Spacecraft Habitability (part 2)

- Biomechanics of jumping
- Access between levels
- Neutral body posture
- Case study: Skylab interior design
- Stowage and logistics
- Psychosocial issues (very brief!)
- Lander and rover layouts
- Windows and sight lines

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Jump Height and Floor-Ceiling Distance

- Ceiling heights are generally set to ensure that no inadvertent contact arises from any locomotion
- Simple analysis: assume constant jump energy

$$E_j = mgh = mg'h' \Longrightarrow h' = h\frac{g}{g'}$$

- Assuming a 0.5 m jump on Earth, this analysis predicts
  – Jump height on Mars = 1.4 m (3.4 m ceiling height)
  – Jump height on Moon = 3.1 m (5.1 m ceiling height)

Advanced Jump Height Analysis

- In jumping, leg strength is used for both supporting the body's weight and accelerating it upwards
- Assume that the total leg extension force F_j is constant (assumes no degradation of strength from space flight)
- In a lower gravity, more net force should be available for upwards acceleration

$$\frac{v_j'}{v_j} = \frac{F_j - mg'}{F_j - mg}$$

$$s_j = \frac{1}{2}\frac{v_j^2}{\frac{F_j}{m} - g}$$

Results of Partial Gravity Jump Analysis

Location	Simple analysis jump height (m)	% muscle effort available for jump	Ratio of Earth jump velocity V_j'/V_j	Jump velocity V_j (m/sec)	Advanced analysis jump height (m)
Earth	0.5	38	1	3.13	0.5
Mars	1.4	77	1.97	6.17	5.1
Moon	3.1	90	2.32	7.25	16.7

Conclusion on Ceiling Height

- The actual calculation of jump height will be more complicated than either of the techniques presented
- In any event, it will be impractical to build partial gravity habitats with ceiling heights to preclude inadvertent contact
- Microgravity habitats benefit from lower ceiling heights to provide additional translation grasp points
- Both partial gravity and microgravity habitats will probably adopt ~2.5 meter ceiling heights

Multilevel Interior Access

- Jumping analysis pertains here as well
- Ascending a stairway on Earth
  - Step height 0.18 m
  - Vertical velocity 0.36 m/sec
  - Requires 280W for 80 kg human
- At constant power,
  - Mars vertical velocity 1 m/sec; loft of 0.13 m
  - Lunar vertical velocity 2.2 m/sec; loft of 1.6 m
- To what extent do we have to design to accommodate continued deconditioning?

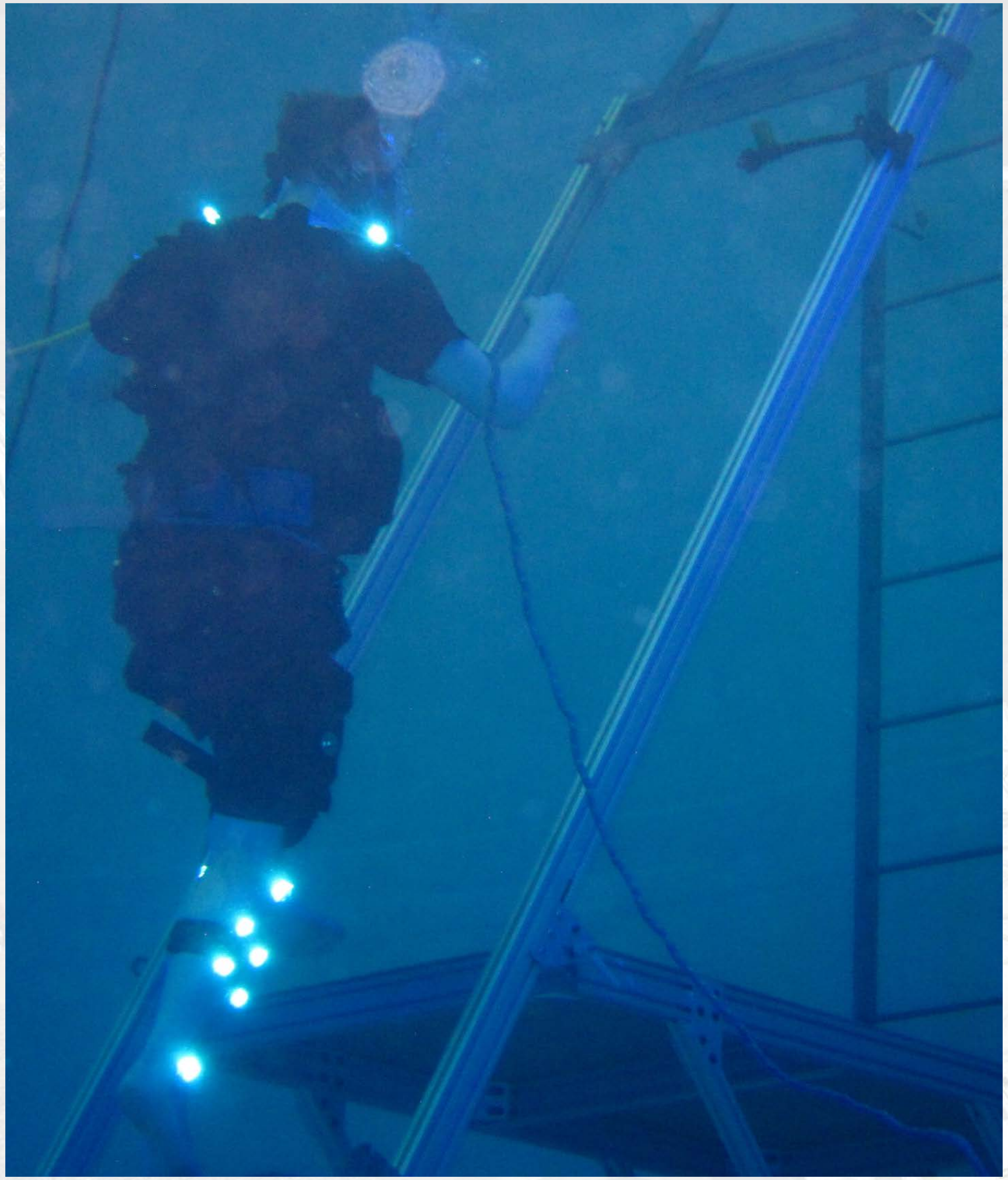
Stairways vs. Ladders

- Stairways require dedicated deck space for horizontal length of run on both decks
- At 40° rise angle, "standard" stairway will require footprint of 2.9 m x 0.75 m
- For two deck, vertically oriented cylinder with 5 m diameter, this represents an 11% loss of both floor area and interior volume
- Ladders present problem with translation between levels while carrying items, but take up less space

Partial Gravity Sims of Ladder Use

Initial Tests of Inclined Steps

Motion Capture for Stair Climbing



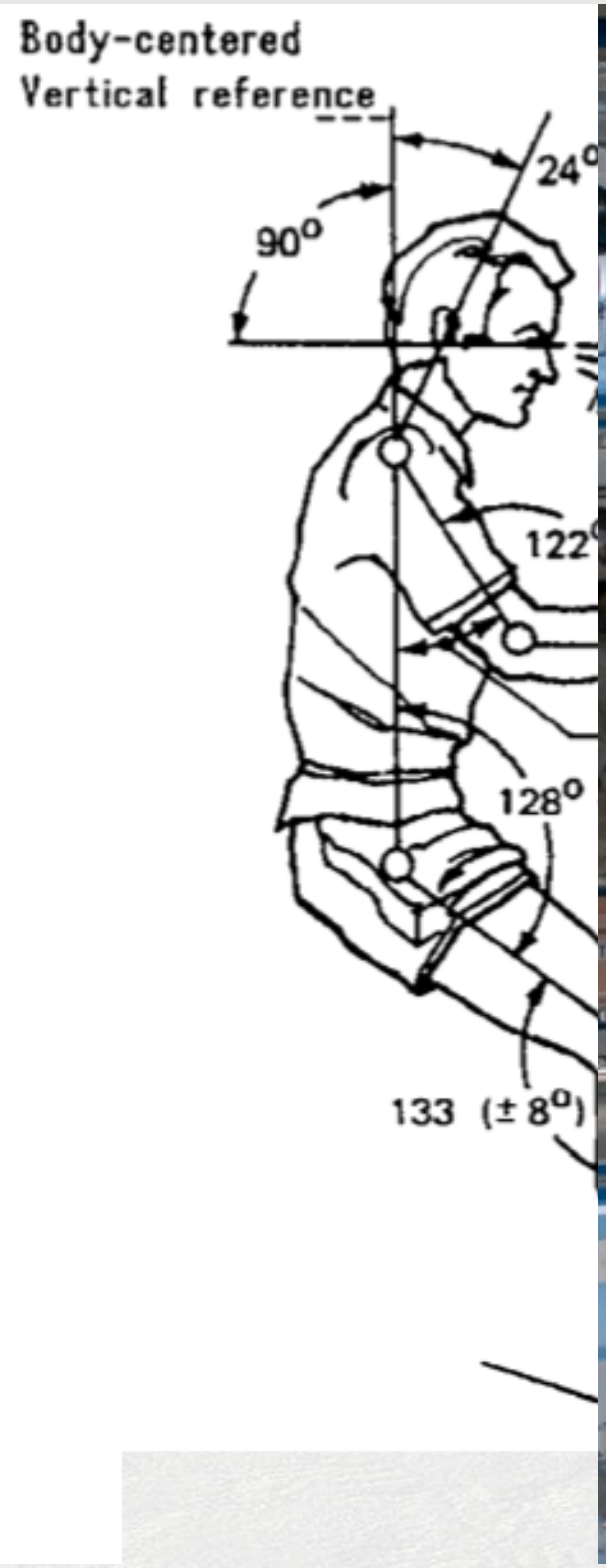
Impact of Jumping and Climbing

- Ceiling surfaces will be well within reach of even a moderate "bounce"
- Mobility modifications will be motivated by repeated head impacts
- Multilevel access will be a unique solution for each gravitational environment
  - Lunar system may be just a single intermediate platform
  - Mars system may look like stairway with 0.5-0.7 meter riser heights
- Need further research to better understand optimum stairway angles, riser heights, etc.

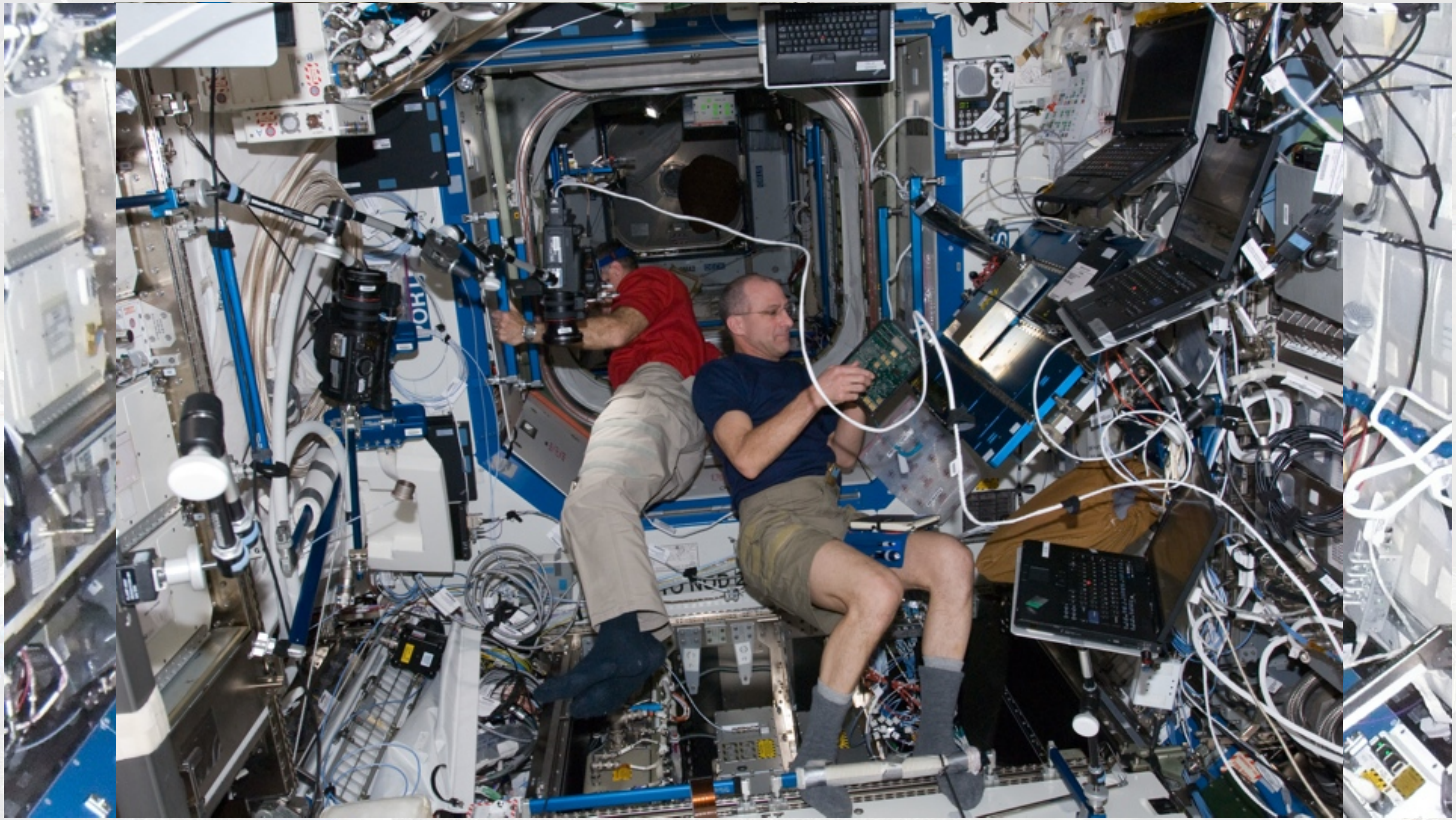
Interior Accommodations

- Partial gravity habitats use conventional interior spaces
  - Tasks divided between “standing”, “seated”, “reclining”
  - Orientation is fixed by gravity vector
- Microgravity workstations organized around neutral body posture
  - Pose assumed by body in microgravity when postural muscles are relaxed
  - Relative orientation fixed mostly by convention and need

Microgravity Neutral Body Posture



Other Examples of ISS Body Posture



Conclusion on Interior Accommodations

- Gravitational architecture only utilizes vertical surfaces
  - Floor and ceiling are used for support, transit, and secondary systems (e.g., lighting)
  - Strong desire in space architecture to take advantage of interstitial volumes created by fitting rectangular living volumes into cylindrical/ellipsoidal pressure vessels
- ISS experience indicates that crew readily performs in situ servicing rather than requiring fixed workstations with nominal neutral body posture

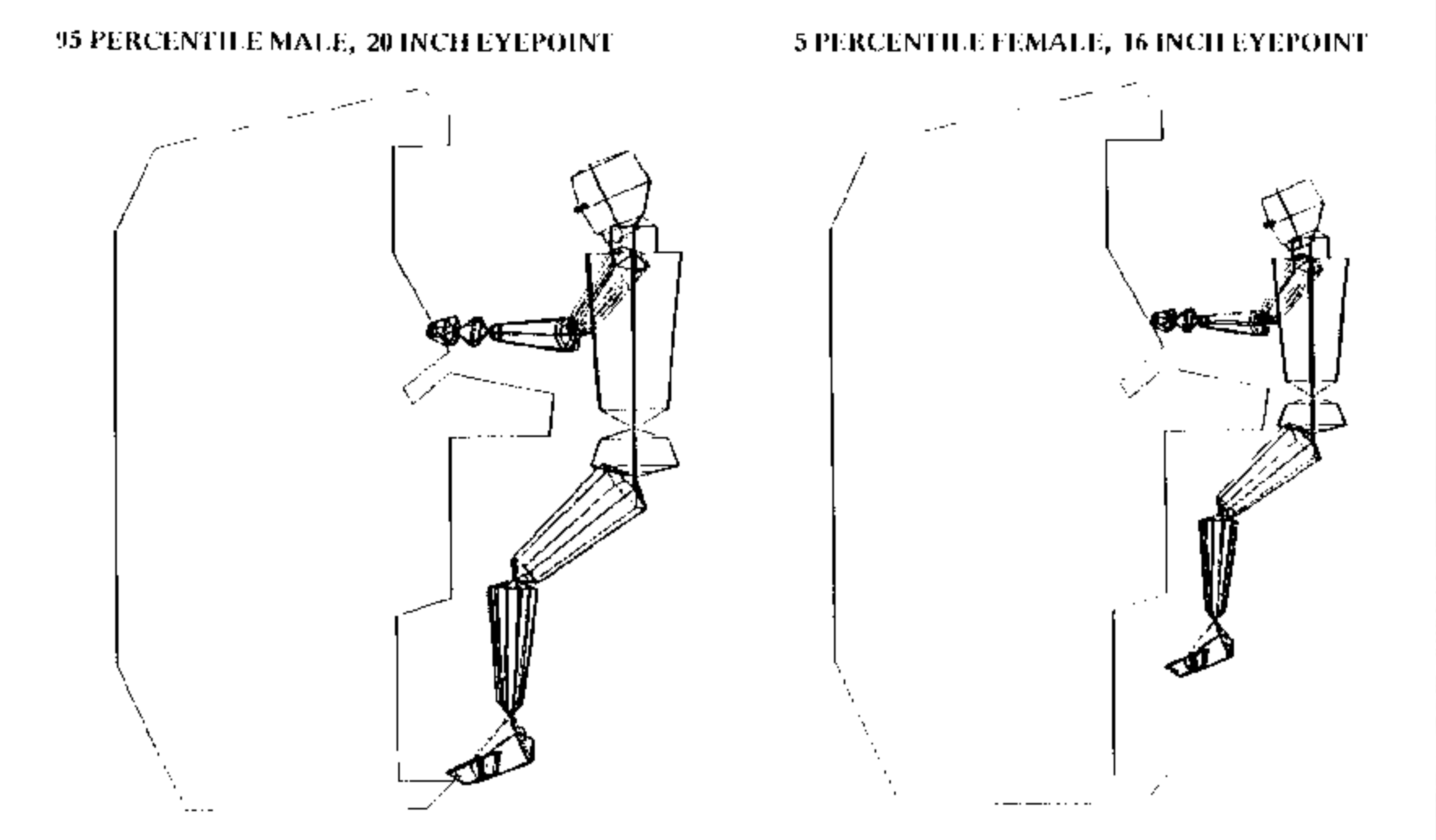
Overall Habitat Design Conclusions

- If habitable volume is the metric of interest, vertical orientations are optimal unless full hemispherical end caps are chosen
- Constant interior orientation is required in partial gravity and desirable for microgravity, but extended occupancy will mitigate demand for constant reference orientation
- Unless extensive deconditioning occurs, human leg strength will create interesting design challenges for habitat interiors

