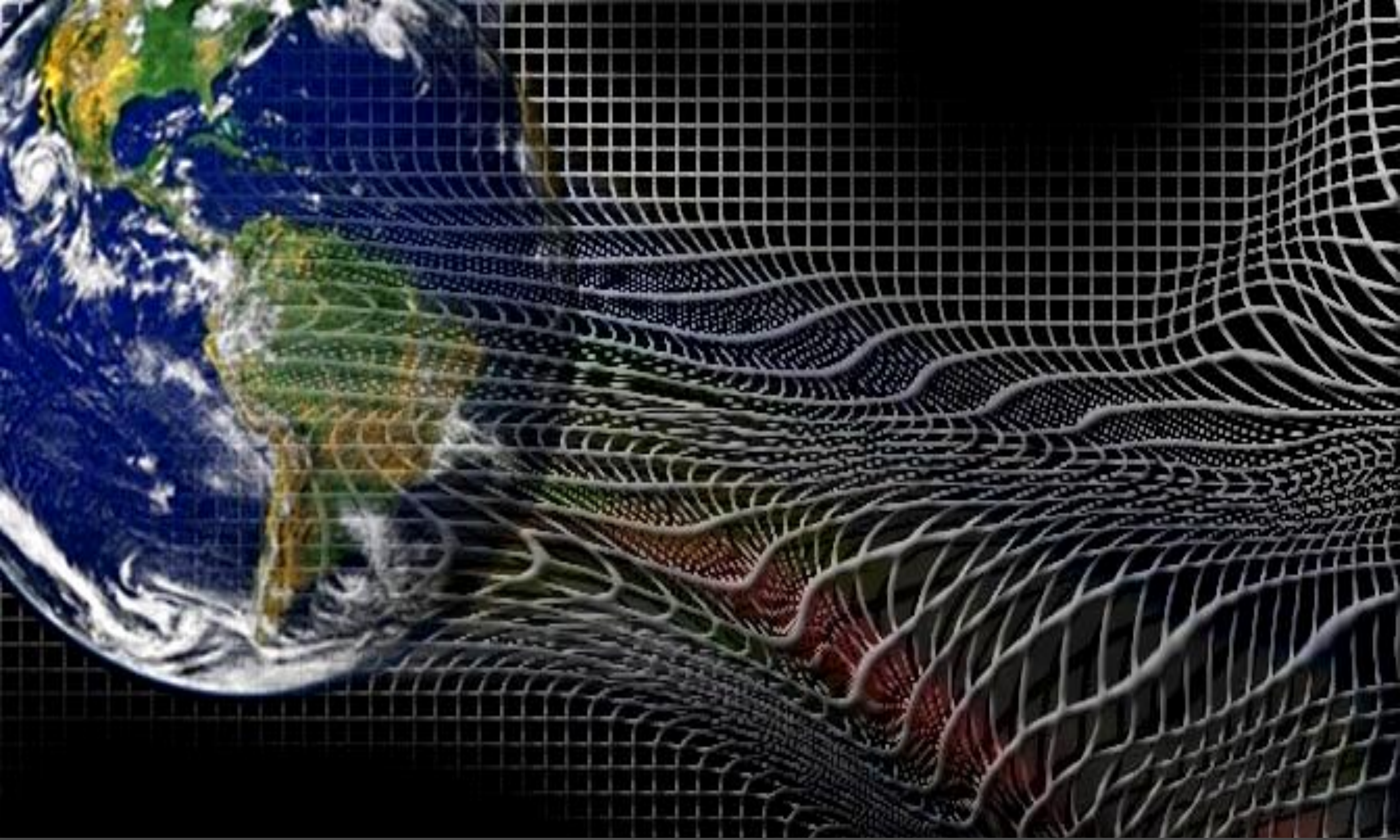
Carnegie Mellon University
SPACE ARCHITECTURE

