Developing a Habitat for Long Duration, Deep Space Missions

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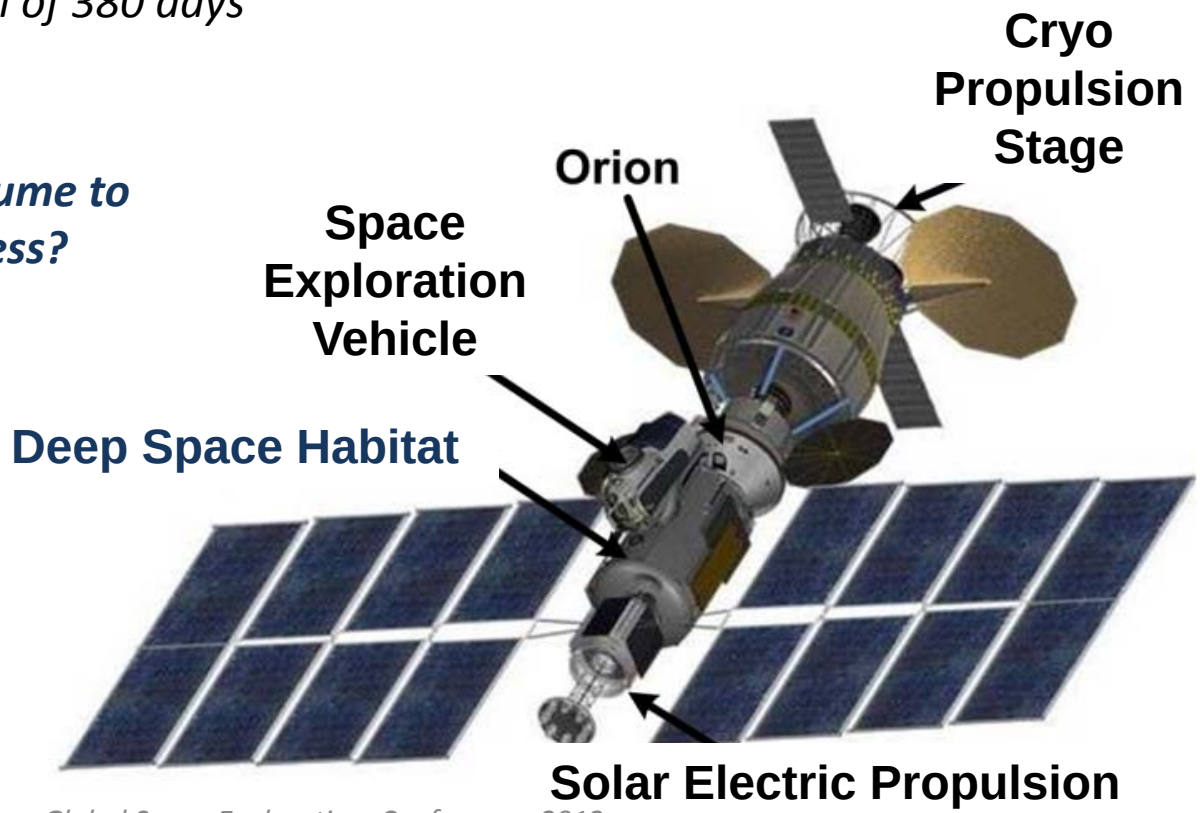
- *Problem Addressed*: Spacecraft design is an iterative process. But where to begin?
- *Solution Proposed:* "Bottoms Up" analysis to establish a point of departure volume and layout
- *Possible Applications:* Used here to initially size a deep space habitat, but could be useful for initial estimates of other habitable spacecraft
- *Conclusions:* Methodology produced a solution that fits within the bounds of historical spacecraft design precedent

Background and Issue

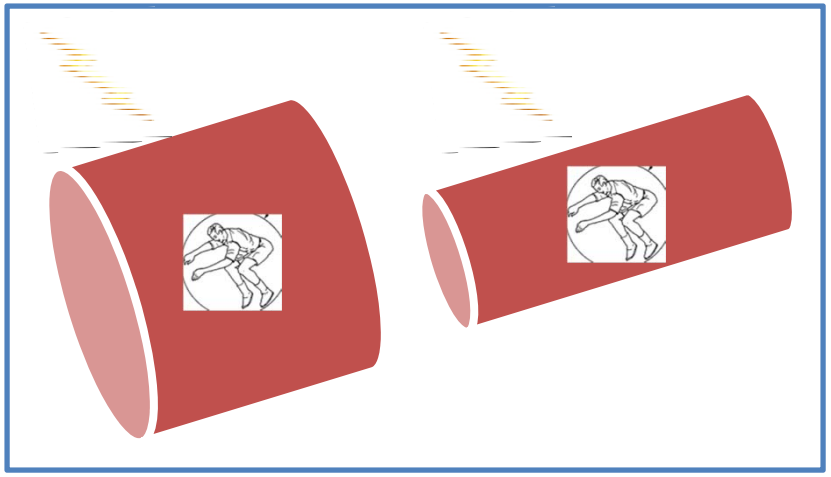
- **Mission**
  - Design Reference Mission 34B
  - 157 days transit from Earth, followed by 30 days at NEA 2008EV5 and 193 day return to Earth
    - *Crewed mission total of 380 days*
  - 4-crew
- **Issue**
  - ***What size DSH to assume to start the design process?***