Overall Habitat Design Conclusions

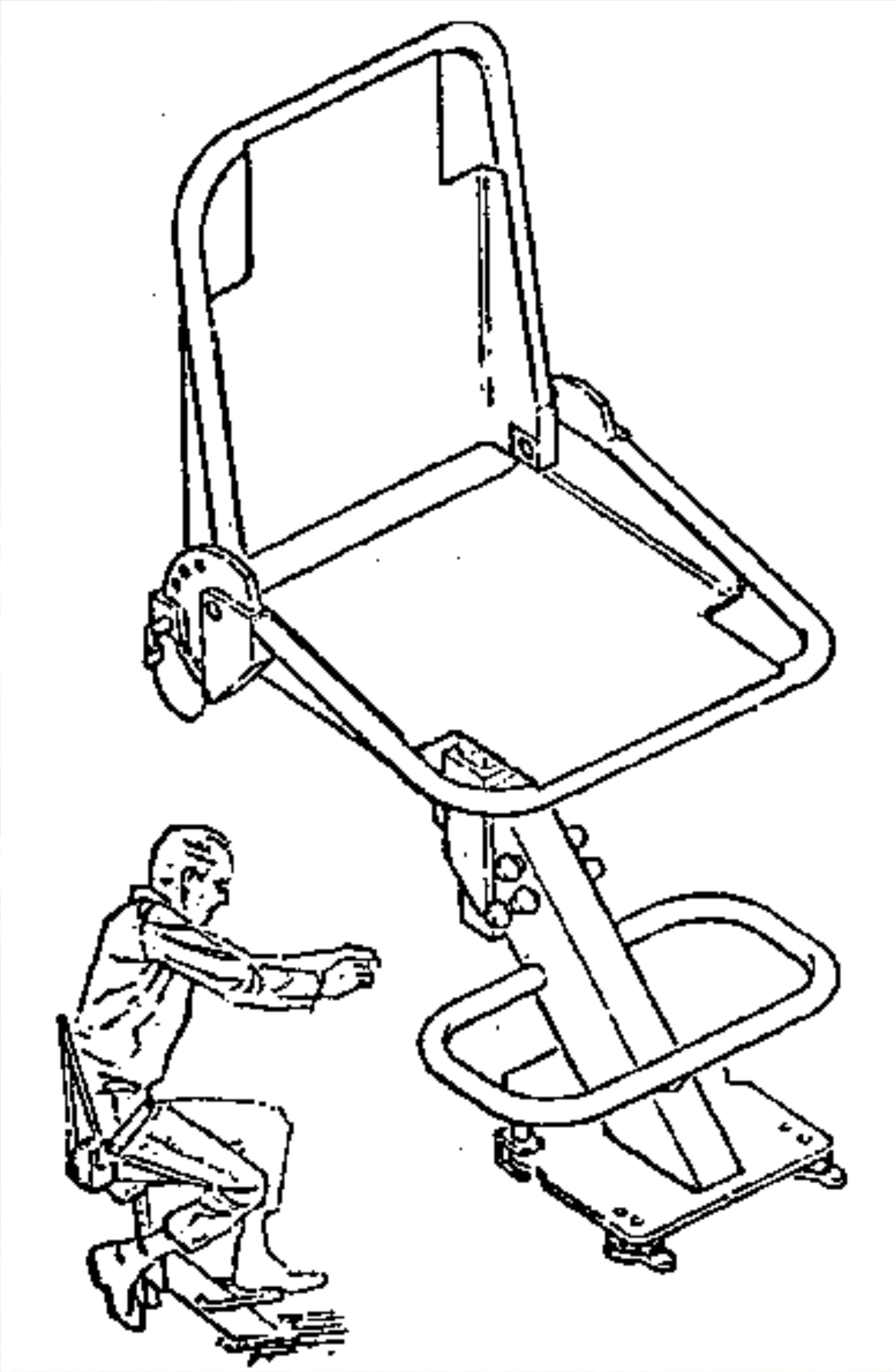
- Partial gravity and microgravity habitat interiors will tend to look alike
  - Common ceiling heights
  - General adoption of single reference orientation
- They will not, however, function alike – nor will they function like Earth habitats
  - Differences in interior translation, interdeck access, work station design, etc.
- The best way to understand habitat design experimentally is to provide equivalent gravitational environments (e.g., ballasted underwater testing)

0G Workstation Layout



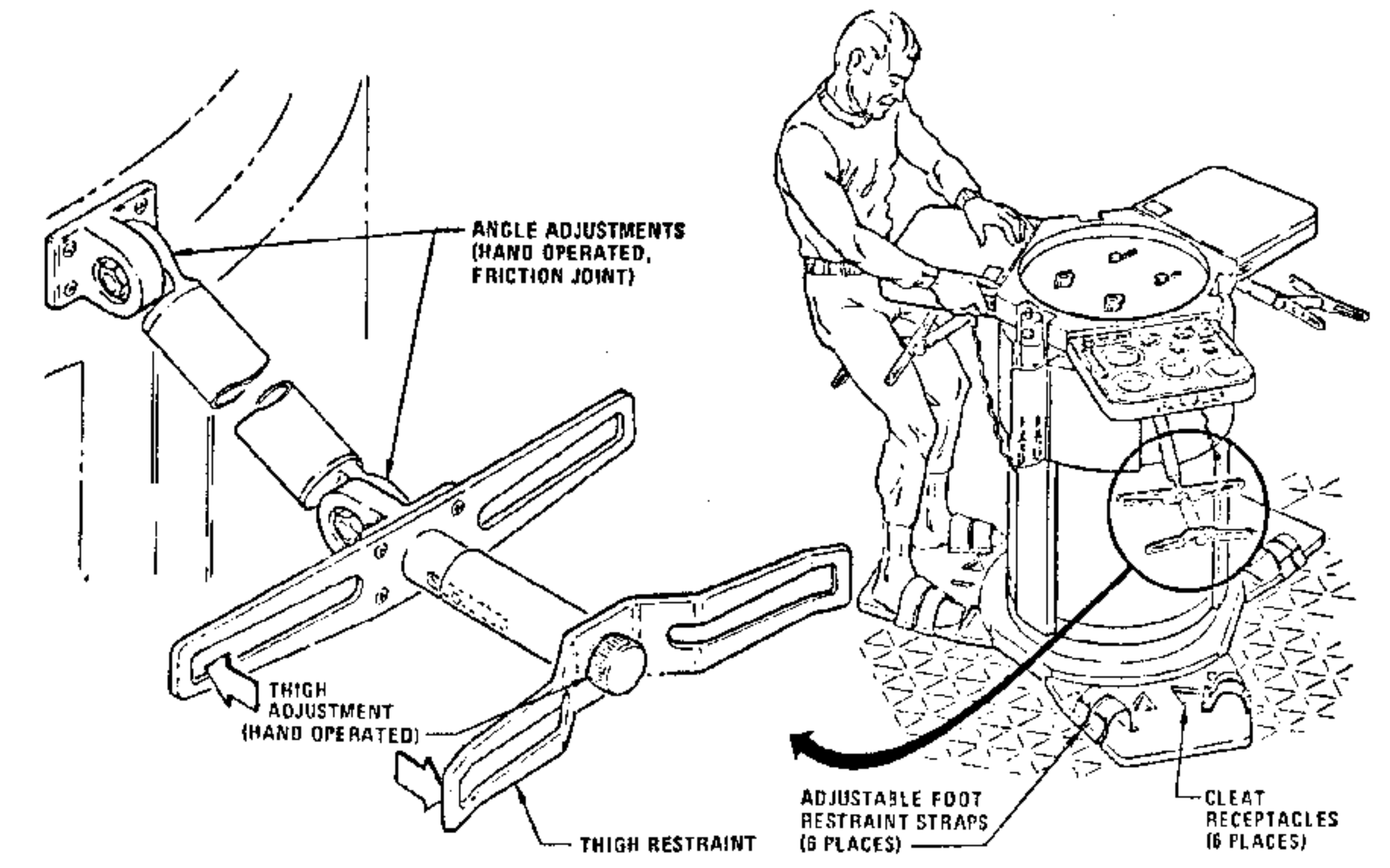
From Nicogossian et. al., Space Biology and Medicine, Vol. II: Life Support and Habitability, AIAA, 1994

Skylab Chair Restraint



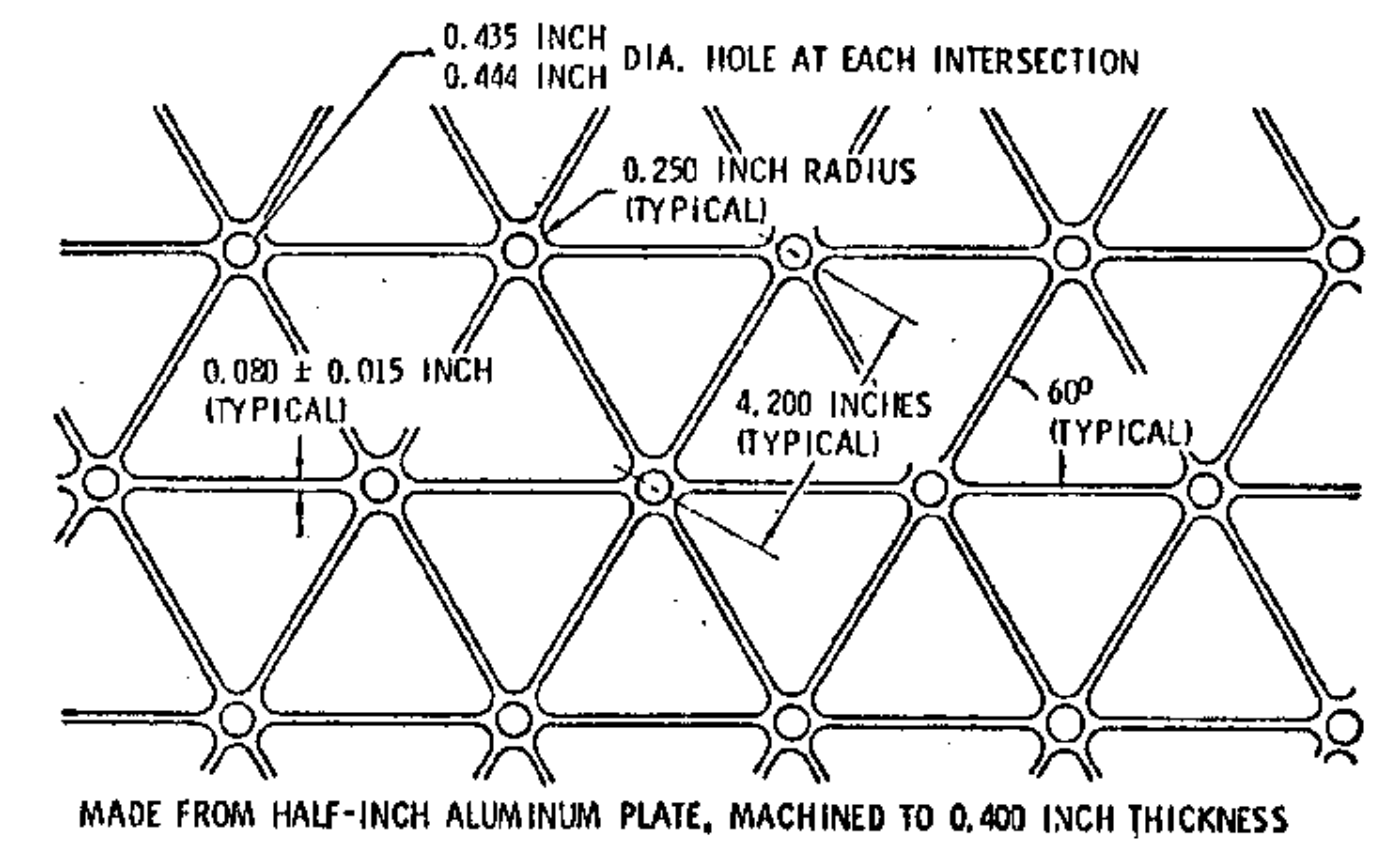
From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

Skylab Table Restraints



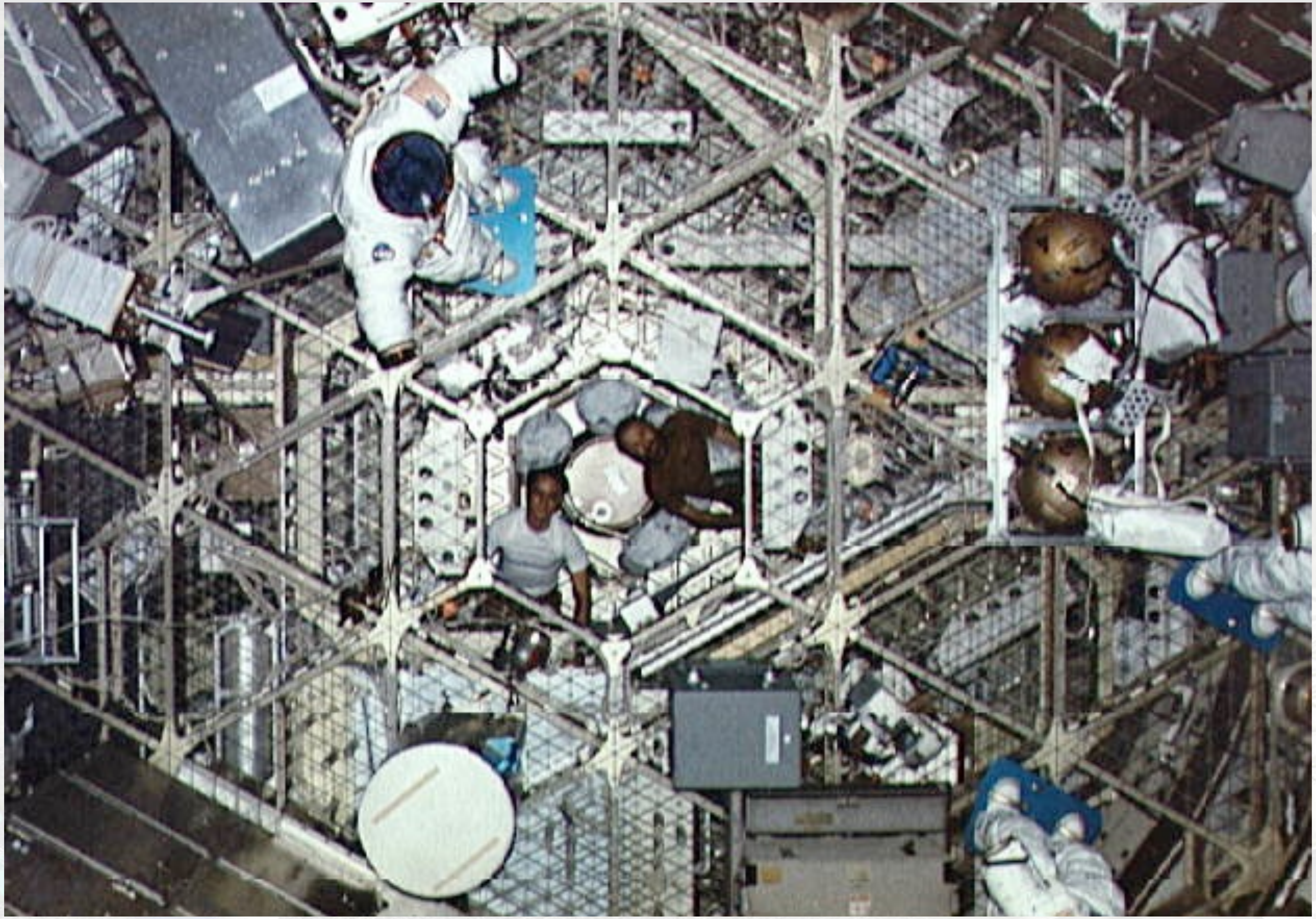
From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

