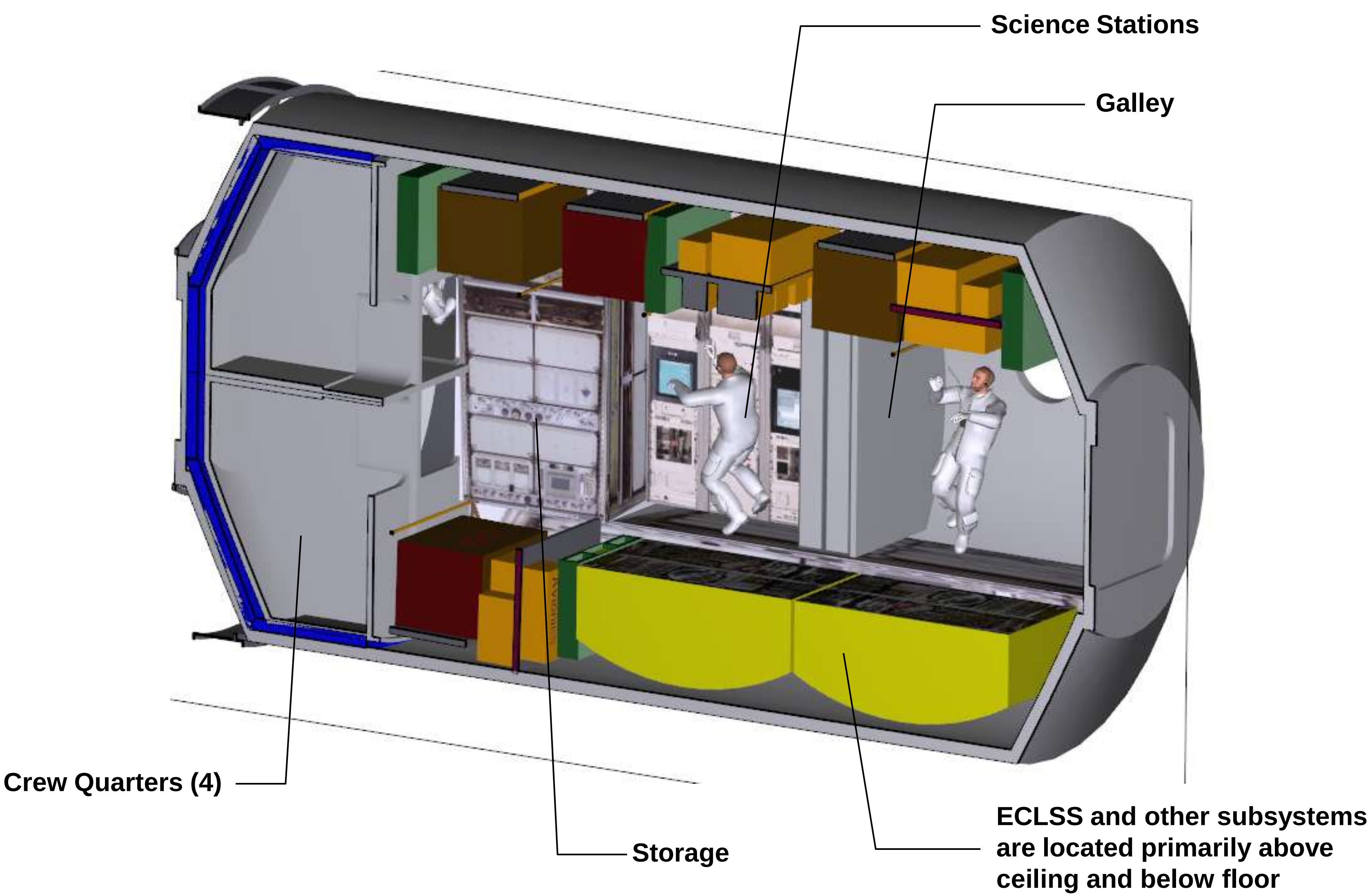
Mike Baysinger

December 15, 2011

Configurations



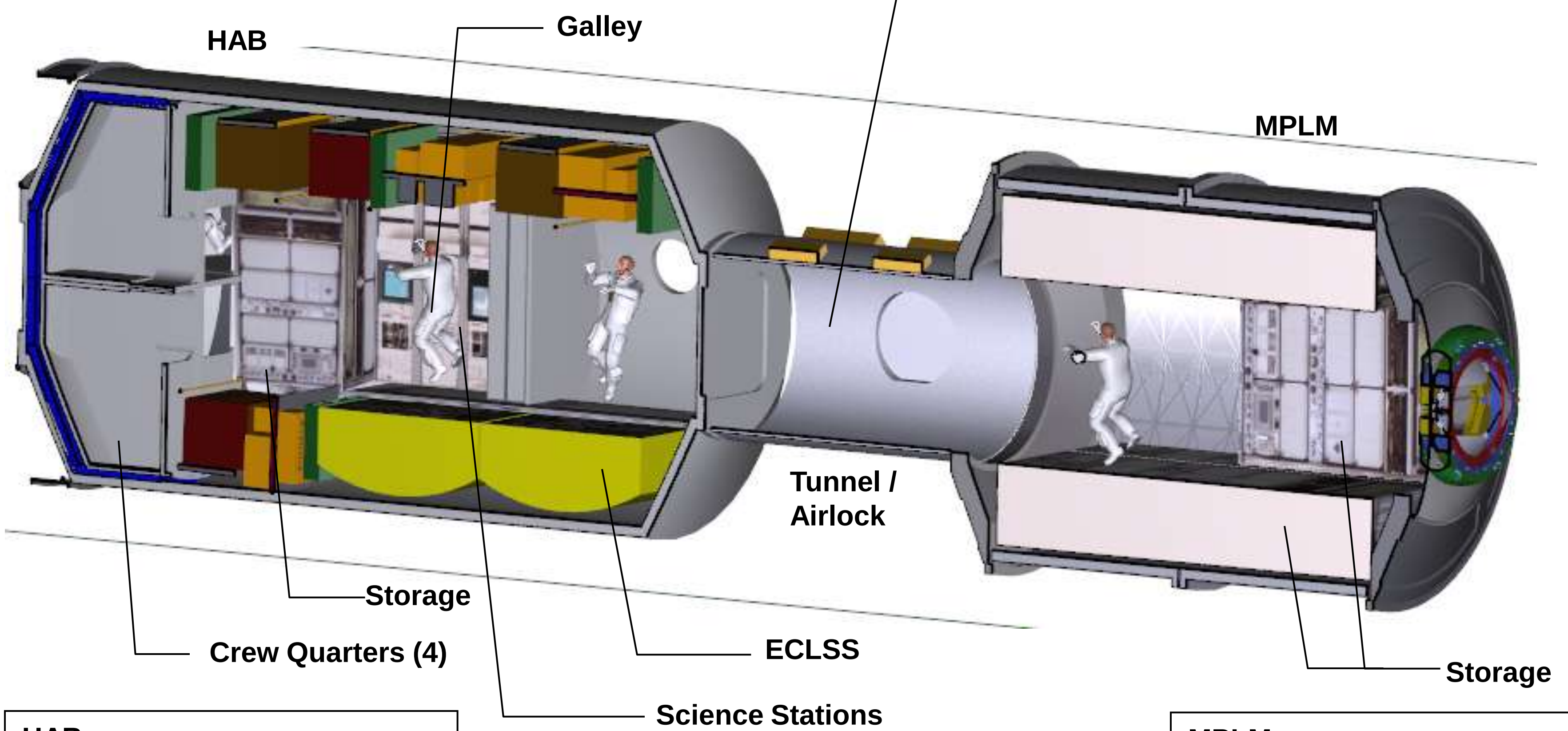
60-Day Configuration



500-Day Configuration

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

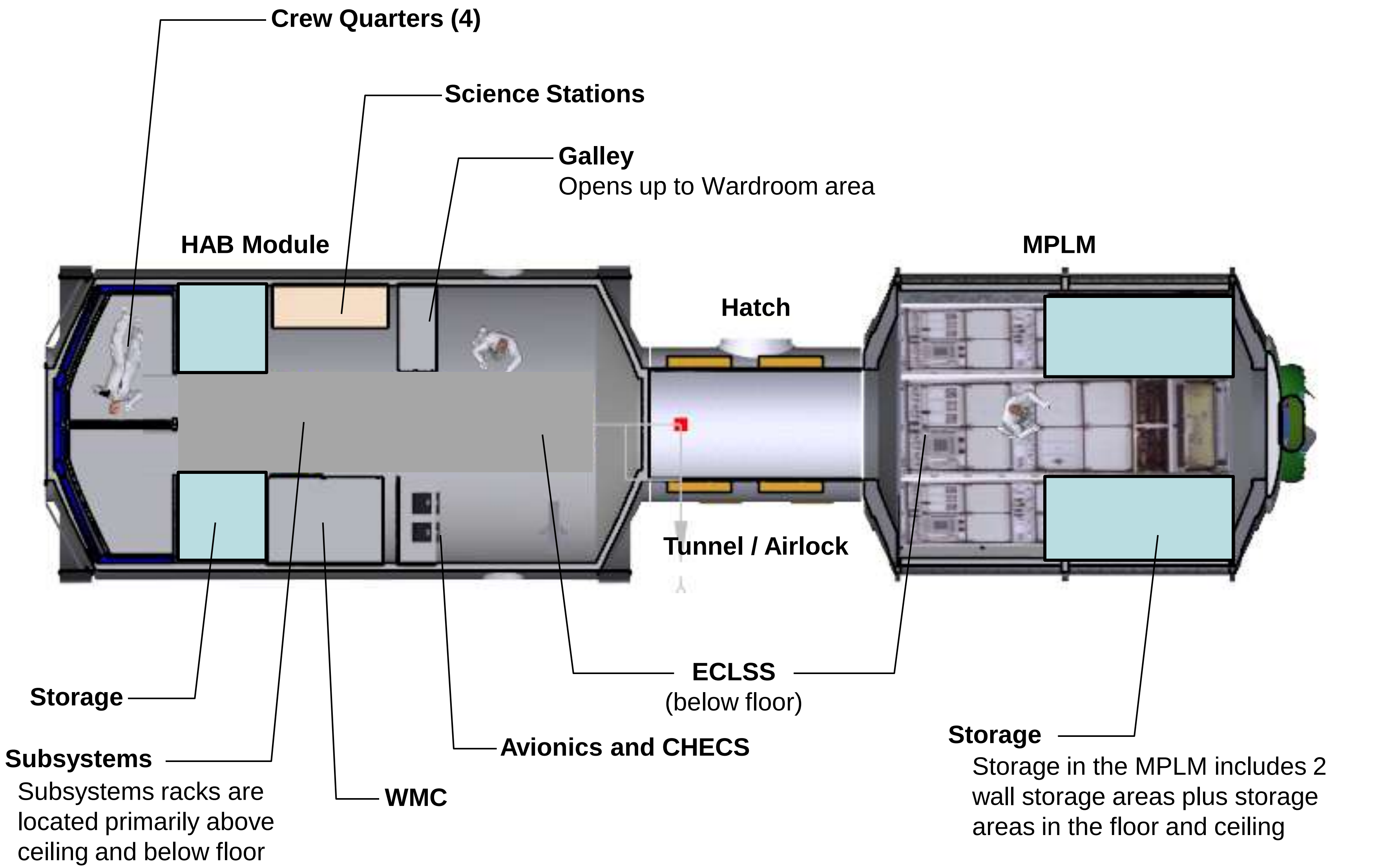
Service Tunnel / Airlock:
Pressurized volume = ~ 10 m^3
Habitable volume = ~ 9 m^3



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

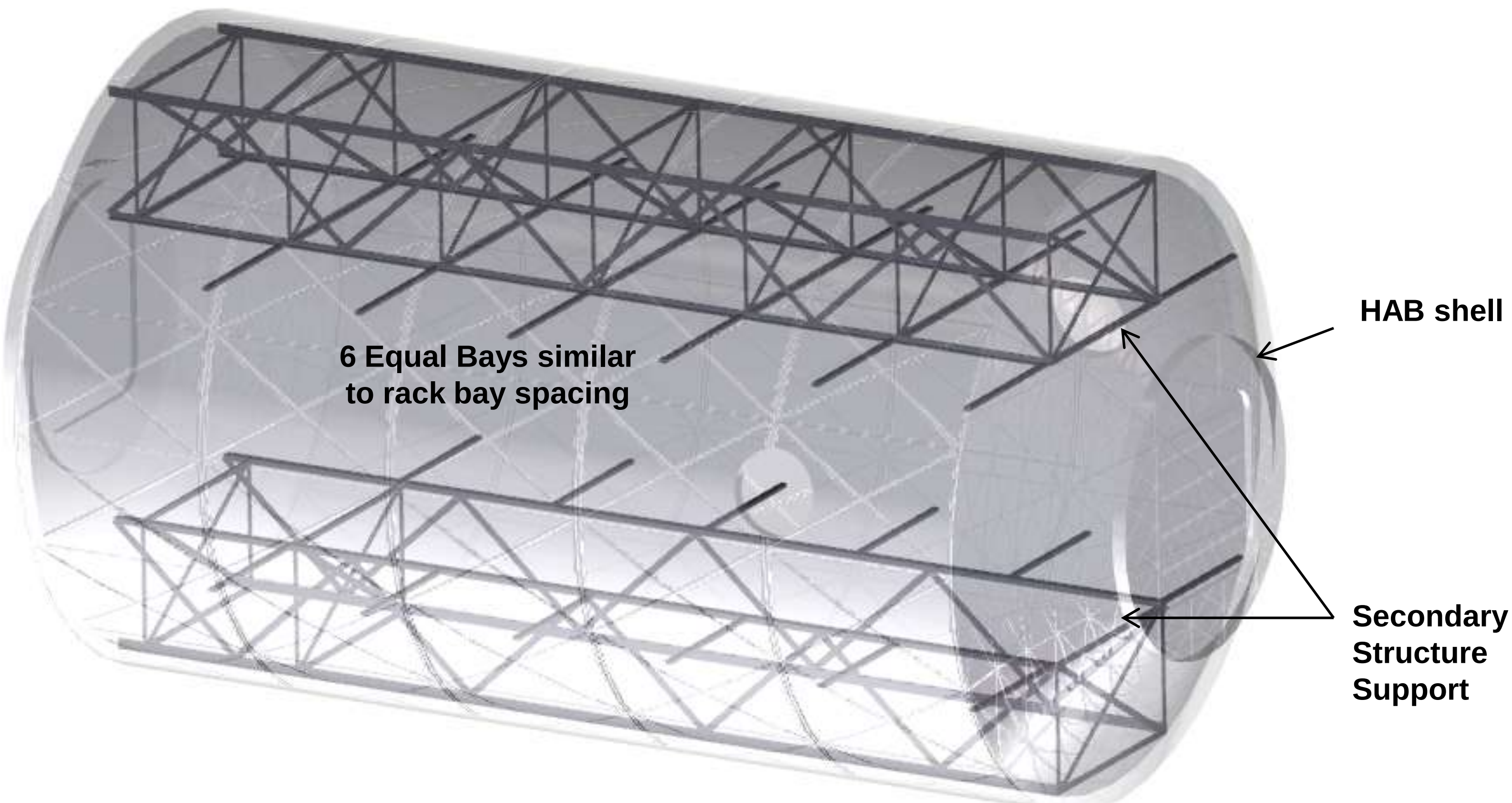
MPLM:
Pressurized volume = ~76 m^3
Habitable volume = ~ 25 m^3
Stowage volume = ~ 33 m^3

500-Day Configuration



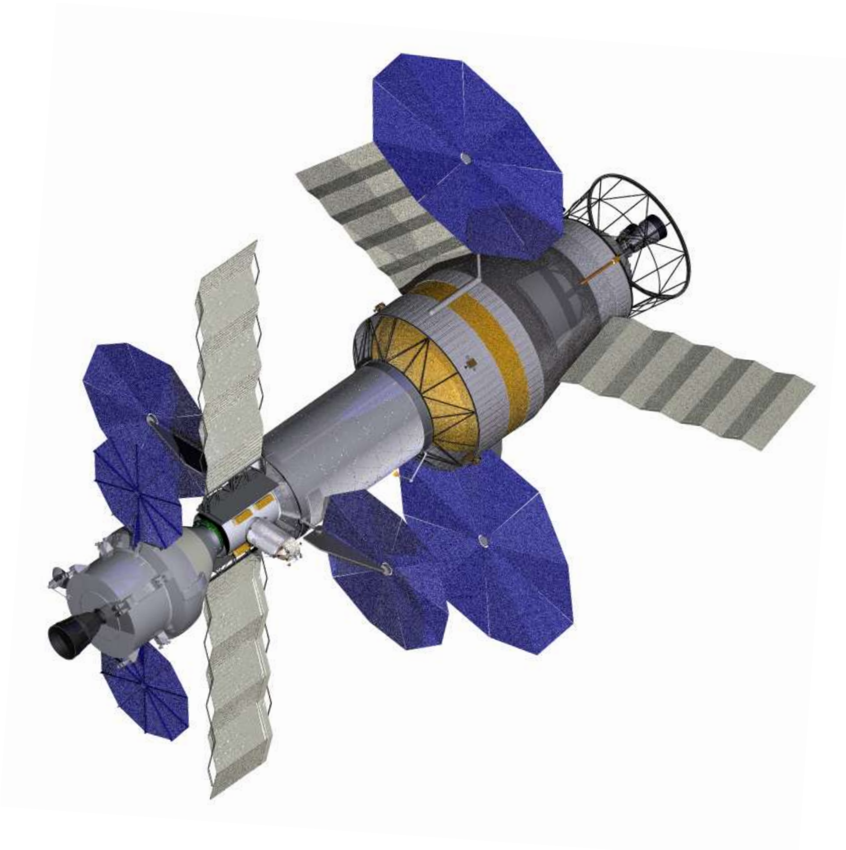
Habitat Plan View

Internal Secondary Structure

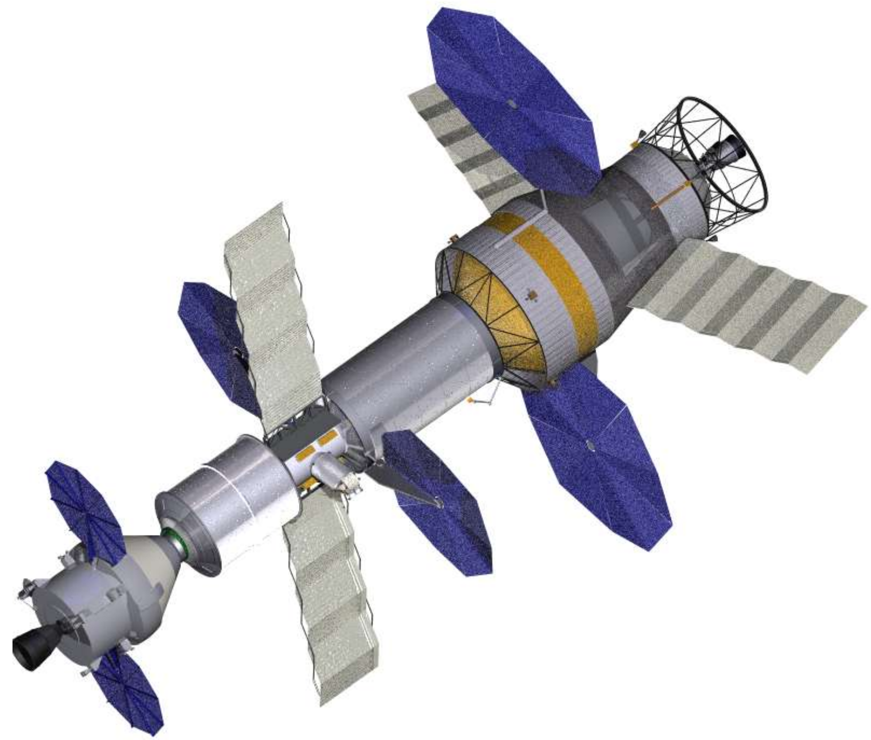


Vehicle Configurations

60-DAY



500-DAY



Delta IV-H Launches

60-Day

500-Day

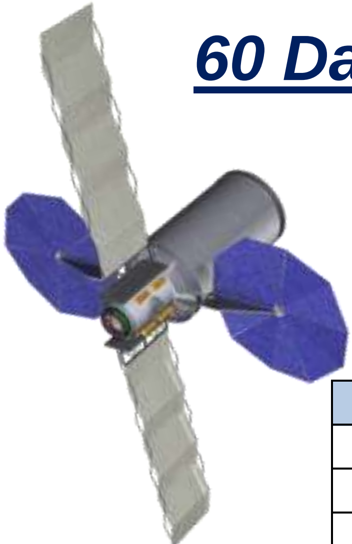
Mass Summary

Dauphne Maples

December 15, 2011

Mass Summary: DSH MPLM Concept

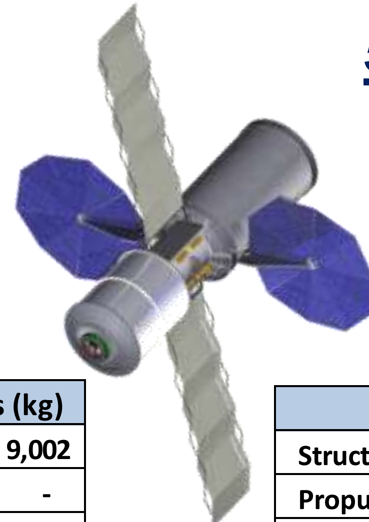
Due to high TRLs, these designs may reduce cost, production, and flight-readiness schedule.



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

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



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

Category	Mass (kg)
Structures	14,116
Propulsion	-
Power	924
Avionics	1,321
Thermal	2,868
Environment Protection	4,826
ECLSS	6,890
Crew Systems	807
EVA	272
Dry Mass	32,022
Stowed Provisions	2,766
Consumable Fluids	6,187
Non-Propellant Fluids	457
RCS Propellant	-
DSH Wet Mass	41,430
Project Mgrs Reserve (PMR) (10%)	4,143
Total Wet Mass w/PMR	45,573

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

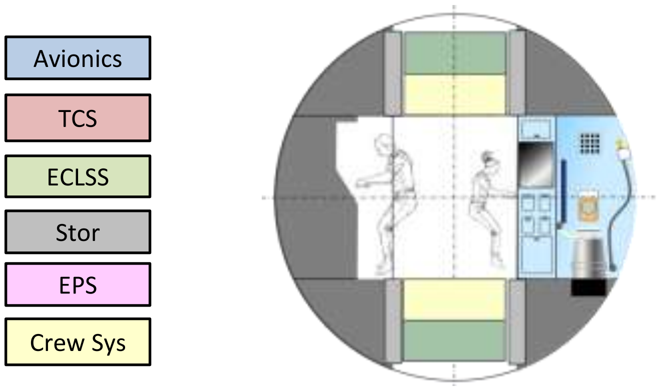
Habitation and Autonomy

500-Days without resupply

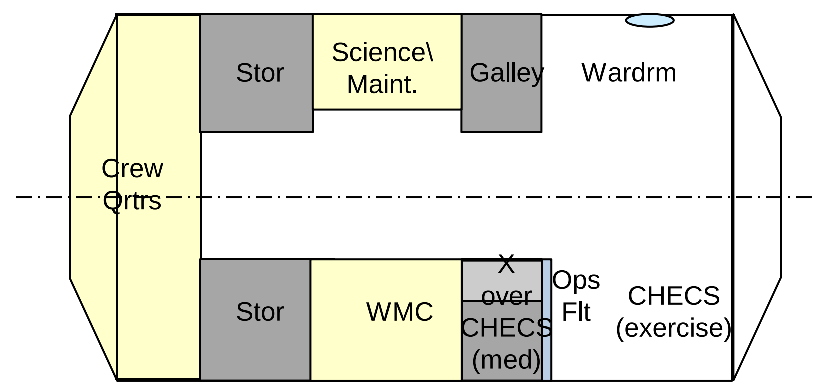
Activity	DSH Accommodation
Privacy, personal space	Large crew quarters, no through traffic, quiet end of module, acoustic insulation, personal control over temperature/air flow, adjustable lighting, data/power access, private communications
Eating, group meetings	Open area to accommodate all 4 crew,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

Longitudinal Sections

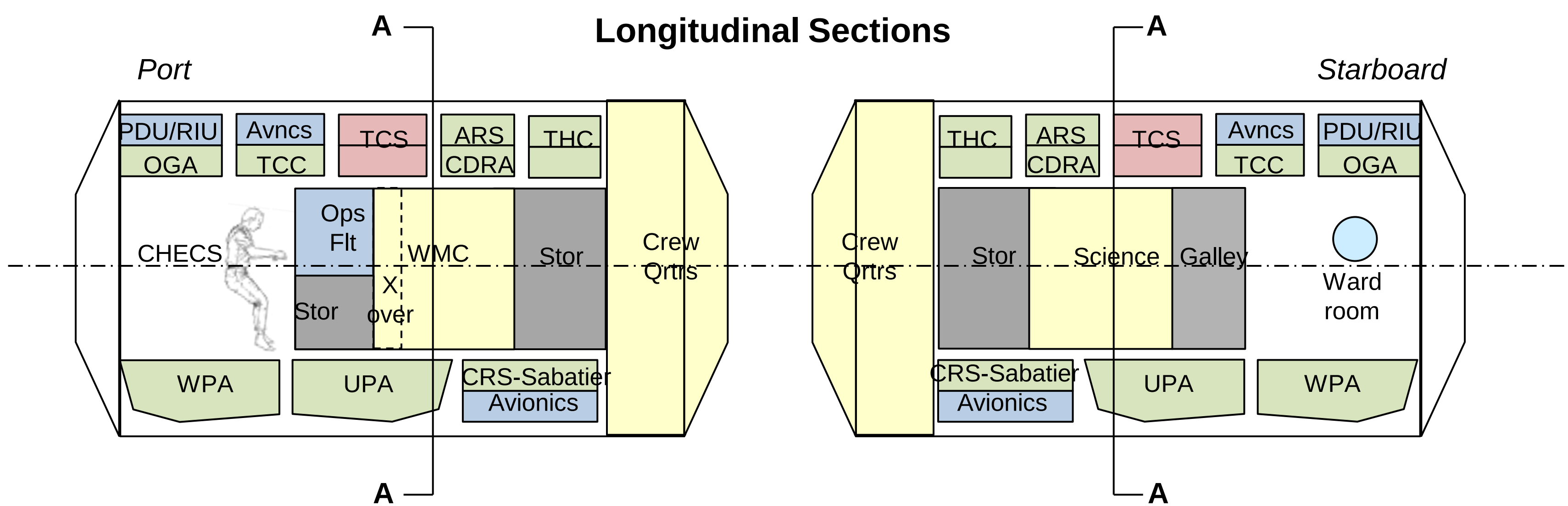
Transverse Section AA



Plan

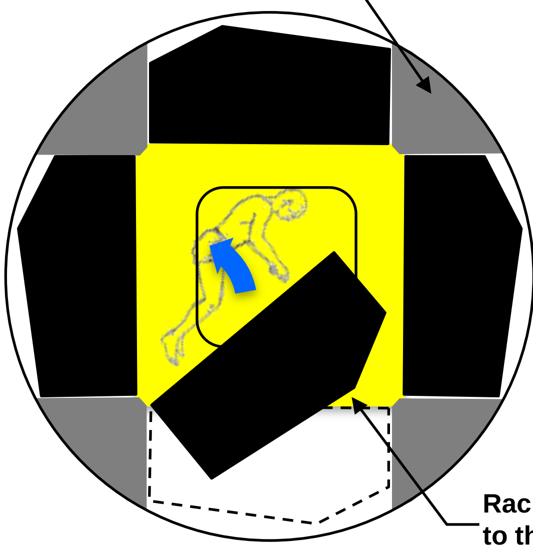


Longitudinal Sections

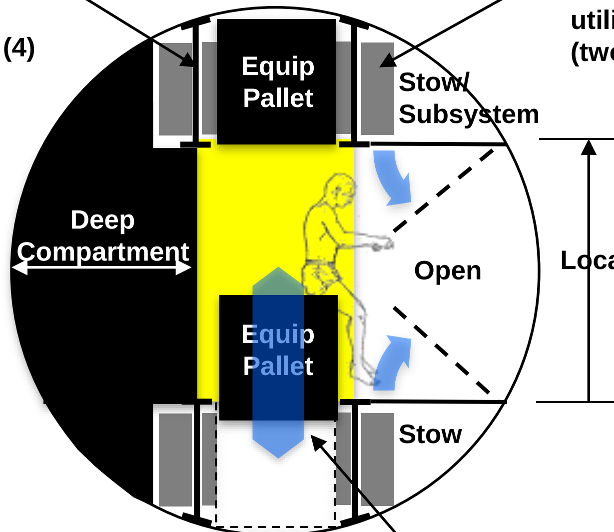


Rack vs. Shell/ORU

ISS Rack Based Layout



Shell/ORU 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

Designed for ORU level Interchangeability

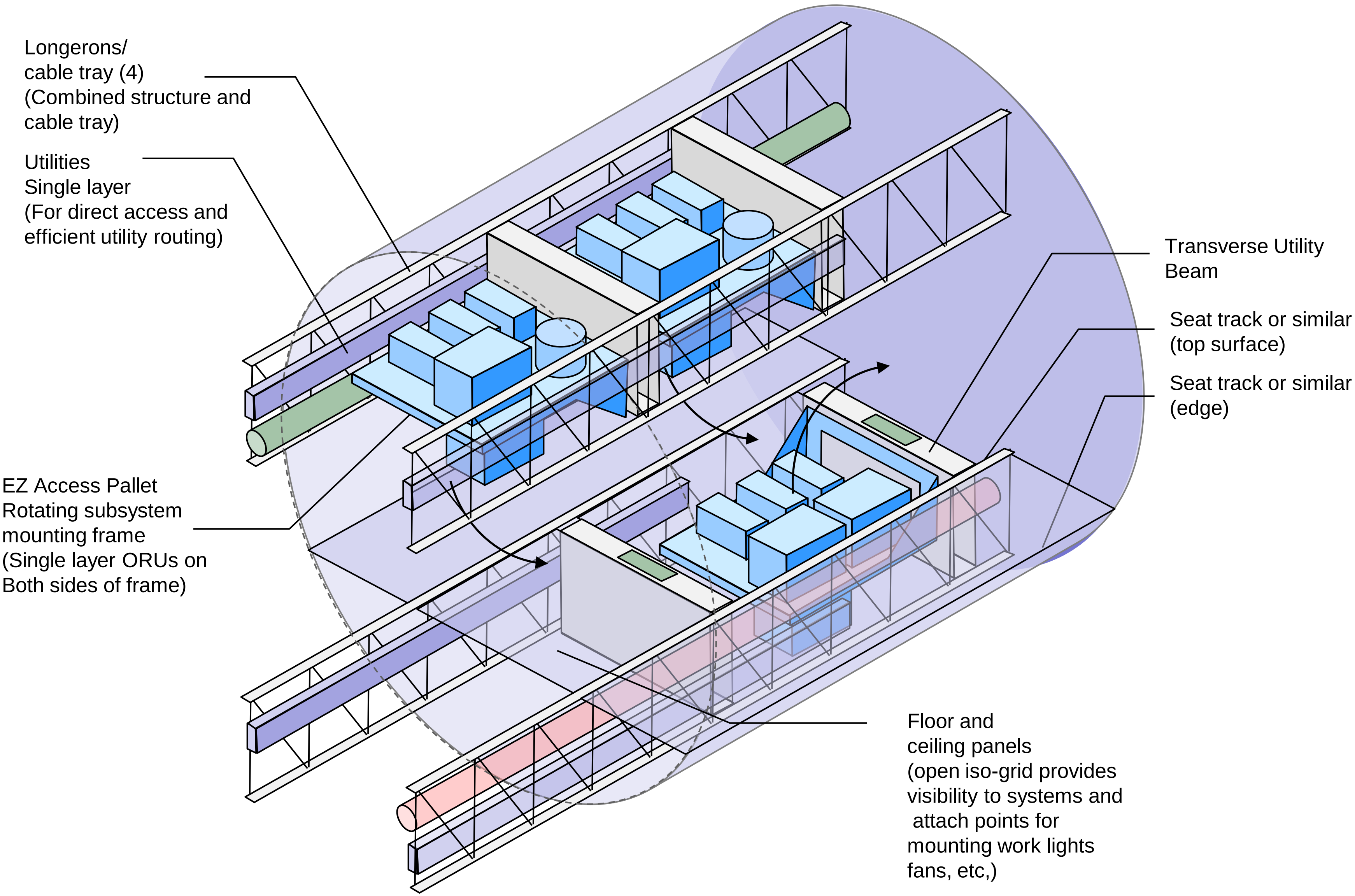
Two-sided equipment pallet
Crew activities in wall
Subsystem to ceiling/floor
Dedicated utility interface