Approach

- **Established Maximum Outer Diameter & Orientation**
- **Defined mission system functions**
  - Volume required, Frequency, and Duration
- **Combined Like Functions That Can Share Volume without Conflict**
- **Determined Module Length Needed for Estimated Functional Volume**
- **Developed Layout that:**
  1. Minimizes transit time between related crew stations
  2. Accommodates expected levels of activity at each station
  3. Isolates stations for health, safety, performance, and privacy
  4. Provides a safe, efficient, and comfortable work/living environment

Establish Diameter and Orientation

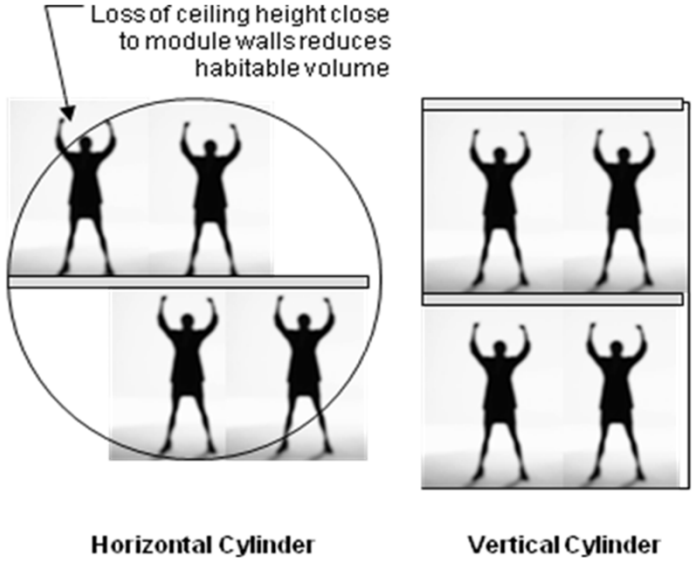


Make It Big Enough…

- ❑ Short/squat module offers more potential radiation protection than long/skinny module

…But Not TOO Big

- ❑ Keep transportation constraints in mind
  - 7.3 m diameter x 15 m long fits inside available transport aircraft, but need to leave room for plumbing, wiring, shields
- ➢ ***Assume Max. Outer Shell Diameter of 7.0 m (22.97 ft)***



Vertical Cylinder Makes More Sense Than Horizontal Cylinder

Evaluate Functional Volumes

Functions potentially requiring volume INSIDE Module

Individual Crew Care
- Full Body Cleansing
- Hand/Face Cleansing
- Exercise
- Personal Hygiene
- Urination/Defecation
- Sleep
- Private Recreation/Leisure
- Clothing Maintenance
- Dressing/Undressing
- Medical Care

Group Crew Care
- Meal Prep
- Eating
- Meal Cleanup
- Group Recreation/Leisure

Spacecraft Ops
- General Housekeeping
- Maintenance/ repair
- Subsystem Monitoring and Control
- Integrated Stack Command & Control
- CPS Dock/Command & Data interface
- SEP Dock/Command & Data interface
- SEV Dock/Command & Data interface
- MPCV Dock/Command & Data interface

Mission Ops
- Meetings
- Planning/Scheduling
- SEV Crew Transfer
- MPCV Crew Transfer
- EVA
- Pre/Post EVA Ops
- IVA Support of EVA
- Proximity Ops
- Training
- Payload Support
- Life Sciences Experiments
- Materials Processing Experiments

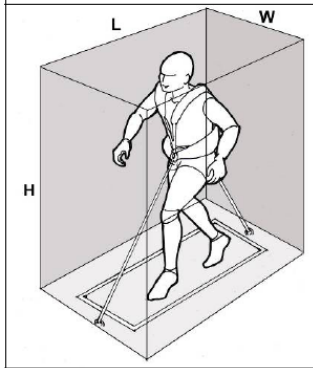
Logistics & Resupply
- Food, Water, Clothes, Medicine, Subsystem Spares

Subsystem Equipment
- Life Support
- Thermal
- Power
- EVA
- C&DH
- GNC
- Structures
- Mechanisms
- Propulsion
- C&T