Isogrid Flooring Design

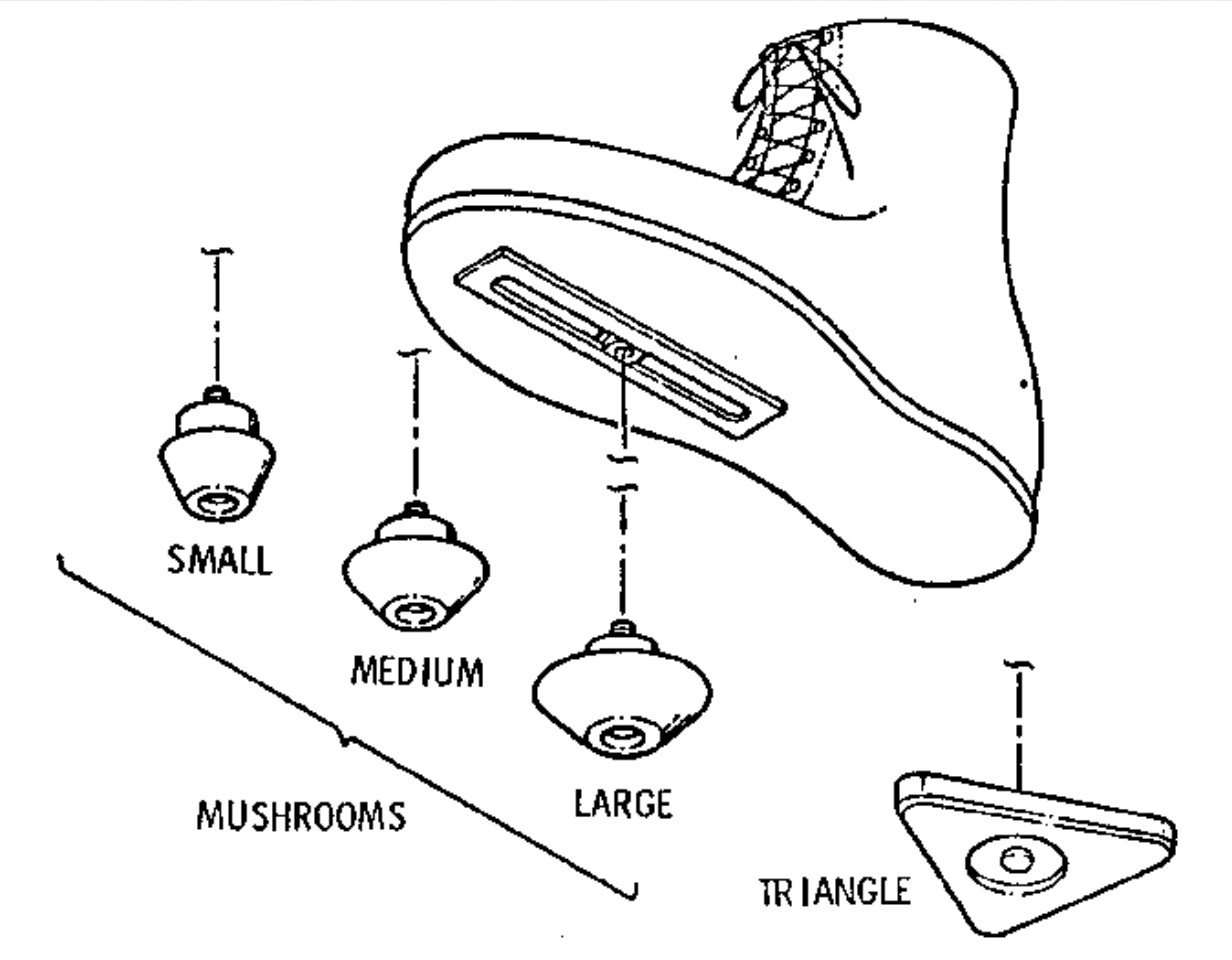


From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

Skylab Orbital Workshop Module

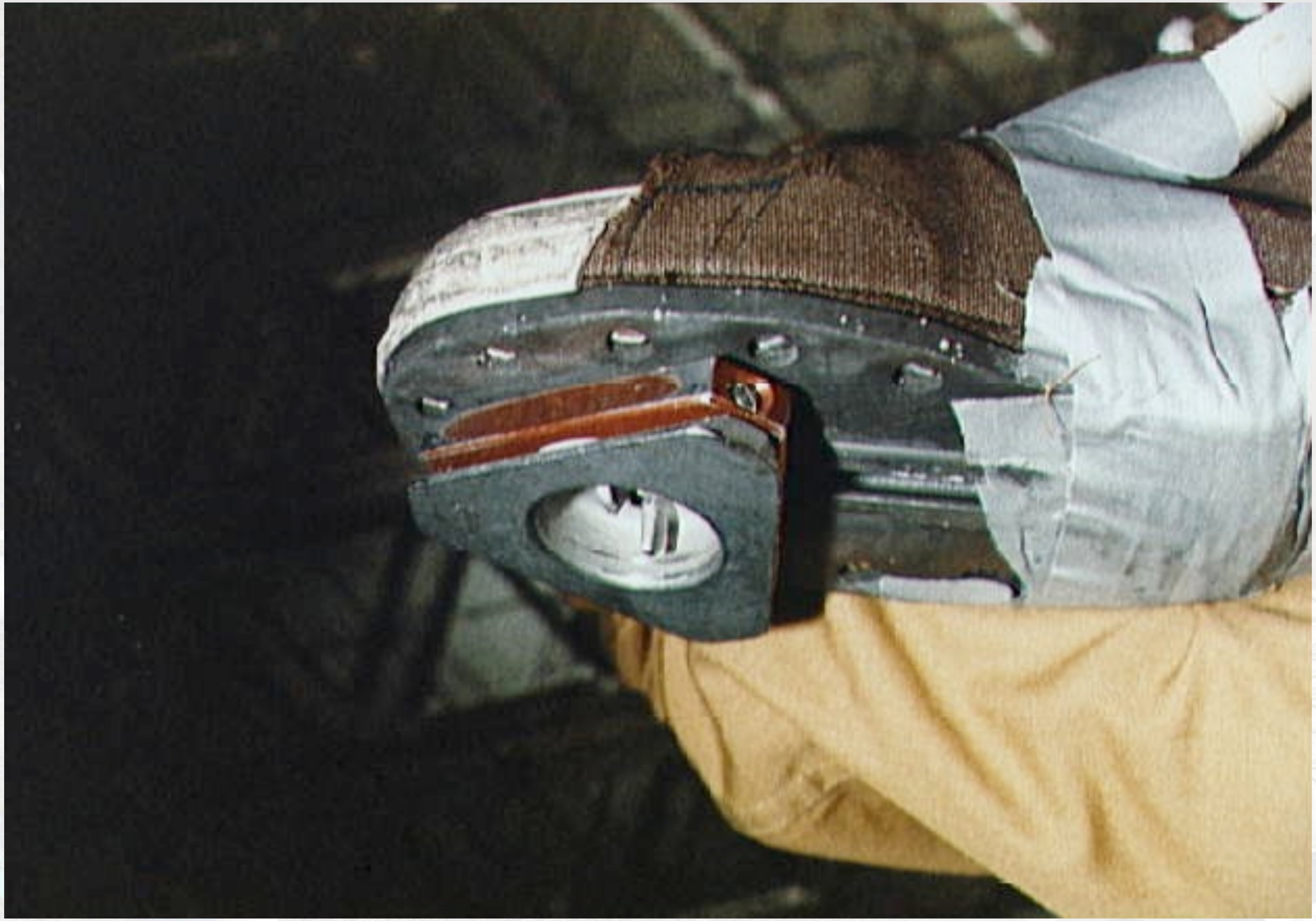


Cleat Restraint System

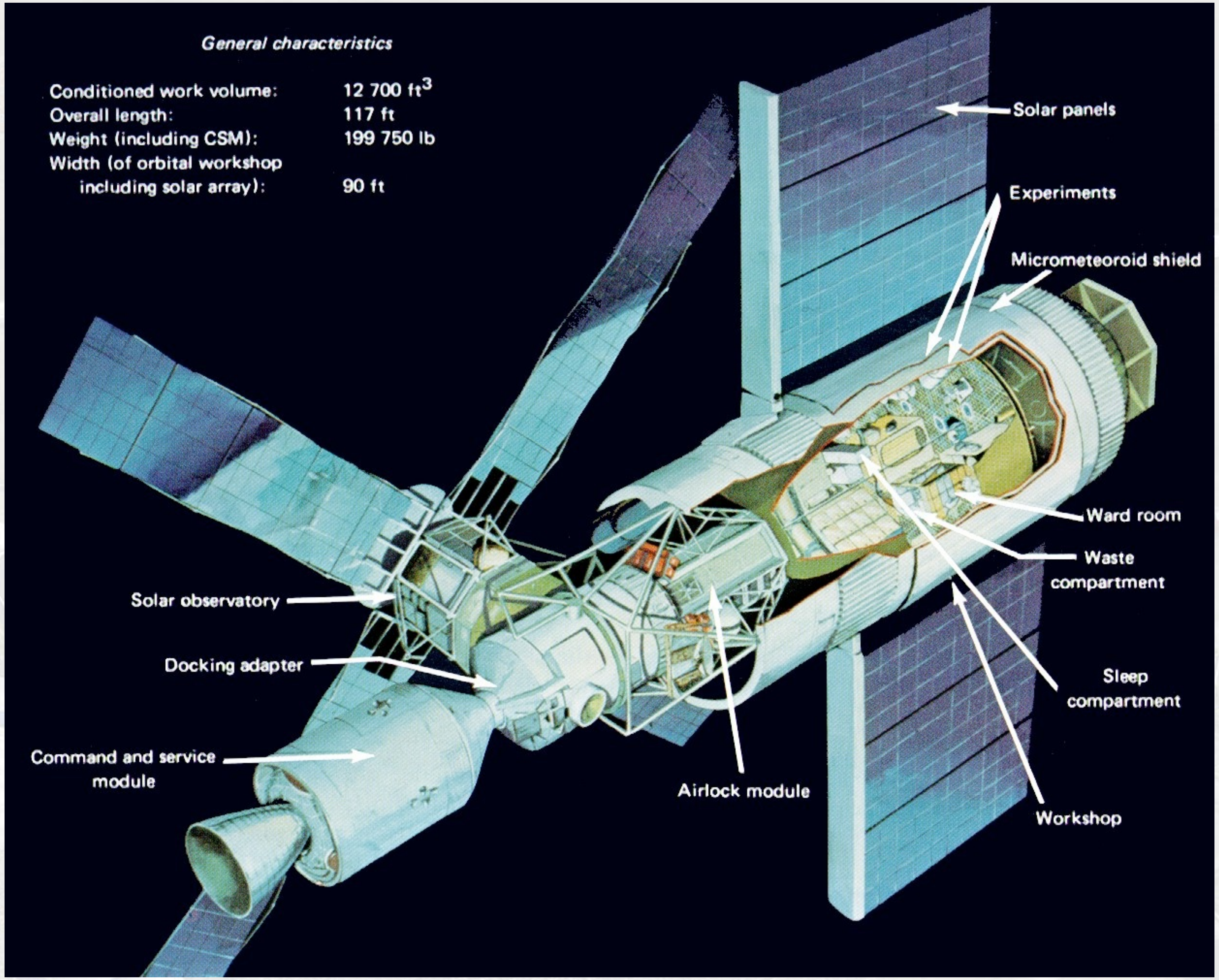


From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

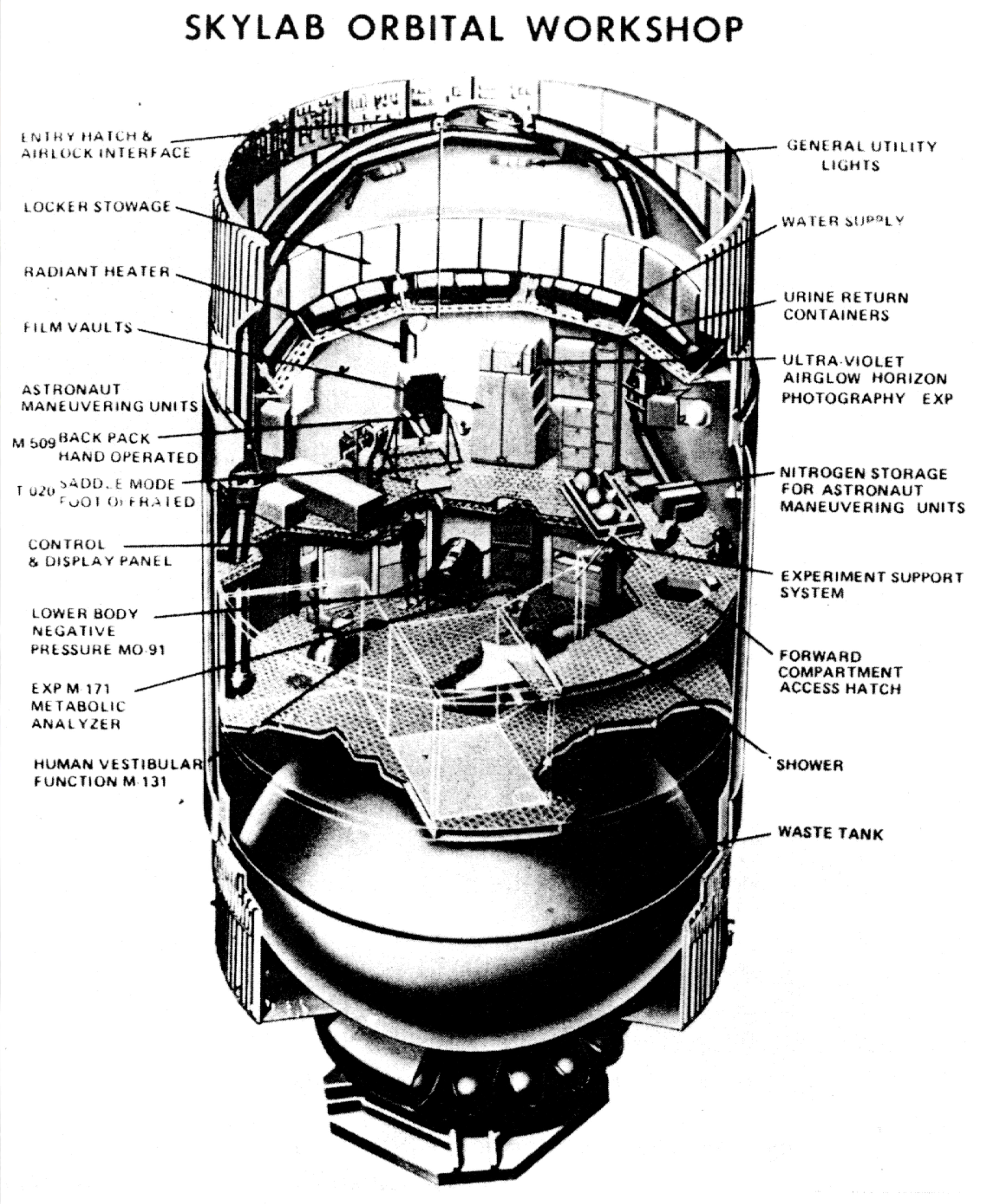
Skylab Triangle-Cleat Shoe



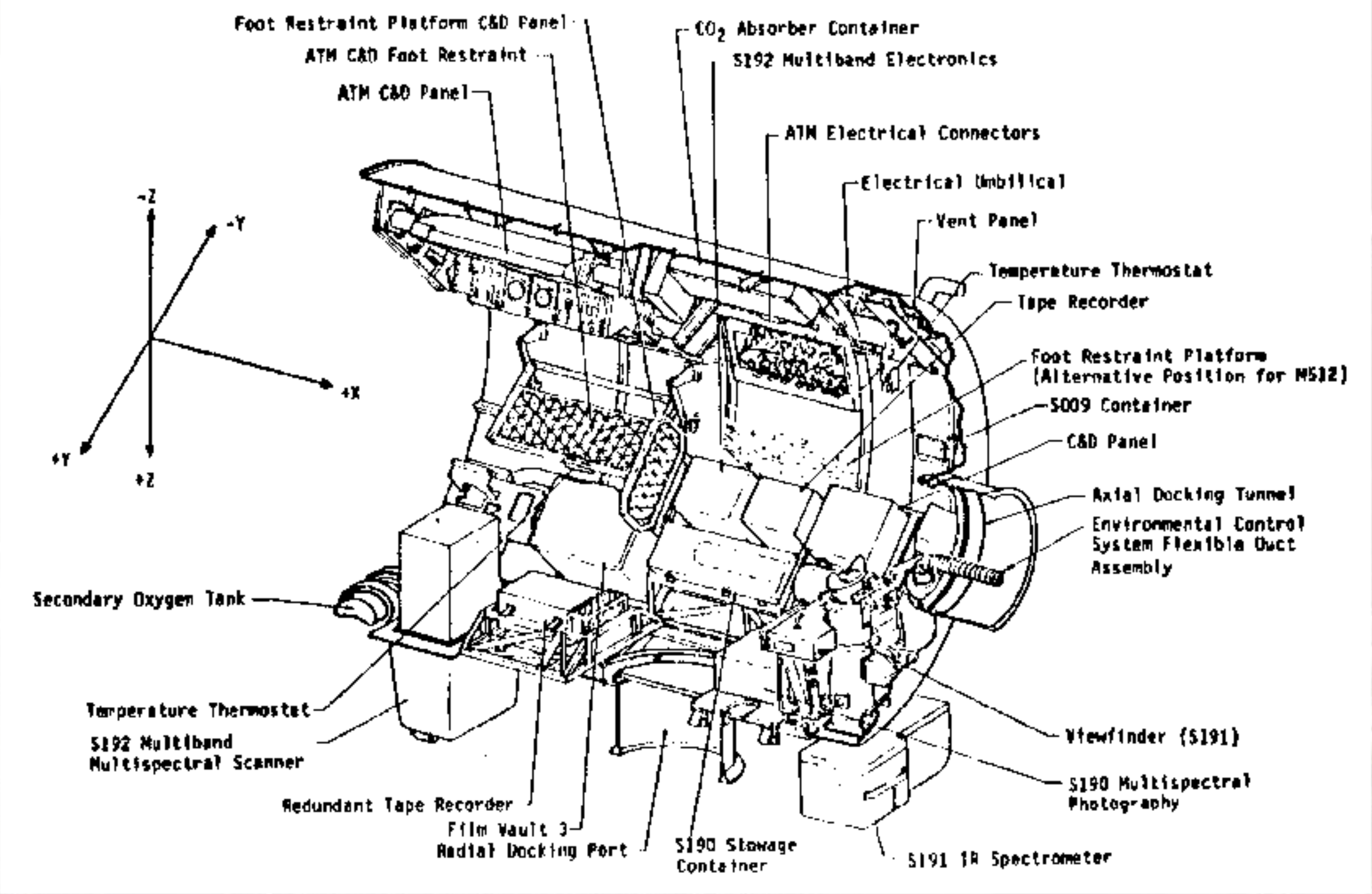
Skylab Exterior Configuration



Skylab Orbital Work Shop Interior

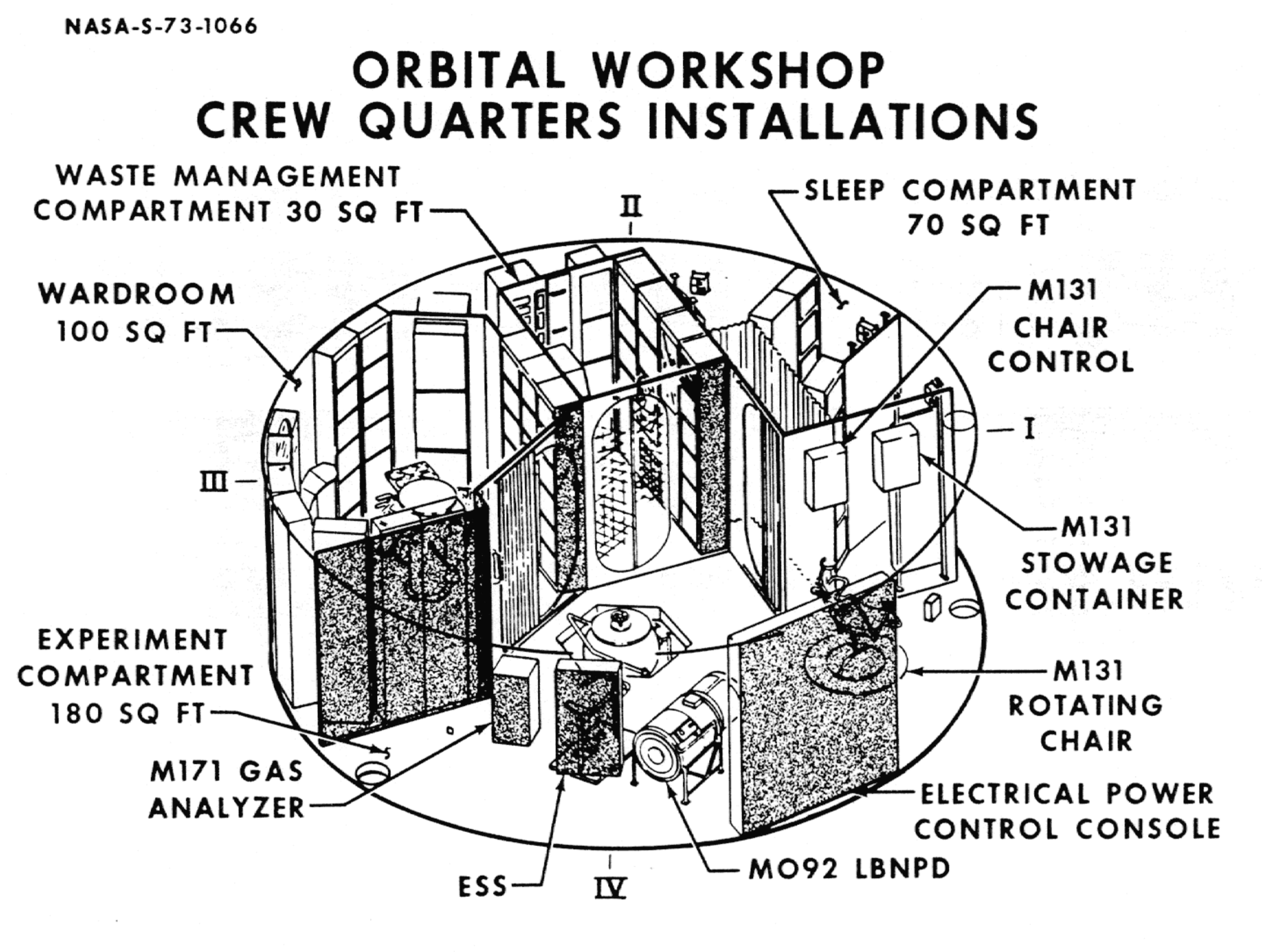


Skylab Multiple Docking Adapter Layout



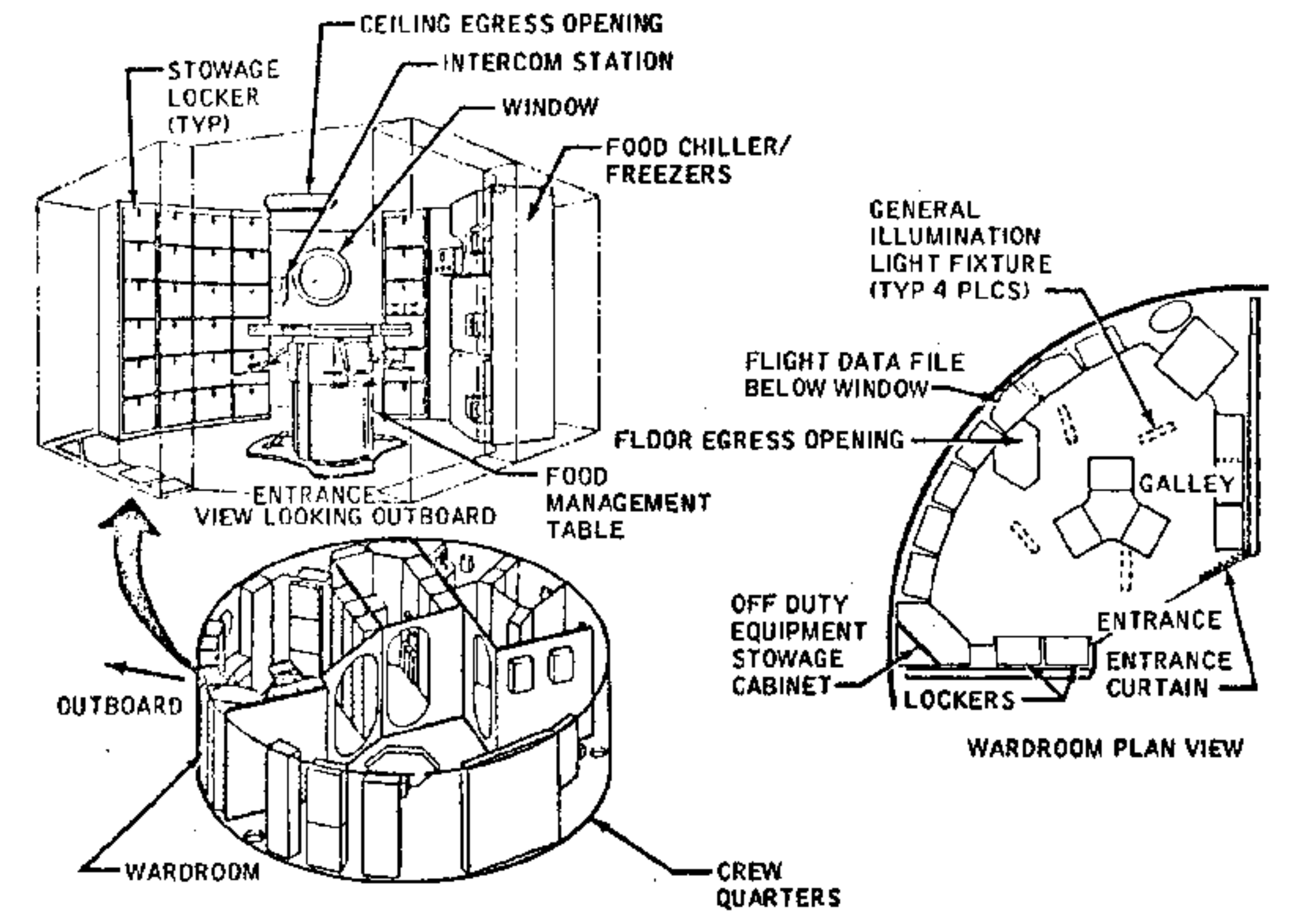
From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

Skylab Living Quarters Layout



Skylab Sleeping Compartments

Skylab Wardroom Layout



From MSFC Skylab Crew Systems Mission Evaluation, NASA TM X-64825, 1974