Air Tight: Building Inflatables/ Inflatable Construction: Planning and Details

Kriss J. Kennedy
Architect



Building an Atmosphere

Building Inflatables/ Inflatable Construction: Planning and Details

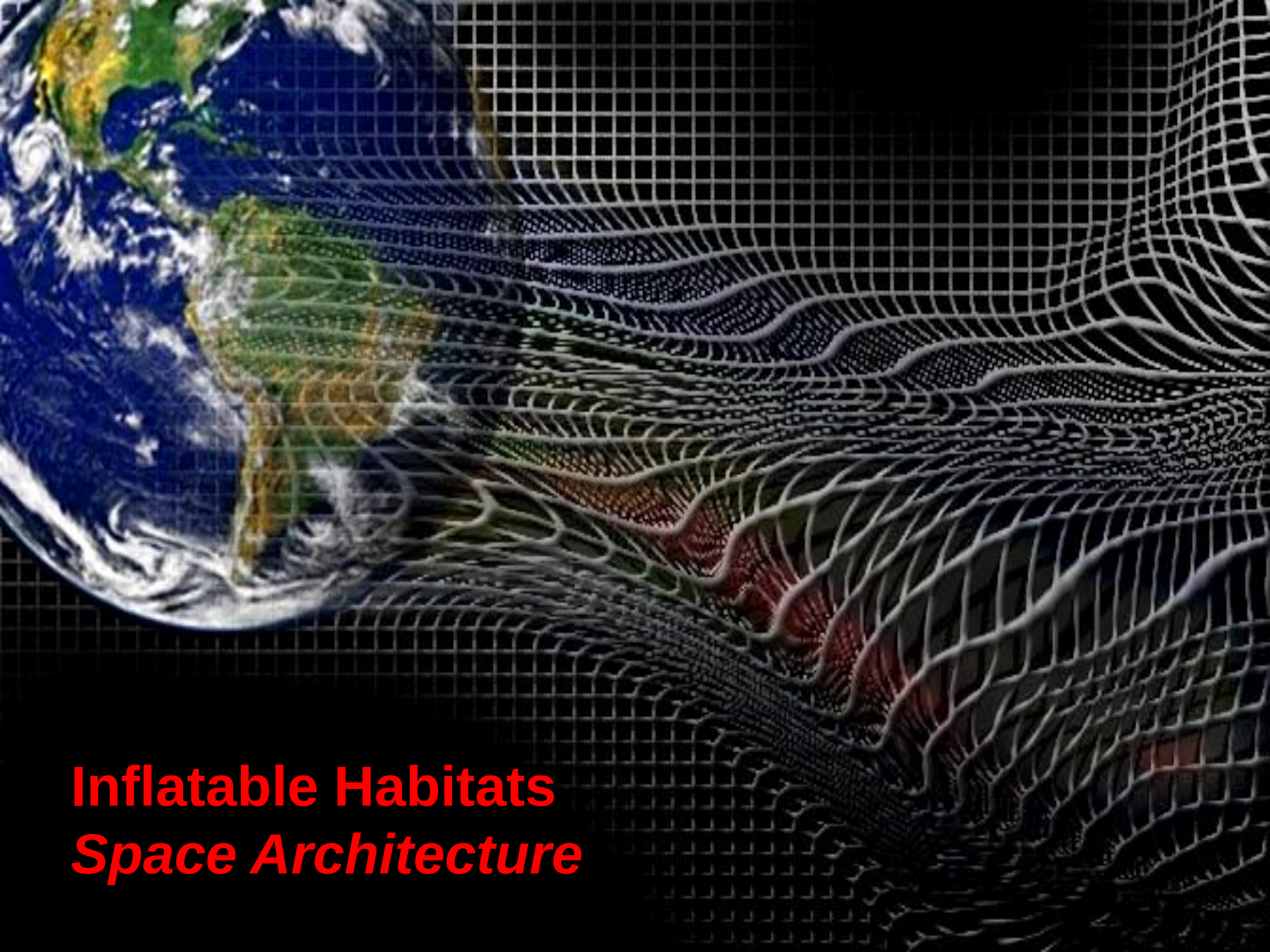
Carnegie Mellon University Space Architecture

- 1.29.16 Building an Atmosphere
  - A design-build seminar consisting of students from Physics, Mechanical and Civil Engineering, Robotic, Material Science, Art, and Architecture who will work together on a deployable “closed-loop” inflatable greenhouse for Mars in theory, and an Earth analogue physical mockup on campus.
- Kriss Kennedy
  - Air Tight: Building Inflatables/ Inflatable Construction: Planning and Details