Contingencies
- Fire
- Toxic Atmosphere
- Cabin Depress
- Radiation Event
- Fatality

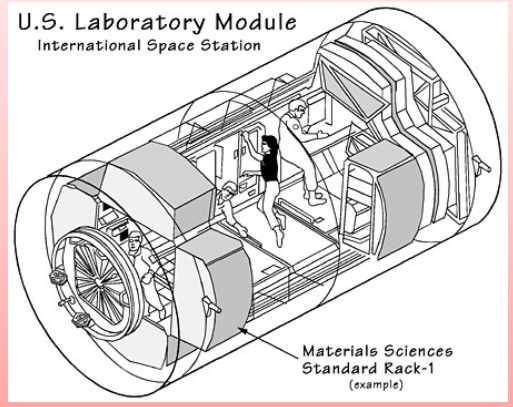
Examples of Initial Sizing Assumptions

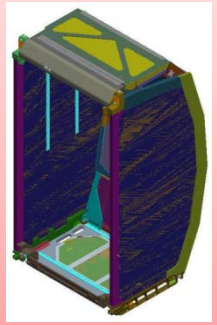
Activity envelopes per NASA Human Integration Design Handbook (HIDH)

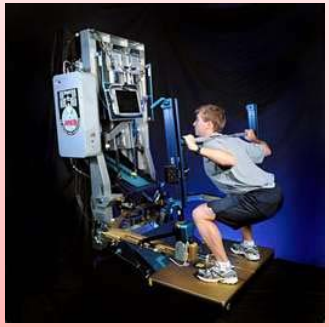
Figures of Human Body Postures and Volumes	Applicable Functions	Dimensions (m)		Volume (m^3)
	Exercise-1 (Treadmill with Vibration Isolation System (TVIS))	H	2.10	**6.12**
		L	2.37	
		W	1.23	

Consumables data from International Space Station (ISS)

Subsystem equipment volume estimates from ISS







Evaluate Frequency/Duration

Some functions require dedicated volumes due to technical constraints

Other functions are so rare that they can easily share volume

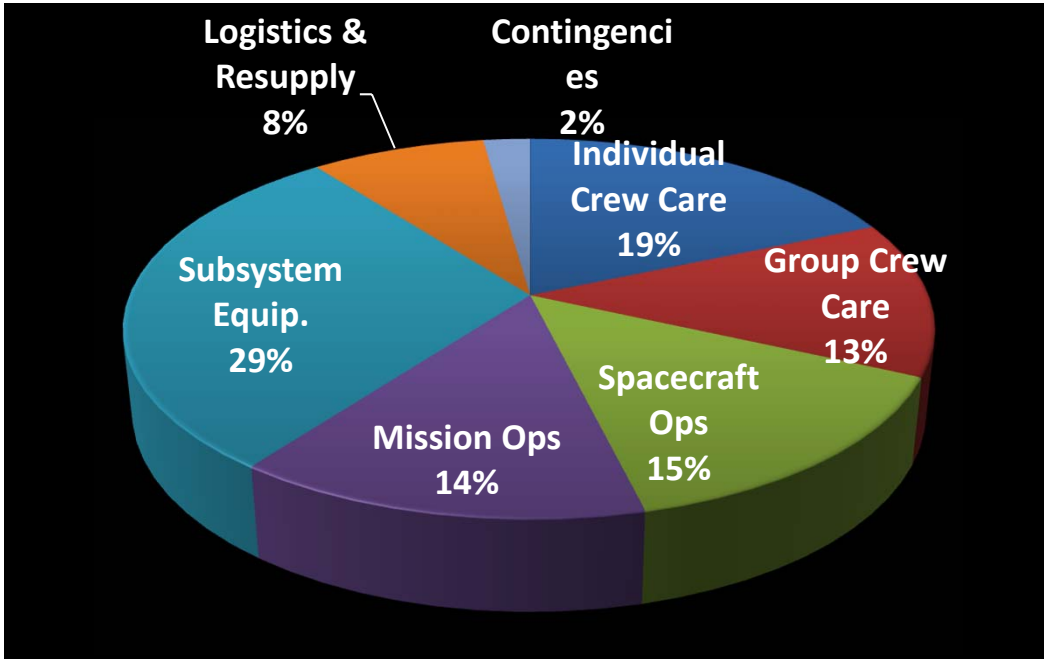
Function	Volume (m3)	Location	Dedicated Area?	Can Share Volume with These Functions		Frequency	Duration	Rationale & Assumptions
Emergency Medical Care	0	Stationary	No	Life sciences	Sleep	Contingency	Hours	Emergency medical equipment stowed at Life Sciences workstation; actual equipment is booked in line 68, medical spares
Full-body cleansing	4.34	Stationary	Yes			Weekly	Minutes	Per HIDH (2.06 m tall x 1.06 m deep x 2m wide)
Exercise	17.25	Stationary	Yes			Daily	Hours	Dedicated/stationary due to vibration isolation requirement; Volume based on ARED (6.61 m3) + T2 volume (1 rack = 1.571 m3) + NASA-STD-3001 body volume (2.95 m3 resistive + 6.12 m3 running (2.1 m H x 2.37m L x 1.23m W);
Eating	11.26	Stationary	Yes	Meetings and teleconferences	Small-group recreation and leisure	Daily	Hours	Stationary--near meal prep; but can share with other group activities. HDIH recommens 2.69 m3 per crew; Sized for 4 crew (4 x 2.69m3) + table (0.5 m3)
Meetings and teleconferences	11.26	Stationary	No	Eating	Small-group recreation and leisure	Daily	Hours	Same as eating