Skylab Waste Management Compartment

ISS Stowage

Dragon (1) Resupply Mission

ISS Stowage

Stowage

- Number of items stowed proportional to volume, crew size, duration, complexity of mission
  - Mercury: 48 items
  - Gemini: 196
  - Apollo: 1727
  - Shuttle: 2600
  - Skylab: 10,160
  - ISS: >20,000
- After you stow it, how do you find it?

Internal Cargo Integration

Angela Hart/0C4
281-244-2308

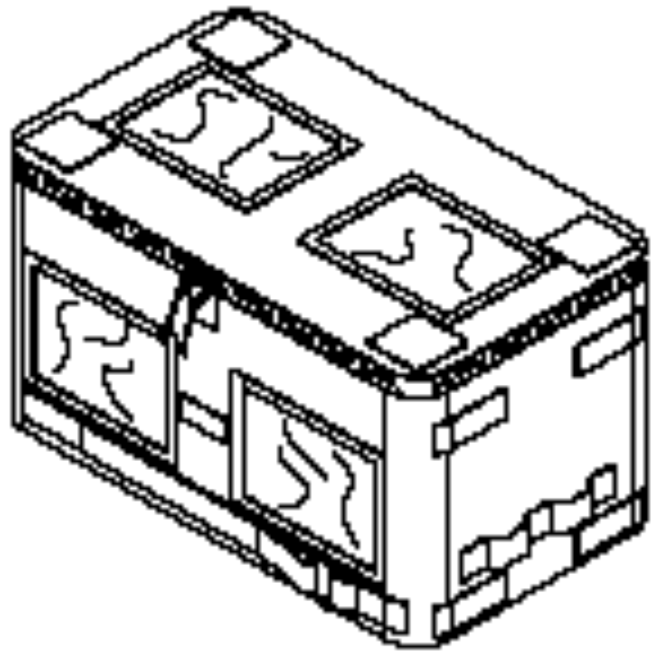
Cargo Transfer Bag (CTB)

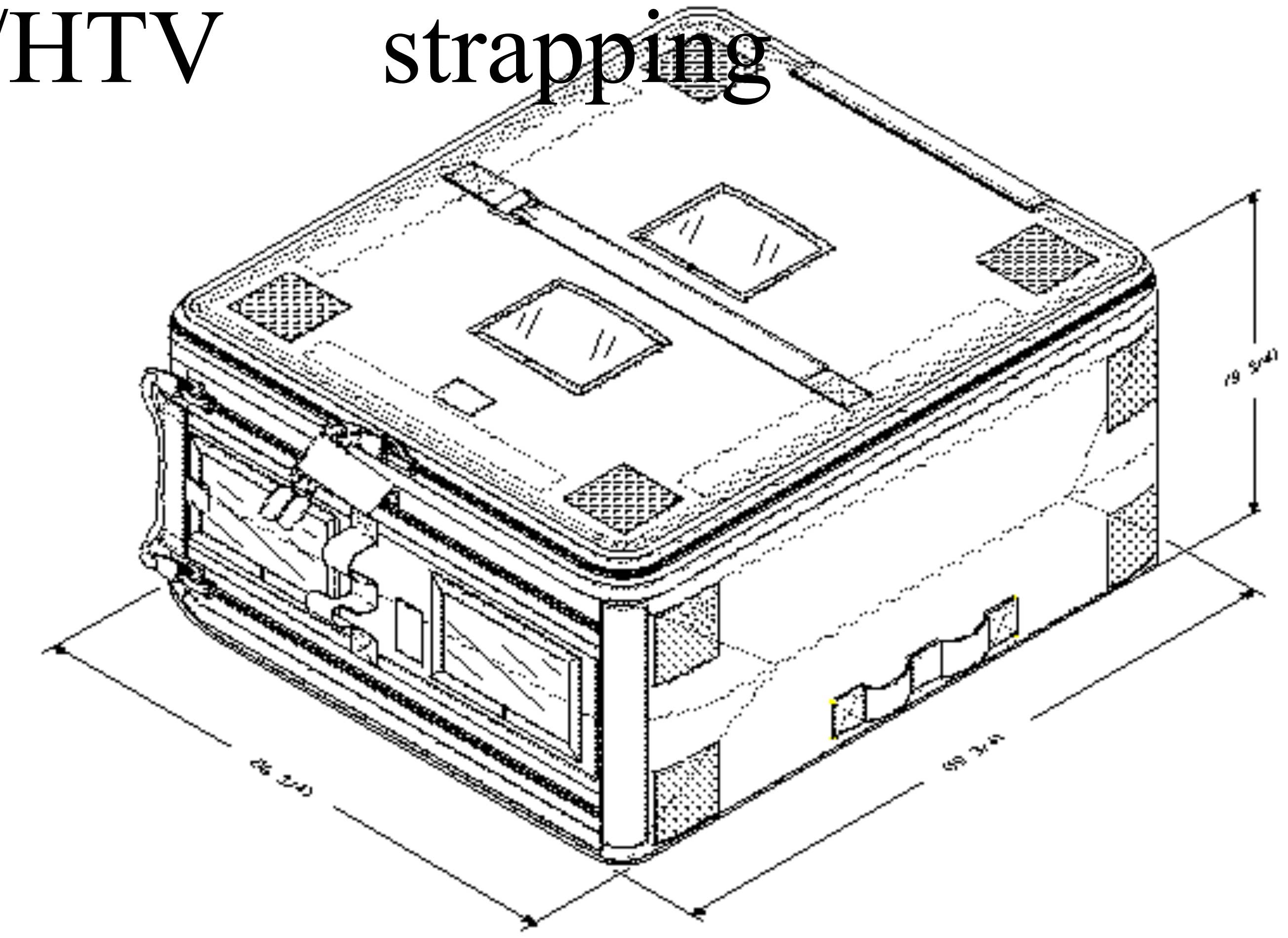
- Cargo Transfer Bags (CTBs) are Nomex stowage bags that contain removable, reconfigurable dividers used for packaging cargo for launch, disposal or return.
- CTBs are available in half, single, double, and triple sizes.
- Each configuration has a zipper closure and a removable mesh netting restraint system located inside of the CTB.