Local vertical for crew

Head-to-toe air flow
Overhead lighting

Easy access Cable Tray

EZ Access Architecture



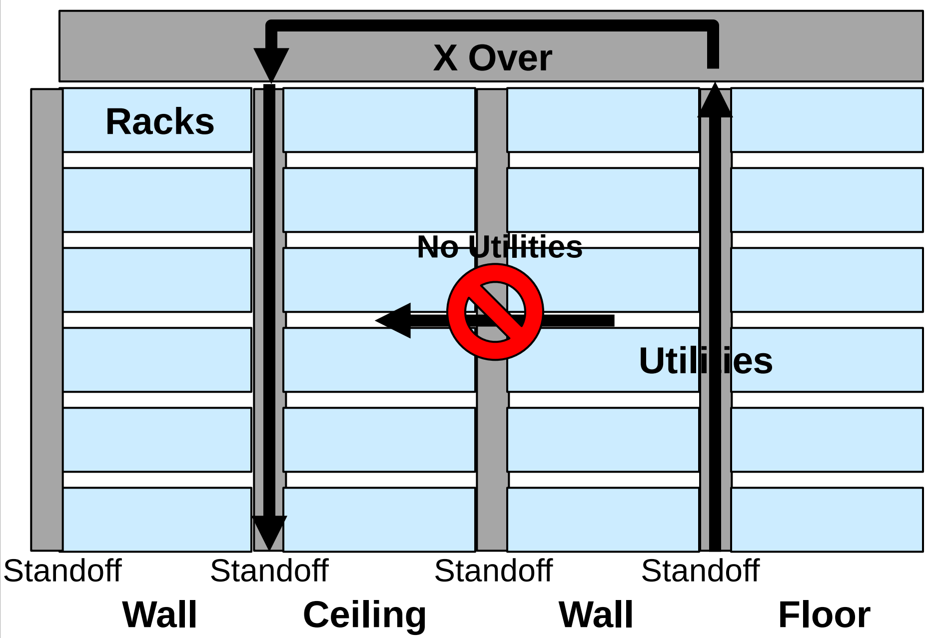
Utility Layout Comparison

ISS Rack Based

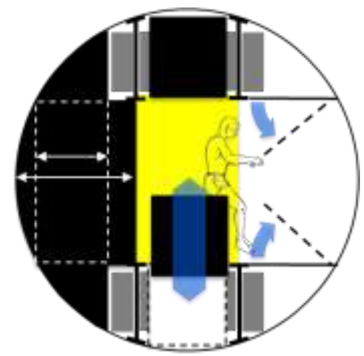
End X-Over
- Long utility runs
- Larger dia ducts
- Noise

Standoff Lighting
- Two sides
- Easily obscured

•Standoff Air Supply
- Two sides
- Easily obscured



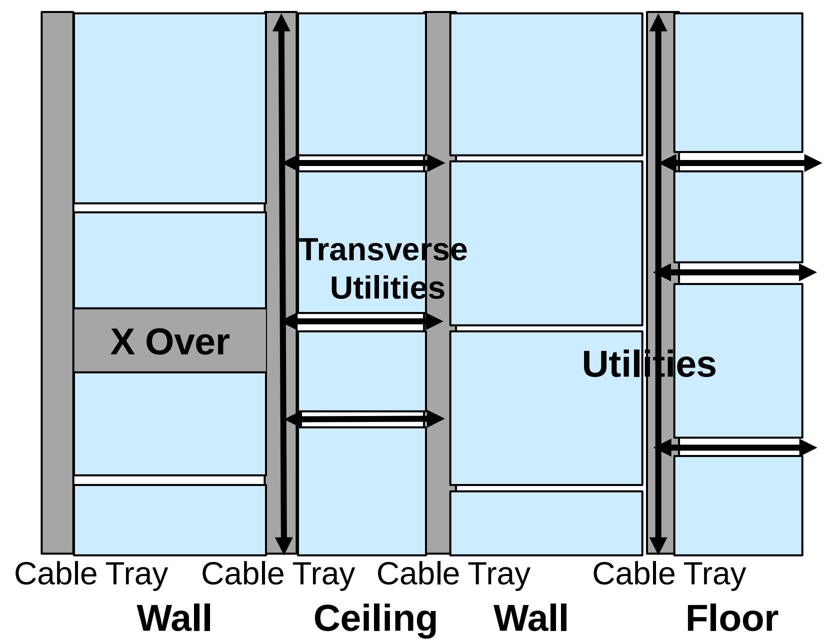
Shell/ORU Based



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

Central Lighting
- One light
- Good illumination

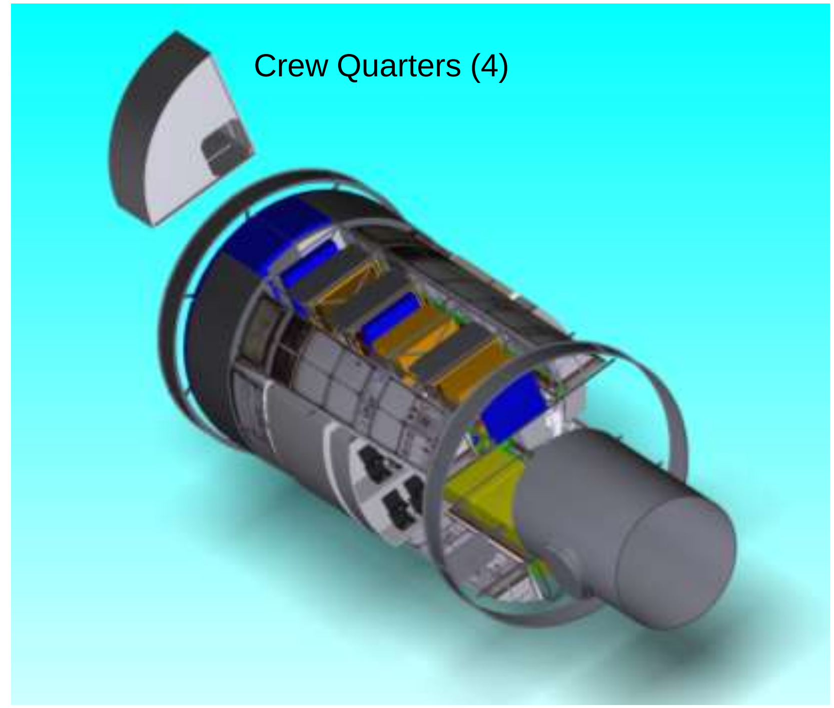
•Central Air Supply
- One diffuser
- Good distribution



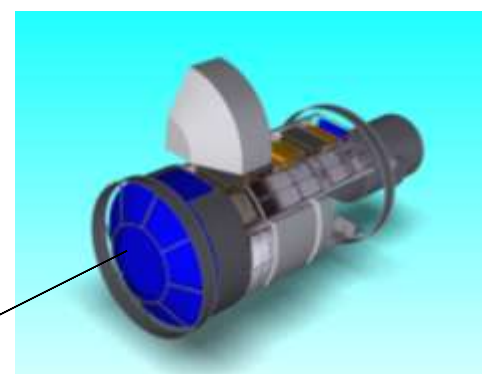
Crew Quarters

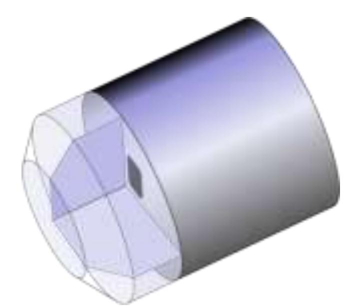
ISS (~2 m^3 each)

DSH (~ 4 m^3 each)

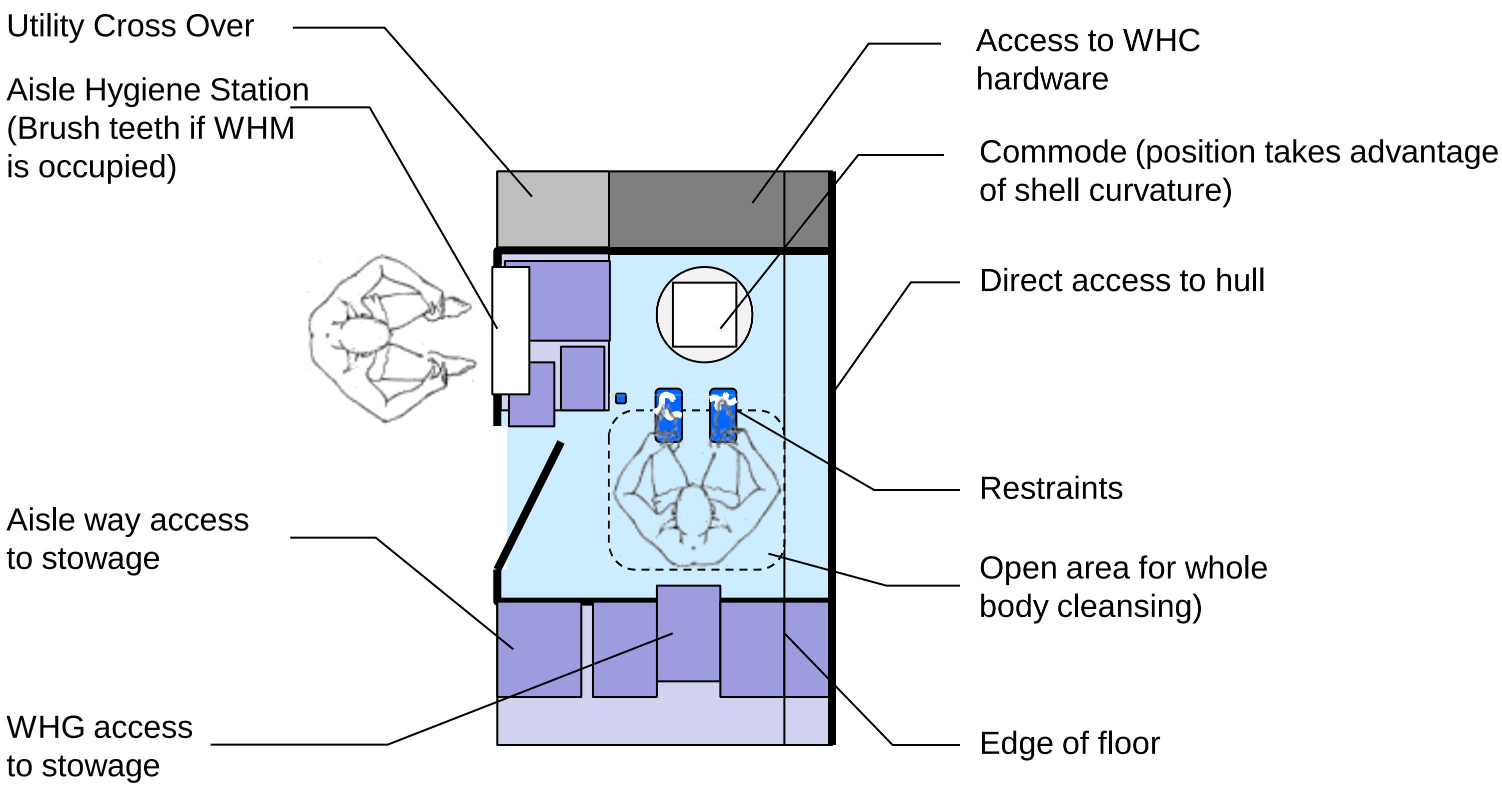


Radiation Protection





DSH Waste Hygiene Compartment

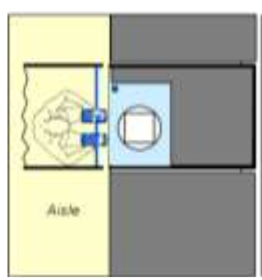


ISS

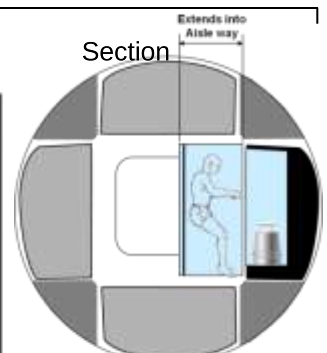
Interior WHC

Exterior WHC

Plan

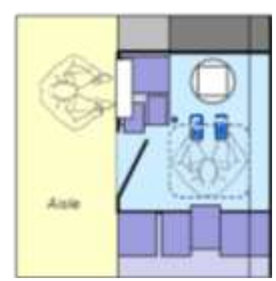


Section

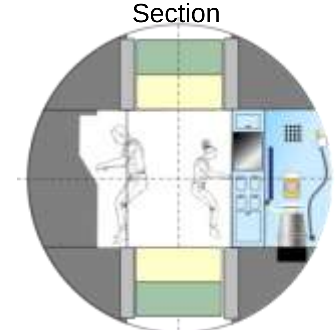


DSH

Plan



Section



Accessibility Zoning

ISS Access

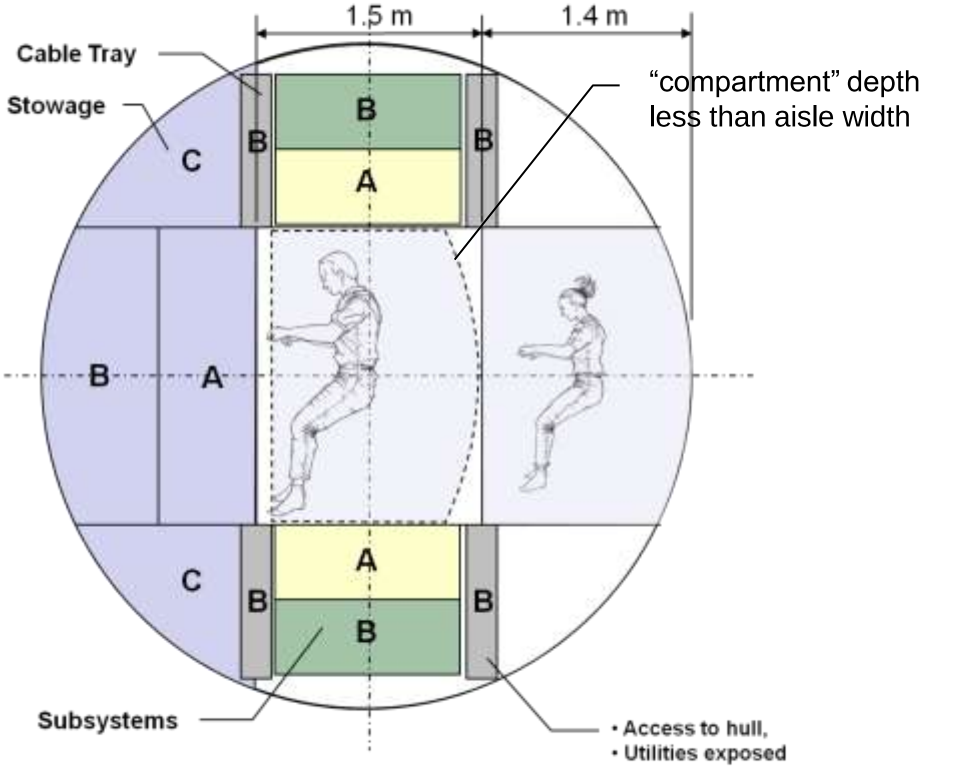
ISS Stowage

No immediate access to hull

- No access behind standoff
- Utilities enclosed

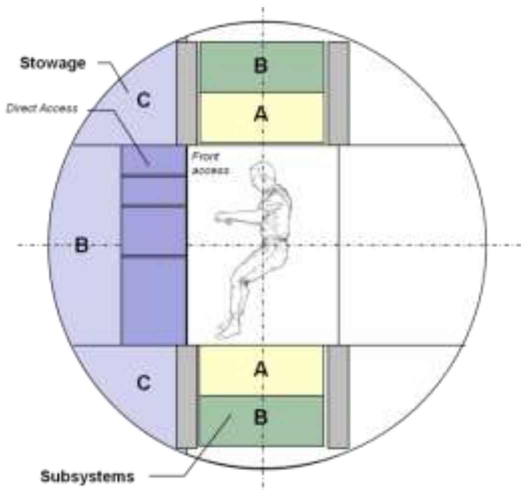
Shell/ORU

Zone	Access
A	Immediate Physical & Visual
B	Indirect
C	Infrequent

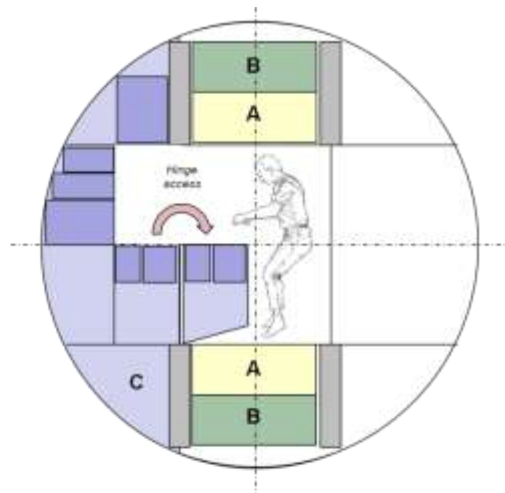


Stowage Concepts

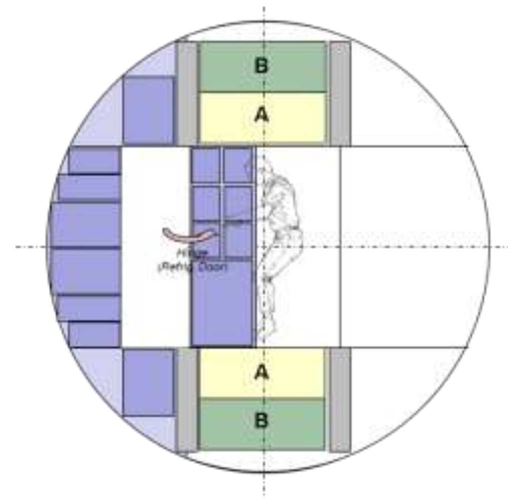
Front Access



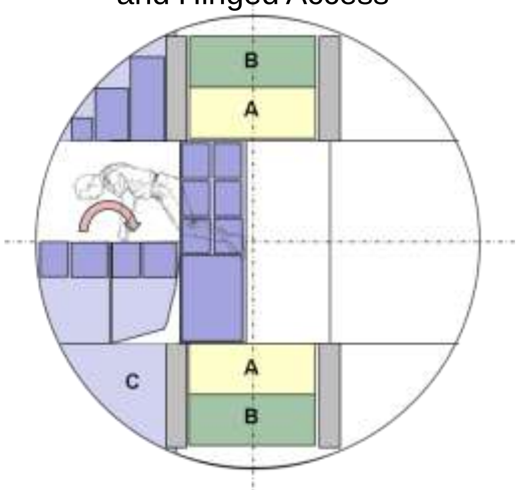
Center Hinged Access



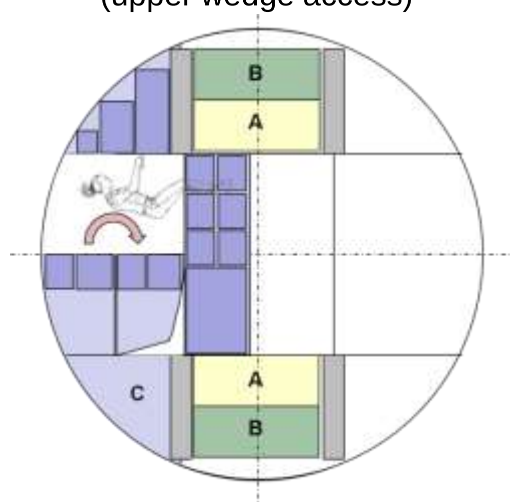
Refrigerator Door
Side Hinged Access



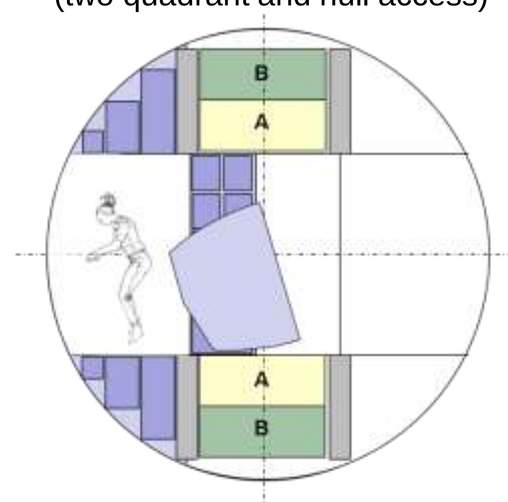
Combo
Combined Refrigerator and Hinged Access



Combo
(upper wedge access)



Combo
(two quadrant and hull access)



Crew Systems Mass by Mission

Component	60-Day Mission Basic Mass (kg)	60-Day MGA %	60-Day Predicted Mass (kg)	500-Day Mission Basic Mass (kg)	500-Day MGA %	500-Day Predicted Mass (kg)
Galley	150	3	154	150	3	154
Wardroom	50	3	52	50	3	52
Crew Quarters	248	5	260	248	5	260
Restraints	24	3	25	24	3	25
Crew Health Care (Medical)	73	3	75	173	3	178
Crew Health Care (Exercise)	91	3	94	91	3	94
Personal Laptops	16	3	16	16	3	16
General Illumination	12	15	14	24	15	28
Crew Systems Total	664		**690**	776		**802**
Stowed Provisions: Personal	80	3	82	100	3	103
Housekeeping Expendables	20	3	21	166	3	171
Operational Spares	100	3	103	175	3	180
Maintenance Equipment	40	3	41	80	3	82
Photography	4	3	4	4	3	4
EVA: Provisions	30	3	31	60	3	62
EVA Suits	246	0.0	246	246	0.0	246
Airlock Services	25	3	25	25	3	25
Total	1210		**1243**	1632		**1675**

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_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.

Water Reclamation ISPR Rack

Carbon Dioxide Removal Assembly

Packaged food

Comparison of Mission/Mass

ECLSS Subsystem	60-Day Mission Basic Mass (kg)	60-Day Mission MGA %	60-Day Mission Predicted Mass (kg)	500-Day Mission Basic Mass (kg)	500-Day Mission MGA %	500-Day Mission Predicted Mass (kg)
Atmosphere Revitalization Sys (ARS)	337	20	404	562	20	674
Atmosphere Cont & Supply System (ACSS)	400	20	480	1200	20	1440
Temp & Humidity Control (THC)	149	20	179	149	20	179
Waste Hygiene Compartment (WHC)	455	20	546.00	455	20	546
Water Recovery & Man (WRM)	1300	3	1339	1300	3	1314
Atmosphere Regen (OGA/ CO_2 Red Assy)	1000	20	1200	1600	20	1860
Fire Detection & Suppression /module	35	30	46	70	30	91
Potable Water Tanks	180	3	185	680	3	700
ECLSS Hardware Total	3856		**4379**	6016		**6890**
ECLSS Expendables	200	3	206	500	3	515
ECLSS Spares	730	3	752	1600	3	1648
H_2O	634	3	653	2520	3	2596
Food, packaged	337	10	371	2403	10	2643
Atmosphere Regen (O_2)	114	3	117	670	3	690
Atmosphere Regen (N_2) leakage	122	3	126	250	3	258
Total	5993		**6603**	13959		**15239**

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.

	STA Hab/Lab	MPLM	Tunnel		ISPR
Length	8.5 m (27.4 m)	6.5m (19 ft)	3.2 m (10.5 ft)	**Height**	2 m (6.1 ft)
Cylindrical section length	7.2 m (25.6 ft)	4.9 m (15 ft)	3.2 m (10.5 ft)	**Width**	1.05 m (3.4 ft)
Diameter	4.3 m (14 ft)	4.3 m (14 ft)	2.5 m (7.6 ft)	**Max. depth**	.86 m (2.8 ft)
Pressurized volume	107 m^3	76.4 m^3	10 m^3	**Volume**	1.57 m^3
Mass of shell incl. CBMs and hatches	3833 kg (8450 lbs)	2502 kg (5516 lbs)	1284 kg (2204 lbs) ~25 kg/m^2 areal mass	**Mass of 6-post rack**	105 kg (230 lbs)

- A new launch adapter must be developed for EELV launch to interface ISS elements and it is not included in stated mass.

Multi-Purpose Logistics Module (MPLM)

Comparison of Mission/Mass

Structural Component	Mass (kg)	MGA %	Predicted Mass (kg)	Mass (kg)	MGA %	Predicted Mass (kg)
	60-Day Mission			500-Day Mission		
STA Lab/Hab outfitted Pressure Shell	3833	10	4216	3833	10	4216
Hab Secondary Structure	2141	20	2569	2141	20	2569
MPLM outfitted Pressure Shell w/2 axial CBM ports	0	20	0	2502	20	3002
MPLM Secondary Structure	0	20	0	1704	20	2044
Tunnel/Ext. Secondary Structure	1782	20	2139	1815	20	2178
20” ISS Window	75	3	77	75	3	77
Total	**7831**		**9002**	**12069**		**14087**

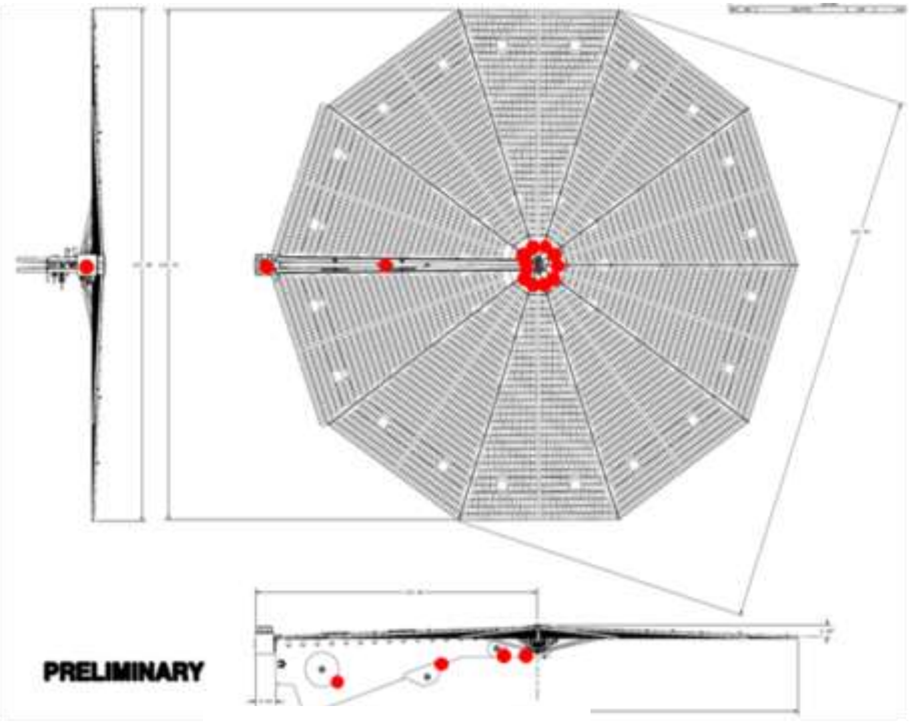
Power System

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

Power System Mass Summary

- Batteries are Off-The-Shelf High-Capacity Lithium Ion Cells in series to provide 122.4 V nominal

Component	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Solar Arrays (with Booms, Actuators)	204	20	245	263	20	316
Power Electronics	75	16	87	75	16	87
Secondary Batteries	153	10	168	204	10	224
Power Cabling	152	30	198	228	30	297
Total	**584**		**698**	**770**		**924**

Avionics

Pete Capizzo

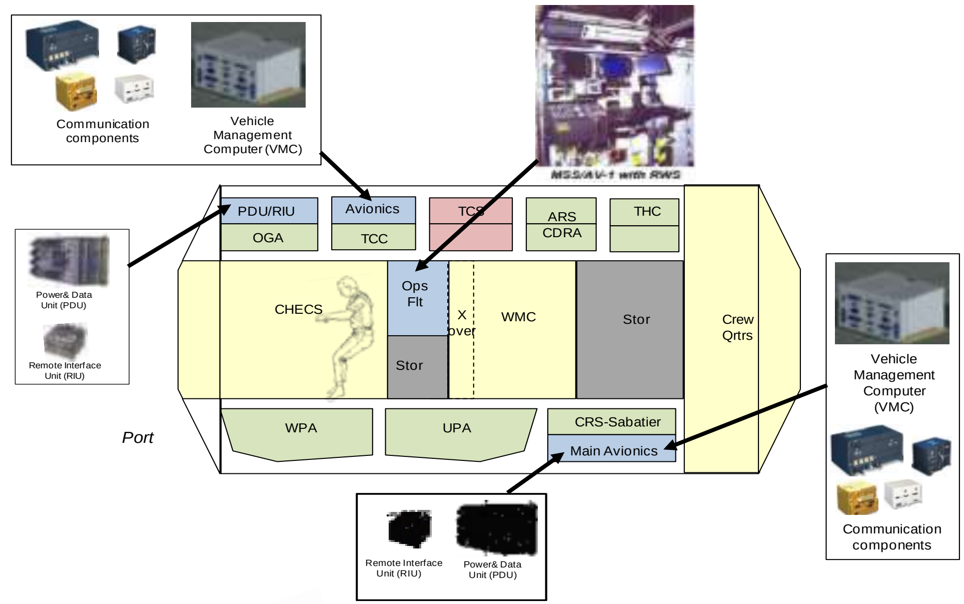
December 15, 2011

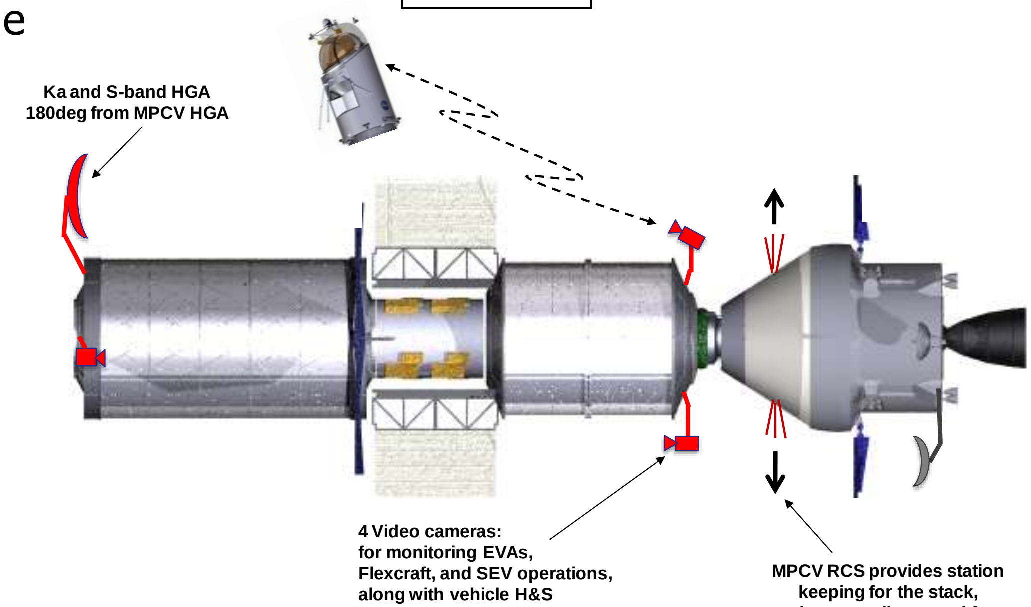
Avionics – MPCV Derived

- 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.