Some functions lend themselves well to sharing

With Shared Volume Assumptions

Function Category	Functional Vol (m3)	
	Total	Shared
Individual Crew Care	59.21	45.15
Group Crew Care	38.41	32.5
Spacecraft Ops	64.01	35.09
Mission Ops	63.88	34.33
Subsystem Equip.	71.7	71.7
Logistics & Resupply	20.02	20.02
Contingencies	5.4	5.4
TOTALS	**322.63**	**244.19**

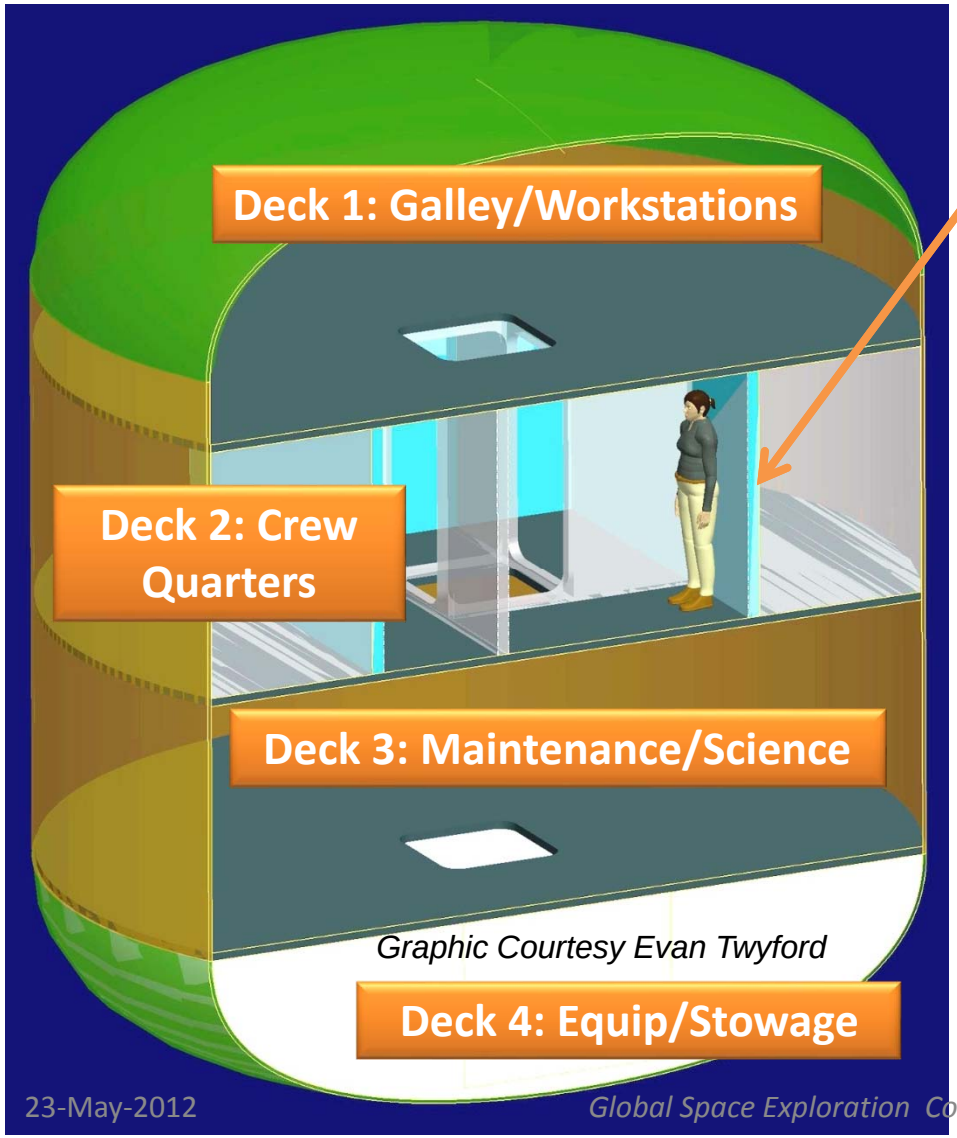
Sharing reduces volume by about 24%



- **After assumptions about which activities can share the same volume: 244.19 m3**
- **Add 10% for structural inefficiencies and unknown unknowns: +24.42 m3**
- **Minimum Volume Needed: 268.61 m3**