Space Architecture…

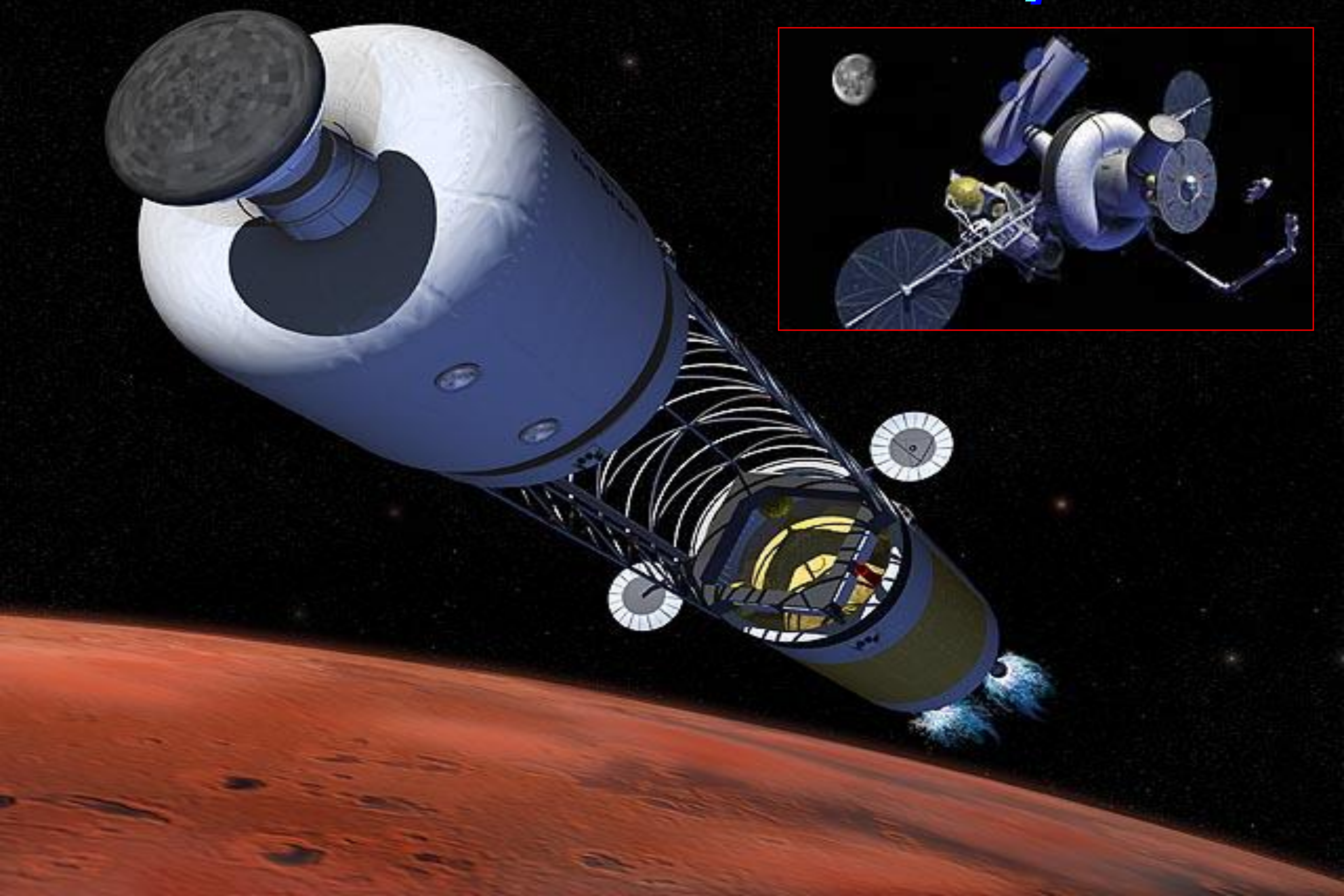
…theory and practice of designing and building inhabited environments in outer space…

…design of living and working environments in space related facilities, habitats, surface outposts and bases, and vehicles…