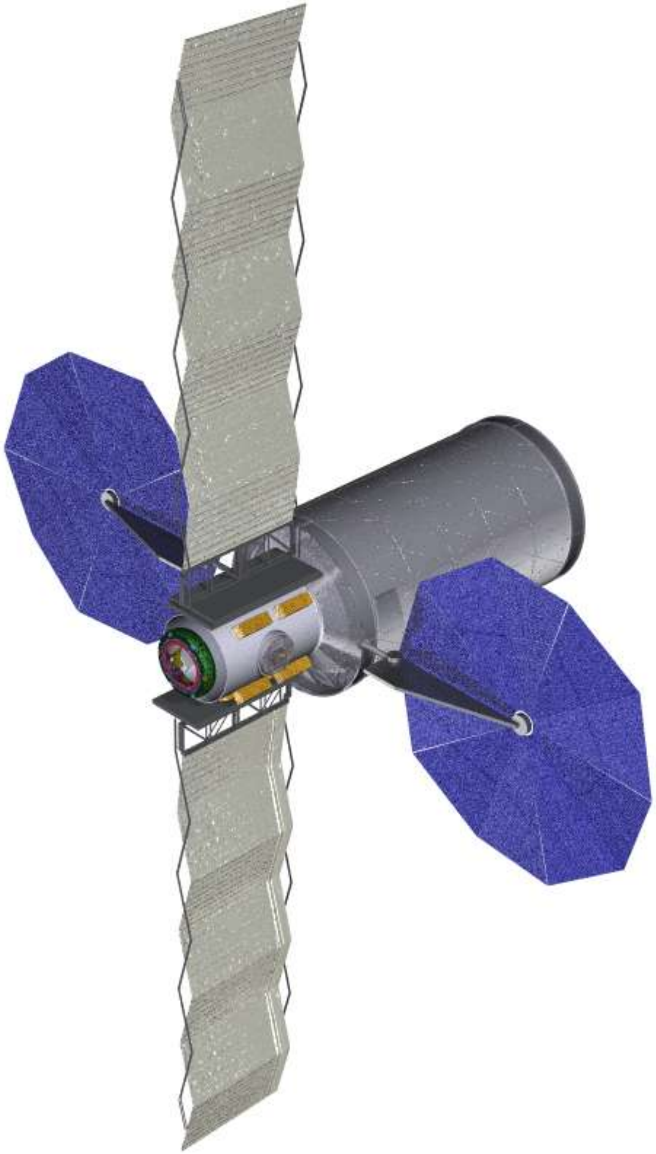


Avionics Mass Comparison

Sub-System	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
AR&D System	11	3	11	11	3	11
Command and Data Handling	220	18	260	220	18	260
Displays & Controls	134	18	158	134	18	158
Communications System	159	18	189	187	18	221
Intercom & Video	56	22	69	56	22	69
Instrumentation	45	30	59	54	30	71
IHM System	50	10	55	70	10	55
Avionics Cabling	290	30	376	348	30	453
Total	**965**		**1176**	**1081**		**1321**

Thermal

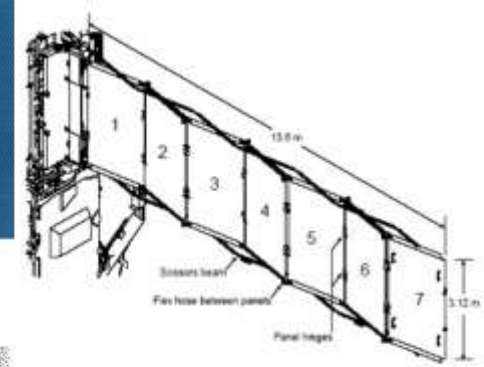
Linda Hornsby
December 15, 2011



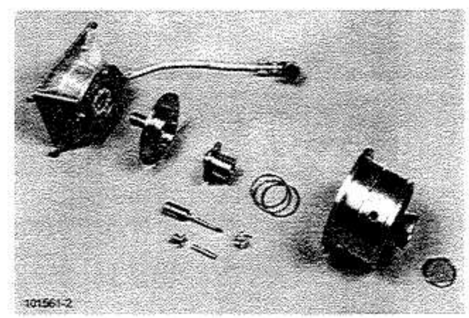
Thermal Control

- 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

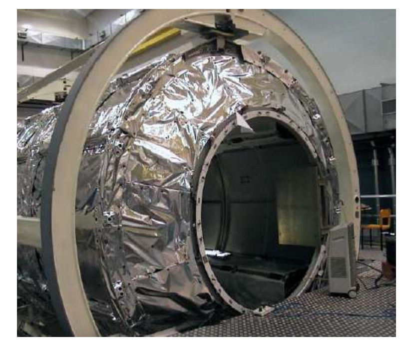
Manual Flow Control Valve



EEATCS/PVR Radiator ORU



PPA Centrifugal Pump Rotating Assembly



External Passive Thermal Control

Regenerative Heat Exchanger

Two Way Mixing Valve

Thermal Mass Comparison by Mission

Subsystem	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Internal TCS Rack LT/MT	226	20	271	226	20	271
Internal Rack Support	270	20	324	300	20	360
Internal TCS Misc.	30	30	39	30	30	39
External Active TCS	376	15	432	376	15	432
External Passive TCS	155	20	187	199	20	239
External Heat Rejection Sys.	1482	3	1526	1482	3	1526
Total	**2539**		**2780**	**2613**		**2868**

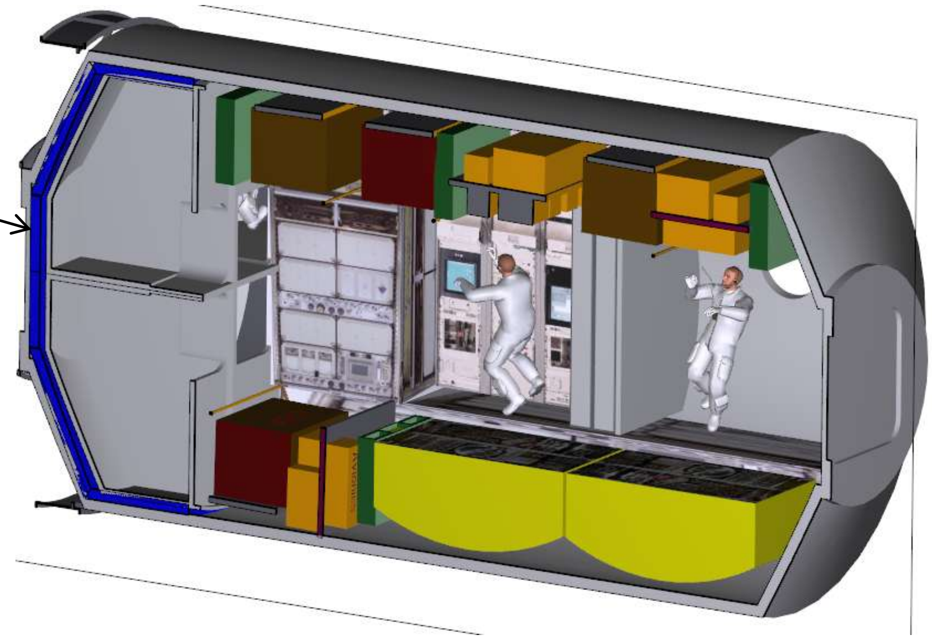
Environments Protection

Tiffany E. Russell

December 15, 2011

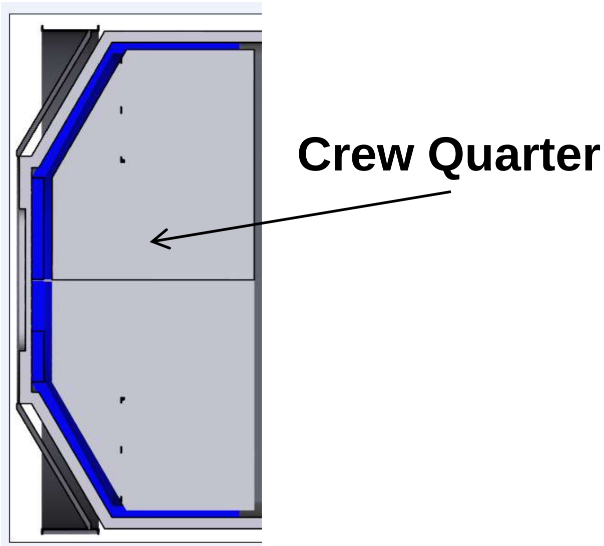
Crew Quarters Protection

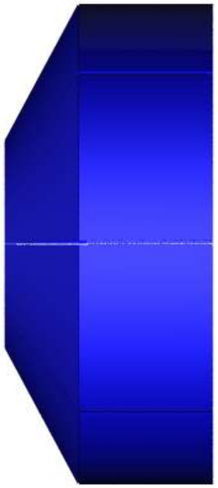
- Environments Protection System consists of two main components
  - External Micrometeoroid Debris Protection Shield (MDPS), MPLM-derived
  - Interior Radiation Water Wall
- Nominal 60 and 500-Day water wall:
  - 0.55 cm thick polyethylene tank
  - 9.9 cm thick water wall
  - Total protection = 11 g/cm^2
  - 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)

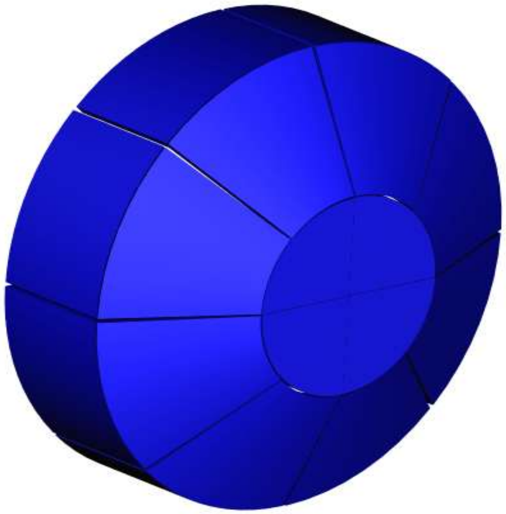


Tank Configuration

- Water Wall surrounding crew quarters comprised of several tanks







Sub-System	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Micro-Meteoroid & Debris Protection System (MPDS)	1121	10	1233	1713	10	1884
Radiation Protection Tanks	332	5	349	332	5	349
Radiation Water	2518	3	2594	2518	3	2594
Total	**3971**		**4176**	**4563**		**4827**

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

*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 m^3
Habitable Volume	~90 m^3
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
HabitatLength	18 m
Habitat Diameter	4.5 m
Mass Growth Allocation*	13.62%
Project Manager's Reserve	10%

Category	Mass (kg)
Structures	14,116
Propulsion	-
Power	924
Avionics	1,321
Thermal	2,868
Environment Protection	4,826
ECLSS	6,890
Crew Systems	807
EVA	272
Dry Mass	32,022
Stowed Provisions	2,766
Consumable Fluids	6,187
Non-Propellant Fluids	457
RCS Propellant	-
DSH Wet Mass	41,430
Project Mgrs Reserve (PMR) (10%)	4,143
Total Wet Mass w/PMR	45,573

*Note: MGA for the 500 day case totaled an average of 13.62% 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 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.

Mass Comparison

MEL - DSH Comparison		60 Day	60 Day	500 Day	500 Day
		EXAMINE Tool		EXAMINE Tool	
Mass Breakdown Structure		Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)
1.0	Structures	3,820.00	9,001.51	5,629.00	14,115.88
2.0	Propulson	0.00	0.00	0.00	0.00
3.0	Power	937.00	698.06	1,141.00	923.76
4.0	Avionics	453.00	1,177.29	453.00	1,320.52
5.0	Thermal	539.00	2,779.55	699.00	2,867.63
6.0	Environmental Protection	2,213.00	4,175.24	2,323.00	4,825.50
7.0	ECLSS	2,599.00	4,379.10	8,391.00	6,889.60
8.0	Crew Systems	790.00	690.32	2,583.00	807.12
9.0	EVA	635.00	271.75	635.00	271.75
Dry Mass			23,172.81		32,021.75
10.0	Stowed Provisions	3,271.00	1,240.12	5,512.00	2,765.55
11.0	Consumables	212.00	1,266.80	1,084.00	6,186.50
12.0	Non-Prop Fluids	0.00	456.50	0.00	456.50
13.0	RCS	0.00	0.00	0.00	0.00
DSH Wet Mass			26,136.23		41,430.30
Project Manager's Reserve (PMR)			2,613.62		4,143.03
Total Wet Mass w/PMR		18,448.00	28,749.85	34,391.00	45,573.33

- **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 2nd Stage Hydrogen Tank (Skylab II)
  - Habitat built inside ELV shroud
- **Radiation Protection Concepts:**
  - ISS sized modules enclosed by SLS 2nd 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

Ground Rules & Assumptions

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/m2 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