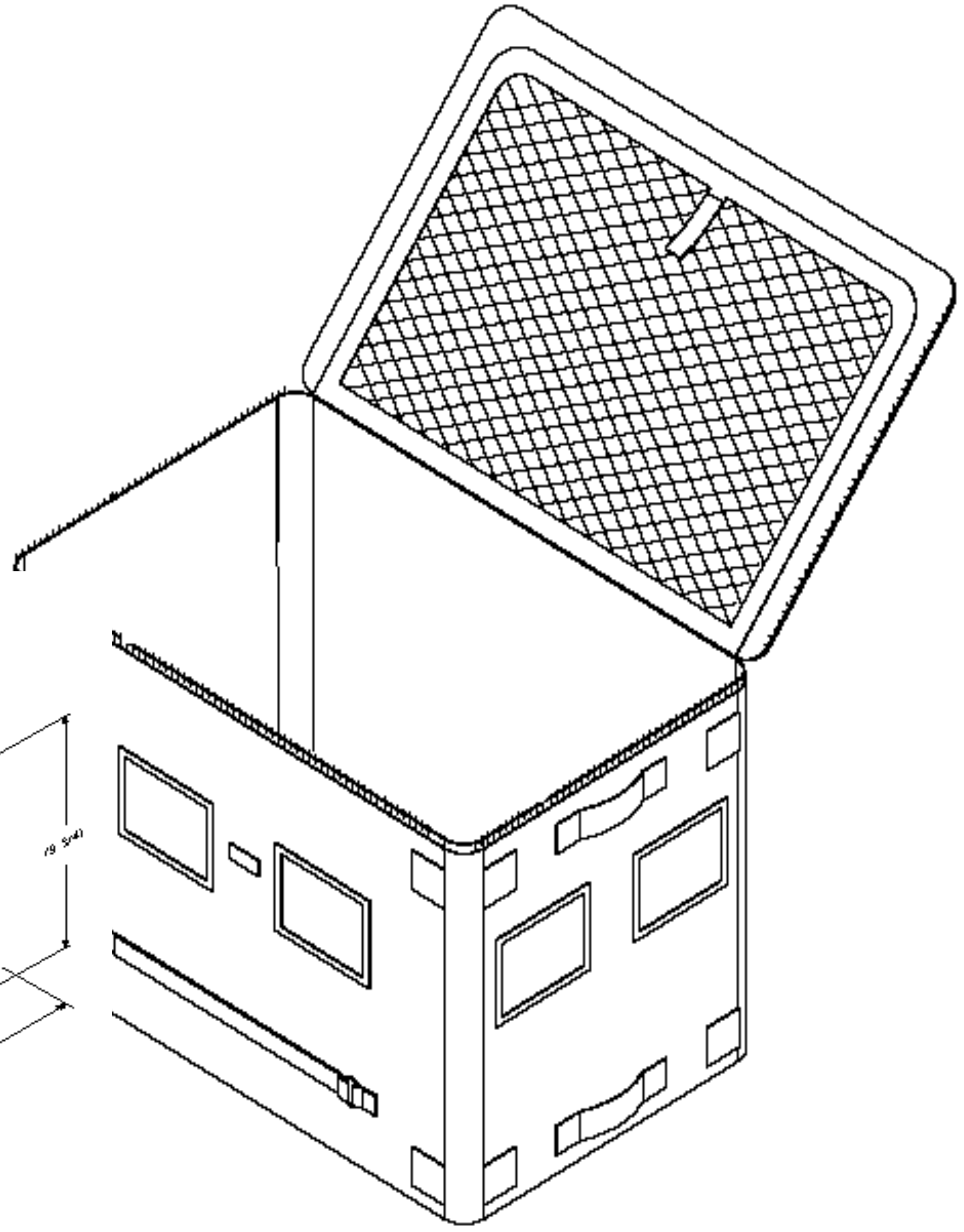
CTB	Approximate Size (external dimensions) L x W x H [cm (in.)]	**Maximum Load Strapped kg (lbs)**	**Maximum Load Locker kg (lbs)**
SEG33111836 Half (1/2x)	24.8 cm x 42.5 cm x 23.5 cm (9 .75 " x 16.75" x 9.25")	13.61 (30)	27.22 (60)
SEG33111837/838 Single (1x)	50.2 cm x 42.5 cm x 24.8 cm (19.75" x 16.75" x 9.75")	27.22 (60)	45.36 (100)
SEG33111839 Double (2x)	50.2 cm x 42.5 cm x 50.2 cm (19.75" x 16.75" x 19.75")	54.43 (120)	81.65 (180)
SEG33111840 Triple (3x)	74.9 cm x 42.5 cm x 50.2 cm (29.5" x 16.75" x 19.75")	81.65 (180)	81.65 (180)

Cargo Transfer Bags
P/N 33111836-40

- Reference JSC 39207, Cargo Transfer Bag (CTB) Certification and Acceptance Requirements Document and JSC-39233 Rev. D, Cargo Transfer Bag (CTB) Interface Design Document (IDD) for actual CTB design, installation, volume, and interface requirements, ground handling, packaging and stowage requirements
- CTBs are certified for launch/return stowage configurations inside hard side lockers (RSR/ Middeck) and TBD ATV/HTV strapping configurations.







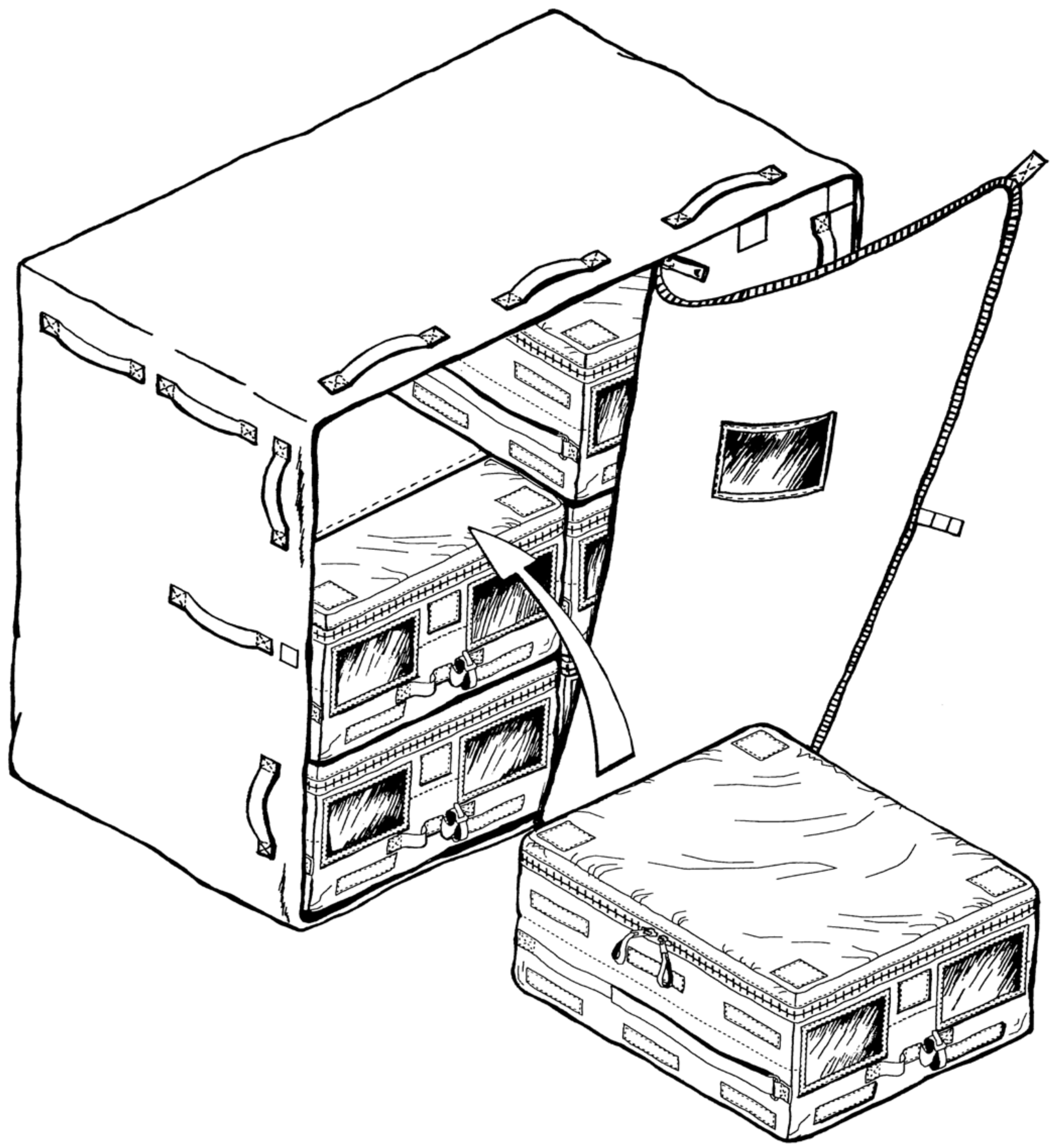
Historical CTB Weights

CTB	Total Bags Used	Bag Tare Kg (lbs)	Cargo Avg. Kg (lbs)	Crew Provision Kg (lbs)
Half	239	1.0 (2.2)	5.13 (11.3)	5.07 (11.2)
Single	223	1.81 (4.0)	10.26 (22.6)	9.42 (20.8)
Double	21	2.04 (4.5)	20.51 (45.2)	N/A
Triple	15	2.81 (6.2)	30.76 (67.8)	N/A

M01 Bags
P/N SEG32105875-301

- JSC 28169, Interface Control Document (ICD) for International Space Station (ISS) Resupply Stowage Platform 1 Stowage System.
- M01 bag is certified to carry 300 lbs of cargo (includes cargo and associated installation hardware) for RSP MPLM strapping configuration and TBD lbs for ATV/HTV strapping configuration.
- Weight 10.64 lbs (empty bag).
- Volume of M01 bag is 13 ft3.
- A total of 6 Cargo Transfer Bag Equivalents
- (CTBEs) can be stowed inside an M01 bag.
- The external dimensions are:

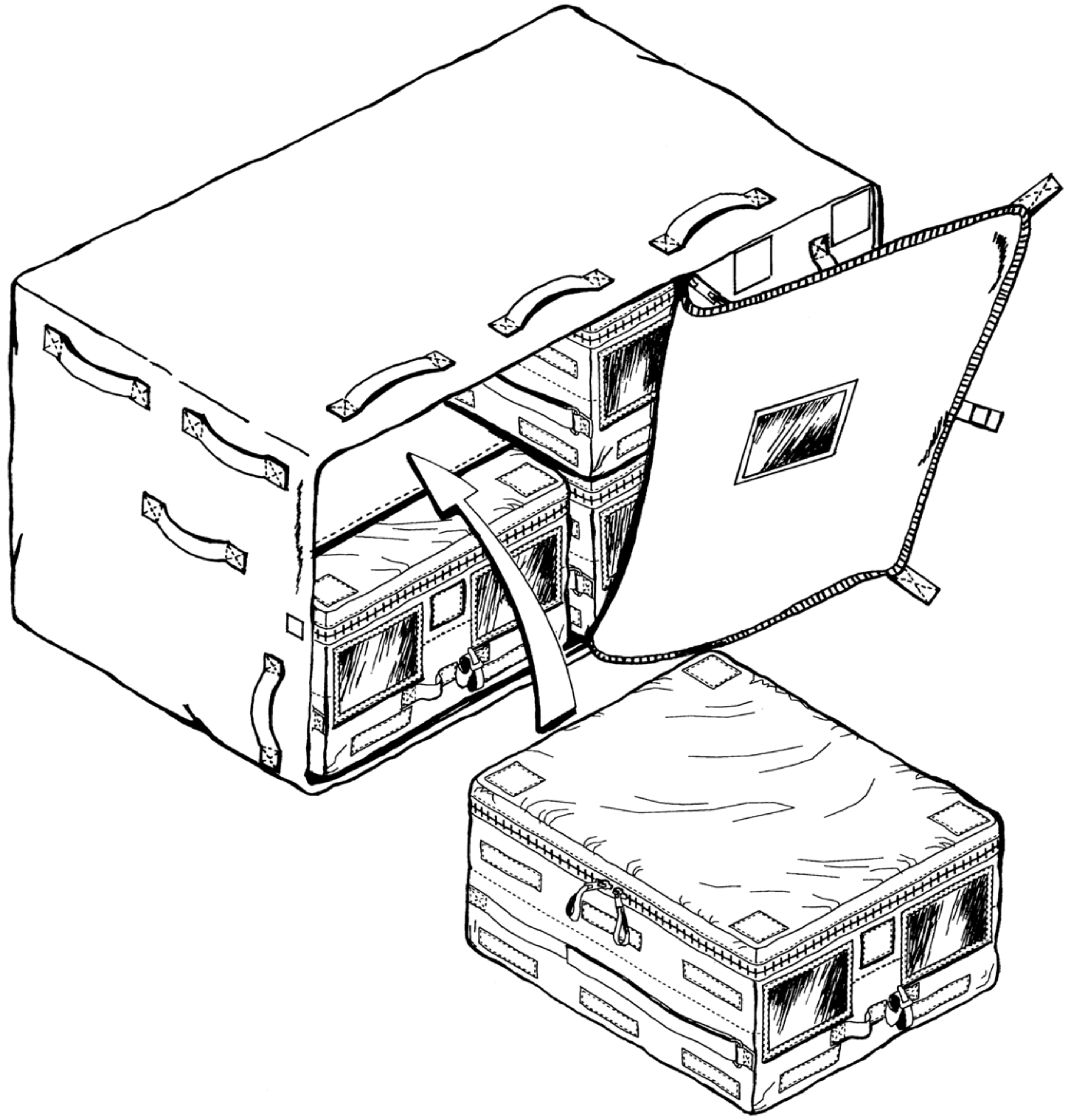
35.3” (W) x 21.0” (D) x 32.2” (H).



M02 Bags
P/N SEG32105876-301

- JSC 28169, Interface Control Document (ICD) for International Space Station (ISS) Resupply Stowage Platform 1 Stowage System.
- M02 bag is certified to carry 90.8 kg (200 lbs) of cargo (includes cargo and associated installation hardware) for RSP MPLM strapping configuration and TBD lbs for ATV/HTV strapping configuration
- Weight 6.83 lbs (empty bag).
- Volume of M02 bags is 8 ft3.
- A total of 4 CTBEs can be stowed
- inside an M02 Bag.
- The external dimensions are:

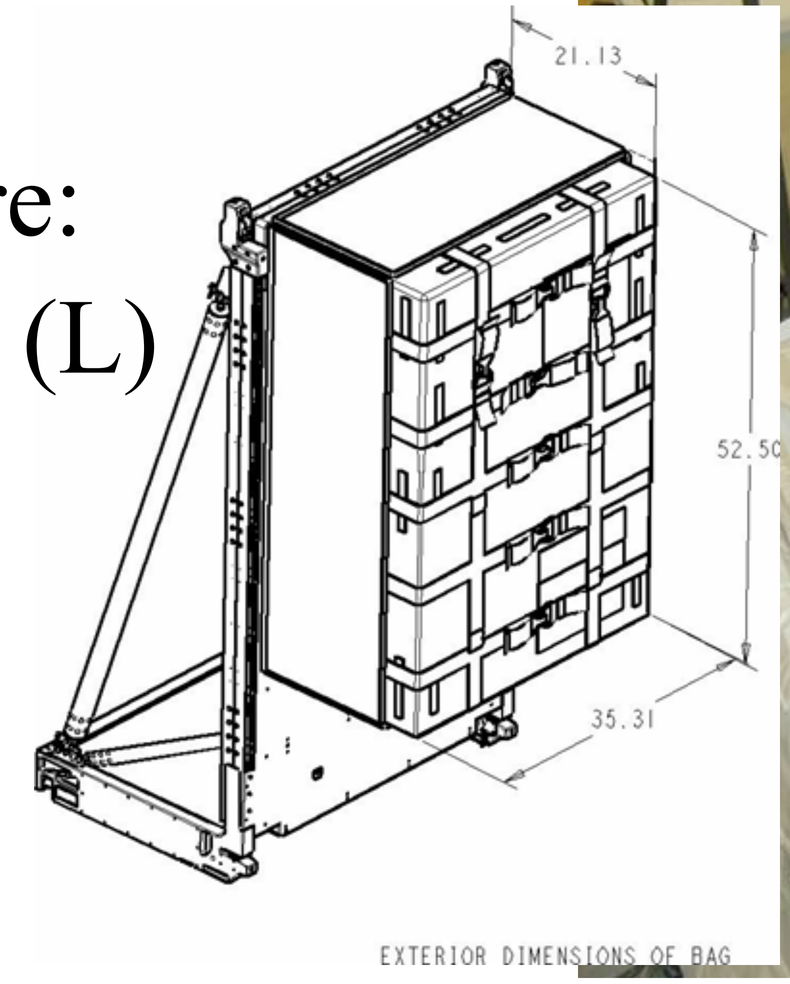
35.3” (W) x 21.0” (D) x 20.0” (H).