7 m dia x 8 m long cylinder with elliptical domes is 274.9 m3

Summary of Layout Features



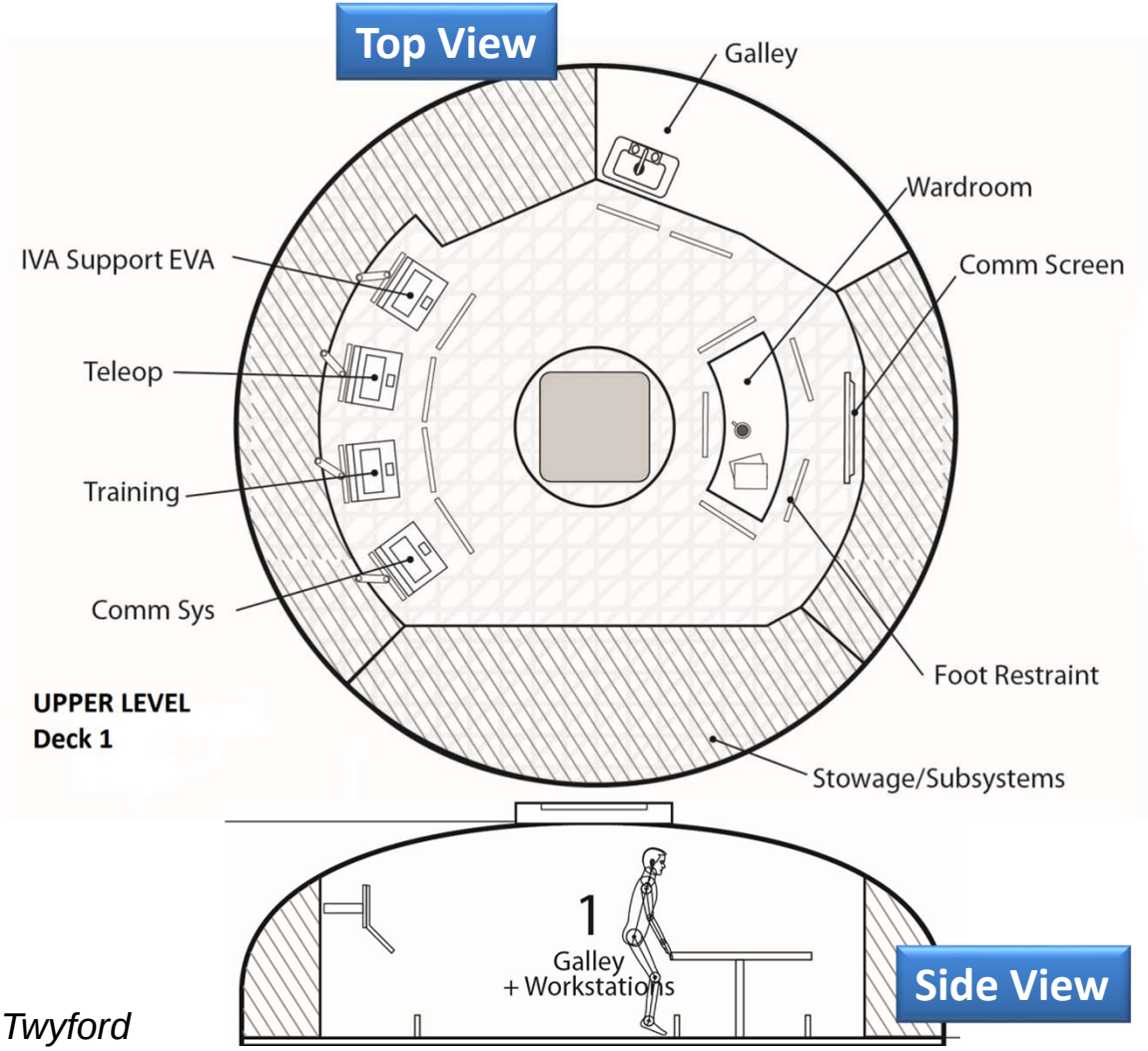
Notional "Water Wall"

- **Shape:** Vertical Cylinder
- **Outer Diameter:** 7.0 m
- **Length:** 8m
- **Volume**: 274.9 m3
- **End Domes:** Elliptical
- **Decks:** 4
- **Hatches:** 3
- **Docking Ports**: 4