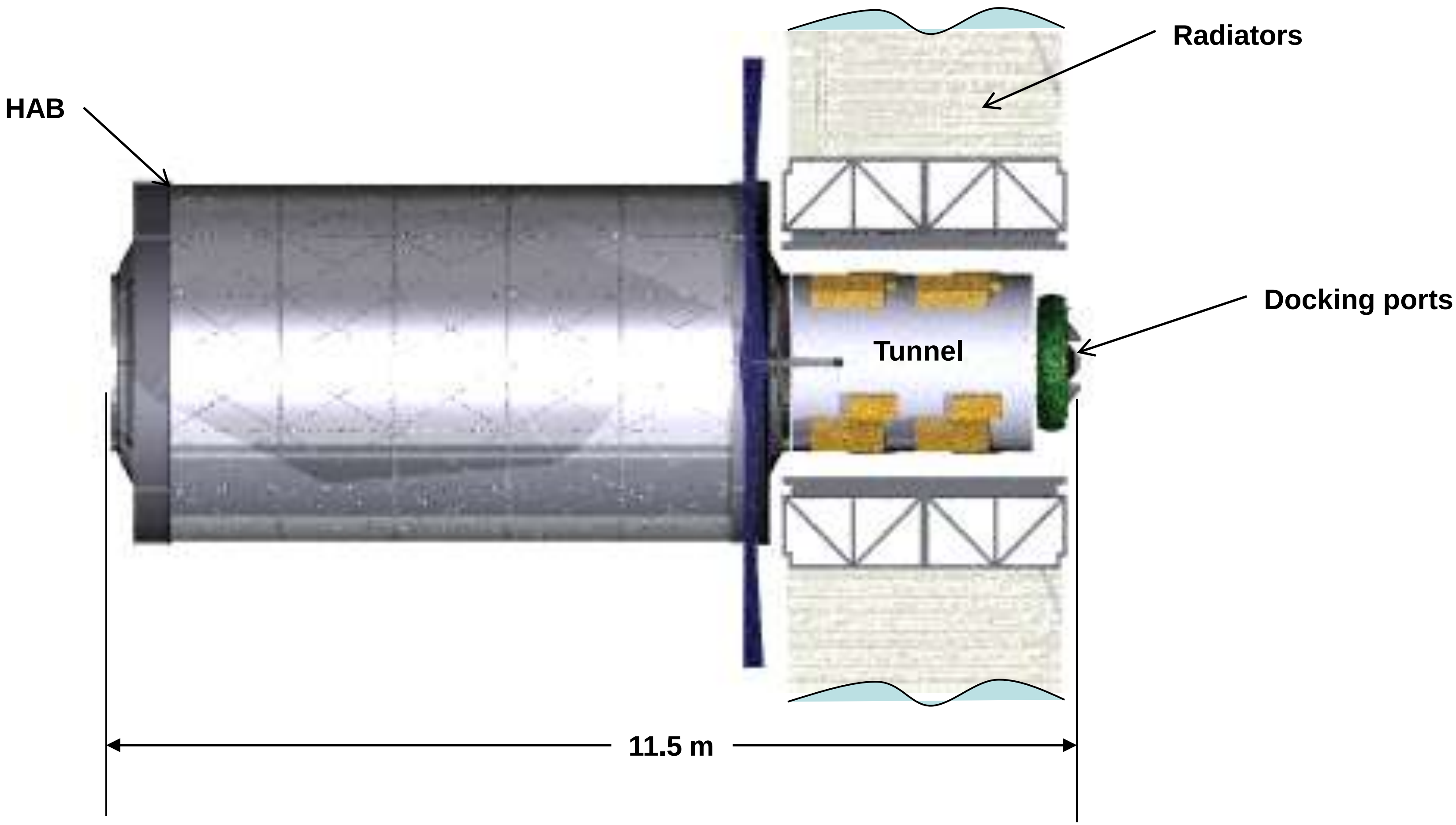
60-Day Launches

Xx kg ≤ Mass ≤ xx,000kg

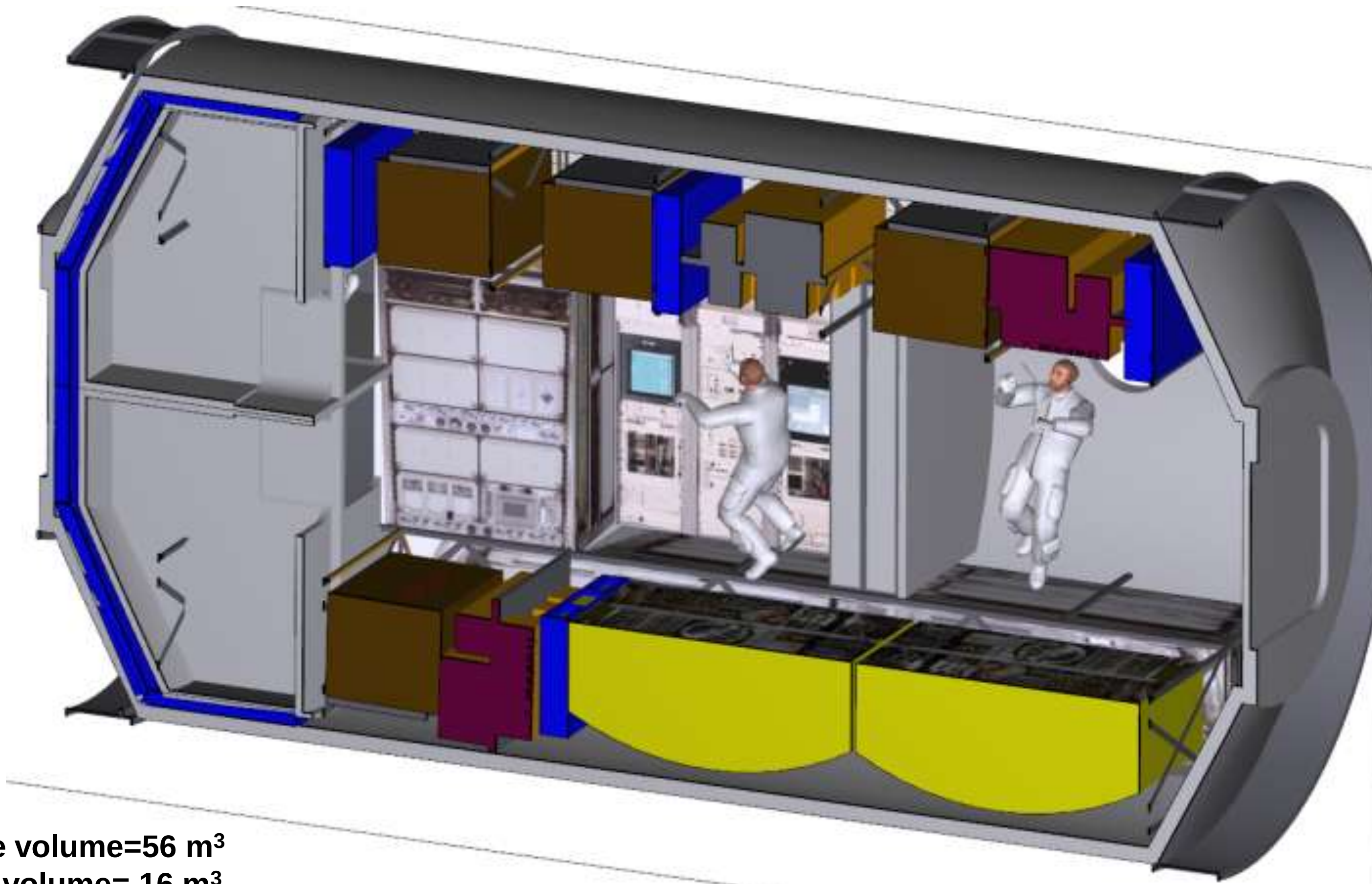
60-Day Launches

Xx kg ≤ Mass ≤ xx,000kg

60-Day

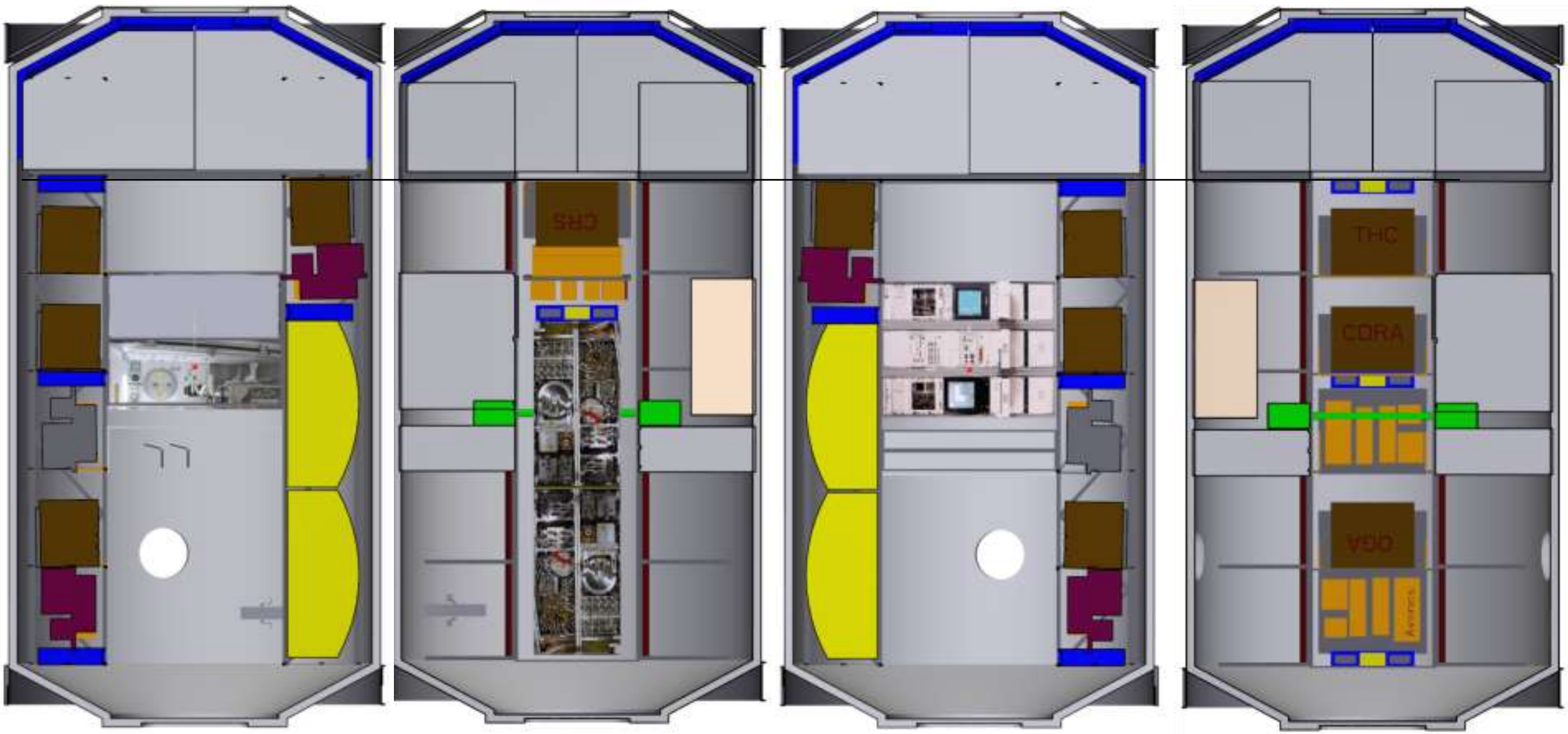


60-Day

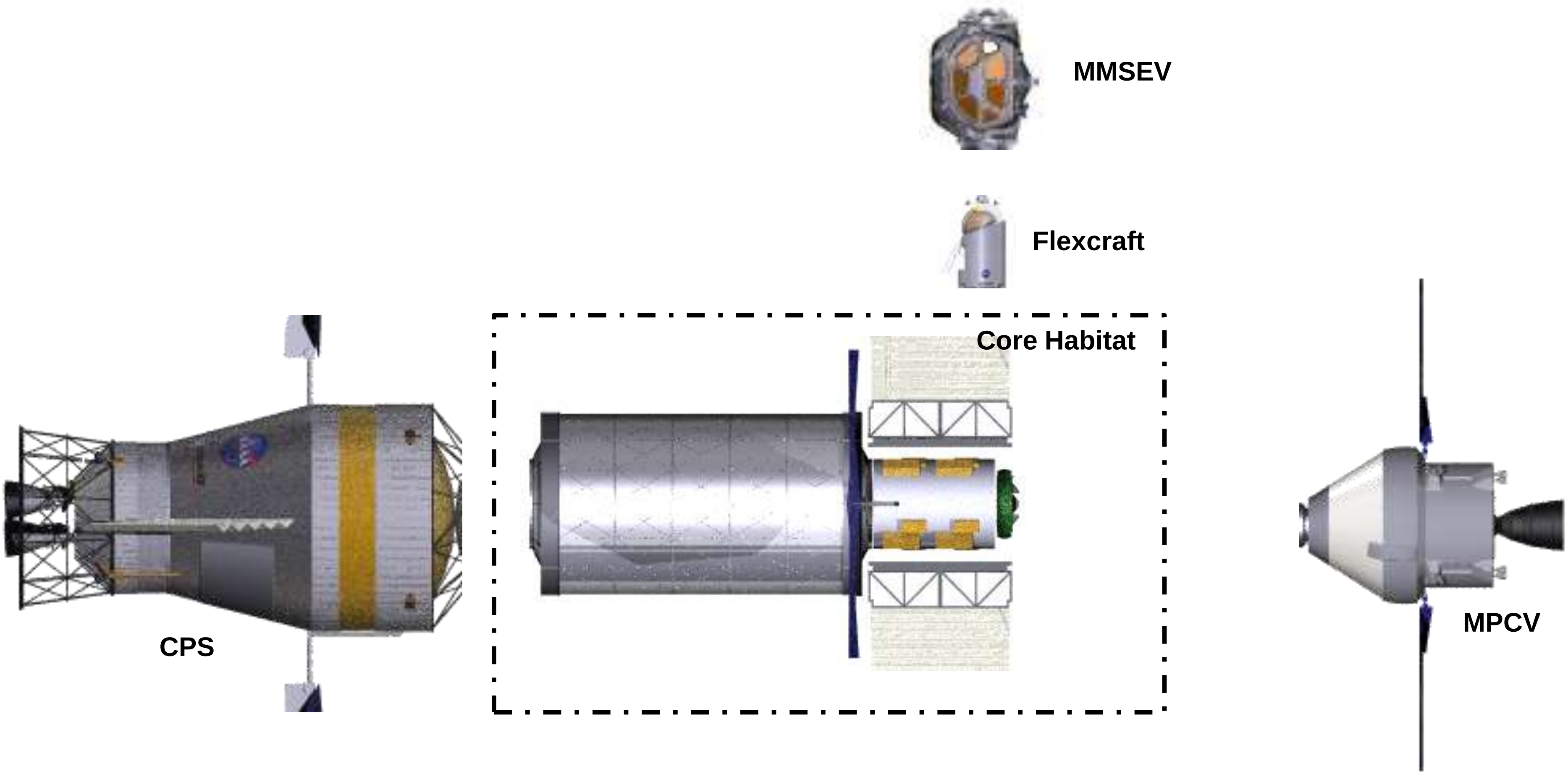


Habitable volume=56 m^3
Stowage volume= 16 m^3

60-Day

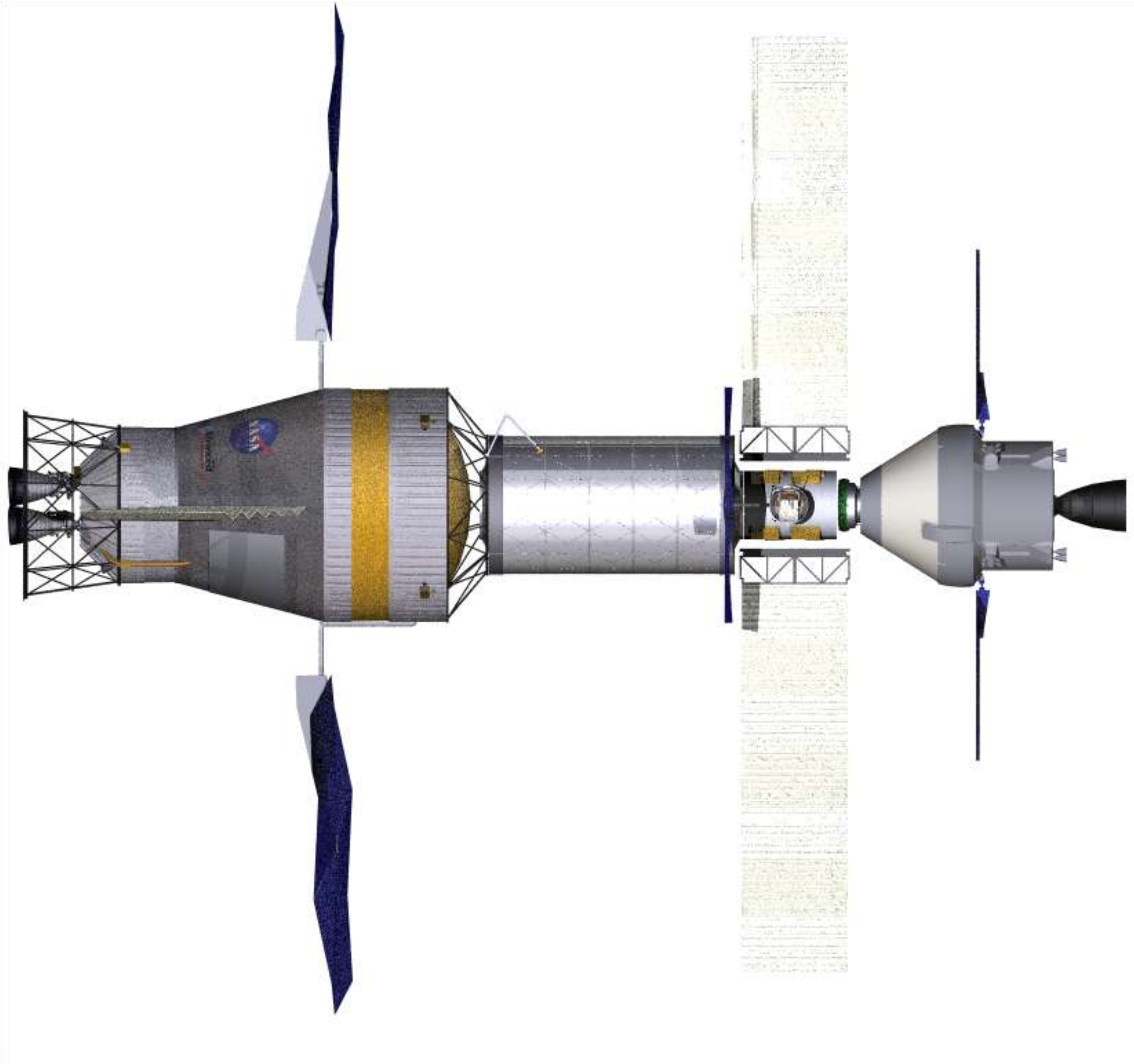


60-Day

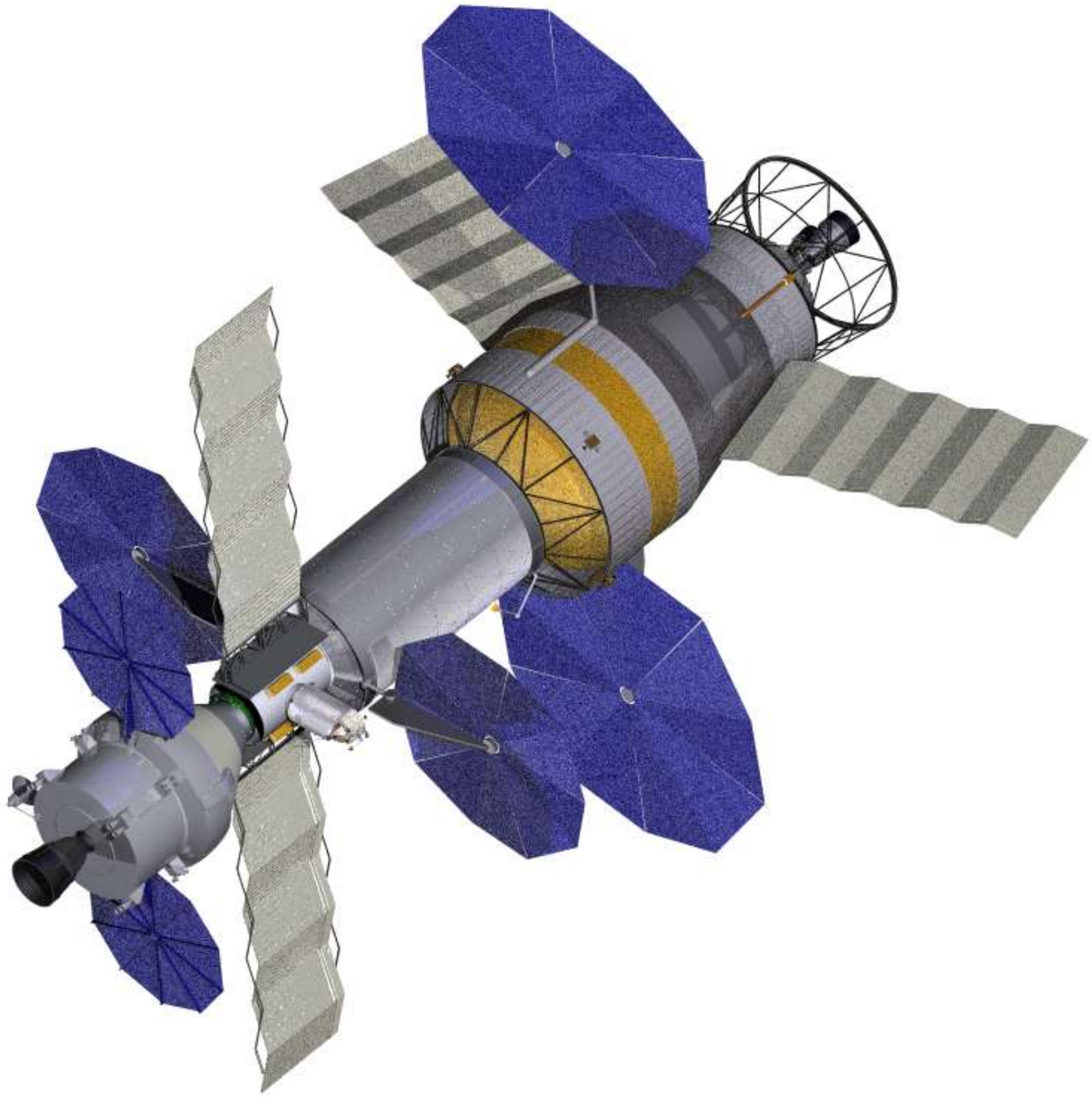


MPLM

60-Day



60-Day



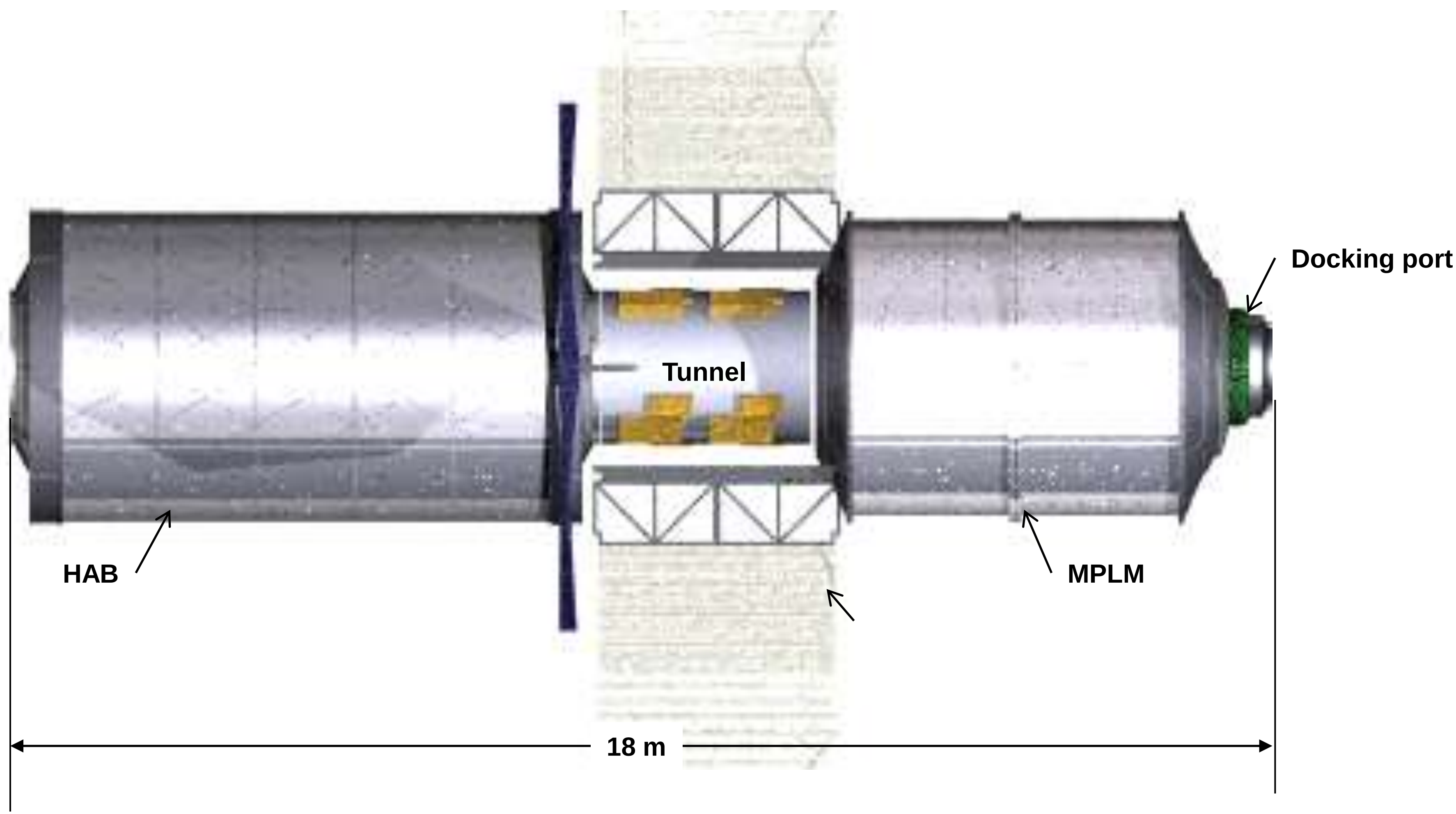
500-Day Launches

x,000kg ≤ Mass ≤ x,000kg

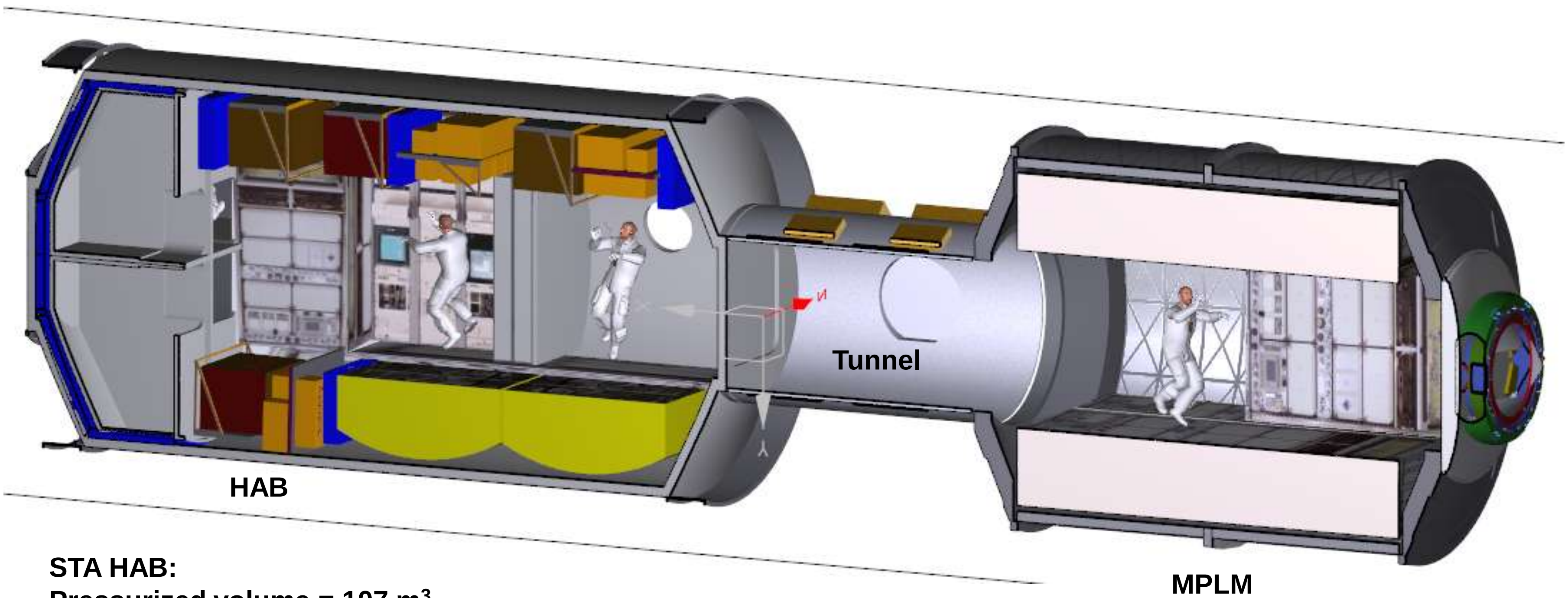
HAB

MPLM, Tunnel
Radiators, Solar Arrays

500-Day



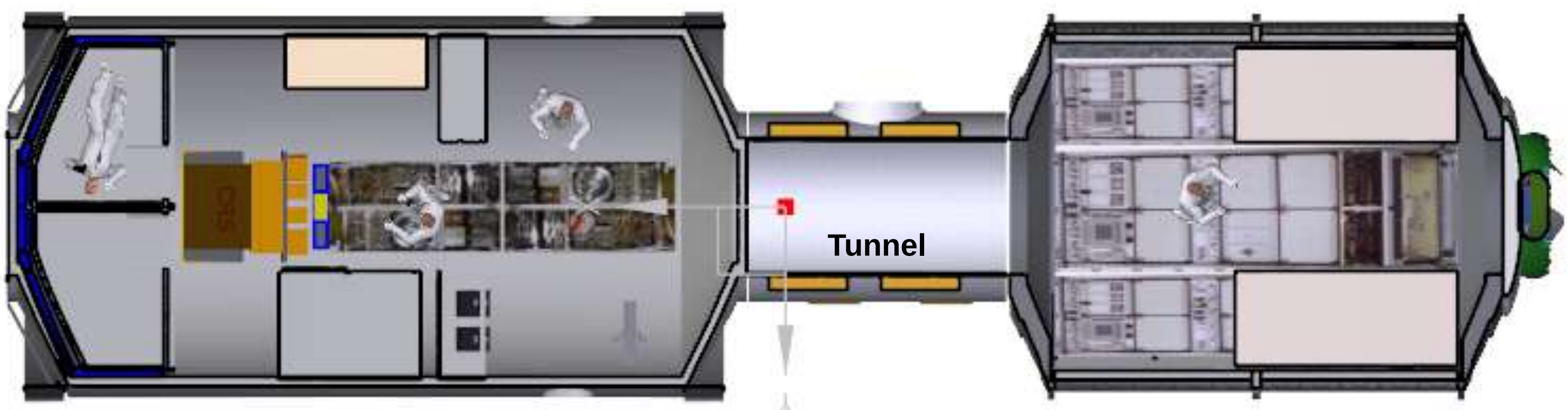
500-Day



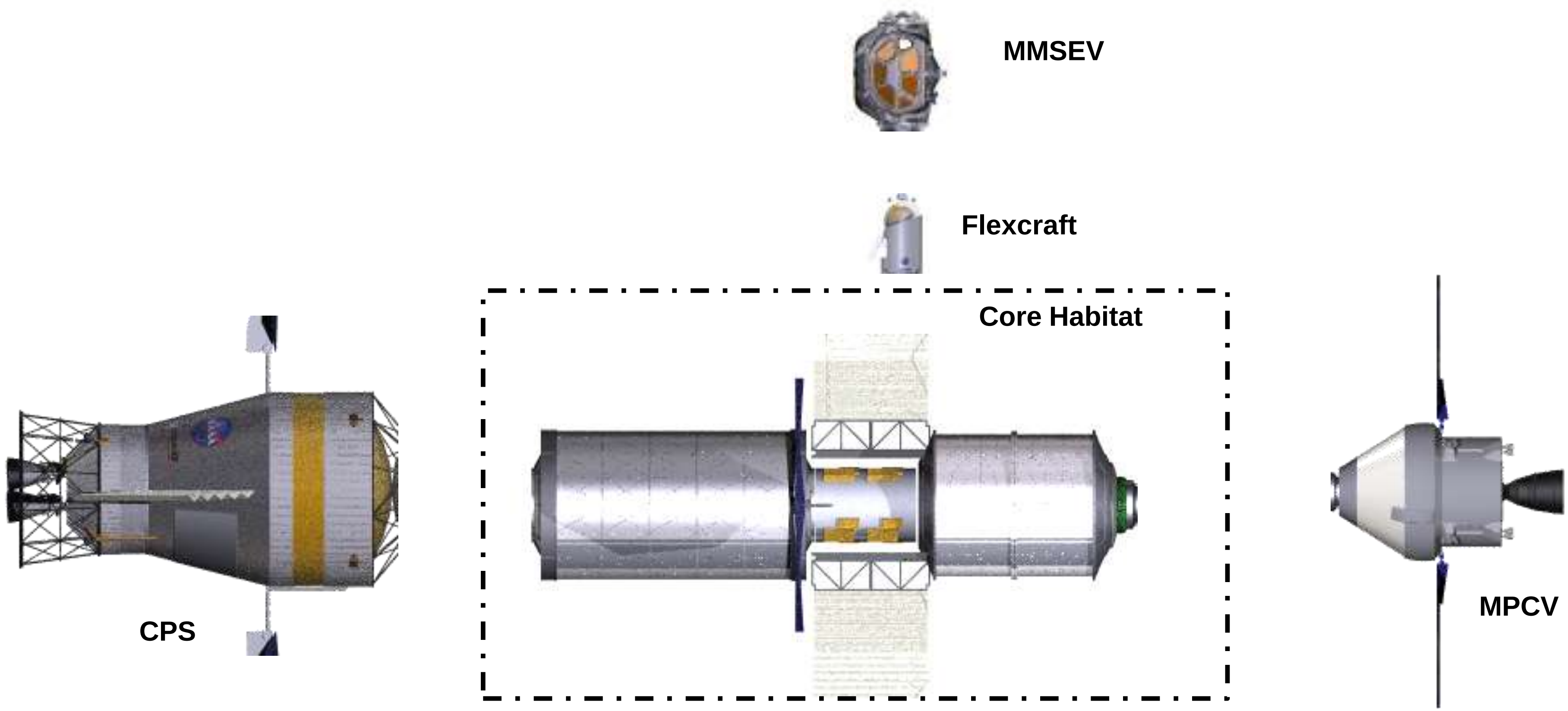
STA HAB:
Pressurized volume = 107 m³
Habitable volume = 56 m³
Stowage volume = 16 m³

MPLM:
Pressurized volume = 76 m³
Habitable volume = 25 m³
Stowage volume = 33 m³

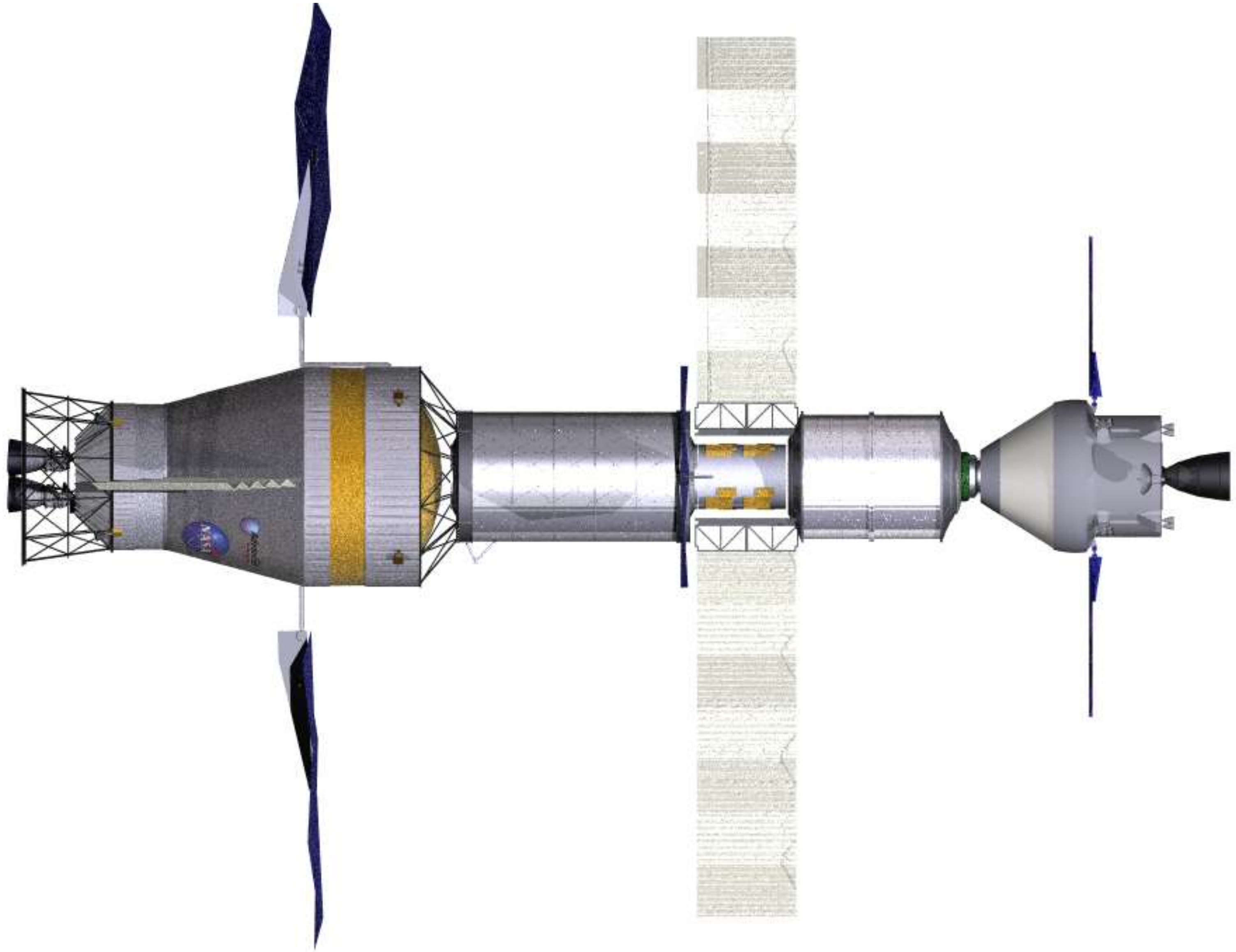
500-Day



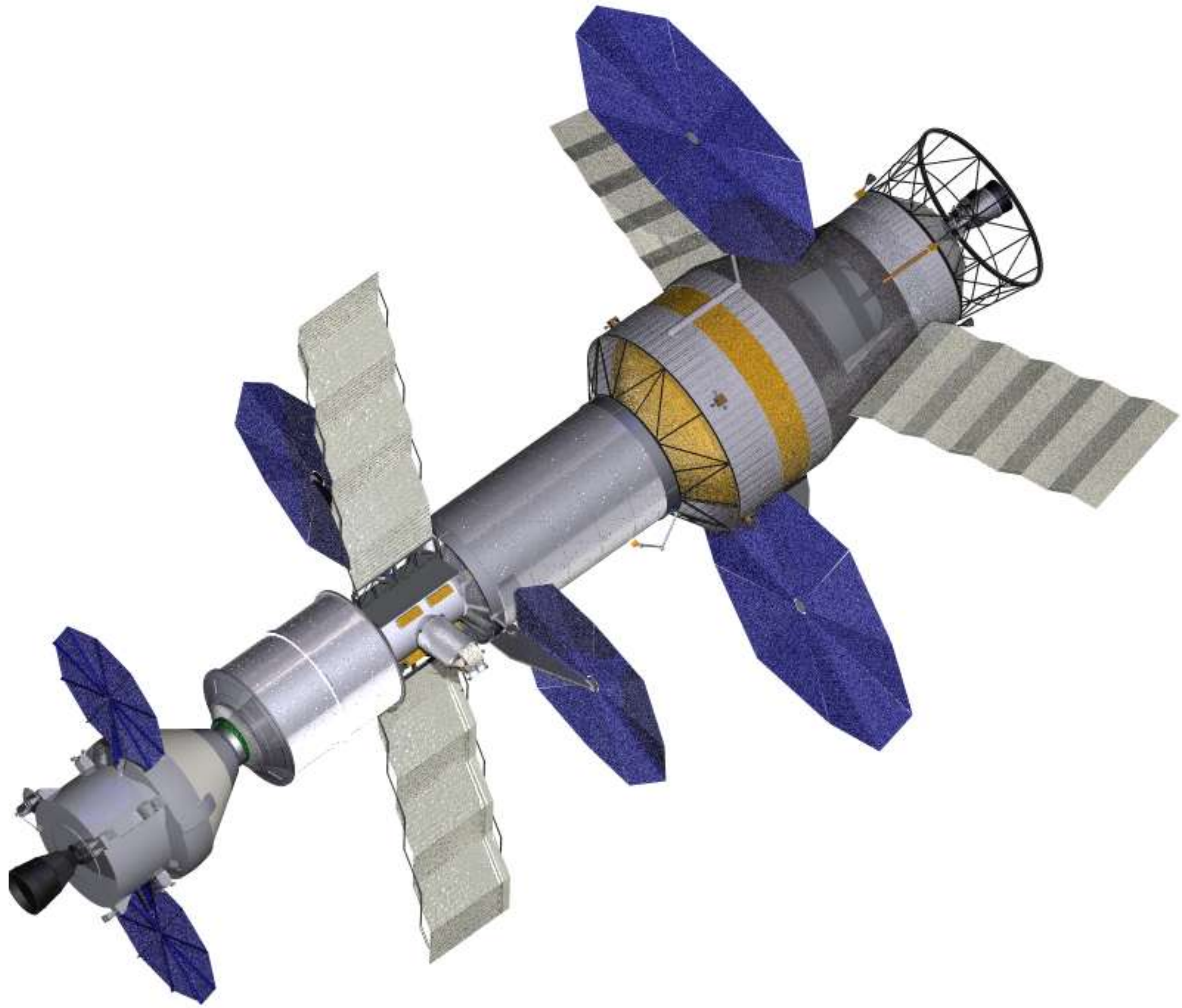
500-Day



500-Day



500-Day



Mass

Dauphne Maples

December 15, 2011

Mass Summary: 60 Days

MEL - DSH 60 Day Case		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
Mass Breakdown Structure					
1.0	Structures	7831.30	14.94%	1170.21	9001.51
2.0	Propulsion	0.00	0.00%	0.00	0.00
3.0	Power	584.36	19.46%	113.70	698.06
4.0	Avionics	964.72	22.03%	212.57	1177.29
5.0	Thermal	2539.40	9.46%	240.15	2779.55
6.0	Environmental Protection	3971.00	5.14%	204.24	4175.24
7.0	ECLSS	3856.00	13.57%	523.10	4379.10
8.0	Crew Systems	664.00	3.96%	26.32	690.32
9.0	EVA	271.00	0.28%	0.75	271.75
Dry Mass		20681.78	12.04%	2491.04	23172.81
10.0	Stowed Provisions	1,204.00	3.00%	36.12	1240.12
11.0	Consumables	1,207.00	4.95%	59.80	1266.80
12.0	Non-Prop Fluids	415.00	10.00%	41.50	456.50
13.0	RCS	0.00	0.00%	0.00	0.00
DSH Wet Mass		22,303.78			26,136.23
Project Manager's Reserve (PMR)					2,613.62
Total Wet Mass w/PMR					28,749.85

Mass Summary: 500 Days

MEL - DSH 500 Day Case		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
Mass Breakdown Structure					
1.0	Structures	12093.27	16.73%	2022.60	14115.88
2.0	Propulsion	0.00	0.00%	0.00	0.00
3.0	Power	770.36	19.91%	153.40	923.76
4.0	Avionics	1081.20	22.13%	239.32	1320.52
5.0	Thermal	2612.80	9.75%	254.83	2867.63
6.0	Environmental Protection	4563.00	5.75%	262.50	4825.50
7.0	ECLSS	6016.00	14.52%	873.60	6889.60
8.0	Crew Systems	776.00	4.01%	31.12	807.12
9.0	EVA	271.00	0.28%	0.75	271.75
Dry Mass		28183.63	13.62%	3838.12	32021.75
10.0	Stowed Provisions	2,685.00	3.00%	80.55	2765.55
11.0	Consumables	5,843.00	5.88%	343.50	6186.50
12.0	Non-Prop Fluids	415.00	10.00%	41.50	456.50
13.0	RCS	0.00	0.00%	0.00	0.00
DSH Wet Mass		37,126.63			41,430.30
Project Manager's Reserve (PMR)					4,143.03
Total Wet Mass w/PMR					45,573.33