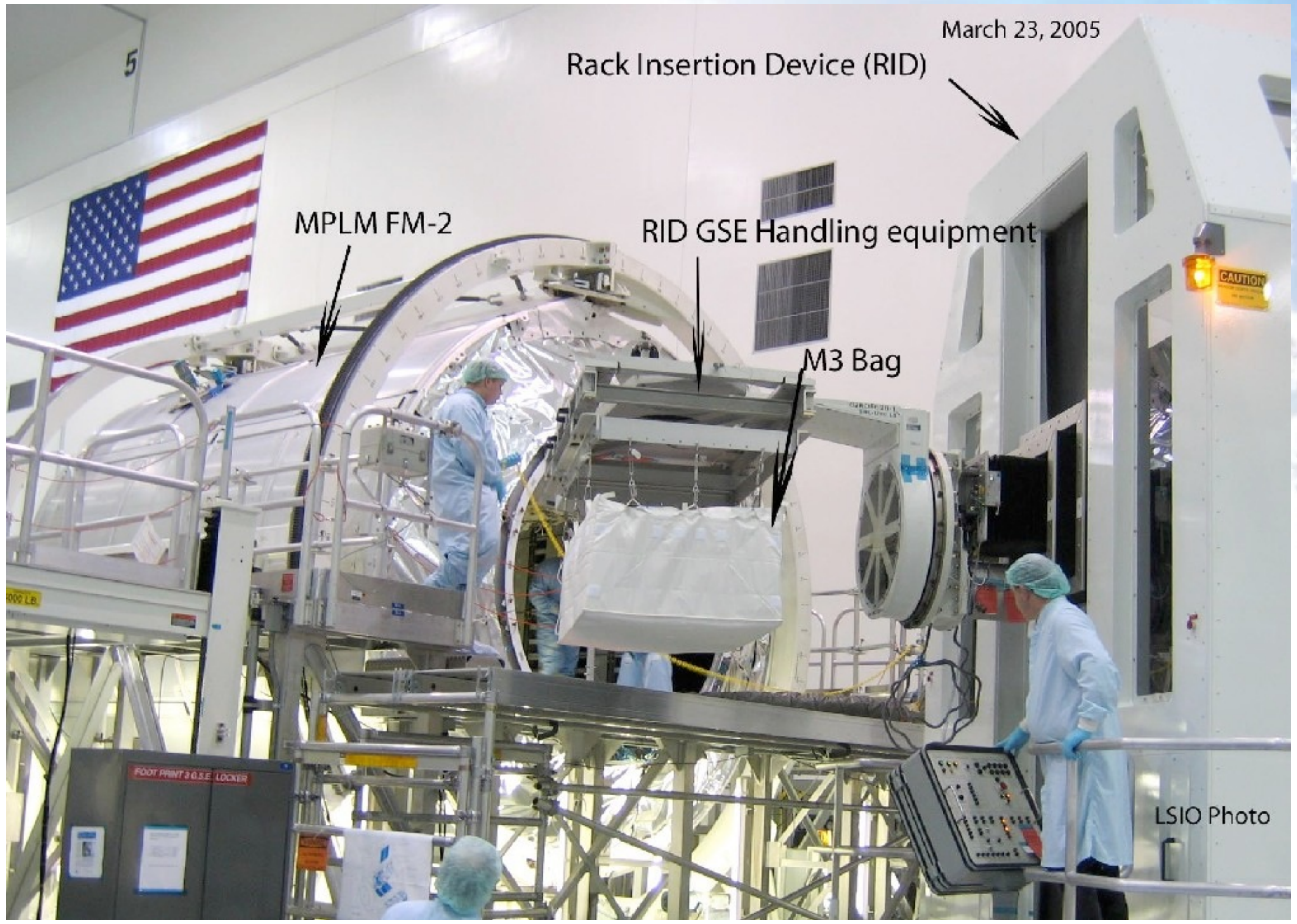
M03 Bags
P/N 33117683

- JSC 28169, Interface Control Document (ICD) for International Space Station (ISS) Resupply Stowage Platform 1 Stowage System.
- M03 bag is certified to carry 226.8 kg (500 lbs) of cargo (includes cargo and associated installation hardware) for RSP MPLM strapping configuration and TBD lbs for ATV/HTV strapping configuration.
- Weight 16.5 lbs (empty bag).
- Volume of M03 bags is 22.0 ft^3.
- A total of 10 CTBEs can be stowed
- inside an M03 Bag.
- The external dimensions are:

35.3“ (W) x 21“ (D) x 52.5“ (L)



M03 Bag Installation



- **Some oversized hardware/bags may require special FSE.**

Food Containers

- Food Containers –
  - US Non-Collapsible, SEG48101834-301
    15” x 12.0” x 4.85”
  - Collapsible, 17КС.260Ю 3200-0
    14.875” x 12” x 4.875” (Collapsed)
    14.875” X 12” X .59” (Uncollapsed)
- Mass (Full) – 14.3 lbs
- Mass (Empty) –
  - Non-Collapsible – 3.75 lbs
  - Collapsible – 2.2 lbs

Standard Waste Containers

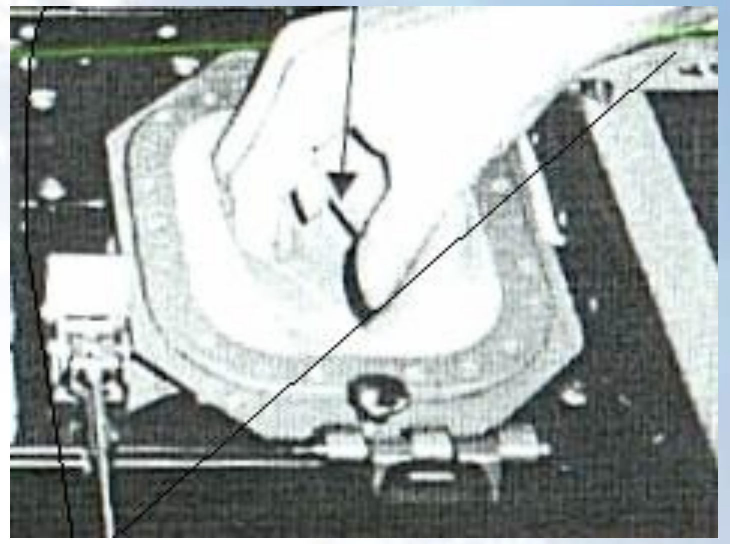
- Bags (compressible)
  - KBO-M generally use for dry trash
  - Table Food Bag (TFB) and/or Rubber-Lined Bag (RLB) used for wet trash
- Human waste containers (hard)
  - EDV and KTO
- Hardware (ORUs, filters, fans, etc.)
  - Odd sizes and shapes

KBO-M

- Soft Trash Bag, OpNOM: KBO-M
- PN: 11ϕ 615.8715-OA15-01
- Heavy duty rubberized cloth bag. Metal band around the top and rubber flaps to keep the trash inside.
- Acceptable for undamaged alkaline batteries, some bio waste directly into container – i.e. kleenex; hazardous waste must be properly contained prior to insertion
- Dimensions (Stowed) - 11.75” x 11.75” x 2”
- Dimensions (Full) - 17” long x 11.5” diameter ring x 8” diameter
- Mass (Full) – 17.5 to 20 lbs

Food Waste Bag

- Food Waste Bag, OpNOM:
  Food Waste Bag
  PN: 11 ϕ 615.8716-OA15
- Soft, rubberized cloth bag used to place table scraps, and other small wet waste items. This bag can be used for wet or dry trash.
- Dimensions (Stowed) – 10” x 5” x 0.2”
- Dimensions (Full) – 8” x 5” diameter
- Mass (Full) – 2 lbs



Rubber Lined Bag

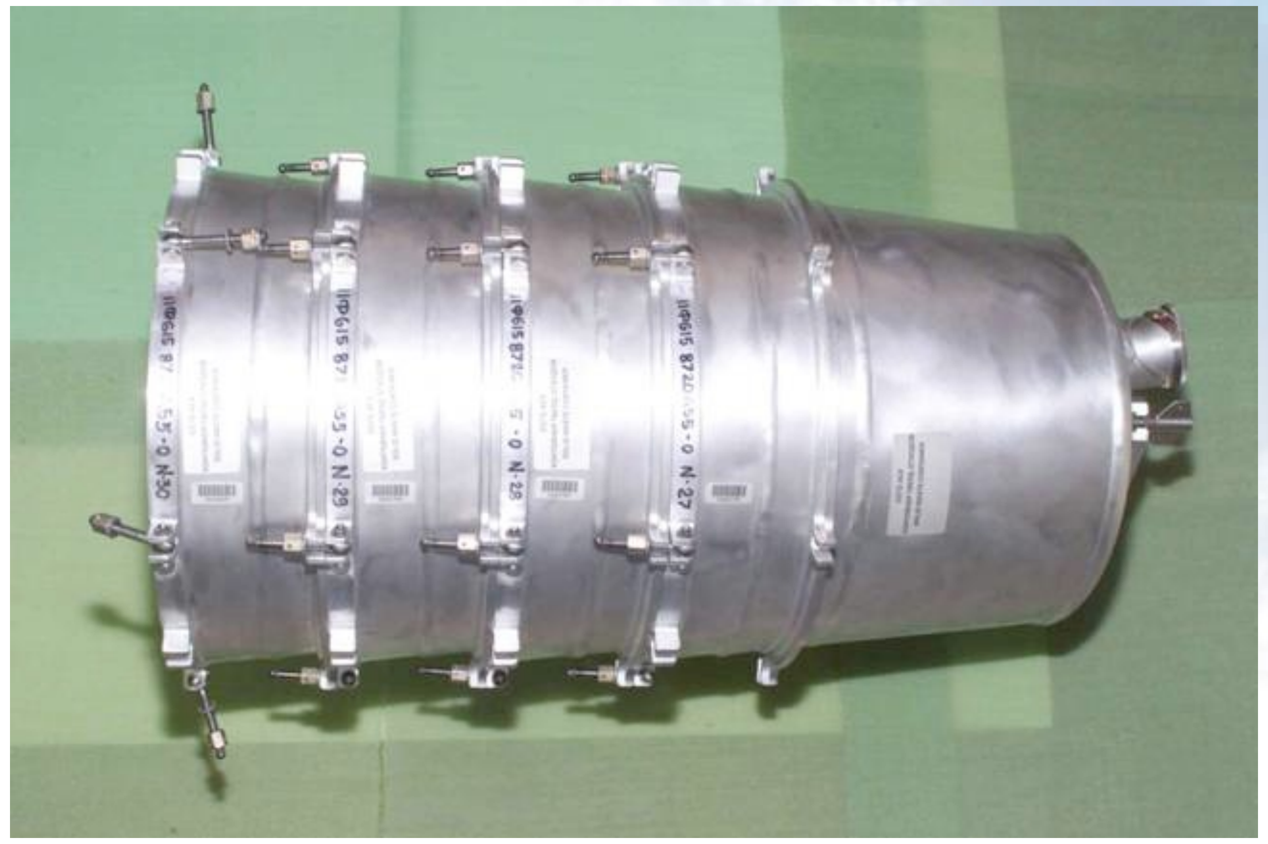
- Rubber Lined Bag, OpNOM: Rubber Lined Bag PN: 11ф615.8716-20A15,
- Rubberized cloth lined bag can contain up to 3 full KBO-M bags or approximately 8 table bags. It has a draw string closure and is nominally closed tighter with the rubber ties known as “szkoo’tee”. Can be wiped down and reused. Preferred by crew for wet trash. Not as heavy duty as the KBO-M, but larger.
- Dimensions (Stowed) - 11.75” x 11.75” x 2.2” (folded around KBO-M)
- Dimensions (Full) – 25” x 15”
- Mass (Full) – 23.7 lbs

EDV

- EDV, OpNOM: EDV
  PN: 11ϕ 615.8711-0A15-1
- Primarily used for urine and wastewater collection. Limited Life: 90-days of on-orbit operations (defined as any operations where the hydro-connector is connected/disconnected).
- Dimensions (Stowed) - EDVs usually launched in set of 6 buckets and separately 6 lids. With rack attachment spike and lid
  - Top - 13.1” (Diameter) x 21.57” (H)
  - Bottom 9” (diameter)
  - EDV Bucket - 17.3” (H) x 13” (Diameter)
  - EDV lid - 4.1” (H) x 13” (Diameter)
- Dimensions (Full) - Without rack attachment spike and lid
  - Top - 13” (Diameter) x 15.7” (H)
  - Bottom - 9”(Diameter)

KTO

- Solid Waste Container, OpNOM: KTO PN: 11 ф 615.8720A55-0,
- The KTO is used for solid waste and can contain biological waste.
- Dimensions (Stowed) –
  - Body - 13" (H) x 13 " (diameter)
  - Lid - 2" (H) x 13" diameter
- Dimensions (Full) – 15" (H) x 13" diameter
- Mass (Full) – 25.4 lbs



Example Stowage in Progress for Disposal

Rubber lined bags

Strapped ORUs

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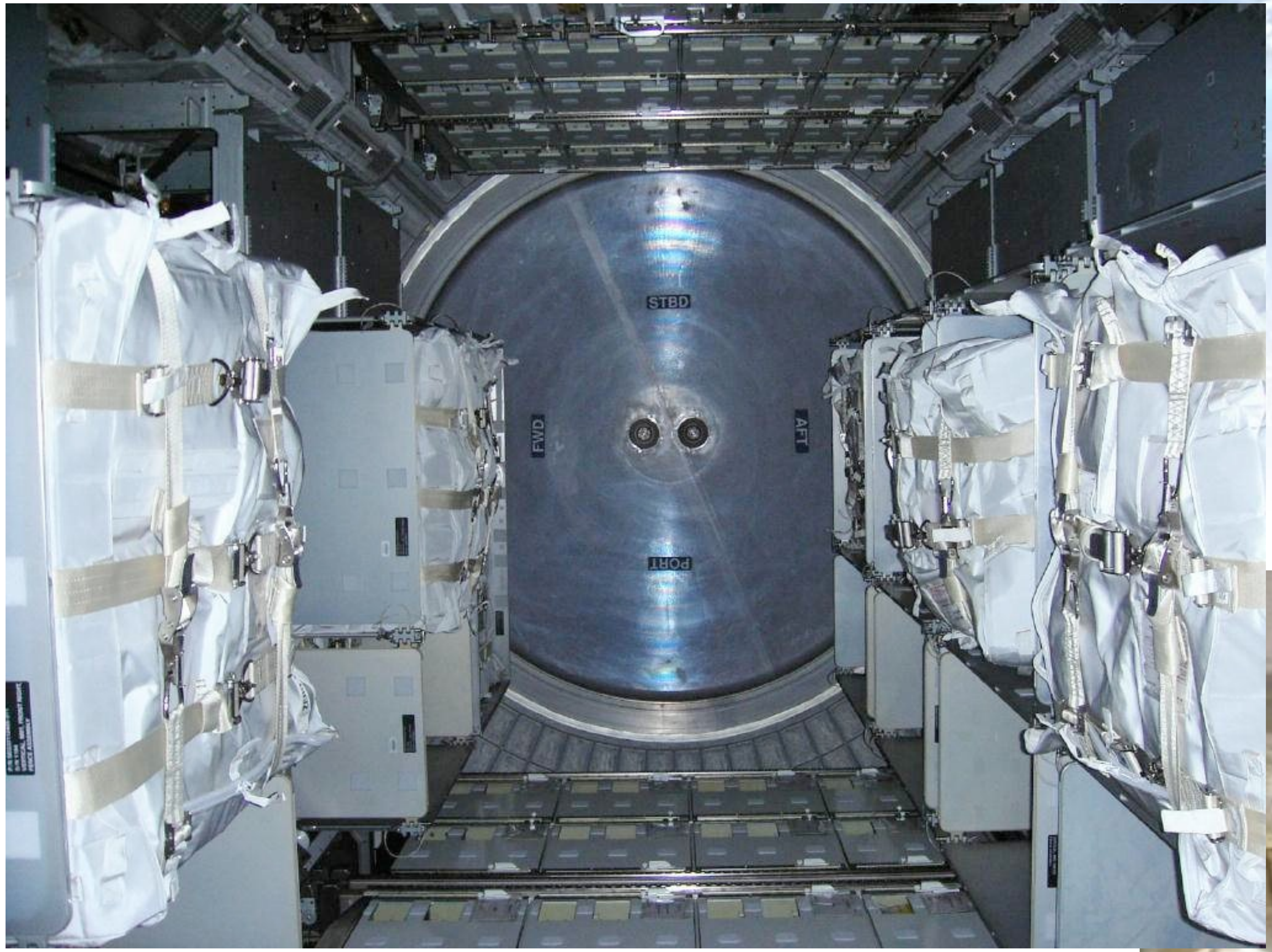
Example Stowage in MPLM for Launch



Historical Delivery Dates for Launch Integration

% Cargo	Delivery Template	Type Cargo
40	Launch minus (L-) 4 to 3 months	All cargo types, Hard mounted items
10	L- 2 months	All size CTBs/Mbags
35	L – 1 month	All size CTBs/5 and 10 MLE bag, some hardmount, Middeck lockers
10	L-2 weeks	All size CTBs/5 and 10 MLE bag, Middeck lockers
5	L-24 to 6 hours	All size CTBs, Middeck lockers

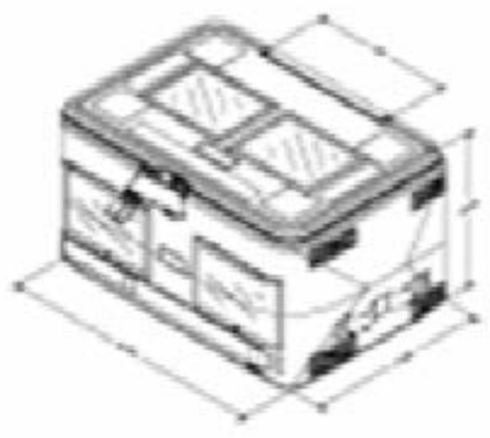
Estimated Delivery Internal Cargo Types

% Cargo by Item	% Cargo by Volume	Type Cargo
< 5	< 5	Hardmounted Items
15	35	Oversized Items (larger than triple CTB)
75	50	Cargo Transfer Bags (1/2, single, double, triple)
10	10	Non-bag items (food containers, waste containers, etc)

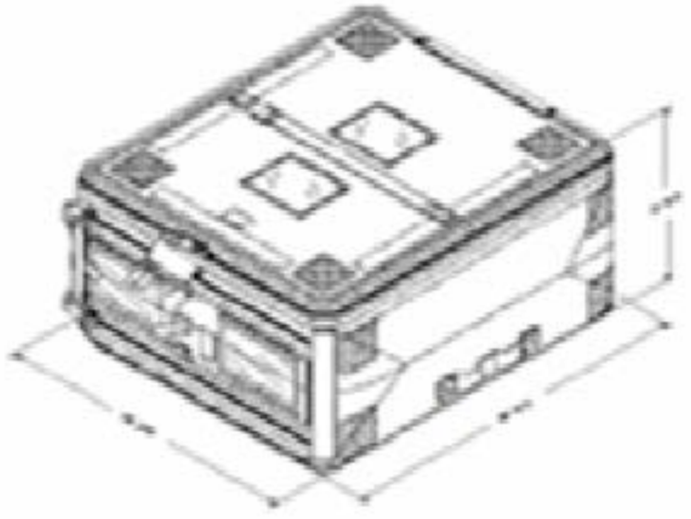
On-Orbit Estimates for Cargo Transfer

- Cargo operations minimum stay time is based on the time required to unload (Internal and External)
  - Internal Estimates:
    - Typical MPLM flight transfer estimated between 80 and 120 hours transfer (Approximately 200 CTBe) depending on the amount of cargo, that includes transferring the resupply items to ISS and stowing the return items in MPLM.
    - Cannot necessarily increase crew participation to increase hours. Inefficiencies in the operations due to limited working space.
    - Typically no more than 3 - 4 crew members dedicated to transfer
    - Typically no more than 6 hours per day/ 5 days per week.
    - Rack Transfer Estimates – Approximately 2 crew - 1 hour (2 crew hours) together to transfer 1 rack to ISS. Not including connecting up to the ISS utlities
- Maximum stay time is the time to fill the vehicle with waste based on waste generation rates.
  - Increased capability improves operational flexibility