Interface	Hatch	Docking Sys.
MPCV	Deck 1	Deck 1
MMSEV	Deck 3	Deck 3
SEP	--	Deck 4
Contingency	Deck 3	Deck 3

Deck 1: The Great Room

- **Spacecraft Control**
  - Subsystem Consoles
  - Subsystem Equipment
- **Dining**
  - Galley
  - Ward room
- **Planning**
  - Teleconference Area
  - Meeting Area
- **Group Recreation**
- **Volume:**
  - 67.9 m3 (2399.7 ft3)



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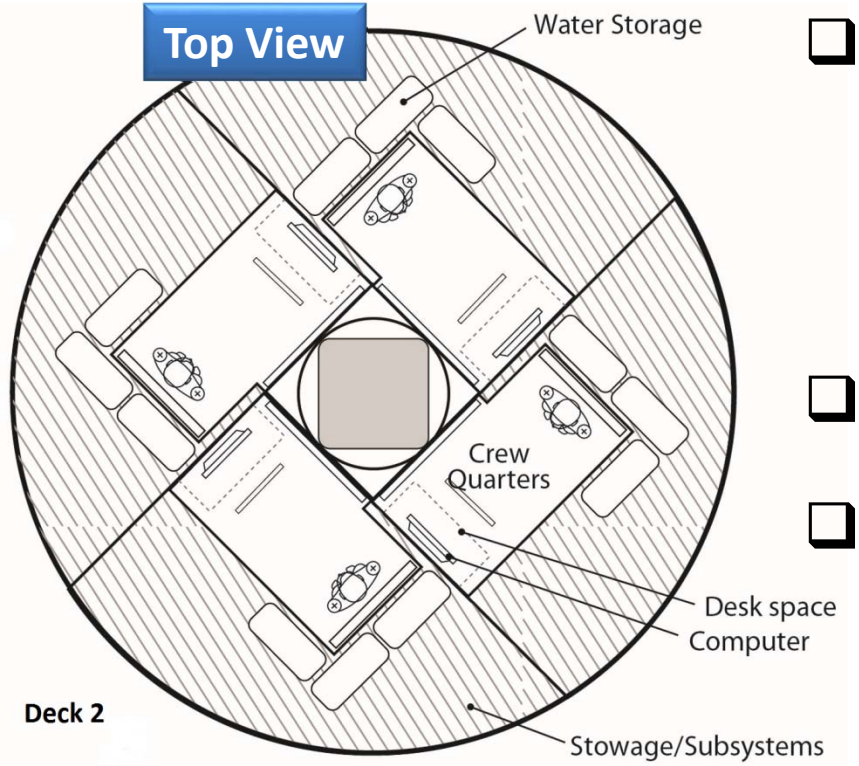
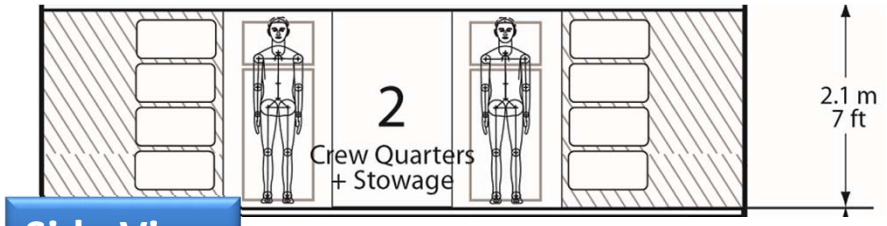
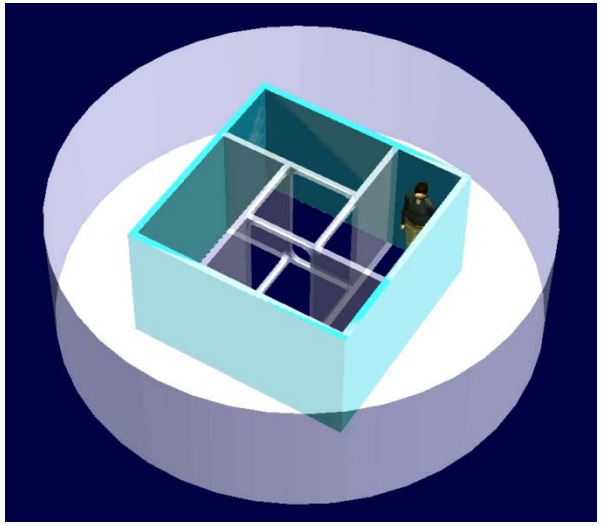
Deck 2: Bedrooms





- **Crew Quarters**
  - Water wall for radiation protection
  - No moving equipment mounted above ceiling or below floor to minimize noise
  - Central passageway
- **Stowage**
  - Additional radiation protection
- **Volume**
  - 80.8 m3 (2854 ft3)