Predicted Mass Comparison: 60 Vs. 500 Days

MEL - DSH Comparison		60 Day	60 Day	500 Day	500 Day
		EXAMINE Tool		EXAMINE Tool	
Mass Breakdown Structure		Mass (kg)	Mass (kg)	Mass (kg)	Mass (kg)
1.0	Structures	3,820.00	9,001.51	5,629.00	14,115.88
2.0	Propulson	0.00	0.00	0.00	0.00
3.0	Power	937.00	698.06	1,141.00	923.76
4.0	Avionics	453.00	1,177.29	453.00	1,320.52
5.0	Thermal	539.00	2,779.55	699.00	2,867.63
6.0	Environmental Protection	2,213.00	4,175.24	2,323.00	4,825.50
7.0	ECLSS	2,599.00	4,379.10	8,391.00	6,889.60
8.0	Crew Systems	790.00	690.32	2,583.00	807.12
9.0	EVA	635.00	271.75	635.00	271.75
Dry Mass			23,172.81		32,021.75
10.0	Stowed Provisions	3,271.00	1,240.12	5,512.00	2,765.55
11.0	Consumables	212.00	1,266.80	1,084.00	6,186.50
12.0	Non-Prop Fluids	0.00	456.50	0.00	456.50
13.0	RCS	0.00	0.00	0.00	0.00
DSH Wet Mass			26,136.23		41,430.30
Project Manager's Reserve (PMR)			2,613.62		4,143.03
Total Wet Mass w/PMR		18,448.00	28,749.85	34,391.00	45,573.33

Crew Systems

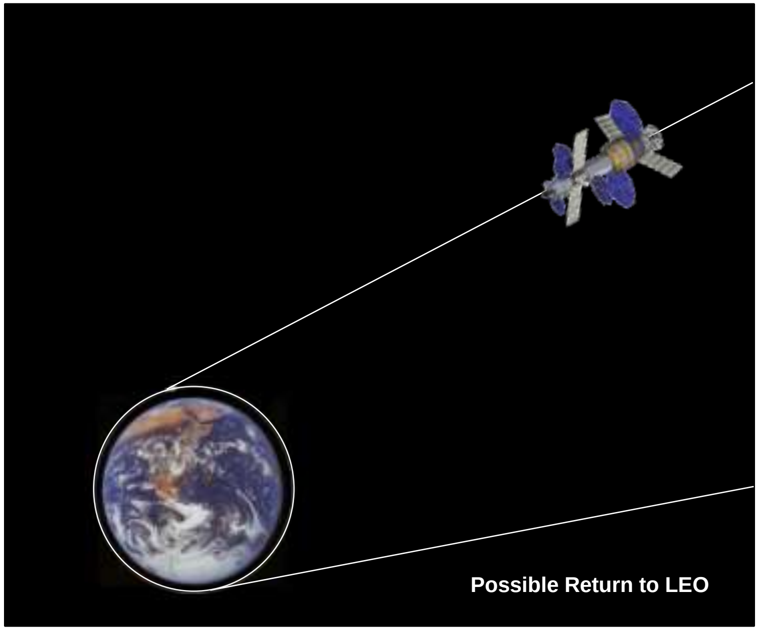
Brand Griffin

December 15, 2011

Deep Space Missions

ISS
Close to Earth

DSH
Distant Missions



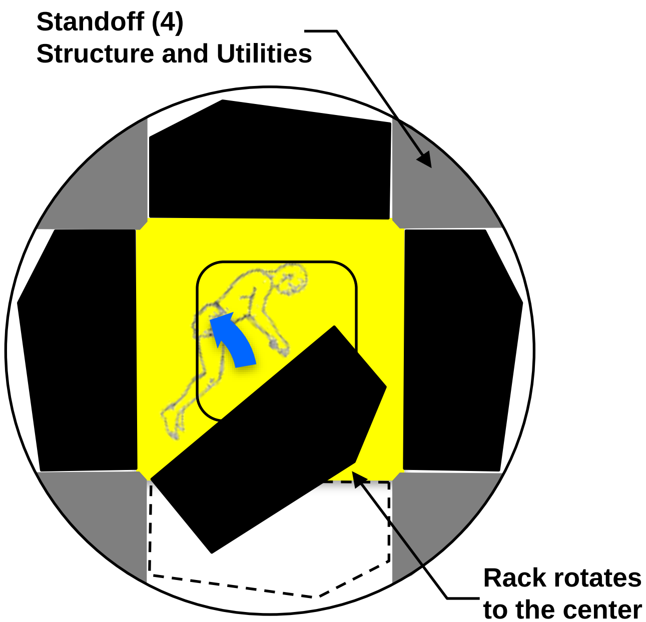
Logistics (rack) Delivery Necessary
- Outfitting (launched with 5 out of 24 racks)
- Resupply consumables
- Parts for servicing and repair

No Habitat on ISS
Rapid (emergency) return

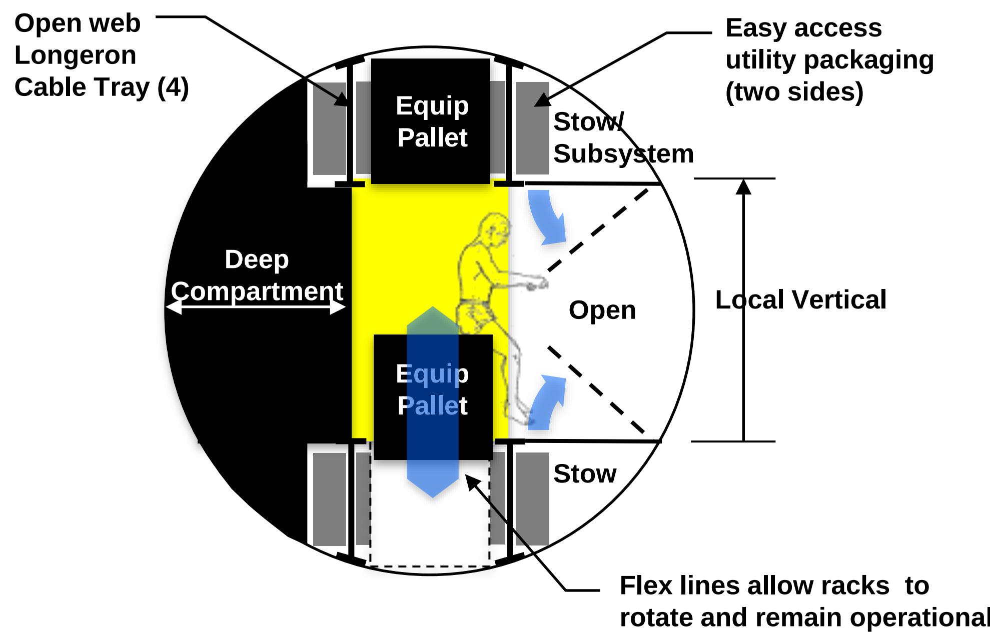
No Logistics Flights
- Departs LEO with all outfitting
- Carries provisions for continuous operations
- Carries provisions for servicing and repair

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

ISS Rack Based Layout



Shell/ORU 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

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

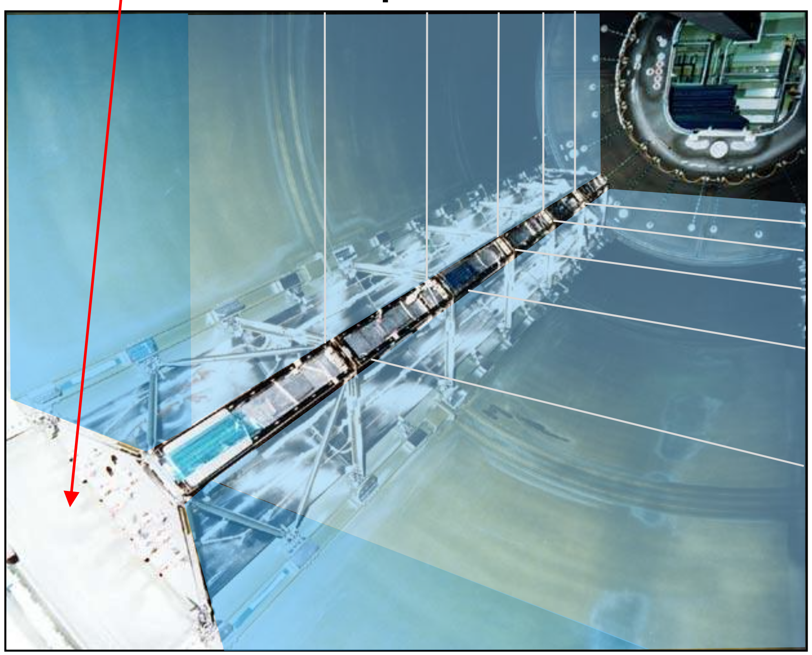
Waste Hygiene Compartment

US Lab (Destiny)

Access for Inspection and Maintenance

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

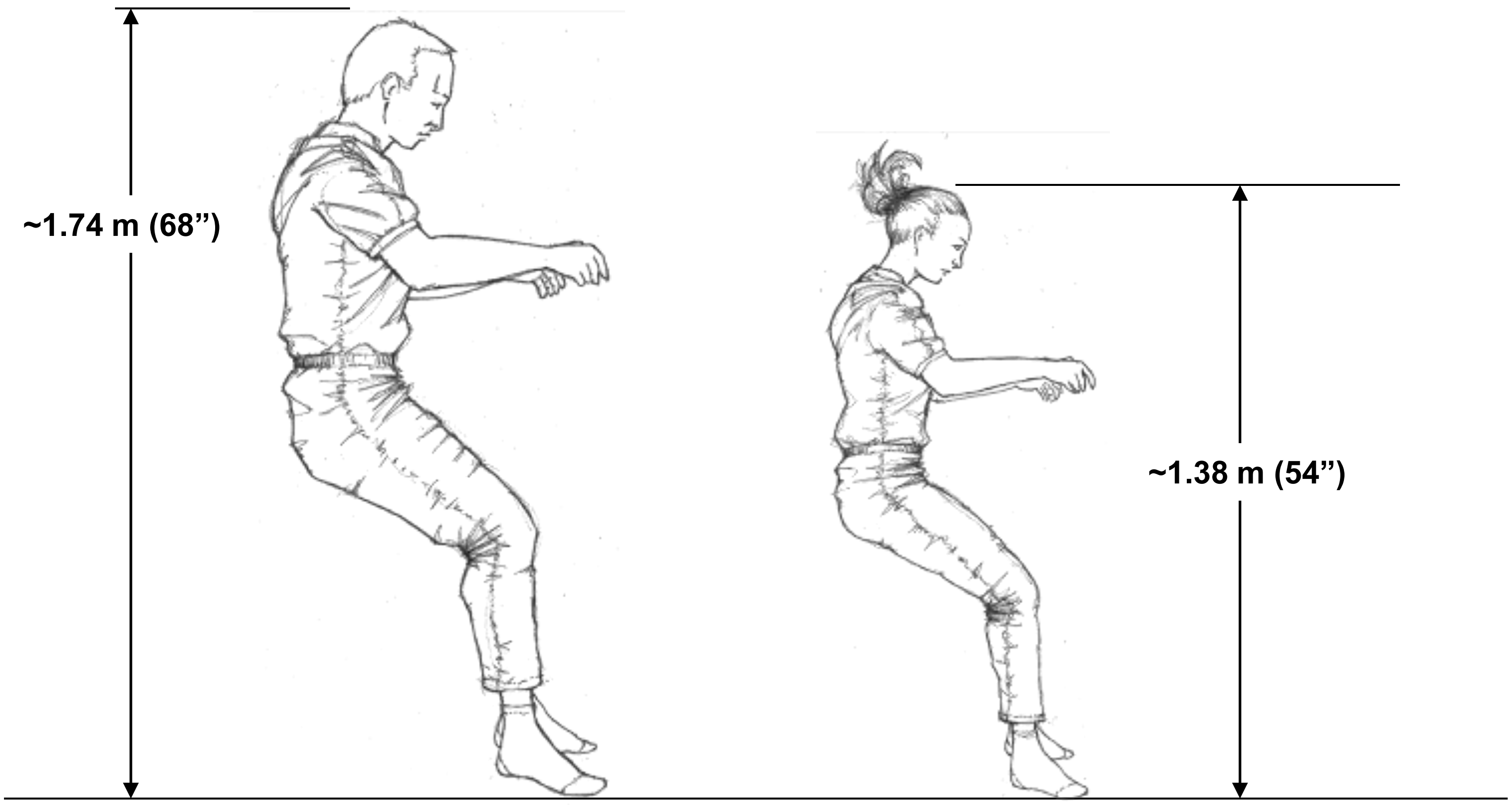
Habitation and Autonomy

500-Days without resupply

Activity	DSH Accommodation
Privacy, personal space	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
Eating, group meetings	Open area to accommodate all 4 crew, restraints for food and crew, one meal together per day
Food Preparation	Open area, microwave, refrigerator
Sleeping	Crew quarters, weightless restraints, change of bedding, radiation protection (storm shelter)
Exercise	Open area, adjustable air flow, easily cleaned, scheduling should not conflict with common meal
Waste Mgt	Larger enclosure than ISS, adjustable airflow, easily cleaned
Personal Hygiene	Enclosed area for whole body cleansing, hand wash, brushing teeth, personal grooming
Recreation, off-duty time	Crew choice, window, exercise, crew quarters or galley wardroom
Mission Operations	Science and flight operation workstations
Autonomy	**DSH Accommodations**
Servicing	Easy access to ORUs and utilities. Service while operational.
Consumables	Bring all consumables for entire mission (plus margin)
Spares	Hot spares, stored spares, design for repair or work around

Weightless Posture

Zero g Projected Height



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																						
Crew	1	2	3	4	5	6	7	8	9	10	11	13	14	15	16	17	18	19	20	21	22	23	24
A	Sleep	Sleep	Sleep	Sleep	Sleep	Off Duty	Exercise	Exercise	Work	Work	Work	Work	Work	Work	Work	Work	Off Duty	Off Duty	Dinner	Off Duty	Sleep	Sleep	Sleep
B	Sleep	Sleep	Sleep	Sleep	Sleep	Off Duty	Work	Work	Exercise	Exercise	Work	Work	Work	Work	Work	Work	Off Duty	Off Duty	Dinner	Off Duty	Sleep	Sleep	Sleep
C	Sleep	Sleep	Sleep	Sleep	Sleep	Off Duty	Off Duty	Work	Work	Work	Exercise	Exercise	Work	Work	Work	Work	Work	Off Duty	Dinner	Off Duty	Sleep	Sleep	Sleep
D	Sleep	Sleep	Sleep	Sleep	Sleep	Off Duty	Off Duty	Work	Work	Work	Work	Work	Exercise	Exercise	Work	Work	Work	Off Duty	Dinner	Off Duty	Sleep	Sleep	Sleep

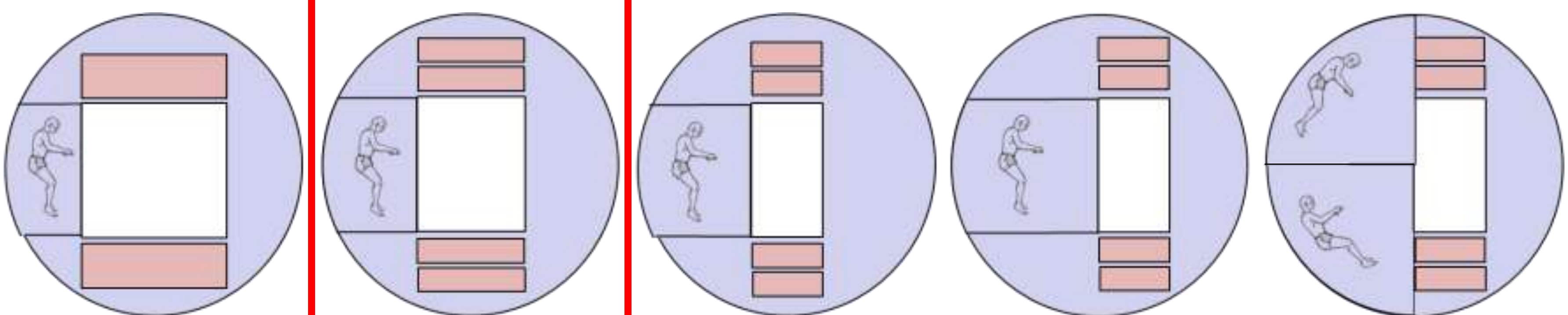
Legend: Sleep, Work, Exercise, Dinner, Off Duty

Alternate Cross Sections

Favored (Shell/ORU Symmetrical ~1.5 m Aisle)

Can be combined (Shell/ORU Asymmetrical 1.0 m Aisle Compartment; Shell/ORU Asymmetrical 1.0 m Aisle Quadrant)

ISS-Rack Symmetrical 2.2 m Aisle	**Shell/ORU** Symmetrical ~1.5 m Aisle	**Shell/ORU** Symmetrical 1.0 m Aisle	**Shell/ORU** Asymmetrical 1.0 m Aisle Compartment	**Shell/ORU** Asymmetrical 1.0 m Aisle Quadrant



ISS-Rack	Shell/ORU Symmetrical ~1.5 m Aisle	Shell/ORU Symmetrical 1.0 m Aisle	Shell/ORU Asymmetrical Compartment	Shell/ORU Asymmetrical Quadrant
"Small compartments Complex utilities Unforgiving	*Moderate compart. Two person translation Good packaging depth Endcone crew qrtrs Works with 50" hatch*	*Ample compart. Tight two per. Trans. Deep packaging Wall crew qrtrs May work with 50" hatch*	*Generous compart. Tight two per. Trans. Good packaging depth Wall crew qrtrs (inline) May work with 50" hatch*	*Generous compart. Tight two per. Trans. Good packaging depth Wall crew qrtrs (stakced) May work with 50" hatch*

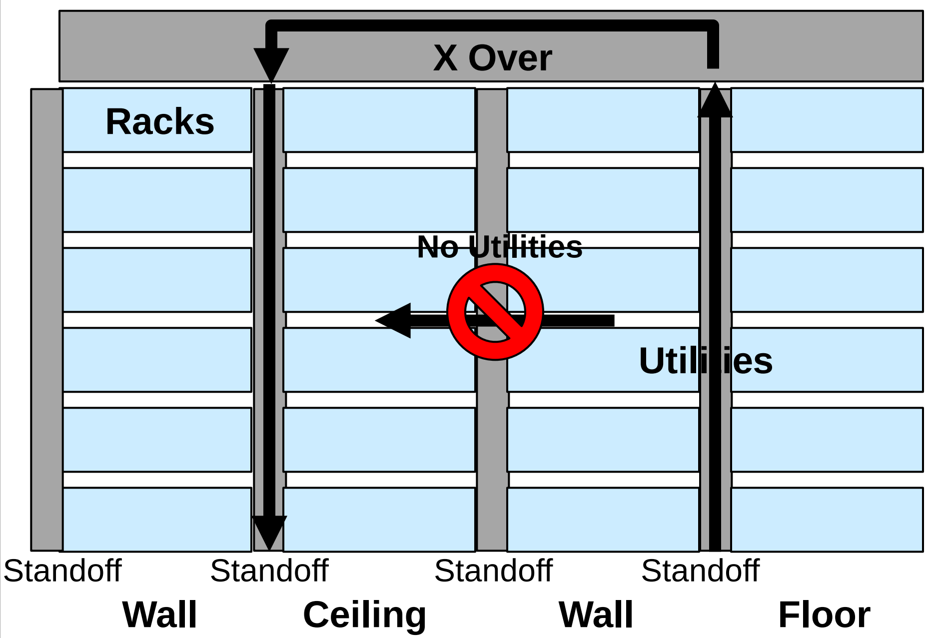
Utility Layout Comparison

ISS Rack Based

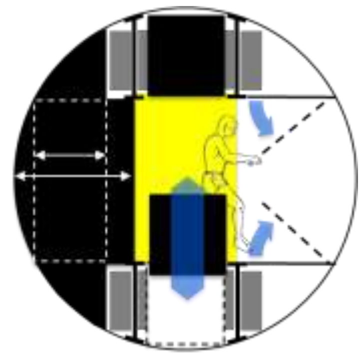
End X-Over
- Long utility runs
- Larger dia ducts
- Noise

Standoff Lighting
- Two sides
- Easily obscured

Standoff Air Supply
- Two sides
- Easily obscured



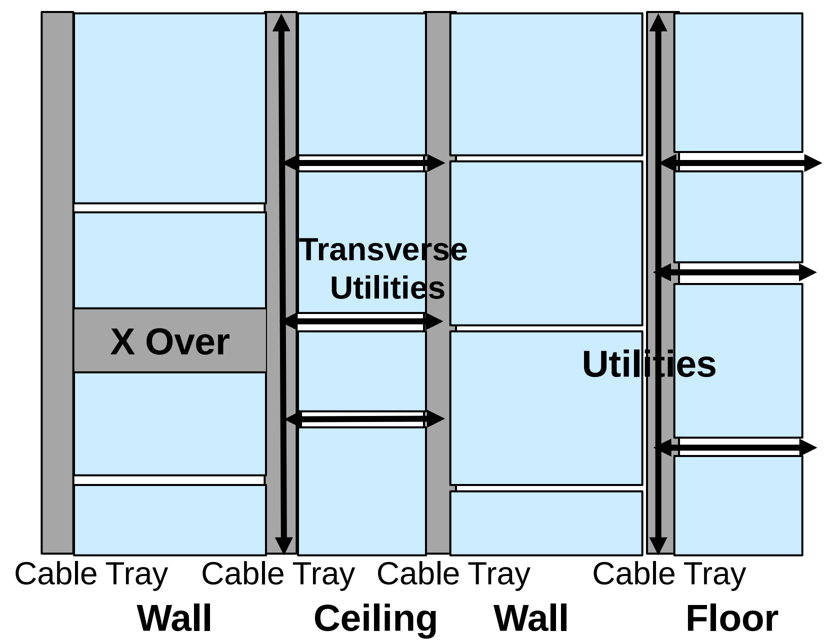
Shell/ORU Based



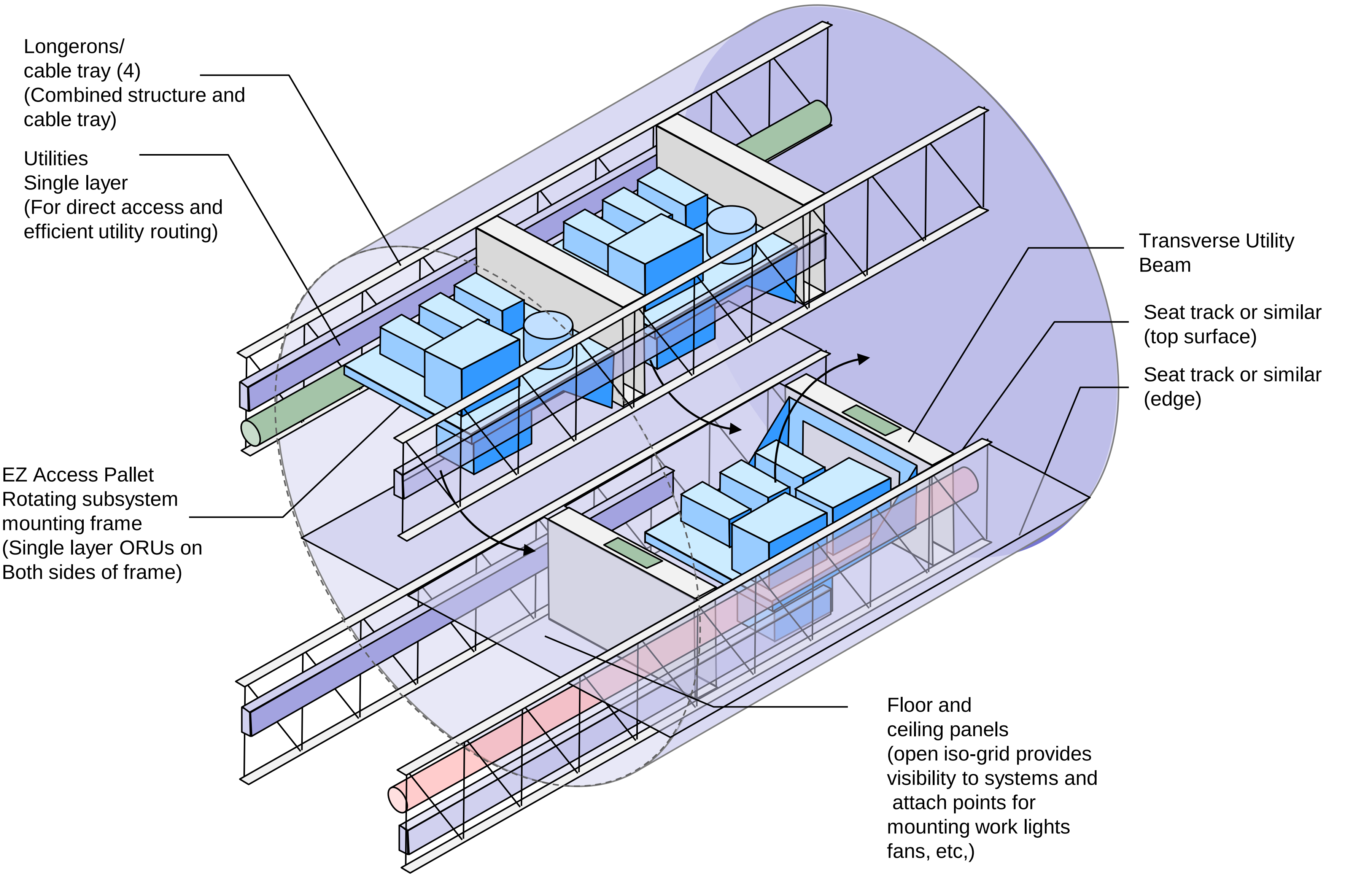
Middle X-Over
- Short utility runs
- Smaller dia ducts
- Less Noise
- More usable length

Central Lighting
- One light
- Good illumination

Central Air Supply
- One diffuser
- Good distribution



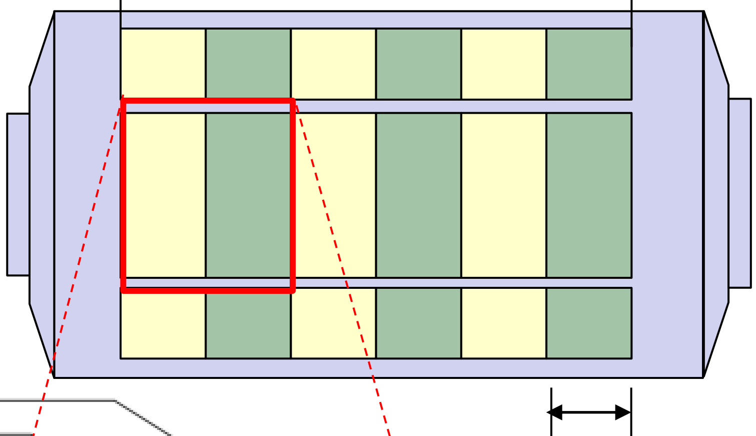
EZ Access Architecture

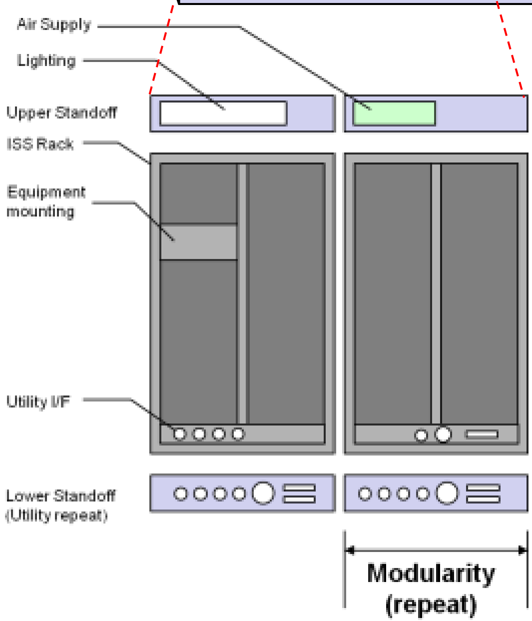


Axial Modularity

ISS

ISS US Lab-6 Rack Bays
(24 racks)

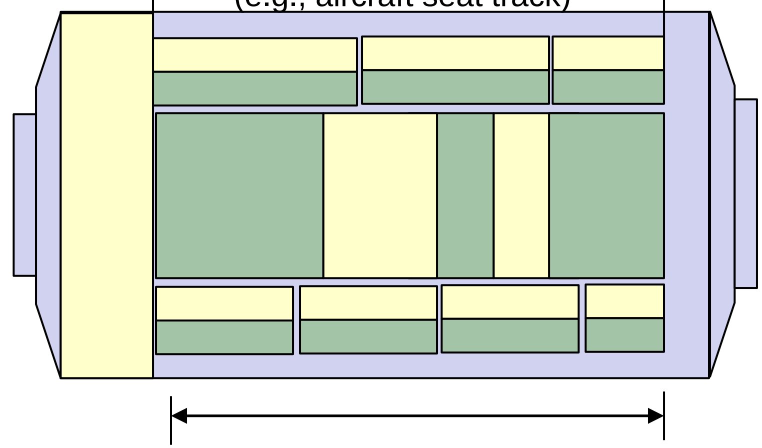




~ 1.05 m Repeat
Coupled with utilities
No fractional racks
(large dimension
impacts layout flexibility)