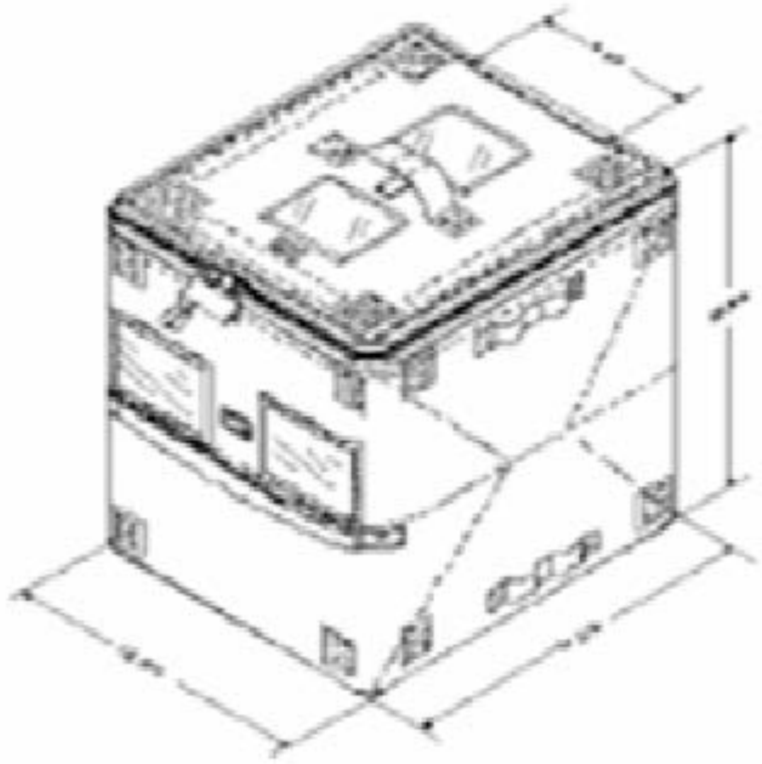
Standardized Stowage - CTBs



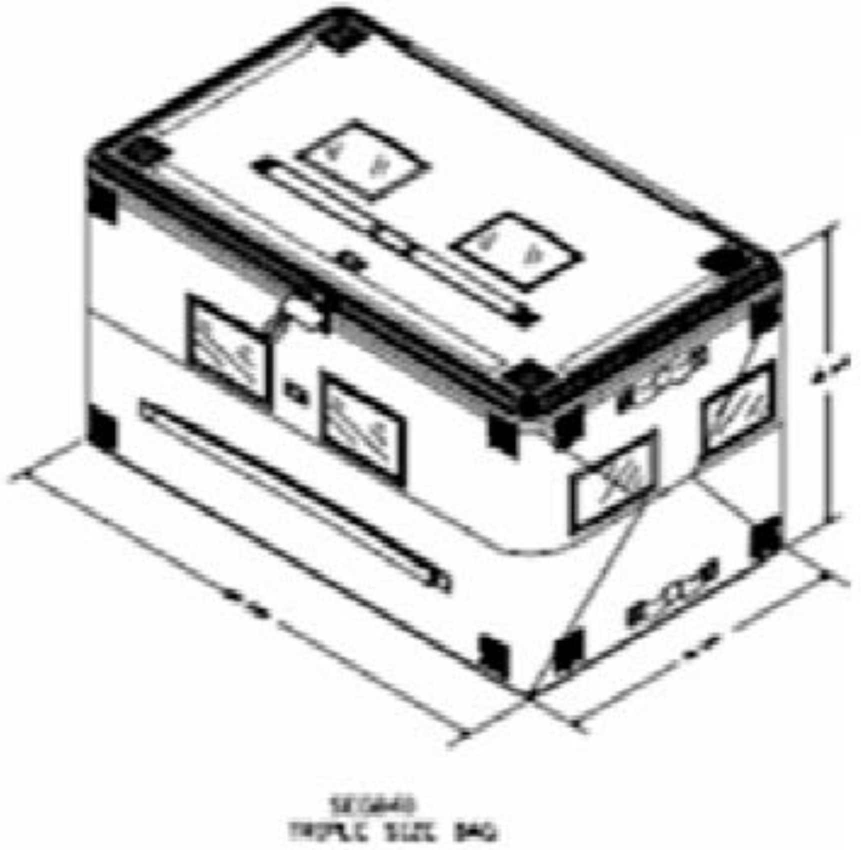
CTB, Half Size-P/N:SEG33111836



CTB, Full Size-P/N:SEG33111838



CTB, Double Size-P/N:SEG33111839



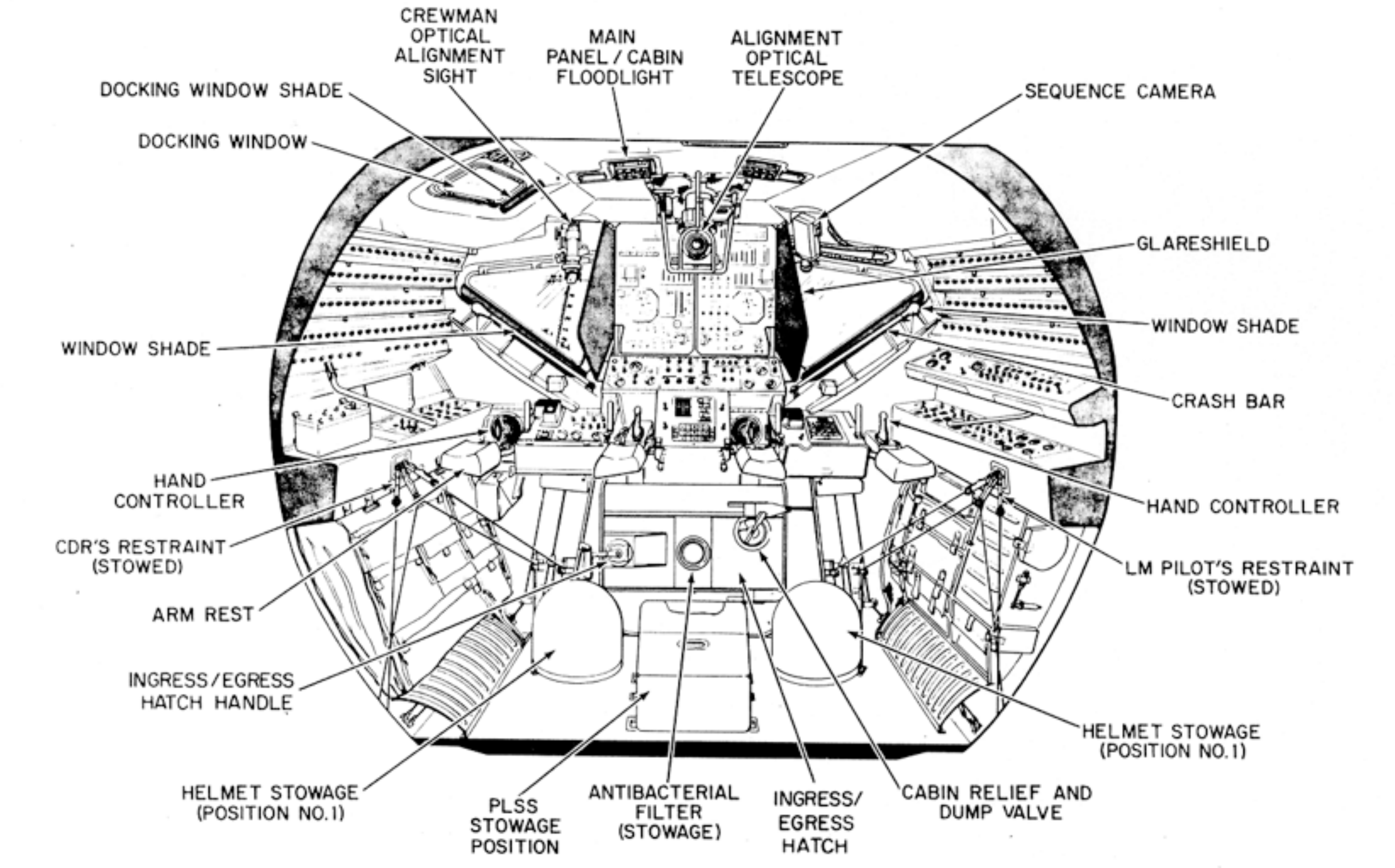
CTB, Triple Size-P/N:SEG33111840

Item	P/N	External Dimensions [mm] (LxWxH)	Maximum Load [kg]
Half Size	SEG33111836	235x426x248	13.62
Full Size	SEG33111838	248x426x502	27.24
Double Size	SEG33111839	502x426x502	54.48
Triple Size	SEG33111840	502x426x749	81.72

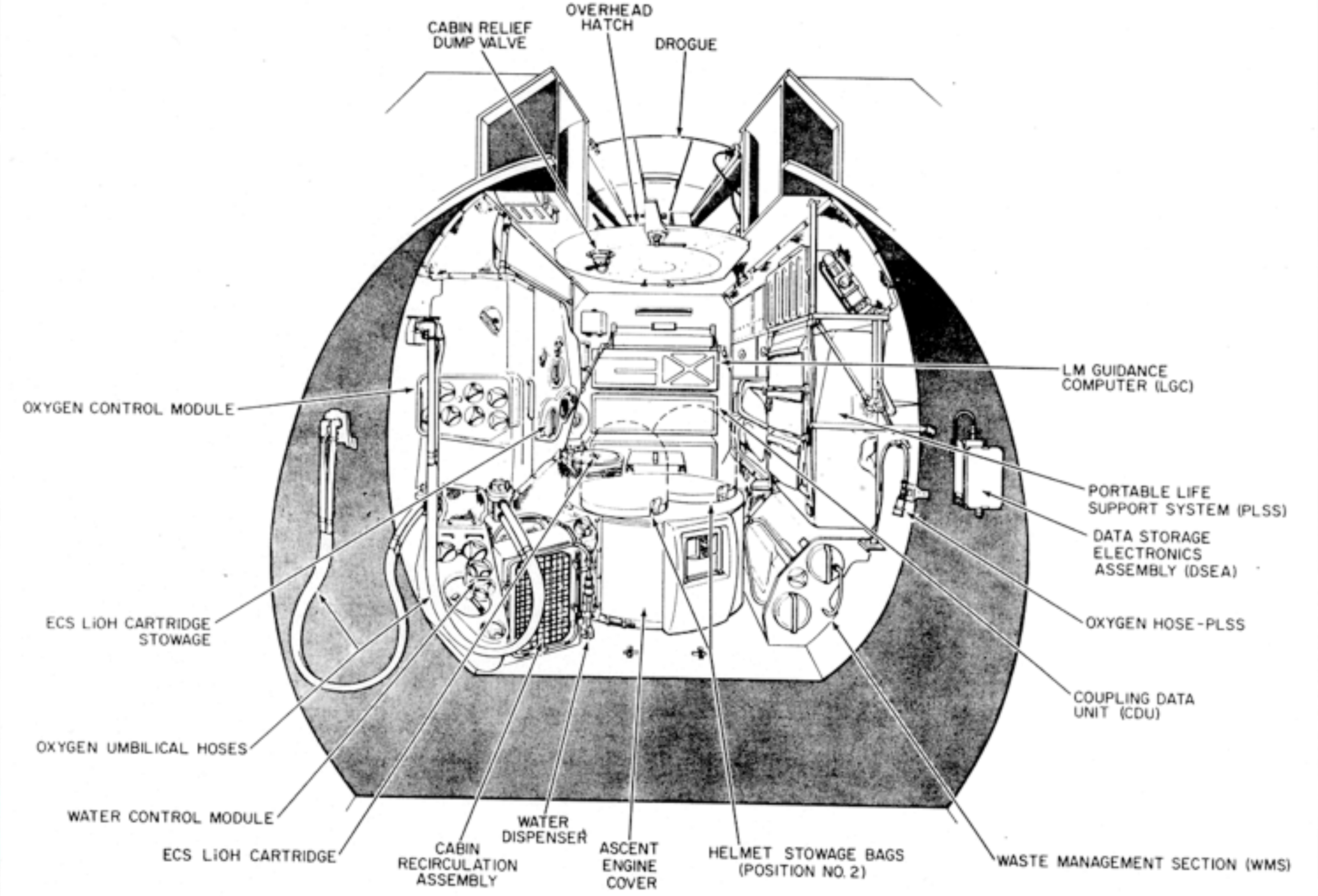
Psychosocial Issues

- Scheduling and planning
- Recreation
- Command structure
- Issues affecting crew morale
  - Environment
  - Food and drink
  - Exercise
  - Hygiene
  - Noise
  - Lighting