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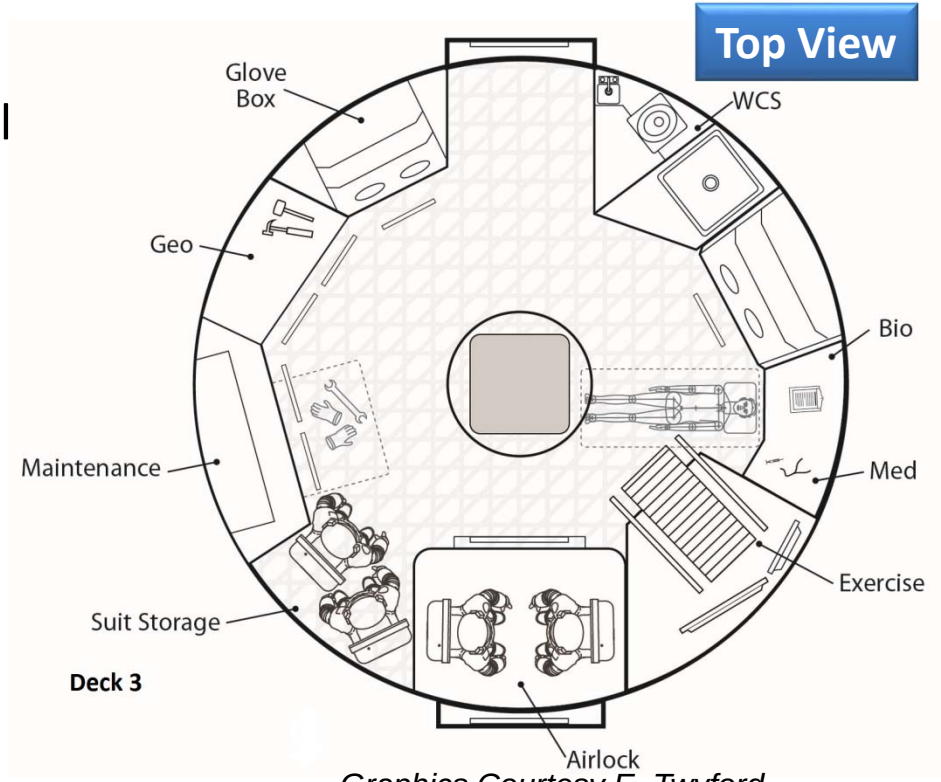
Deck 3: Garage & Bathroom

- **Airlock**
  - TBD whether internal/external
- **Maintenance Area**
  - External ORUs come in thru airlock for repair
- **Waste/Hygiene**
  - Readily accessible from crew quarters
  - Relatively isolated from galley
- **Gym**
  - Treadmill & resistive exercise
- **Science Area**
  - Geology & Life Sciences
- **Volume**
  - 80.8 m3 (2854 ft3)