Shell/ORU

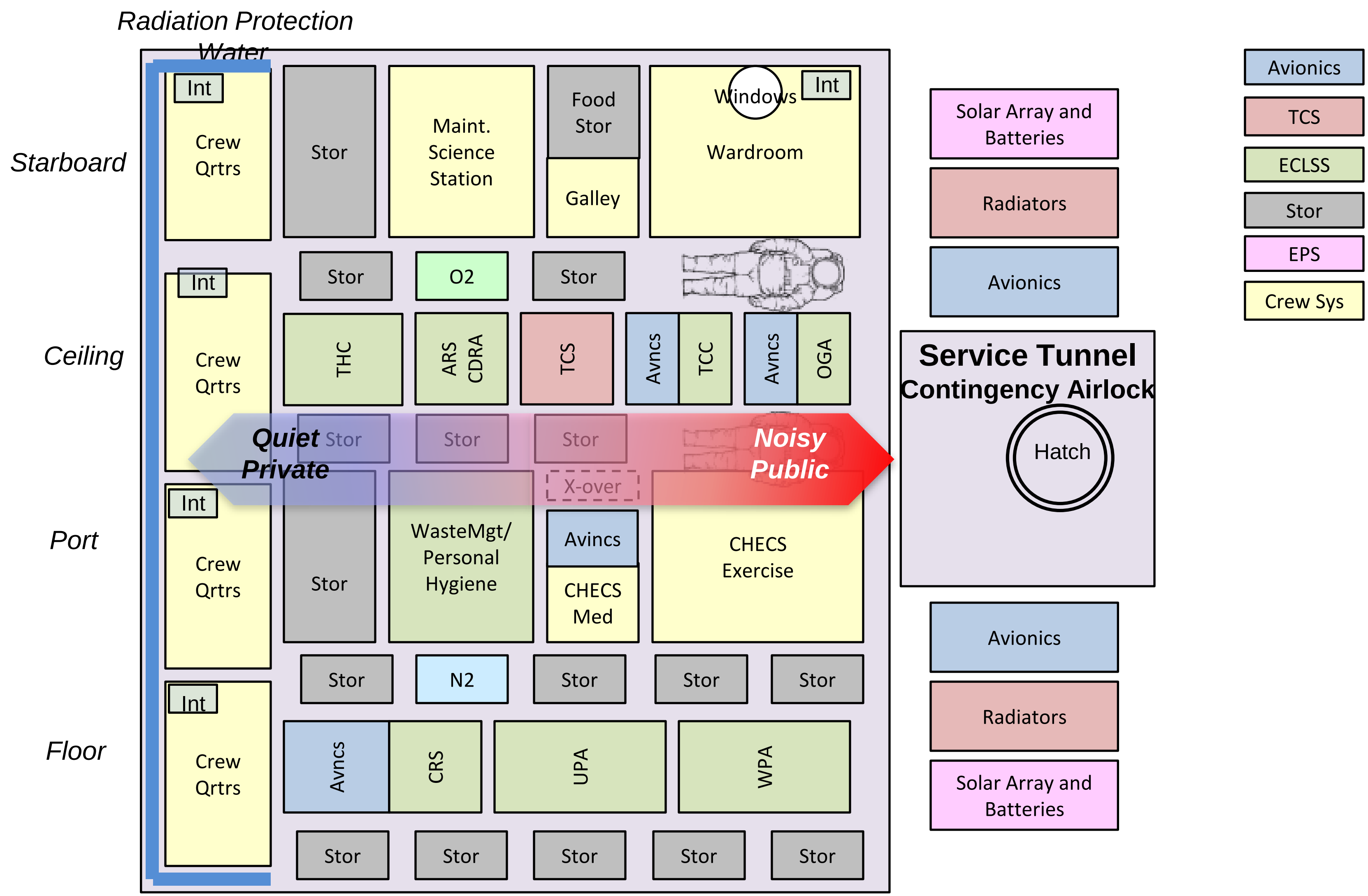
No Rack Bays
Linear structure
(e.g., aircraft seat track)



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

Seat Track and Attachments

Rack Topology
Aisle ~1.5 m



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

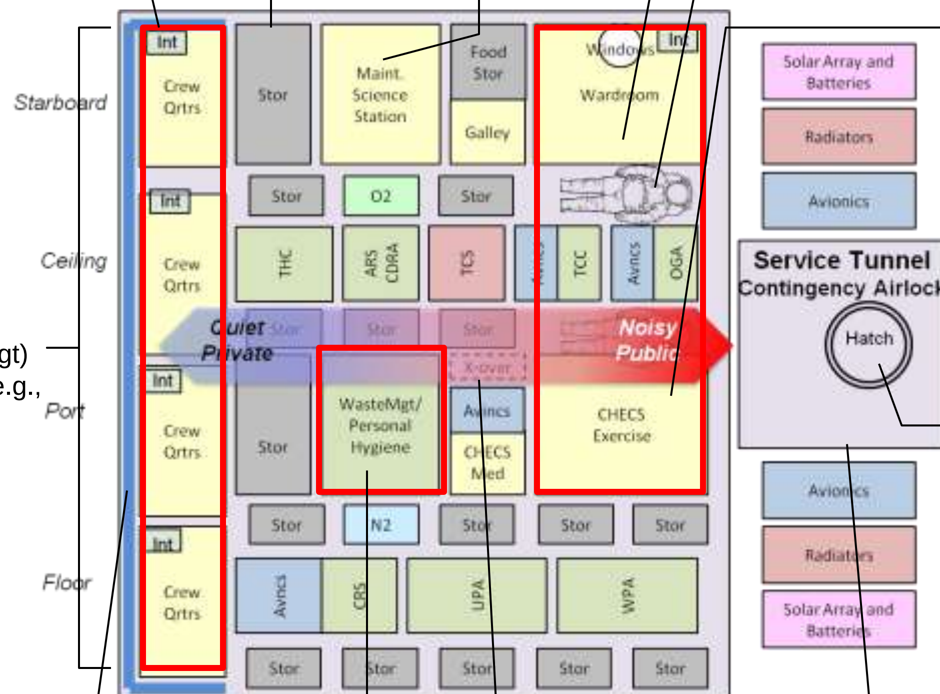
Maint/Science
- Workstation
- Open to aisle

Wardroom
- Open area with window
- Dining and group gathering

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

CHECS
- Open area for exercise
- Adjacent to medical equipment

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



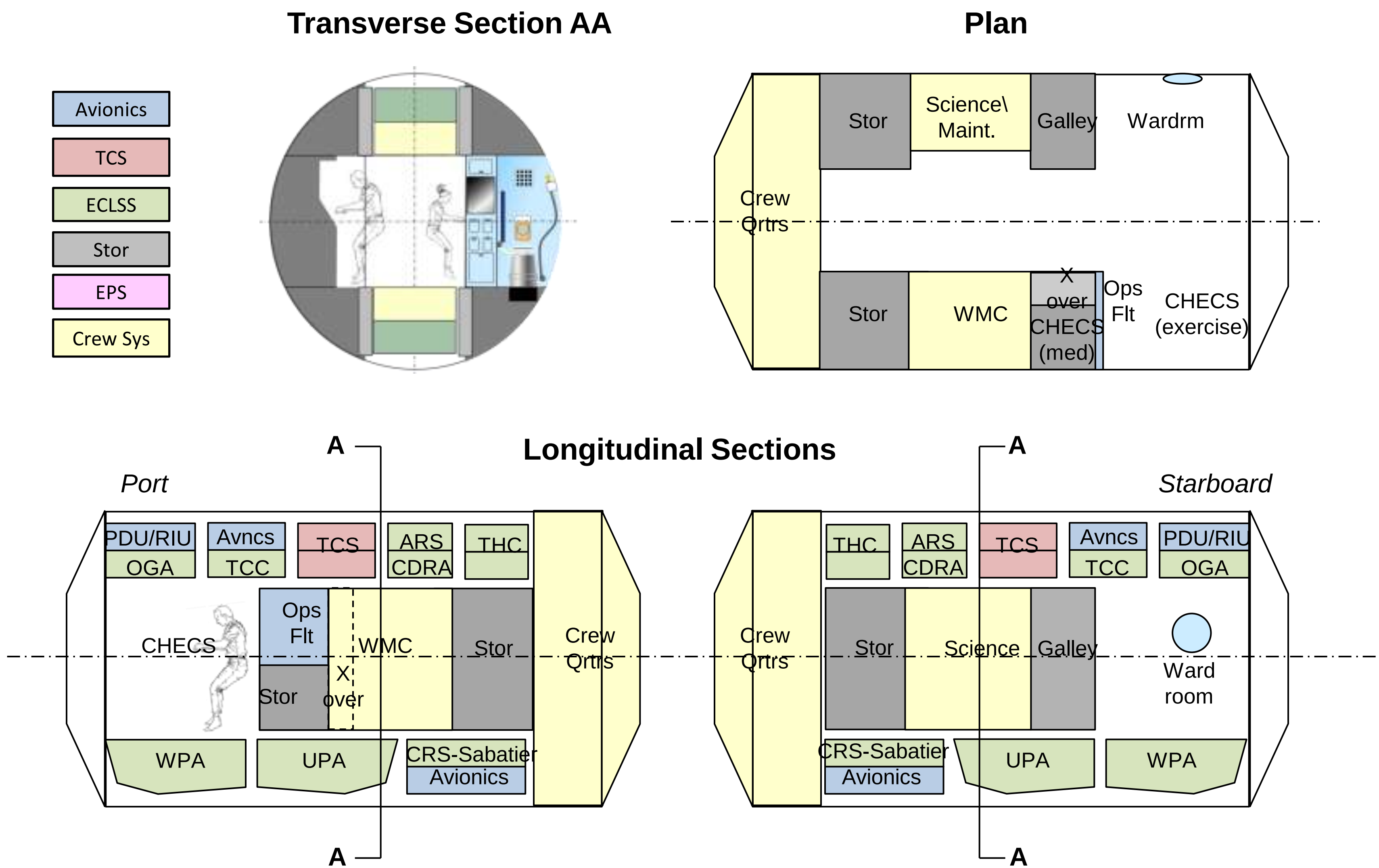
Hatches
- Hab (50 inch)
- MPCV (LIDS)
- FlexCraft docking

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

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

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

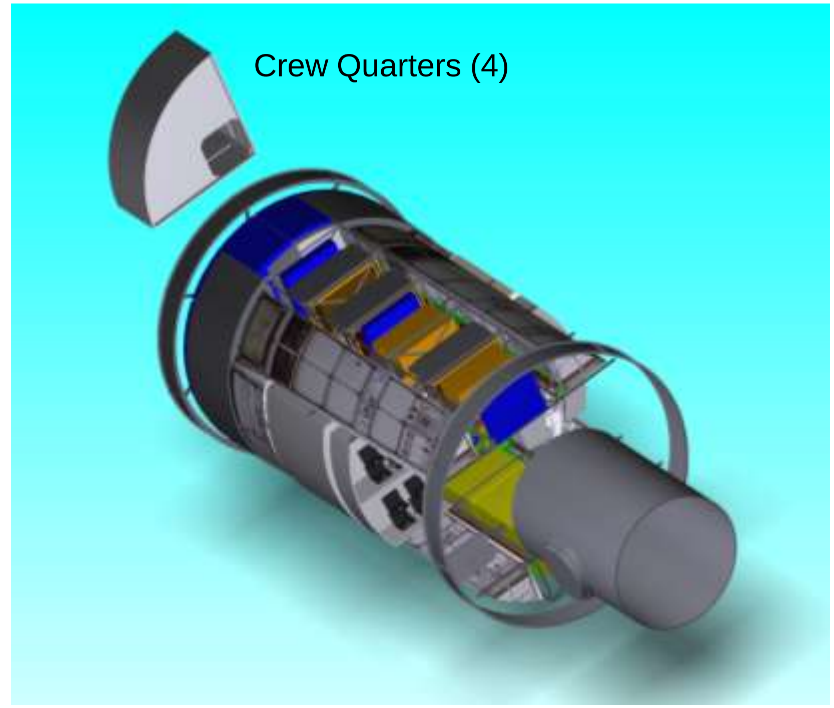
Utility Crossover
- Return air and water
- End-cone location

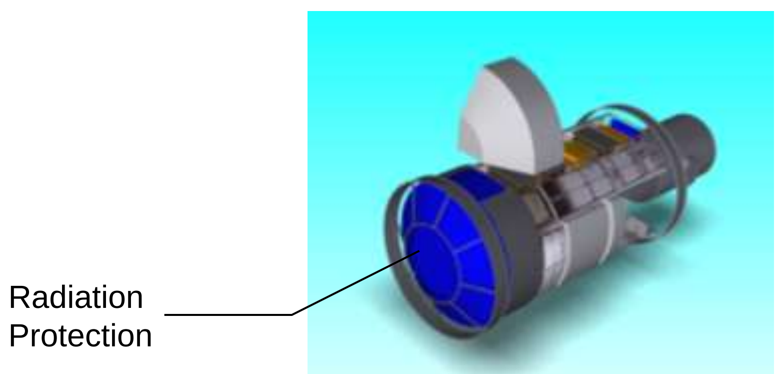

Transverse Section AA
Plan
Avionics
TCS
ECLSS
Stor
EPS
Crew Sys
Crew Qrtrs
Stor
Science\ Maint.
Galley
Wardrm
Stor
WMC
X over
CHECS (med)
Ops Flt
CHECS (exercise)
Longitudinal Sections
A
A
A
A
Port
Starboard
PDU/RIU
OGA
Avncs
TCC
TCS
ARS
CDRA
THC
CHECS
Ops Flt
Stor
X over
WMC
Stor
Crew Qrtrs
WPA
UPA
CRS-Sabatier
Avionics
Crew Qrtrs
THC
ARS
CDRA
TCS
Avncs
TCC
PDU/RIU
OGA
Stor
Science
Galley
Ward room
CRS-Sabatier
Avionics
UPA
WPA

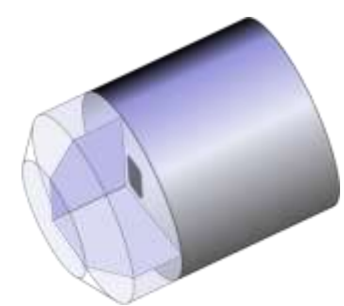
Crew Quarters

ISS (~2 m3 each)

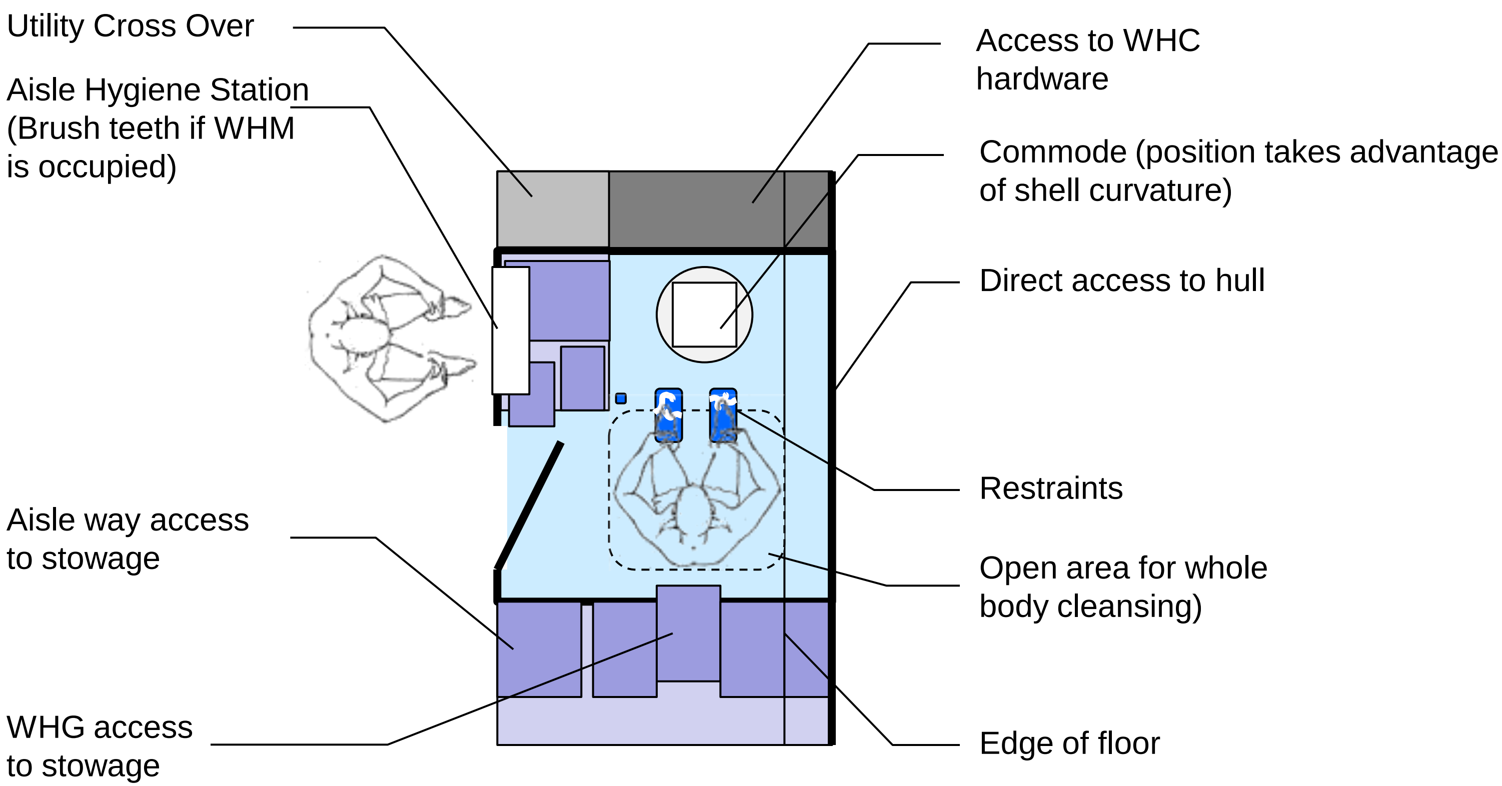
DSH (~ 4 m3 each)







DSH Waste Hygiene Compartment

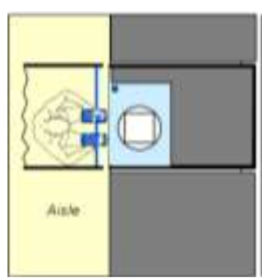


ISS

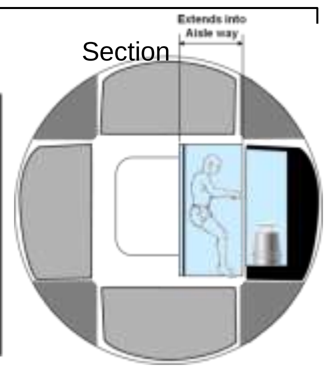
Interior WHC

Exterior WHC

Plan

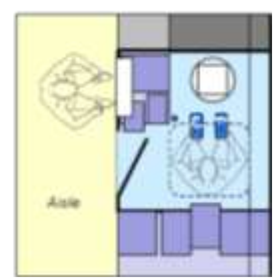


Section

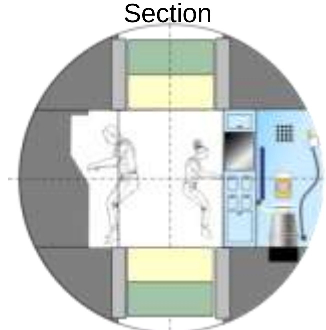


DSH

Plan



Section



Accessibility Zoning

ISS Access

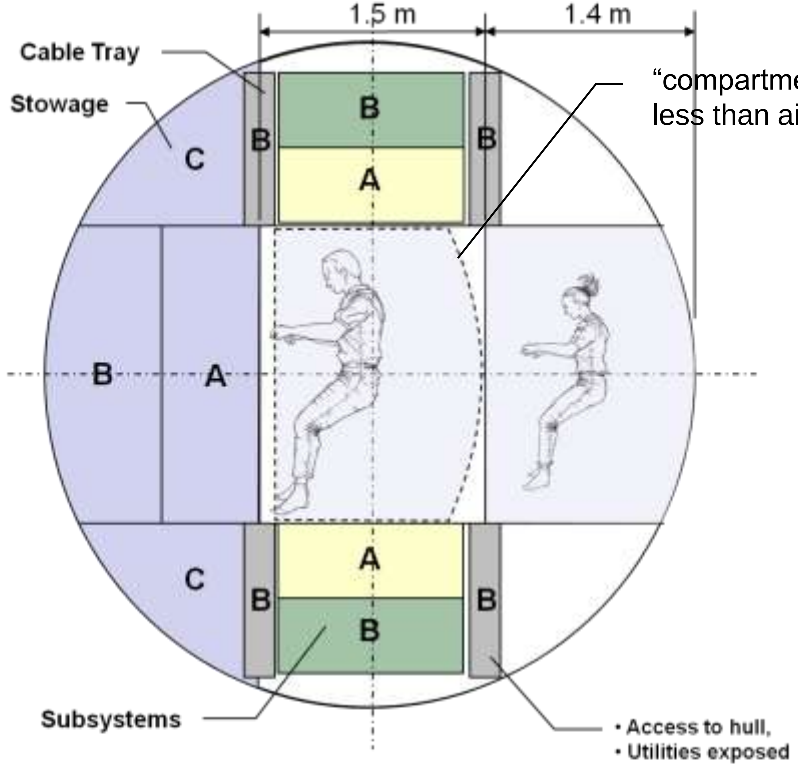
ISS Stowage

No immediate access to hull

- **No access behind standoff**
- **Utilities enclosed**

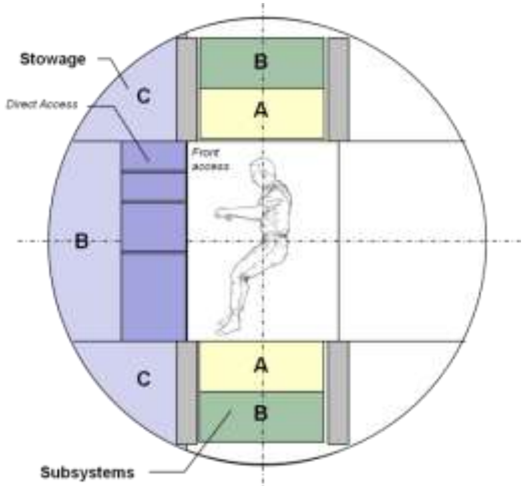
Shell/ORU

Zone	Access
A	Immediate Physical & Visual
B	Indirect
C	Infrequent

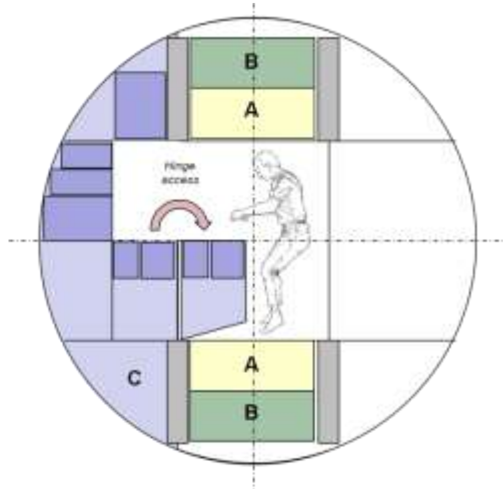


Stowage Concepts

Front Access

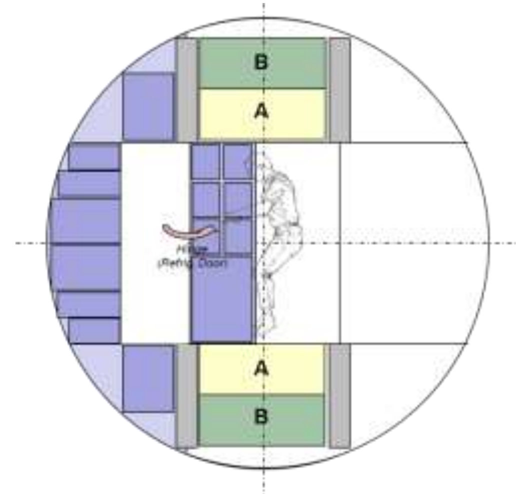


Center Hinged Access



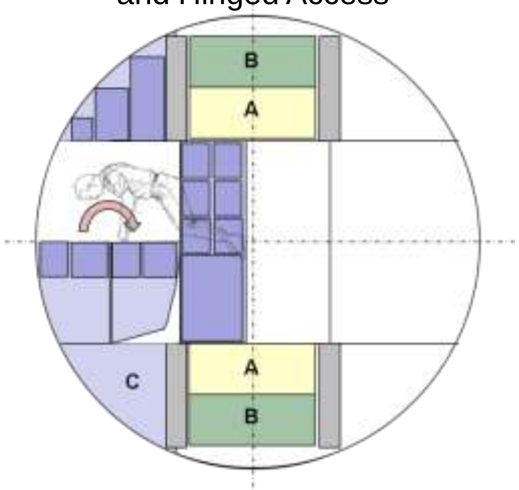
Refrigerator Door

Side Hinged Access



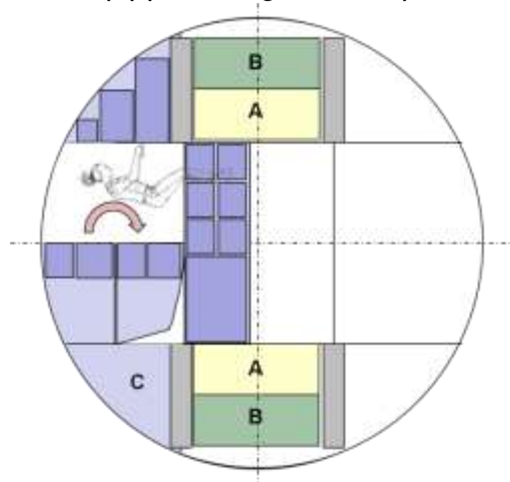
Combo

Combined Refrigerator and Hinged Access



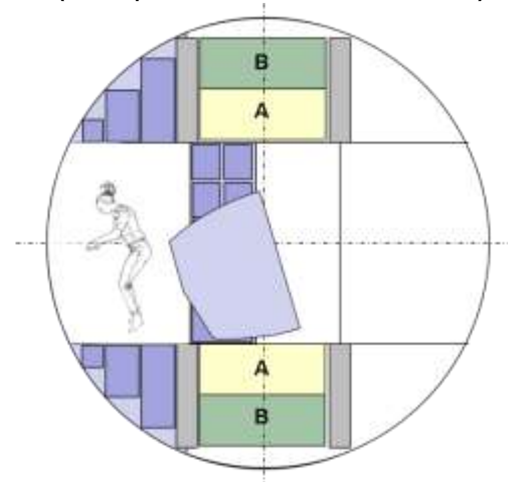
Combo

(upper wedge access)



Combo

(two quadrant and hull access)



Crew Systems Mass by Mission

Component	60-Day Mission Basic Mass (kg)	60-Day Mission MGA %	60-Day Mission Predicted Mass (kg)	500-Day Mission Basic Mass (kg)	500-Day Mission MGA %	500-Day Mission Predicted Mass (kg)
Galley	150	3	154	150	3	154
Wardroom	50	3	52	50	3	52
Crew Quarters	248	5	260	248	5	260
Restraints	24	3	25	24	3	25
Crew Health Care (Medical)	73	3	75	173	3	178
Crew Health Care (Exercise)	91	3	94	91	3	94
Personal Laptops	16	3	16	16	3	16
General Illumination	12	15	14	24	15	28
Crew Systems Total	664		**690**	776		**802**
Stowed Provisions: Personal	80	3	82	100	3	103
Housekeeping Expendables	20	3	21	166	3	171
Operational Spares	100	3	103	175	3	180
Maintenance Equipment	40	3	41	80	3	82
Photography	4	3	4	4	3	4
EVA: Provisions	30	3	31	60	3	62
EVA Suits	246	0.0	246	246	0.0	246
Airlock Services	25	3	25	25	3	25
Total	1210		**1243**	1632		**1675**

Environmental Control & Life Support Systems (ECLSS)

Janie Miernik

December 15, 2011

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, O_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 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 O_2 need be carried.
- N_2 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 back-up CO_2 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 O_2 (and H_2) from H_2O; feeds Sabatier
  - Carbon dioxide reduction – Sabatier (ISS Heritage)
    - Creates H_2O from H_2 and CO_2
- Currently no Vacuum Access on DSH

CDRA

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.

Water Reclamation Rack

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

ECLSS Subsystem	60-Day Mission Basic Mass (kg)	60-Day Mission MGA %	60-Day Mission Predicted Mass (kg)	500-Day Mission Basic Mass (kg)	500-Day Mission MGA %	500-Day Mission Predicted Mass (kg)
Atmosphere Revitalization Sys (ARS)	337	20	404	562	20	674
Atmosphere Cont & Supply System (ACSS)	400	20	480	1200	20	1440
Temp & Humidity Control (THC)	149	20	179	149	20	179
Waste Hygiene Compartment (WHC)	455	20	546.00	455	20	546
Water Recovery & Man (WRM)	1300	3	1339	1300	3	1314
Atmosphere Regen (OGA/ CO_2 Red Assy)	1000	20	1200	1600	20	1860
Fire Detection & Suppression /module	35	30	46	70	30	91
Potable Water Tanks	180	3	185	680	3	700
ECLSS Hardware Total	3856		**4379**	6016		**6890**
ECLSS Expendables	200	3	206	500	3	515
ECLSS Spares	730	3	752	1600	3	1648
H_2O	634	3	653	2520	3	2596
Food, packaged	337	10	371	2403	10	2643
Atmosphere Regen (O_2)	114	3	117	670	3	690
Atmosphere Regen (N_2) leakage	122	3	126	250	3	258
Total	5993		**6603**	13959		**15239**

Structures

Janie Miernik
December 15, 2011

Multi-Purpose Logistics Module (MPLM)

Ground Rules & Assumptions

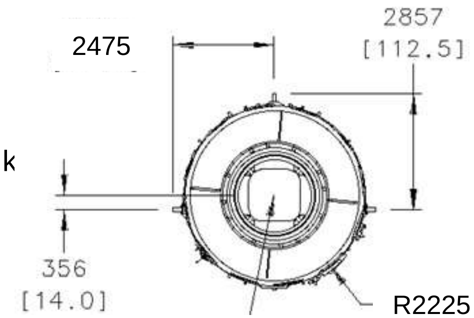
- DSH cabin air pressure = 70.3 kPa (10.2 psi, .7 atm). 1 atm (14.7 psi, 101.3 kPa) when docked to ISS on 60-Day mission demonstrator.
- ISS STA Lab/HAB Module has known mass and is fabricated, not qualified, so is TRL 8.
- MPLM design is used but additional CBM docking port added, TRL drops to 7.
- 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

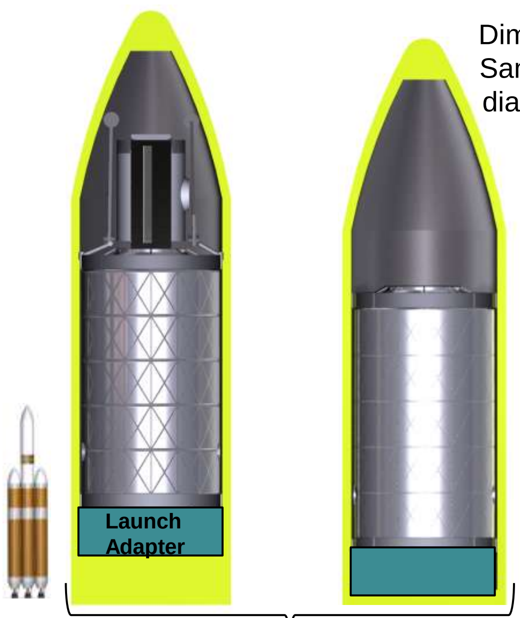
New launch adapter is shown schematically (in teal) and launch mass limitations are given below. ISS element launch adapters would interface element trunnions. There will be mass overage and some mass must be launched by other means and installed on orbit, mostly likely at ISS.