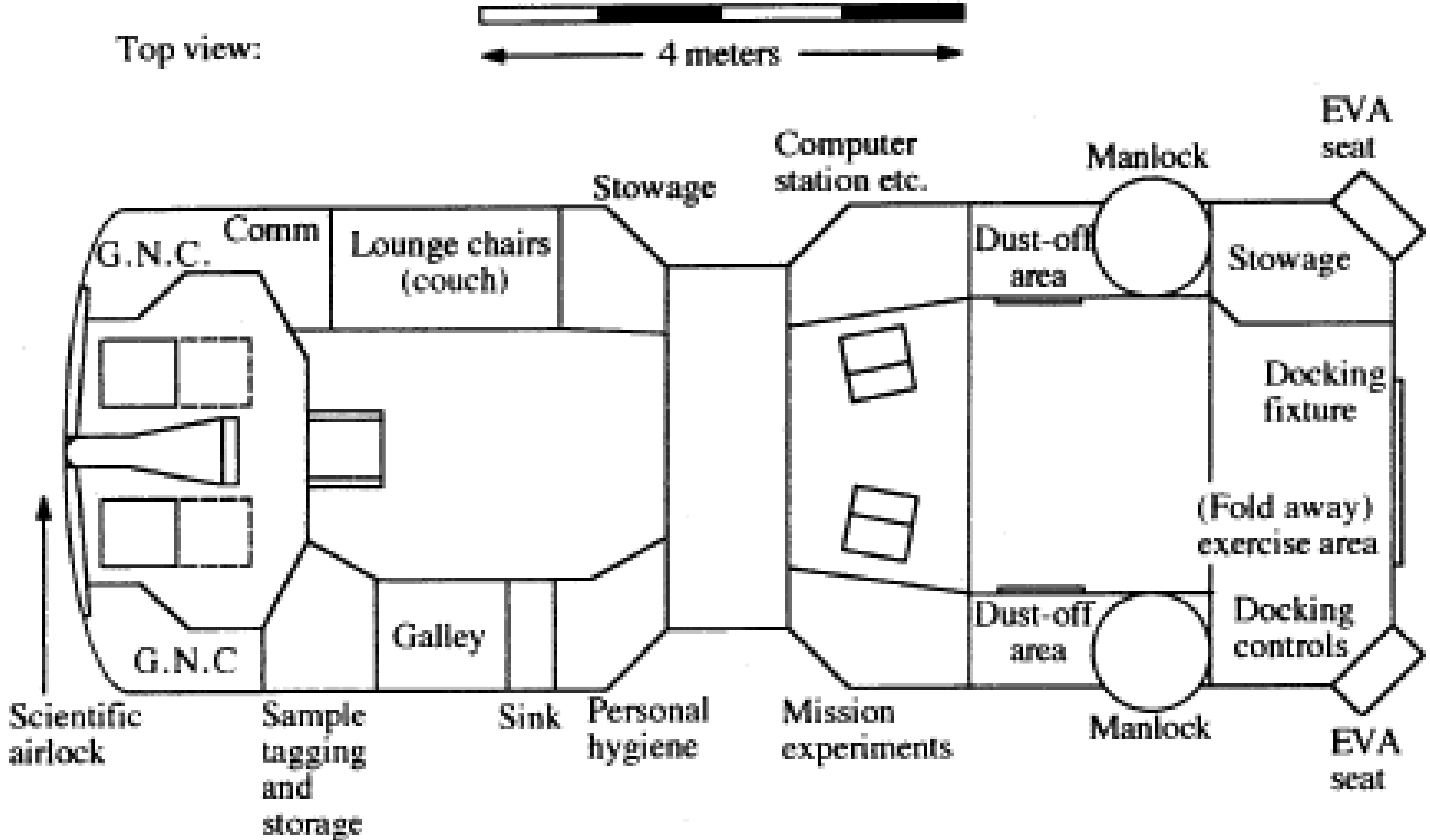
Apollo Lunar Module Interior



Apollo Lunar Module Interior

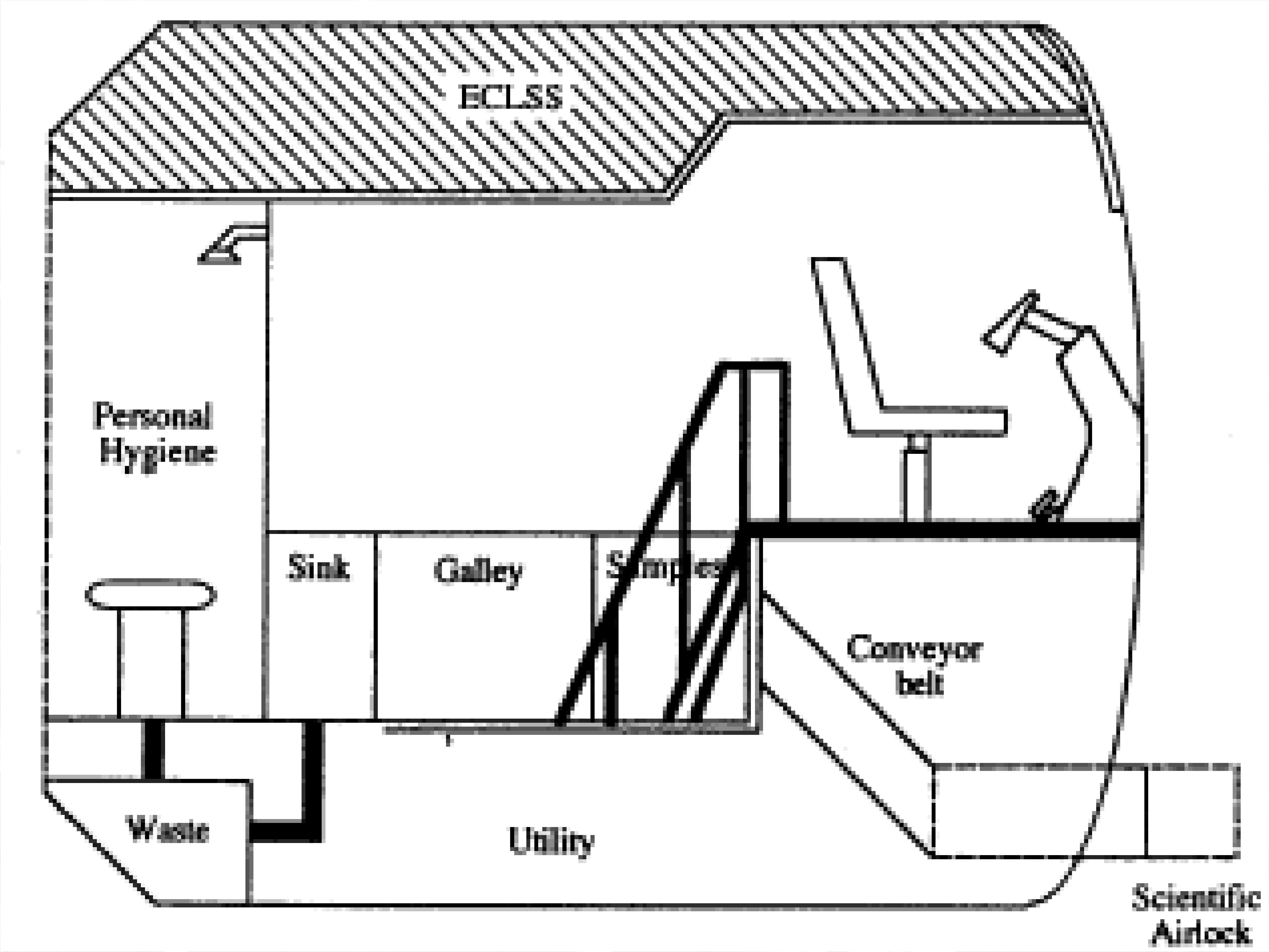


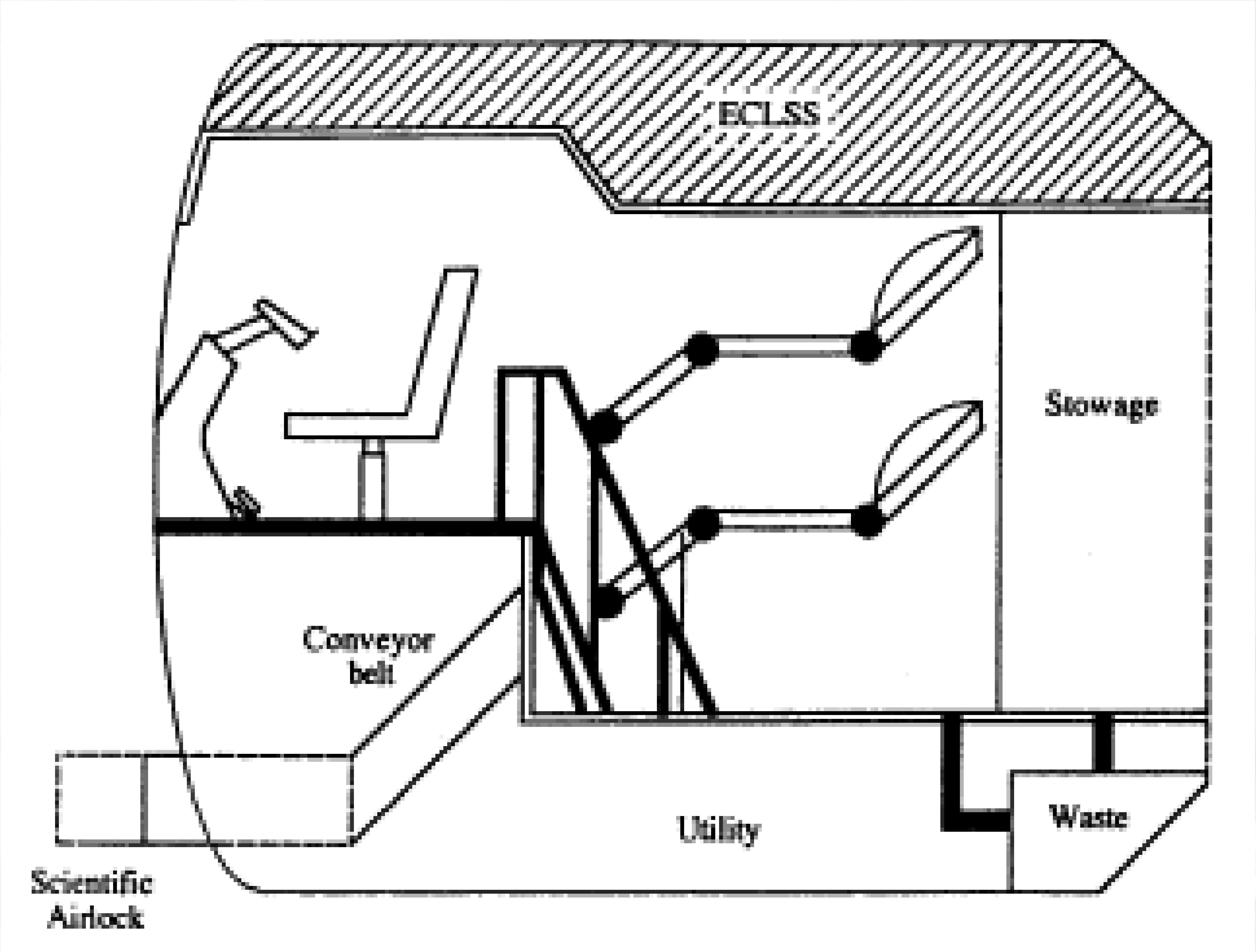
Segmented Rover - Inboard Plan



Bhardwaj et. al., “Design of a Pressurized Lunar Rover - Final Report” NASA CR-192033, Virginia Polytechnic Institute and State University, 1992.

Segmented Rover - Inboard Profiles



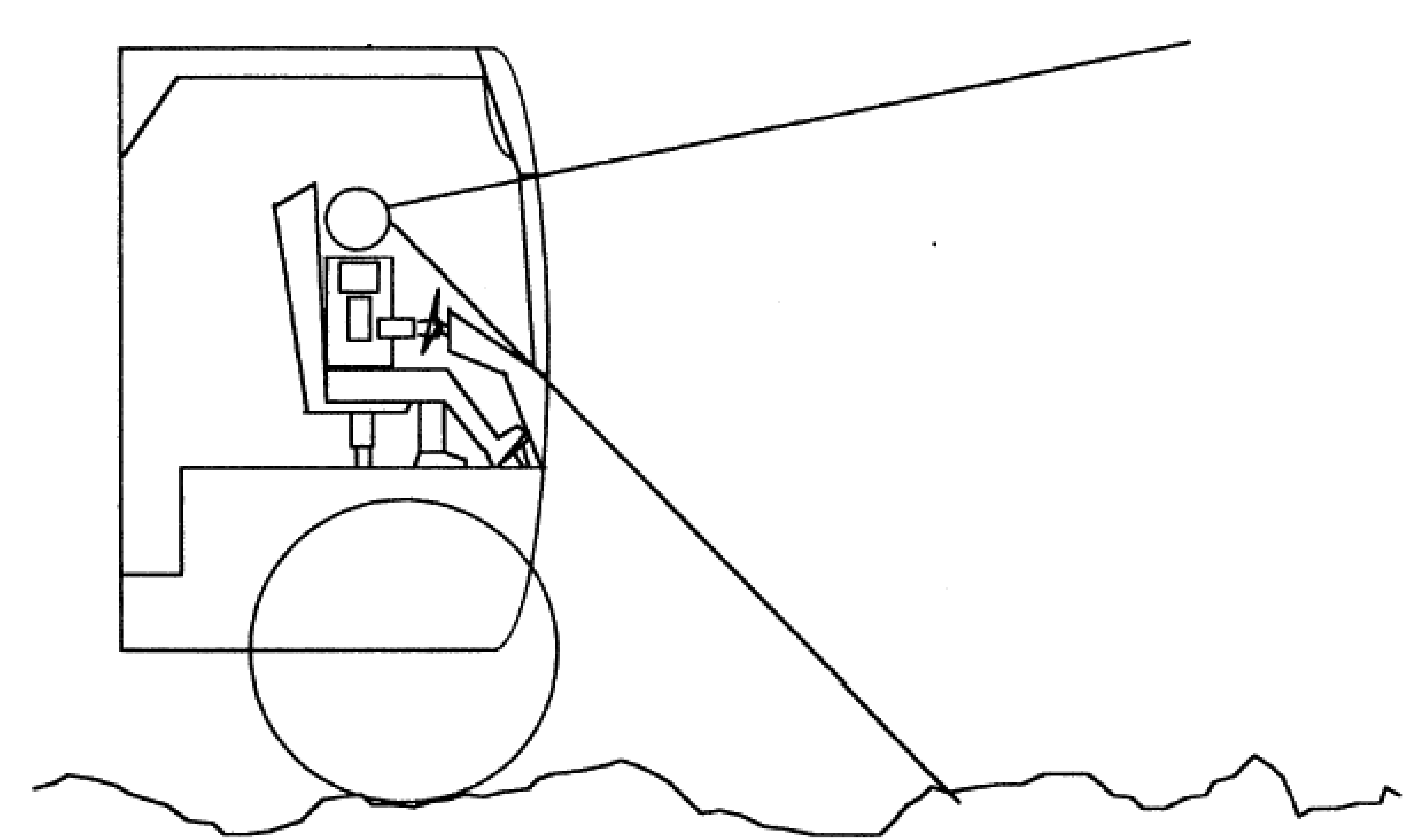


Bhardwaj et. al., “Design of a Pressurized Lunar Rover - Final Report” NASA CR-192033, Virginia Polytechnic Institute and State University, 1992.

TURTLE Interior Mockup - ENAE 484 2008

LER Interior - Driving Stations

Analysis of Sight Lines



Bhardwaj et. al., “Design of a Pressurized Lunar Rover - Final Report” NASA CR-192033, Virginia Polytechnic Institute and State University, 1992.

Shuttle Windows (Fwd Flight Deck)

ISS Cupola (External)

ISS Cupola (Internal)

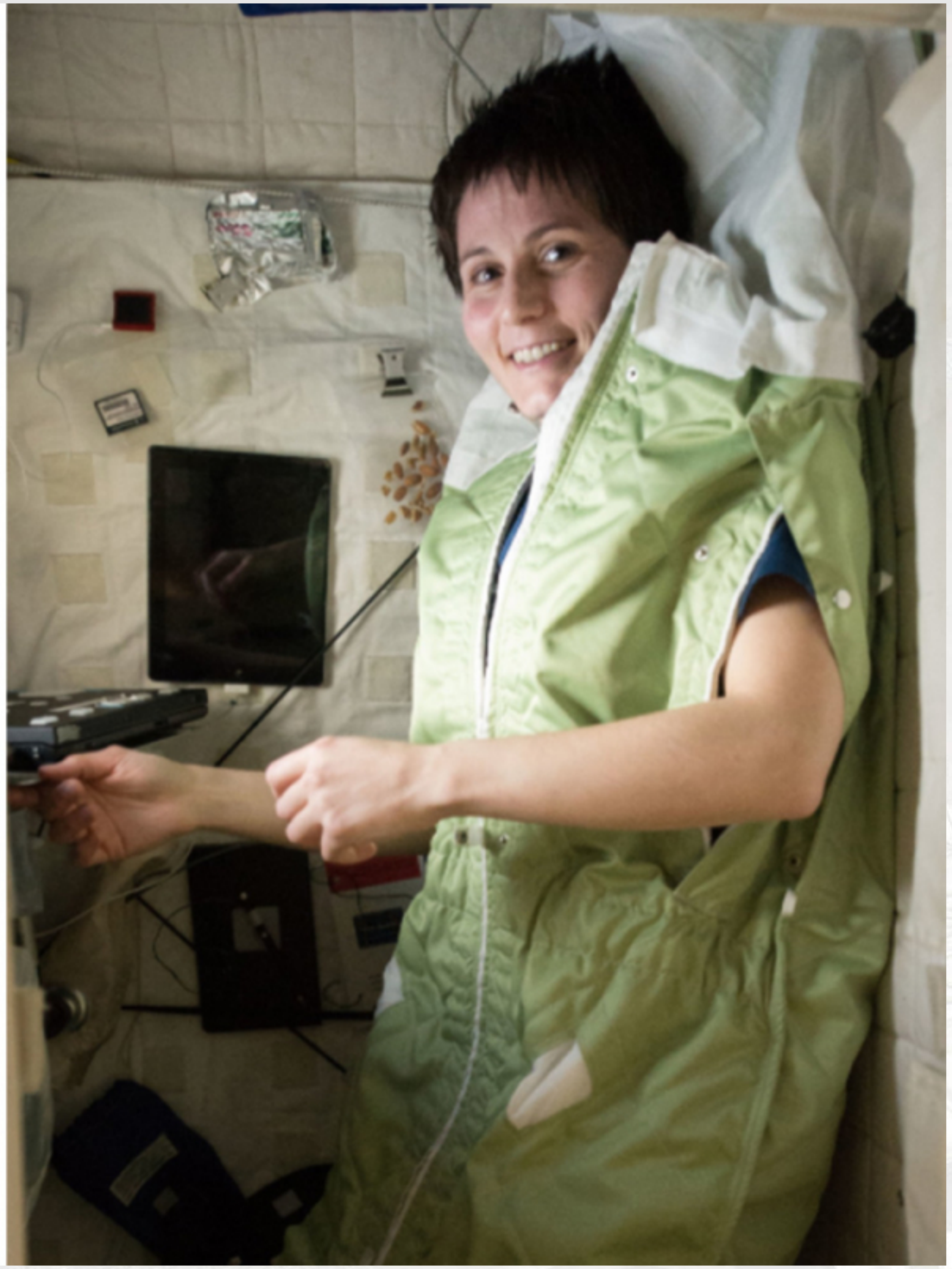
S130E010380

Spacecraft Windows Requirement

At a minimum, all human-tended spacecraft must have at least two windows excluding hatch windows for external situational awareness, safety, piloting and navigation, spacecraft inspections, observation and photo-documentation of engineering anomalies and scientific and environmental phenomena, crew psychological support, physical health reasons (exposure to natural light for vitamin D production and calcium absorption to prevent bone loss), and for supplementary, alternative, and contingency lighting. In addition, one window must be a Category B window [minimum circular clear viewing aperture diameter = 40 cm], as spacecraft inspections and photo-documentation of engineering anomalies and scientific and environmental phenomena, astronomy, and planetary (Earth) observation have historically been major crew activities during on- and off-duty hours. Because of their larger size, Category B windows will also allow more natural light into the cabin than any of the other categories of window except Category A windows, with which a given spacecraft may not necessarily be equipped.

NASA Human Integration Design Handbook, Rev. 1, June 2014

ISS Crew Quarters



SEV Interior - Bunks and Suitports

NASA Crew Quarters Requirements

Private quarters should be provided for each crewmember. For missions ≤ 30 days, the crew quarters can be deployable; for missions > 30 days, crew quarters should be permanent. The crew quarters should be co-located with other "clean" areas of the habitat (e.g., galley, science work- spaces, and medical workspaces); hygiene tasks should be performed in separate, dedicated spaces to limit cross-contamination (Section 4.3).

Each crew quarter should incorporate a rigid enclosure and door, light and sound proofing, adjustable ventilation (air flow speed and direction that is adjustable for personal preference and to mitigate CO_2 buildup), caution and warning indicators (audible and visual), power and data connections (for laptops, tablets, task lighting, general charging), peripheral mounts (for laptops and tablets), customizable mood and spot lighting (relocatable, adjustable color/brightness), flexible temporary stowage (e.g., Velcro, bungees, nets, caddies), adjustable sleeping bag positioning (both orientation and location within the crew quarter), and direct access to any additional personal crew stowage lockers from within the crew quarters. Adjustable aids for stability and translation should be provided to accommodate crew activities such as working on a laptop/tablet, changing clothes, reading, and watching entertainment. The dimensions of the crew quarters should be at least 30" wide x 30" deep and > 78" long to comfortably accommodate crewmembers, while accounting for on-orbit spinal elongation.

- NASA Deep Space Habitability Guidelines, TP-2020-220505, November 2019