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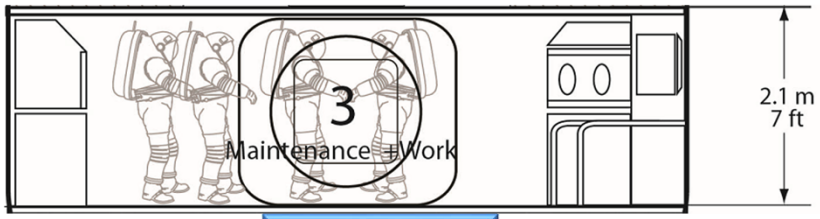
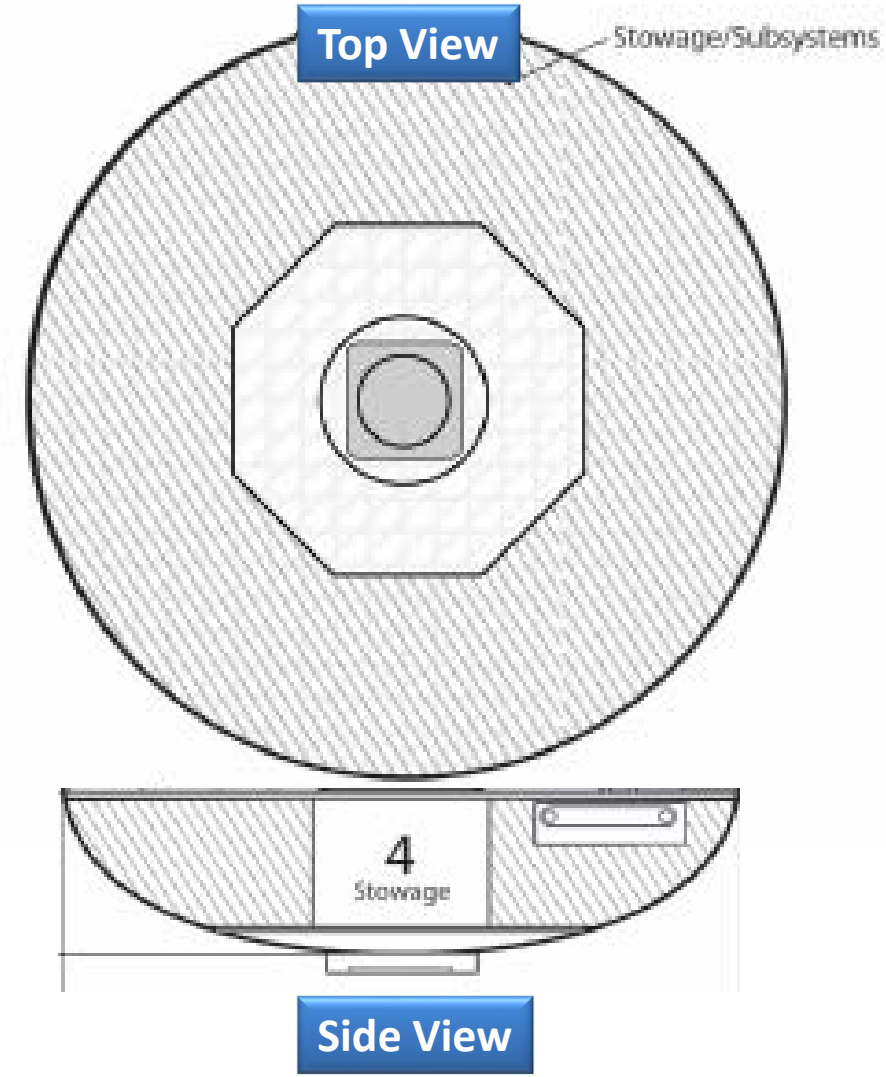


Deck 4: Basement

- **Subsystem Equipment**
  - Noisy or dangerous equipment as far as possible from crew quarters & safe haven
    - Treadmill stabilization
    - High pressure oxygen equipment
- **Stowage**
  - Spare parts
- **Volume**
  - 45.3 m3 (1600.6 ft3)



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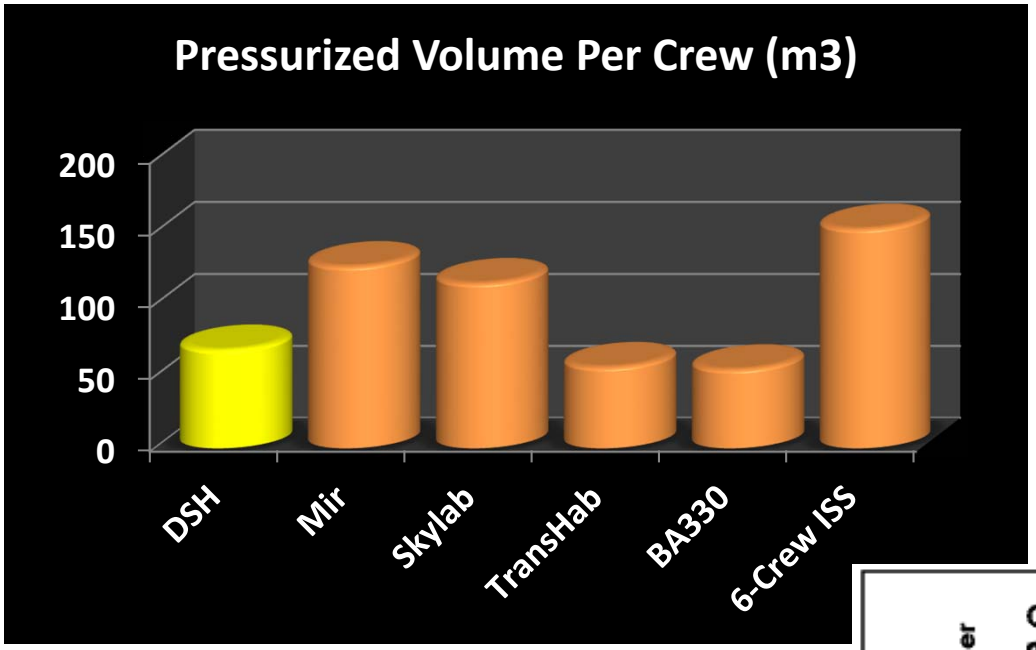
Sanity Check: Historical Comparison

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

Conclusion

Methodology Produces a Reasonable Point of Departure



Initial pressurized volume per crew member compares favorably to historical spacecraft designs

Habitable volume per crew member also seems reasonable with respect to historical design guidance