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 k
Atlas V payload limit to ISS LEO including launch adapter: ~29,000 kg

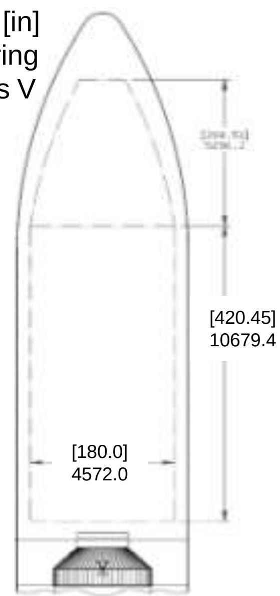
* Launch adapter mass from Boeing Docking Hub proposal for outfitted STA Node



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



Delta IV Heavy



Atlas V HLV

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


Taurus 2 Tunnel Launch


Delta IV Tunnel Launch

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)

Description of Modules and International Payload Racks

	STA Lab/Hab	MPLM	Tunnel		ISPR
Length	8.5 m (27.4 m)	6.5m (19 ft)	3.2 m (10.5 ft)	**Height**	2 m (6.1 ft)
Cylindrical section length	7.2 m (25.6 ft)	4.9 m (15 ft)	3.2 m (10.5 ft)	**Width**	1.05 m (3.4 ft)
Diameter	4.3 m (14 ft)	4.3 m (14 ft)	2.5 m (7.6 ft)	**Max. depth**	.86 m (2.8 ft)
Pressurized volume	106 m^3	76.4 m^3	10 m^3	**Volume**	1.57 m^3
Mass of shell incl. CBMs and hatches	3833 kg (8450 lbs)	2502 kg (5516 lbs)	1284 kg (2204 lbs) ~25 kg/m^2 areal mass	**Mass of 6-post rack**	105 kg (230 lbs)

Comparison of Mission/Mass

Structural Component	60-Day Mission			500-Day Mission		
	Mass (kg)	MGA %	Predicted Mass (kg)	Mass (kg)	MGA %	Predicted Mass (kg)
STA Lab/Hab outfitted Pressure Shell	3833	10	4216	3833	10	4216
Hab Secondary Structure	2141	20	2569	2141	20	2569
MPLM outfitted Pressure Shell w/2 axial CBM ports	0	20	0	2502	20	3002
MPLM Secondary Structure	0	20	0	1704	20	2044
Tunnel/Ext. Secondary Structure	1782	20	2139	1815	20	2178
20” ISS Window	75	3	77	75	3	77
Total	**7831**		**9002**	**12069**		**14087**

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

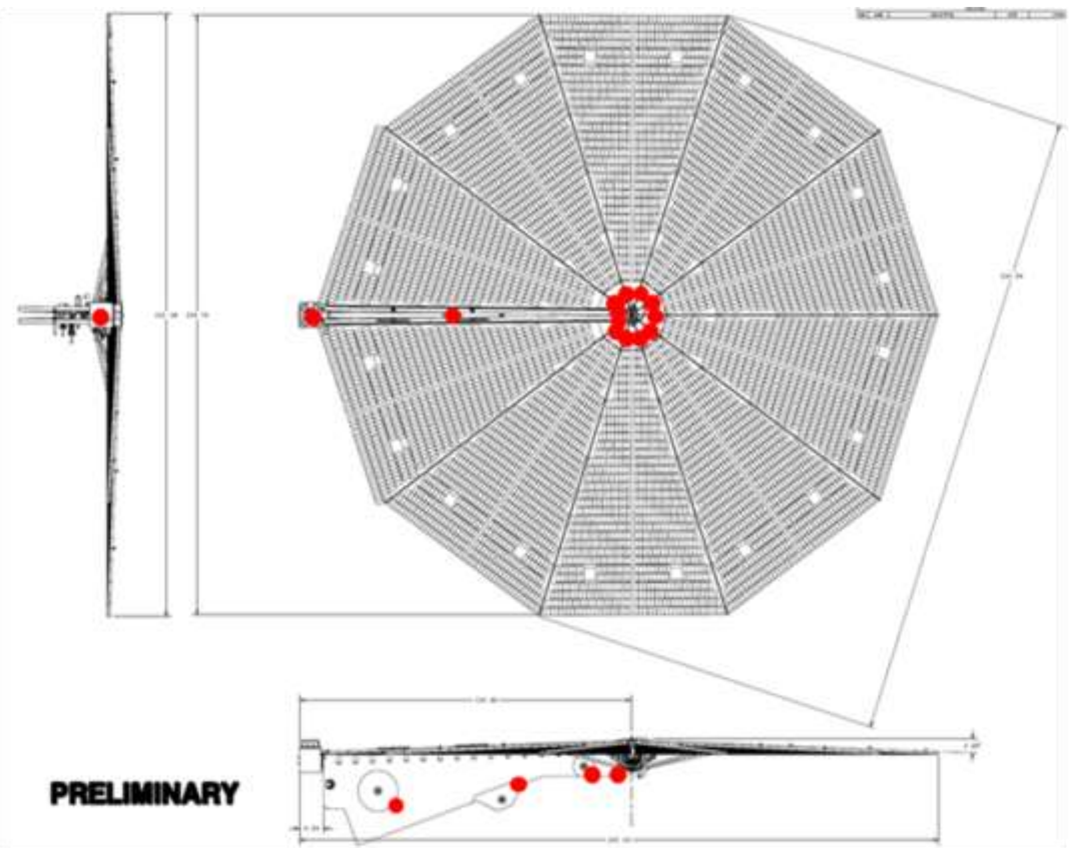
December 15, 2011

Design Approach

- 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.

Solar Array Wing

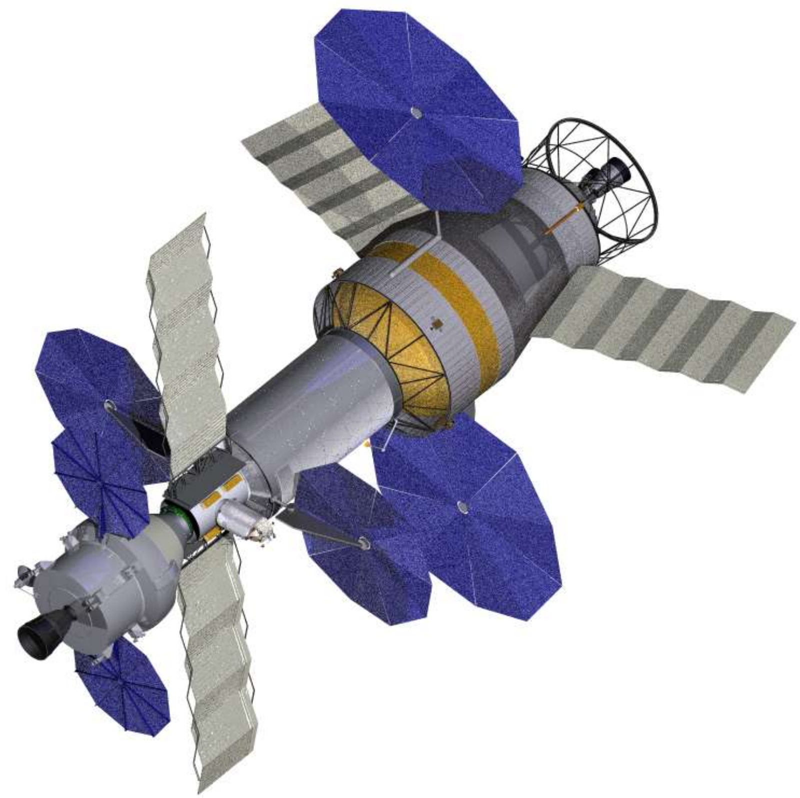
Array Wing is Populated with Multi-Junction Inverted Metamorphic (IMM) Solar Cells currently in development. These offer Higher Conversion Efficiency and Lighter Weight than SOA Cells.



Solar Arrays

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.



Power Electronics
(MPCV Designs)

- 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

Power Electronics
(Enclosure)

- Scaled from existing space-qualified enclosures
- Includes Backplane, redundant Power Supply and Connectors

Secondary Battery

- 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

Component	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Solar Arrays (with Booms, Actuators)	204	2	245	263	20	316
Power Electronics	75	16	87	75	16	87
Secondary Batteries	153	10	168	204	10	224
Power Cabling	152	30	198	228	30	297
Total	**584**		**698**	**770**		**924**

Avionics

Pete Capizzo

December 15, 2011

DSH AES - Avionics

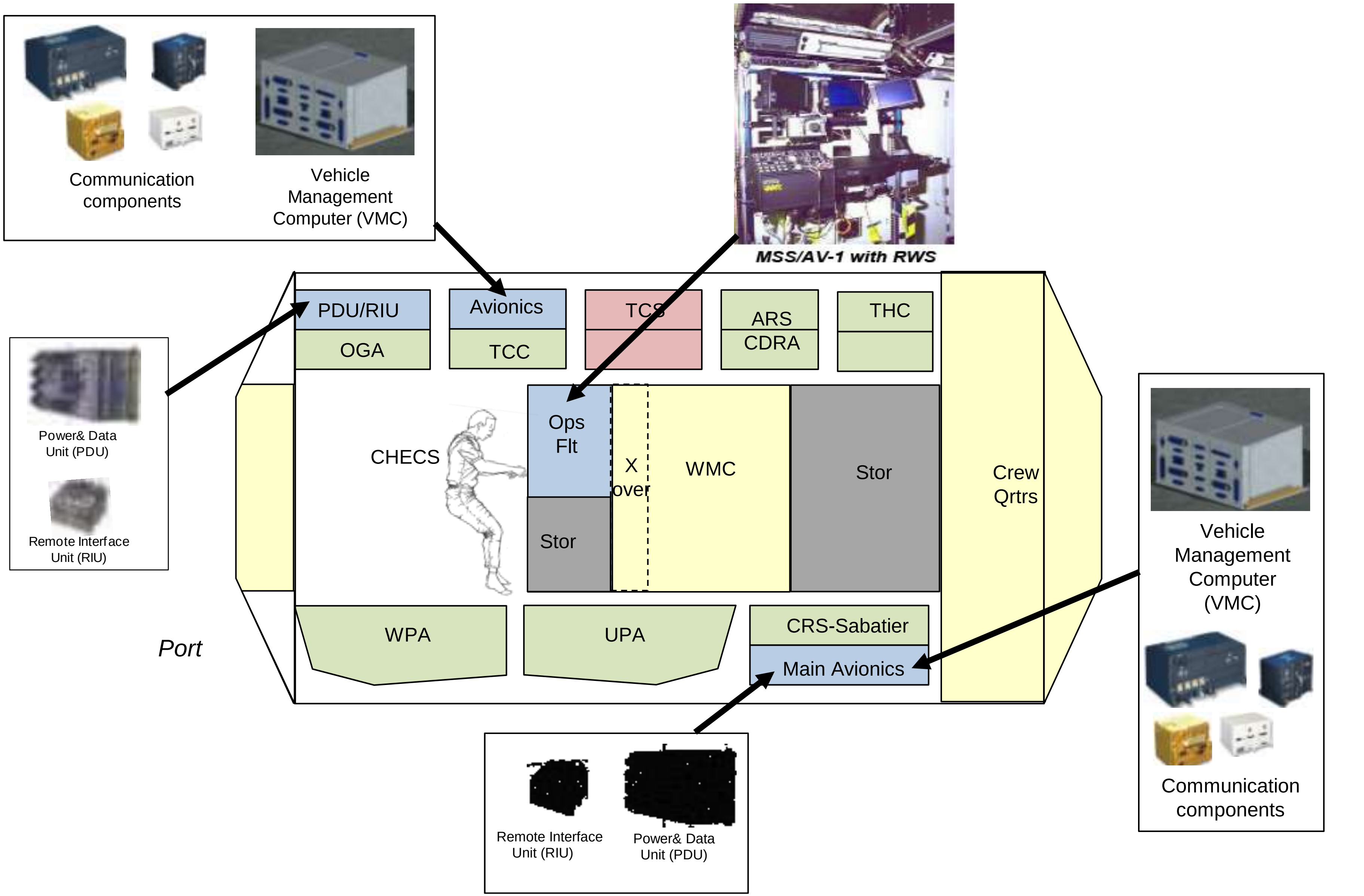
- Avionics Approach
  - The avionics system provides all command, control, data handling, and communications systems for the habitat.
  - The avionics for this DSH has been based on the MPCV crew vehicle avionics. This was judged to be a practical approach since the MPCV vehicle is largely a habitat 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.
  - Its 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.
  - Its 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.

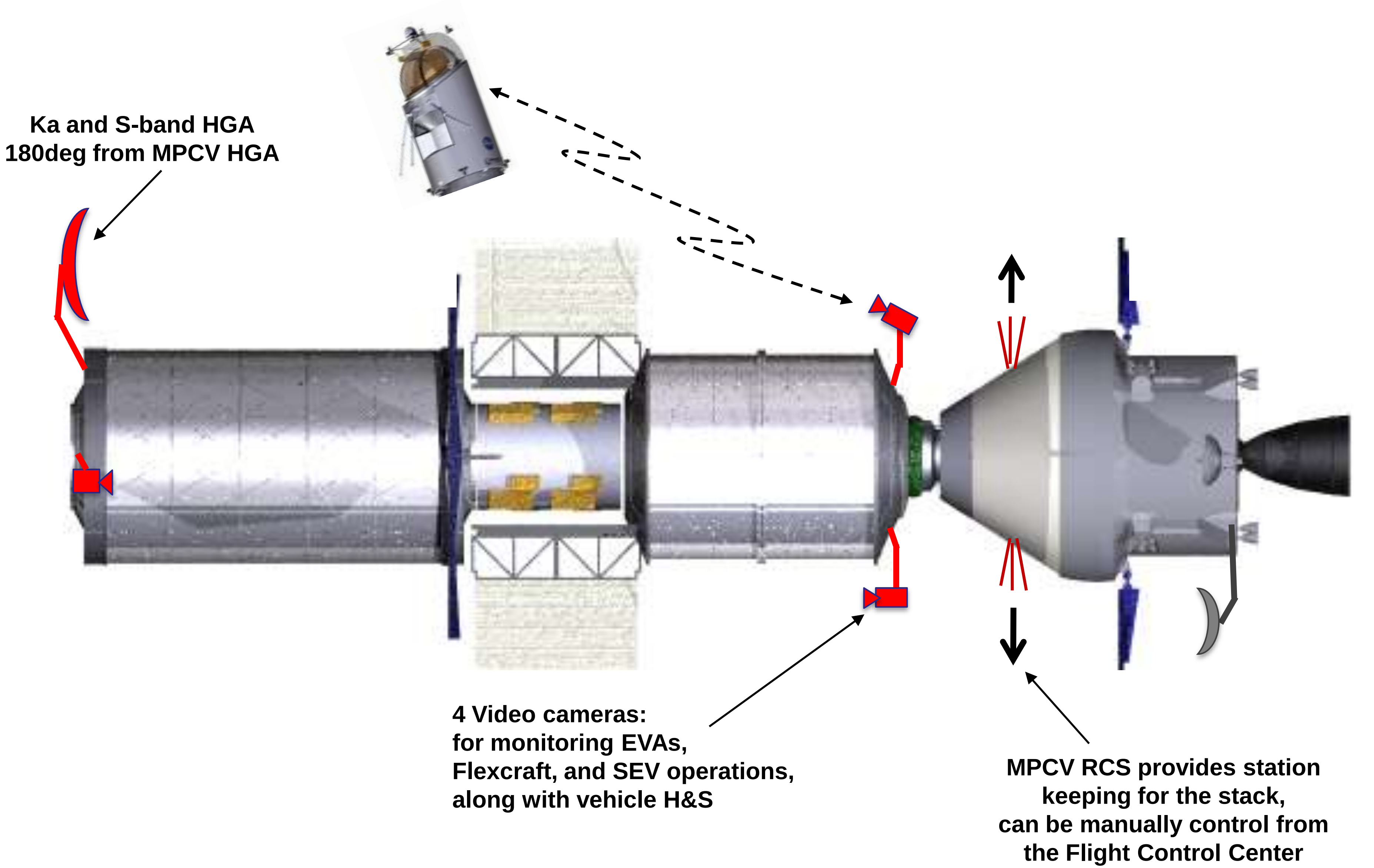
DSH AES - Avionics

- 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 form 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



DSH AES - External Avionics

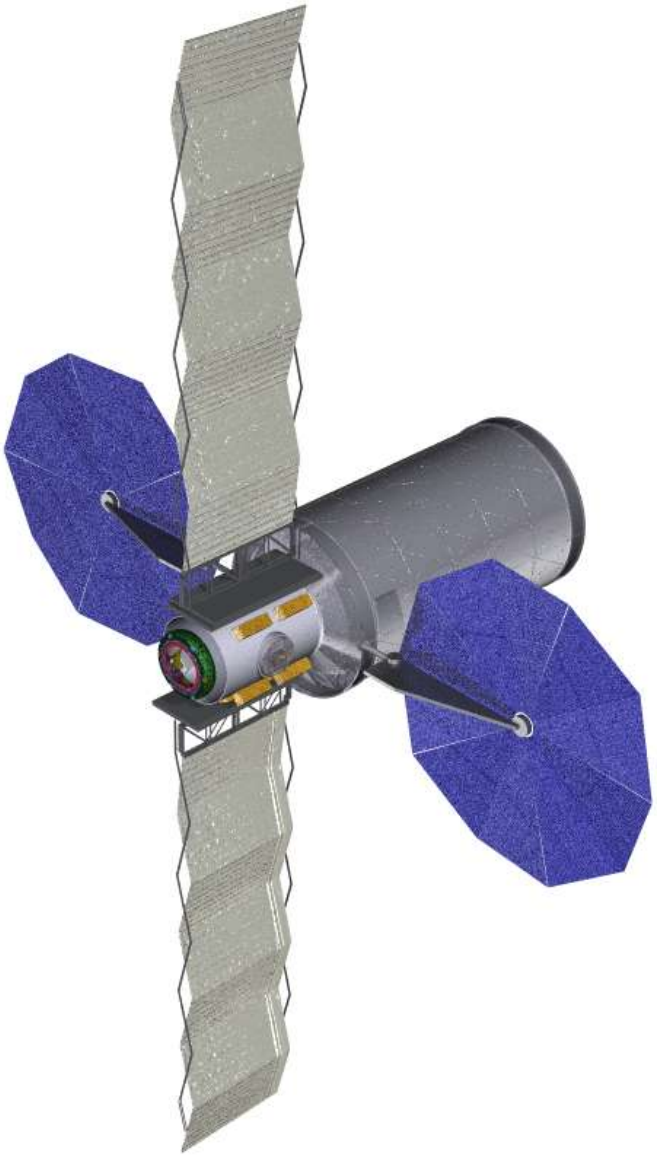


DSH AES – Avionics Mass Summary

Sub-System	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
AR&D System	10.8	3.0%	11.2	10.8	3.0%	11.2
Command and Data Handling	219.9	18.3%	260.2	219.9	18.3%	260.2
Displays & Controls	134.0	18.3%	158.5	134.0	18.3%	158.5
Communications System	159.4	18.6%	189.0	187.4	18.1%	221.3
Intercom & Video	55.5	22.2%	67.8	56.4	22.2%	68.9
Instrumentation	45.4	30.0%	58.9	54.4	30.0%	70.7
IHM System	50	10.0%	55.0	70.0	10.0%	77.0
Avionics Cabling	289.7	30.0%	376.6	348.2	30.0%	542.7
Total	**964.7**		**1177.3**	**1081.2**		**1320.6**

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

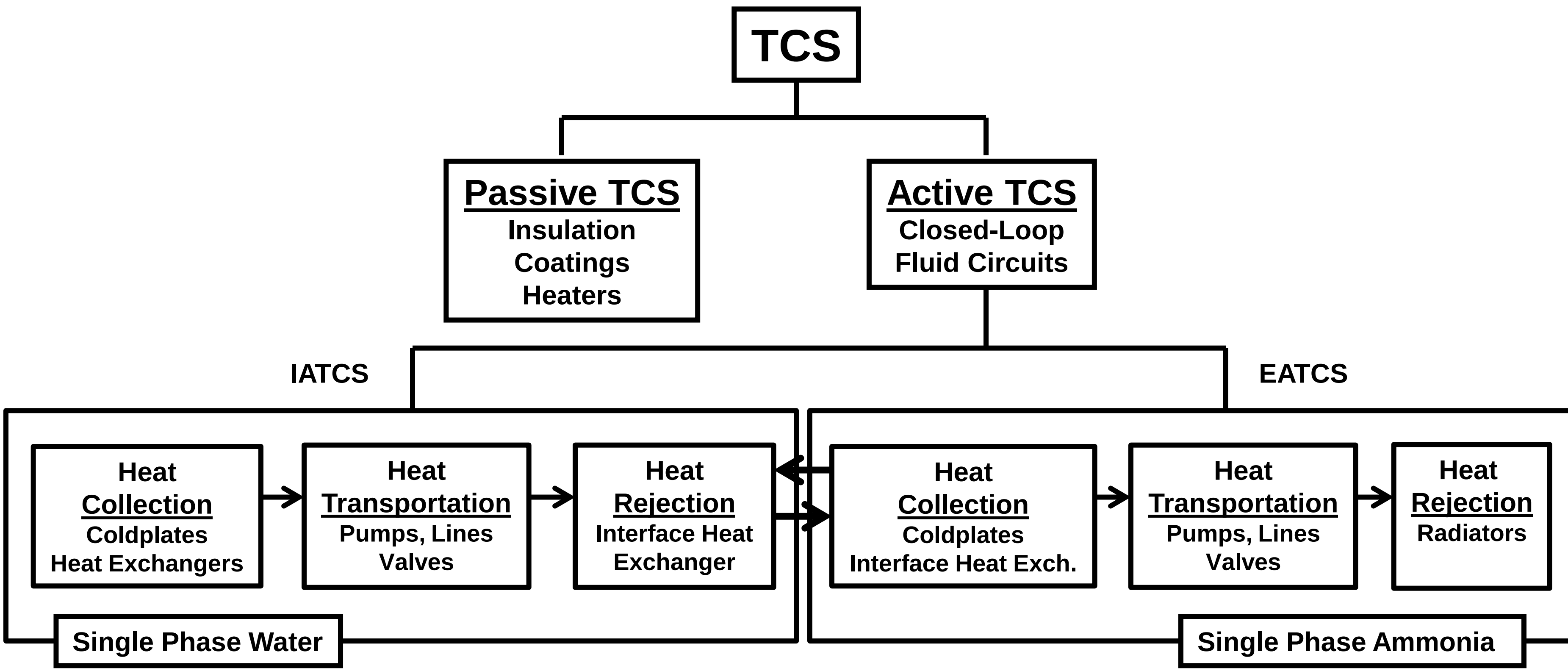
- Thermal Control
  - Active waste heat collection/rejection
    - Redundant internal pumped water loop
    - Redundant external pumped ammonia loop
    - ISS LTL/MTL TCS components (pump package, filters, valves, HX, QDs, etc.)
    - ISS External TCS components (pump package, filters, valves, HX, QDs, 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

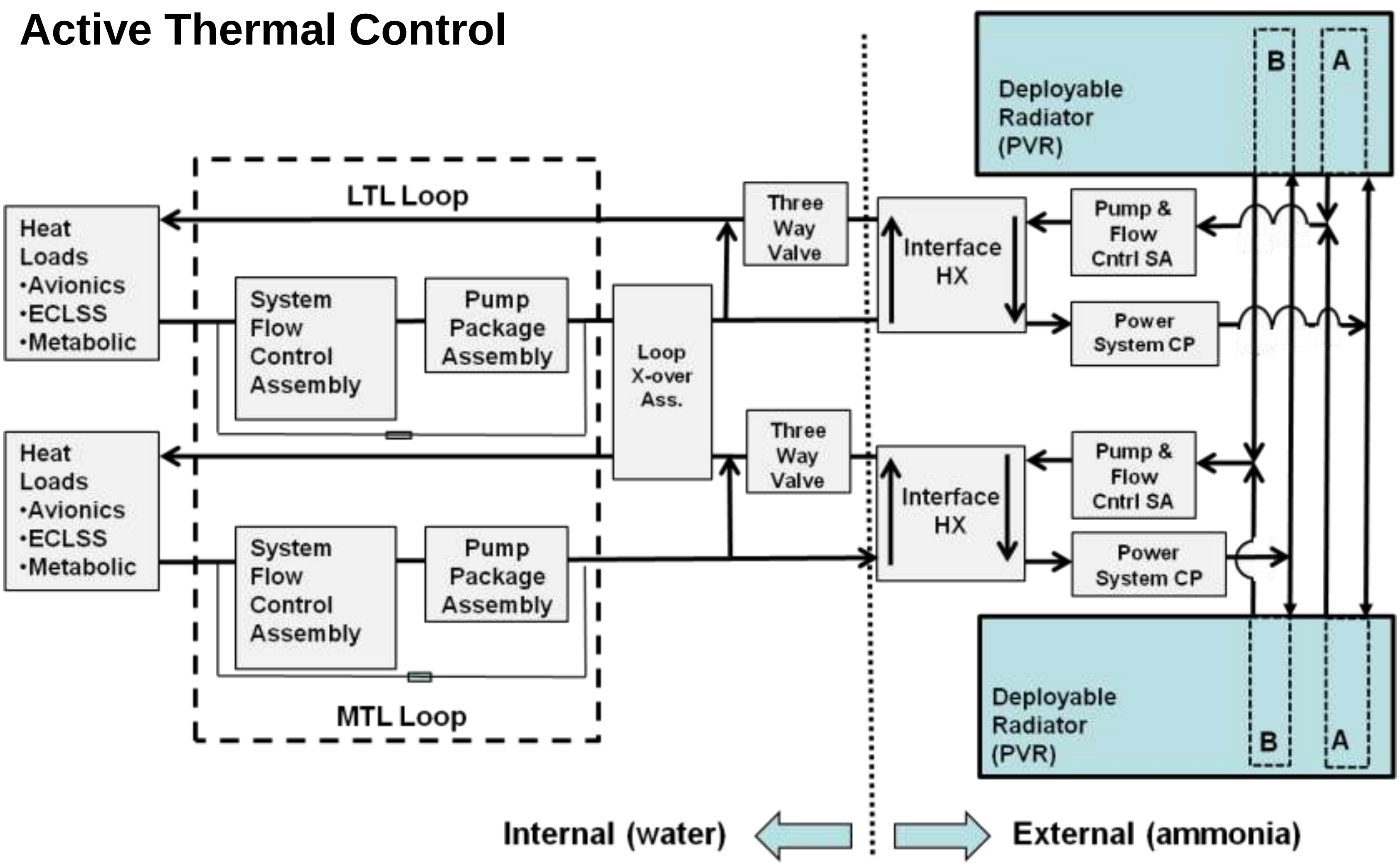
- **External TCS System based on ISS design and flight proven through successful mission operations (TRL 9).**
- **Internal TCS System using ISS flight proven components, removed from racks and redistributed (TRL 8)**
- **Active waste heat collection – redundant internal and external pumped loops with 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**

DSH Thermal Control System Architecture

• An effective TCS is designed to insure that pressurized modules and electronics temperatures are maintained within acceptable range during all mission phases..



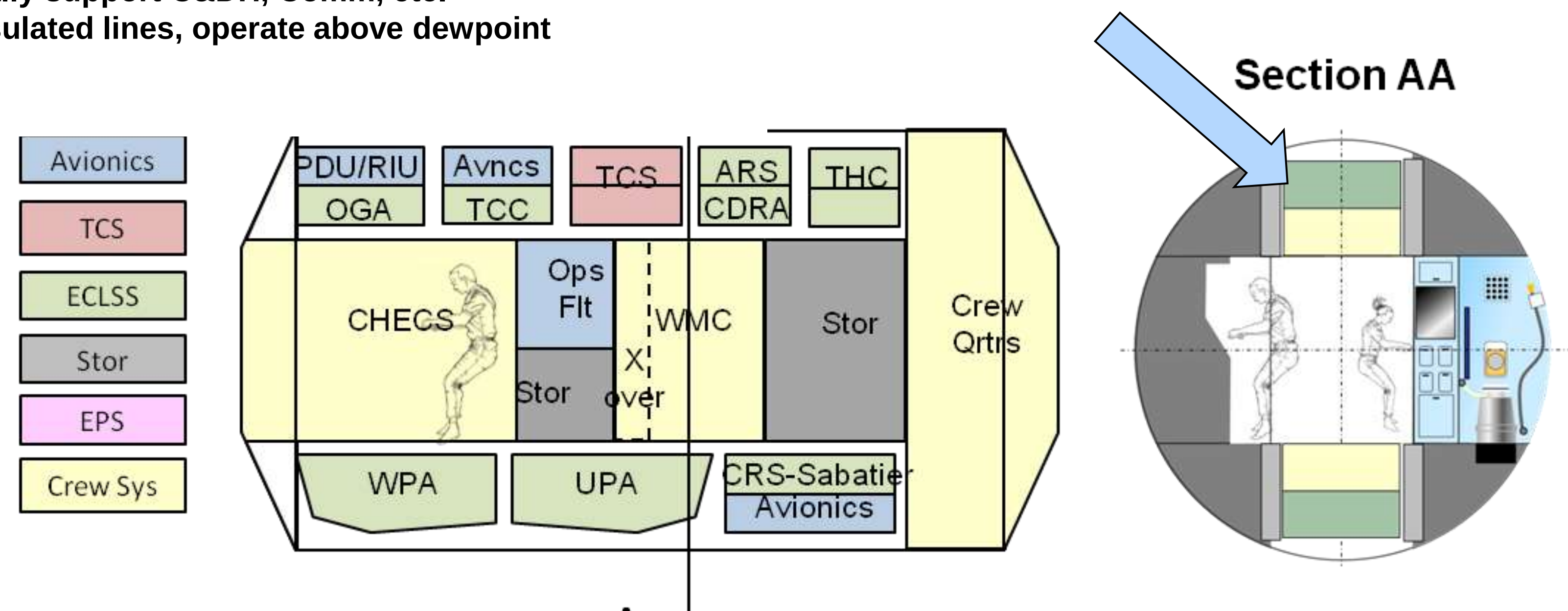
Active Thermal Control Schematic



Internal Active Thermal Control

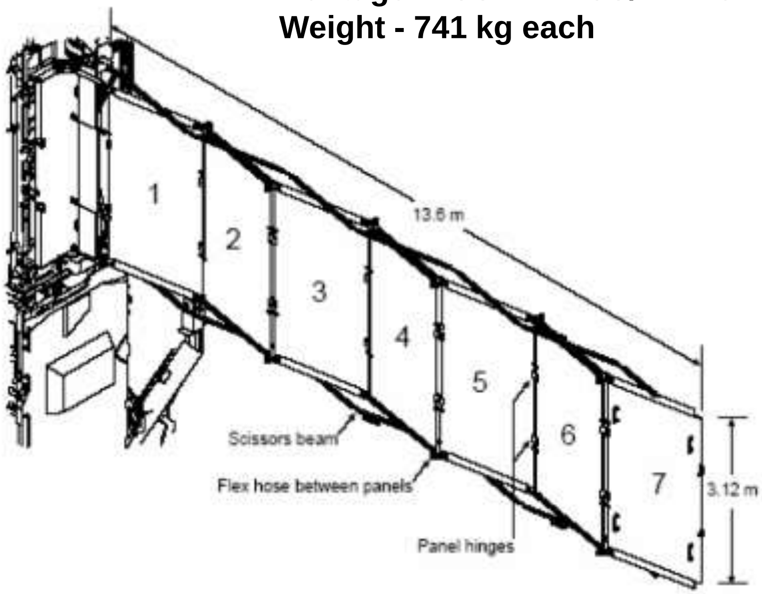
- **Components**
  - -Pump Package Assembly (PPA)
  - -Coldplates
  - -Flow Control Valves (FCVs)
  - -Three-Way Mixing Valves (TWMV)
  - -Loop Cross-Over Assembly
  - -Temperature Sensors
- **Low Temperature Loop (LTL)**
  - -Typically support ECLSS requirements
  - -Insulated lines, operate below dewpoint
- **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.

Heat Dissipation to TCS	
60/500-Days	
Item	**Total Heat Dissipation (W)**
C&DH, Instrumentation	1024
Displays & Controls	452
Communications	525/625
Intercom / Video	292
Cabin Lighting	200/240
Circulation Fans	350/450
Heat Transport Pumps	700
Refrigerator/Freezer	540/1080
ECLSS	6373
Metabolic (4 crew)	544
Power Systems	970/1145
Totals	**11,970/12,925**

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)

MLI Blankets w/Nomex under MDPS

MLI Blankets w/Beta Cloth on End Cone

Thermal Mass Comparison by Mission

Subsystem	60-Day			500-Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Internal TCS Rack LT/MT	226	20	271	226	20	271
Internal Rack Support	270	20	324	300	20	360
Internal TCS Misc.	30	30	39	30	30	39
External Active TCS	376	15	432	376	15	432
External Passive TCS	155	20	187	199	20	239
External Heat Rejection Sys.	1482	3	1526	1482	3	1526
Total	**2539**		**2780**	**2613**		**2868**

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.

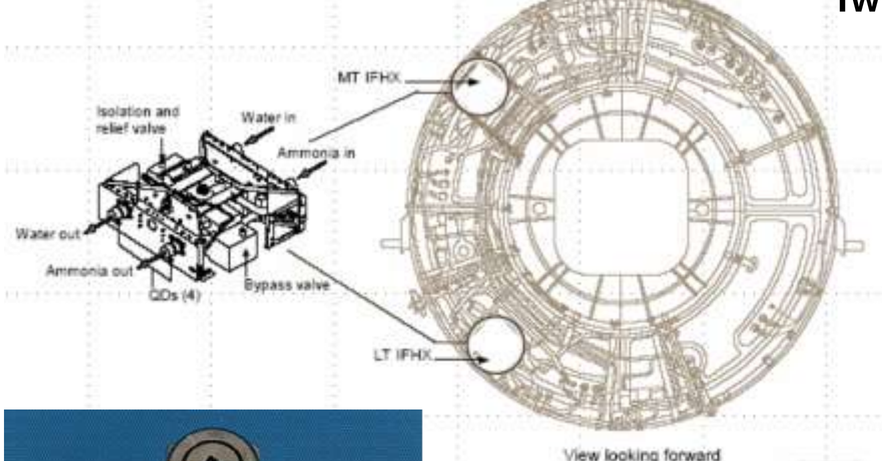
- Spacecraft thermal model can also be used to size shell heaters for different DSH locations. Potential reduction of estimated heater power would save mass for power subsystem, mass savings 50 kg.

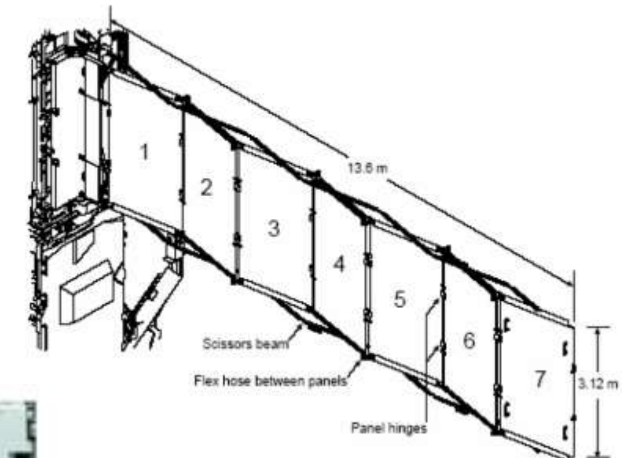
DSH Thermal Control Components

Two Way Mixing Valve

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

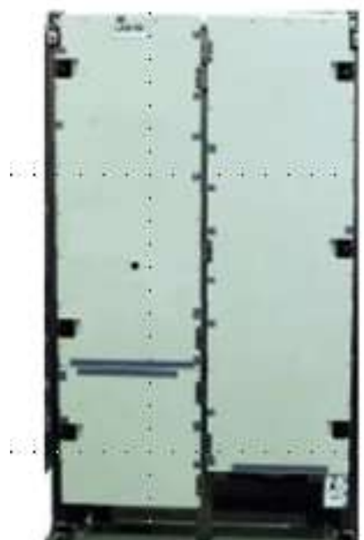
Interface Heat Exchanger
Heritage – ISS EEATCS
Weight - 41 kg
63 cm x 53 cm x 20 cm





Manual Flow Control Valve

Regen HX



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

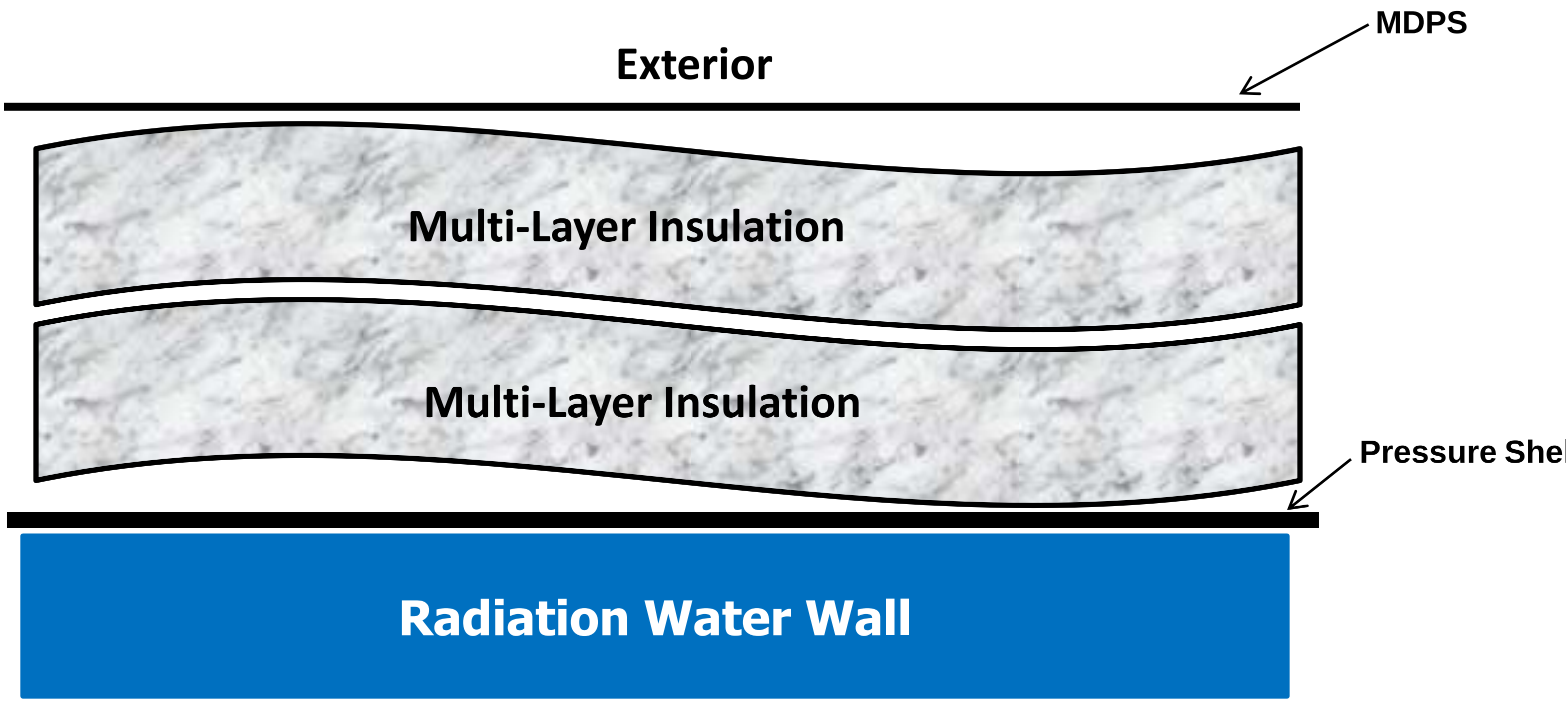
Environments Protection

Tiffany E. Russell

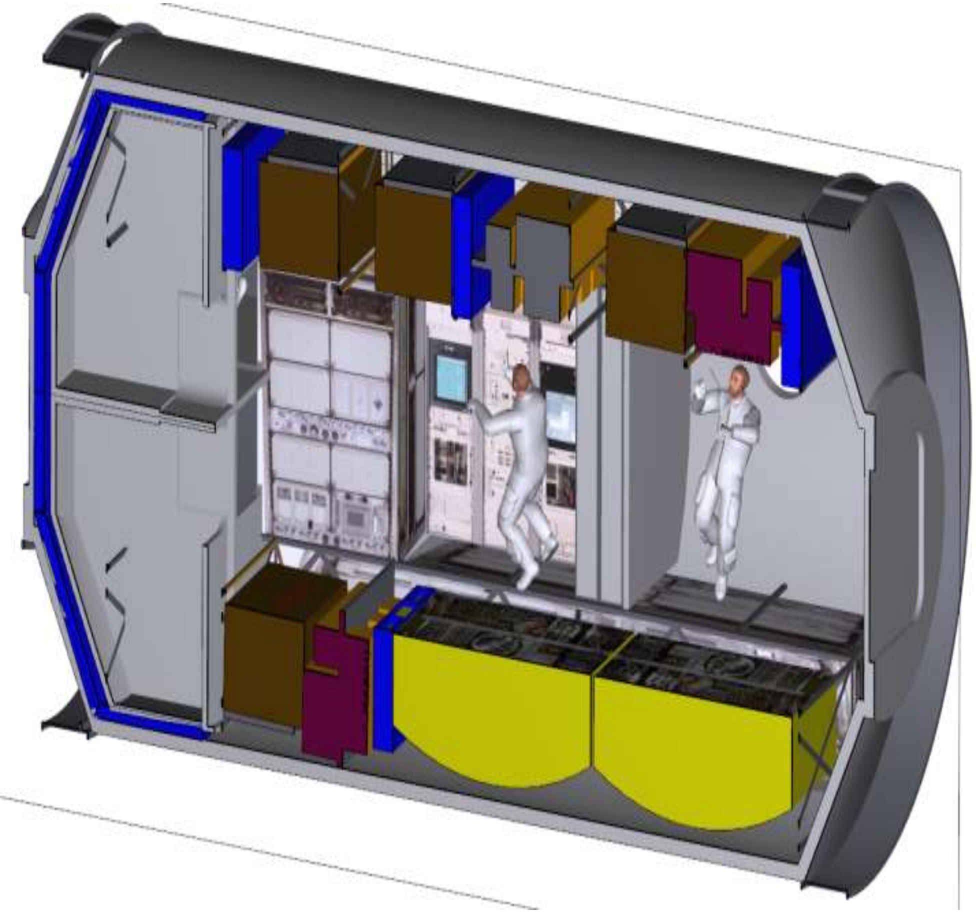
December 15, 2011

System Overview

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



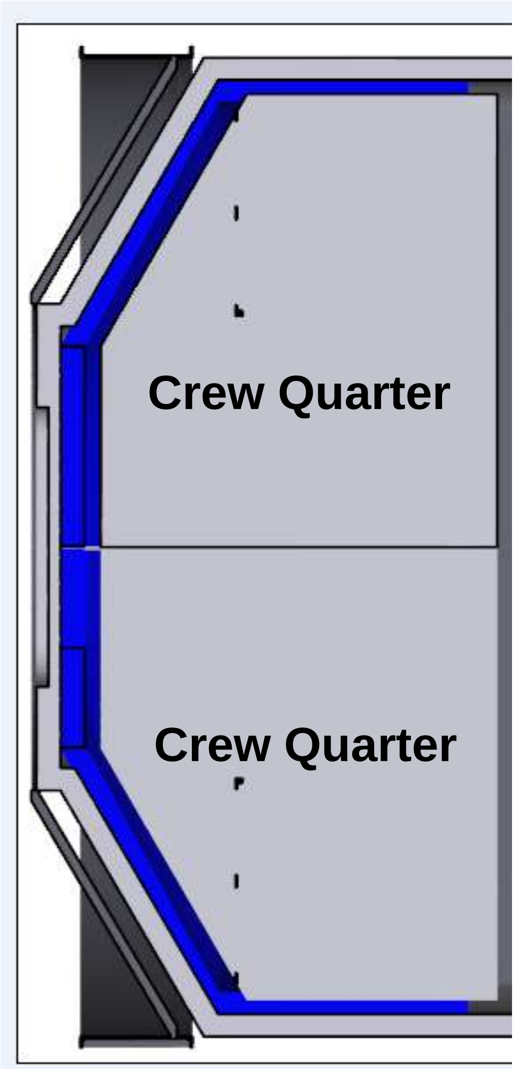
Crew Quarters Protection

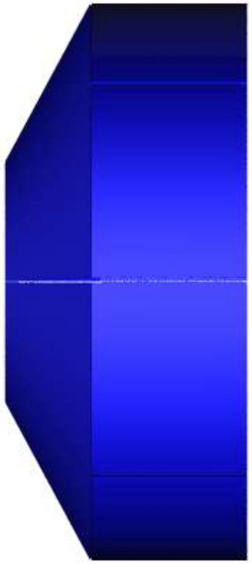


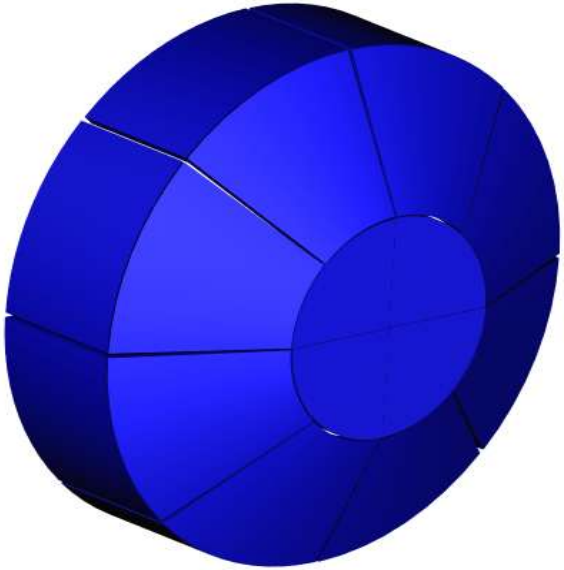
- Nominal 60 and 500 day case, water wall
  - 0.55 cm thick polyethylene tank
  - 9.9 cm thick water wall
  - Total protection = 11 g/cm^2
  - Mass = 2850 kg
- Water wall provides a storm shelter during a Solar Particle Event (SPE)
  - Current design does not include protection against Galactic Cosmic Radiation (GCR)

Tank Configuration

- Tank surrounding crew quarters

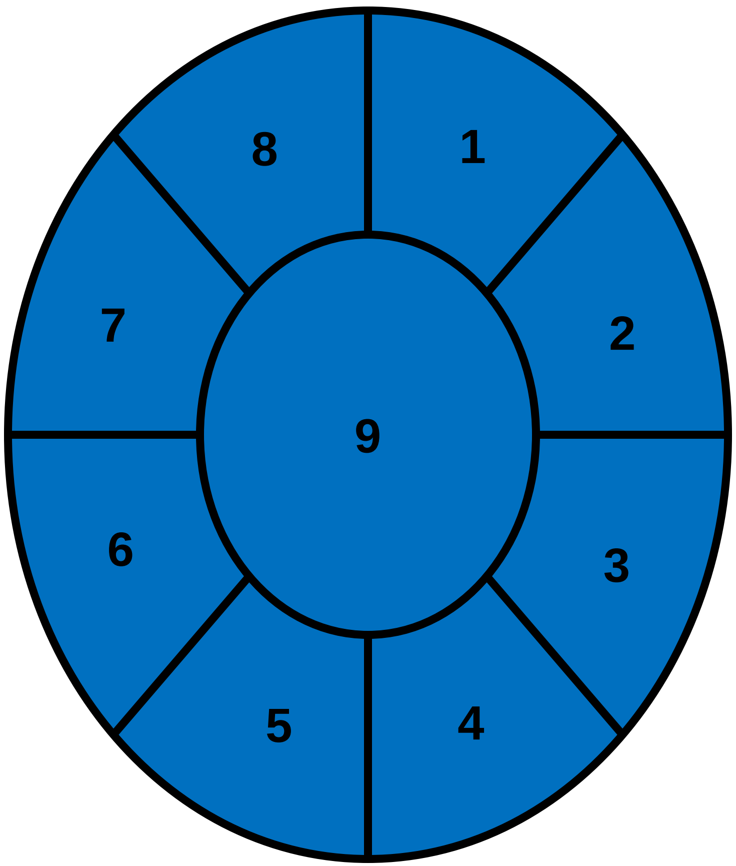




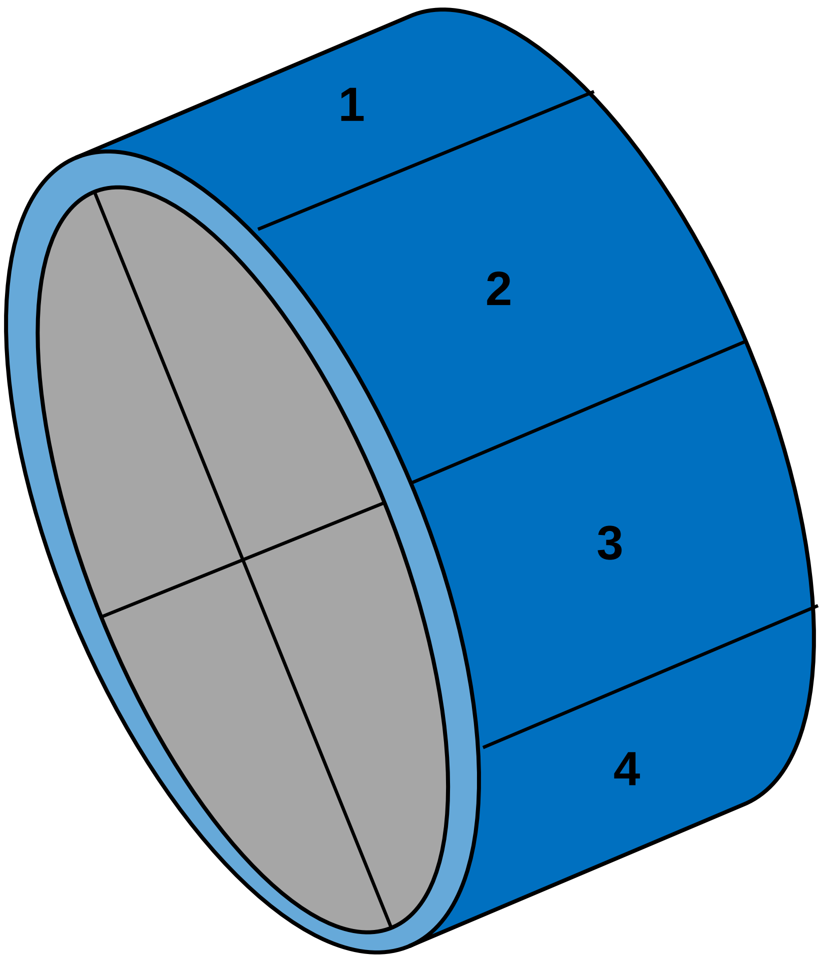


Tank Configuration

- 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_2O 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

	60 day (kg)	500 day (kg)
MDPS	1121	1713
ECLSS	504	1440
Radiation Water Wall	2850	2850
Dual Water Storage System	2346*	1410*

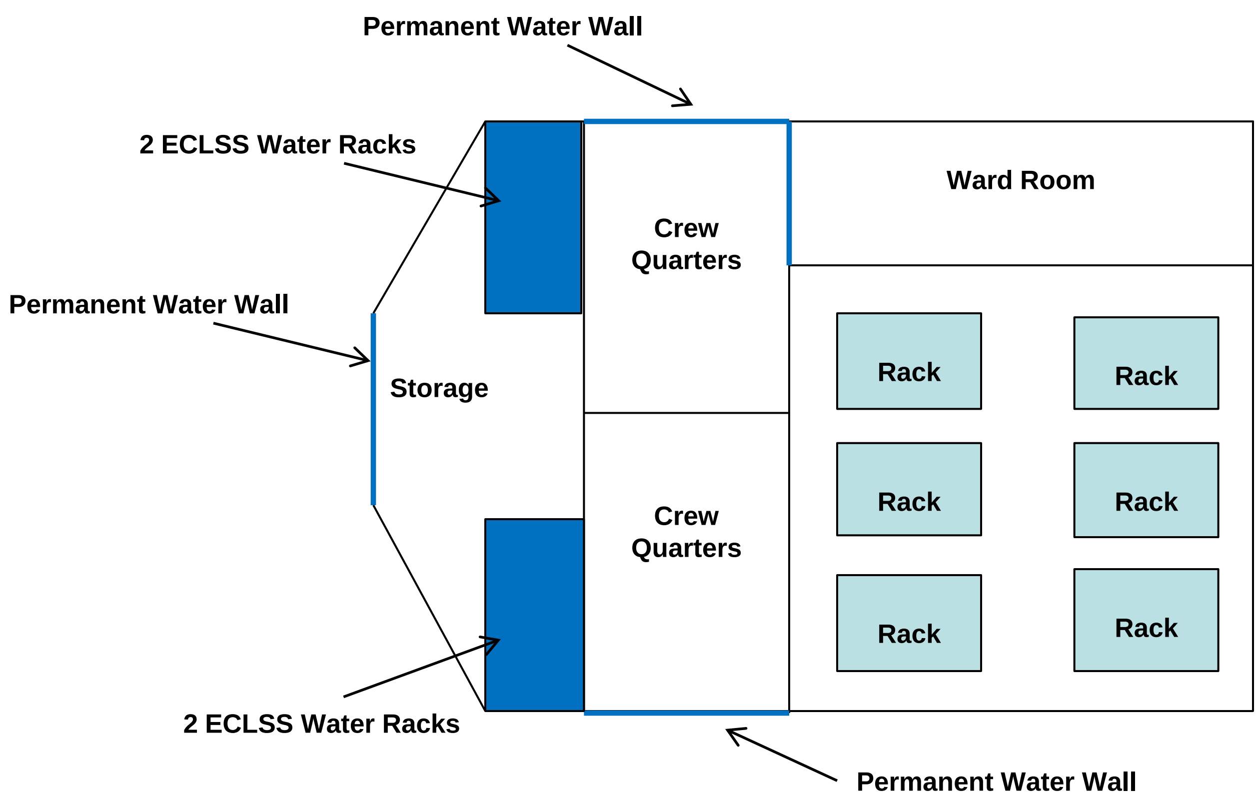
***These numbers do not include the amount of water produced by ECLSS through out the duration of the mission**

Mass Summary

Sub-System	60 Day			500 Day		
	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)	Basic Mass (kg)	MGA (%)	Predicted Mass (kg)
Micro-Meteoroid & Debris Protection System (MPDS)	1121	10	1233	1713	10	1884
Radiation Protection Tank	332	5	349	332	5	349
Radiation Water	2518	3	2594	2518	3	2594
Total	**3971**		**4176**	**4563**		**4827**

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

Pressurized volume	19.6 m^3
Habitable volume	9.3 m^3
Crew size	3-4
Active crewed duration	21.1 days
Quiescent duration	400 days
Main propulsion	1 OME, 33400 N, Isp = 326 s
Auxiliary propulsion	8 R-4D, 490 N, Isp = 308 s
RCS	16 R-1E, 111 N, Isp = 275 s
Delta V requirement	1453 m/s
Propellant tank capacity	8602 kg
Power, uncrewed	2576 W
Power, crewed	3261 W
Solar power generation	10.8 kW max
Total battery energy storage	12608 W-hr
Entry speed	< 11.8 km/s

Category	MPCV-CM	MPCV-SM
	kg	kg
Structure	1700	1250
Protection	2200	90
Propulsion	220	1260
Control/Other	1750	450
Power	520	300
Avionics	690	270
Thermal/ECLSS	1500	870
Growth	450	160
DRY MASS SUBTOTAL	9030	4650
TOTAL WET MASS	9740	13600

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

Description

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

Pressurized Vol.	0.62 m^3
Crew Size	1
Excursion time	< 8hrs
Atmosphere	O2/N2 same as host
Pre-breathe	None
Operations	Shirt sleeve
Design Population	One size fits all
Control	Piloted or tele-op
Equip/sample bin	1

Propellant	GN2 (rechargeable)
Delta-v	21 m/s
Battery energy stor	2700 W-h
ECLSS	Repackaged PLSS
Thermal Control	SWME
Radiation Protection	No excursions during SPE (mission specific Polyethylene liner)

Category	Mass (kg)
Structures	121
Propulsion	51
Power	42
Avionics	40
Thermal	21
ECLSS	44
Docking Mechanism	20
GROWTH	41
DRY MASS	379
Non-Prop Fluids	1
Manipulators	58
INERT MASS	437
Total Less Propellant	437
Propellant	14
TOTAL GROSS MASS	452

08-29-2011

* FlexCraft POC is Brand Griffin/ED04 Advanced Concepts Office

Vehicle Sizing References

David Smitherman

December 15, 2011

ISS Module Internal Volumes

Module/Element	Volume (ft^3) Habitable	Volume (ft^3) Pressurized	Volume (m^3) Habitable	Volume (m^3) Pressurized
USOS	6132	13230	170.66	374.66
US Lab	1228	3938	34.77	111.51
Node 1	1030	2016	26.16	57.09
Node 2	1230	2666	34.83	75.50
Node 3	1190	2666	33.69	75.50
Airlock	589	1192	16.67	33.77
PMA - 1	187	205	5.30	5.81
PMA - 2	157	185	4.45	5.24
PMA - 3	157	185	4.45	5.24
Z1 Dome	53	59	1.50	1.66
Cupola		118		3.34
TeSS	78		2.21	
Crew Quarters (x3)	234		6.63	
ESA	995	2772	28.19	78.49
Columbus	995	2772	28.19	78.49
JAXA	2290	6065	64.84	171.75
JEM-PM	1723	4571	48.79	129.44
JEM-ELM PS	567	1494	16.05	42.31
Russian Segment	3209	10648	90.99	301.54
FGB	903	2423	25.70	68.61
SM	1339	3411	37.92	96.60
DC1	380	523	10.76	14.81
MLM		2472		70.00
MRM1*	207	614	5.85	17.40
MRM2	380	523	10.76	14.81
Soyuz		412		11.66
Progress		270		7.65

*MRM1 information based off calculations done from images, results are considered estimates.

**Information obtained through ECLSS Team, International Partners, and IVC Team analysis.

HAB volume (similar to US Lab)
- **Pressurized: 111.51 m^3**
- **Habitable: 34.77 m^3**

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

Vehicle Habitable Volume Summary

4 Crew / 60-Day Configuration

- DSH-ISS Element Summary
  - HAB (same size as US Lab)
    - Pressurized Volume: ~107 m^3
    - Habitable Volume: ~56 m^3
  - Tunnel
    - Pressurized Volume: ~10 m^3
    - Habitable Volume: ~9 m^3
- Sub-Total
  - Pressurized Volume: ~117 m^3
  - Habitable Volume: ~65 m^3

  - MPCV
    - Pressurized Volume: ~20 m^3
    - Habitable Volume: ~9 m^3
- Total
  - Pressurized Volume: ~137 m^3
  - Habitable Volume: ~74 m^3

4 Crew / 500-Day Configuration

- DSH-ISS Element Summary
  - HAB (same size as US Lab)
    - Pressurized Volume: ~107 m^3
    - Habitable Volume: ~56 m^3
  - Tunnel
    - Pressurized Volume: ~10 m^3
    - Habitable Volume: ~9 m^3
  - MPLM
    - Pressurized Volume: ~76 m^3
    - Habitable Volume: ~25 m^3
- Sub-Total
  - Pressurized Volume: ~193 m^3
  - Habitable Volume: ~90 m^3

  - MPCV
    - Pressurized Volume: 20 m^3
    - Habitable Volume: 9 m^3
- Total
  - Pressurized Volume: 213 m^3
  - Habitable Volume: 99 m^3

4 Crew / 60-Day case

EXAMINE Tool

Design Constraints/Parameters

Pressurized Vol.	92.1 m^3
Habitable Vol.	56.0 m^3
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	20%
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 Subsytem	*901*
Water Subsytem	*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 (waterwa	**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 m^3/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

4 Crew / 500-Day case
EXAMINE Tool

Graphic not to scale

Design Constraints/Parameters

Pressurized Vol.	185.7 m^3
Habitable Vol.	102.2 m^3
Atmospheric Pressure	70.3 kPa
Crew Capacity	4
Crewed Mission Duration	500 d
EOL Solar power generation	15 kW
Total battery energy storage	27 kW-h
Number of Batteries	3
Depth of Discharge	80 %
Power load during battery operati	11.0 kW
ECLSS Closure - Water	Partially Closed
ECLSS Closure - Air	Partially Closed
Habitat Structure	Rigid Cylinder
Habitat Height	9.98 m
Habitat Diameter	5.00 m
Mass Growth Allocation	20%
Project Manager's Reserve	10%

Category	Mass, kg
Structure	**5,629**
Protection	**268**
Propulsion	**0**
Power	**1,141**
Control	**0**
Avionics	**453**
Environ./Active Therm	**12,307**
ECLSS	8,391
Air Subsytem	*1,164*
Water Subsytem	*1,807*
Food	*3,606*
Human Accommodations	*1,274*
Other	*540*
EVA systems	635
Thermal Control System	699
Crew Accommodations	2,583
Growth	**5,940**
DRY MASS SUBTOTAL	**25,739**
Non-cargo	**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 (waterwa	**2,055**
INERT MASS SUBTOTAL	**32,925**
Non-propellant	**1,084**
Propellant	**0**
TOTAL WET MASS	**34,009**

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 m^3/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