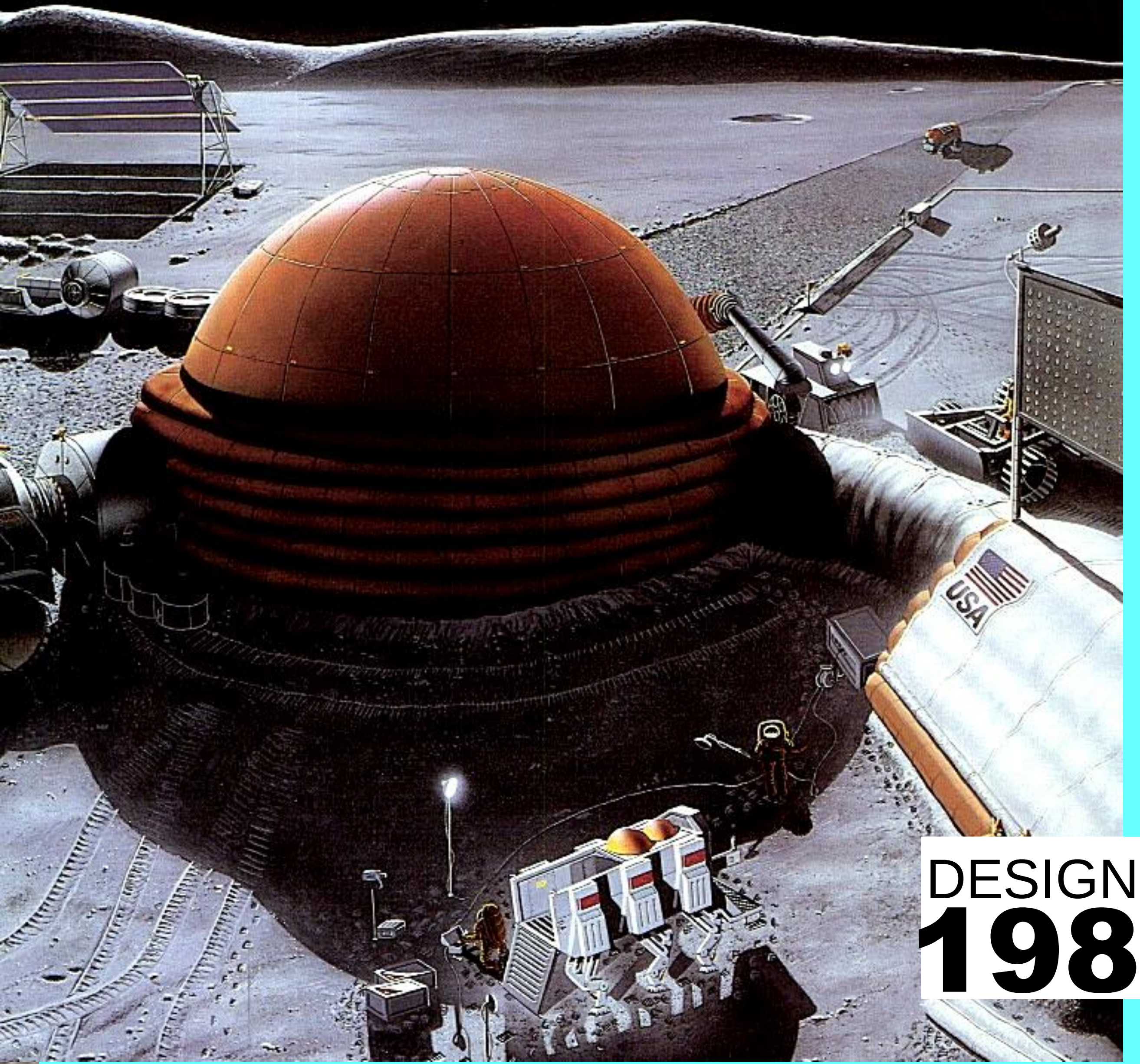


Inflatable Habitats
Space Architecture

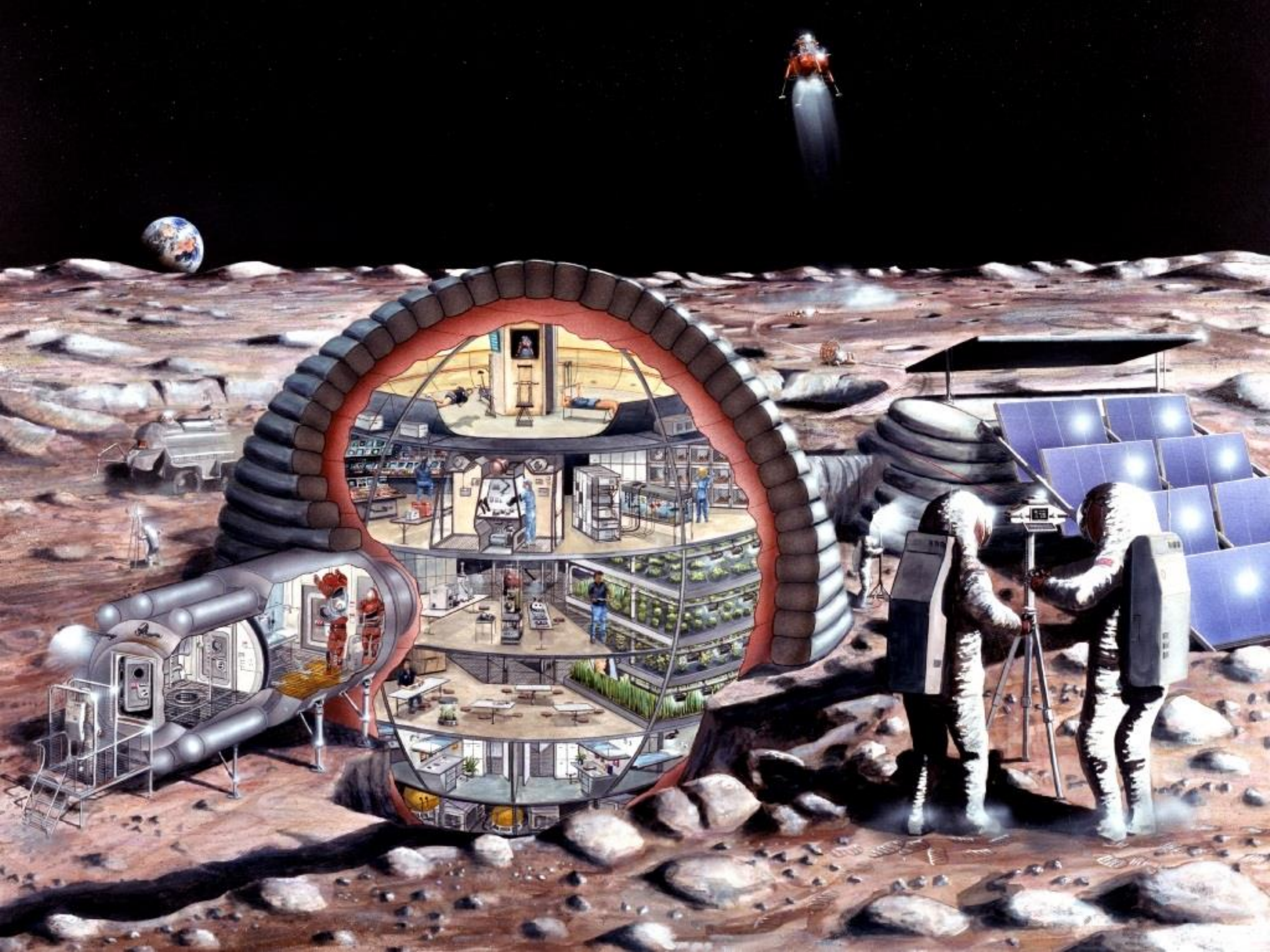
Inflatable Structures in Space



Inflatable Lunar Habitat



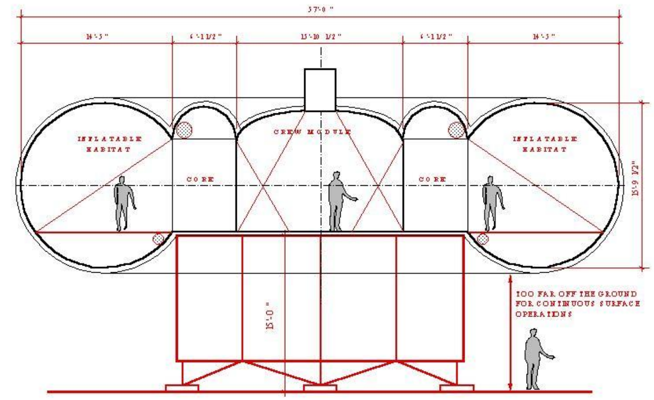
DESIGNED
1989




Inflatable Lunar Habitat
DESIGNED
1992


Mars Base
& Mission
Planning
1996

Mars Surface Hab/Combo Lander

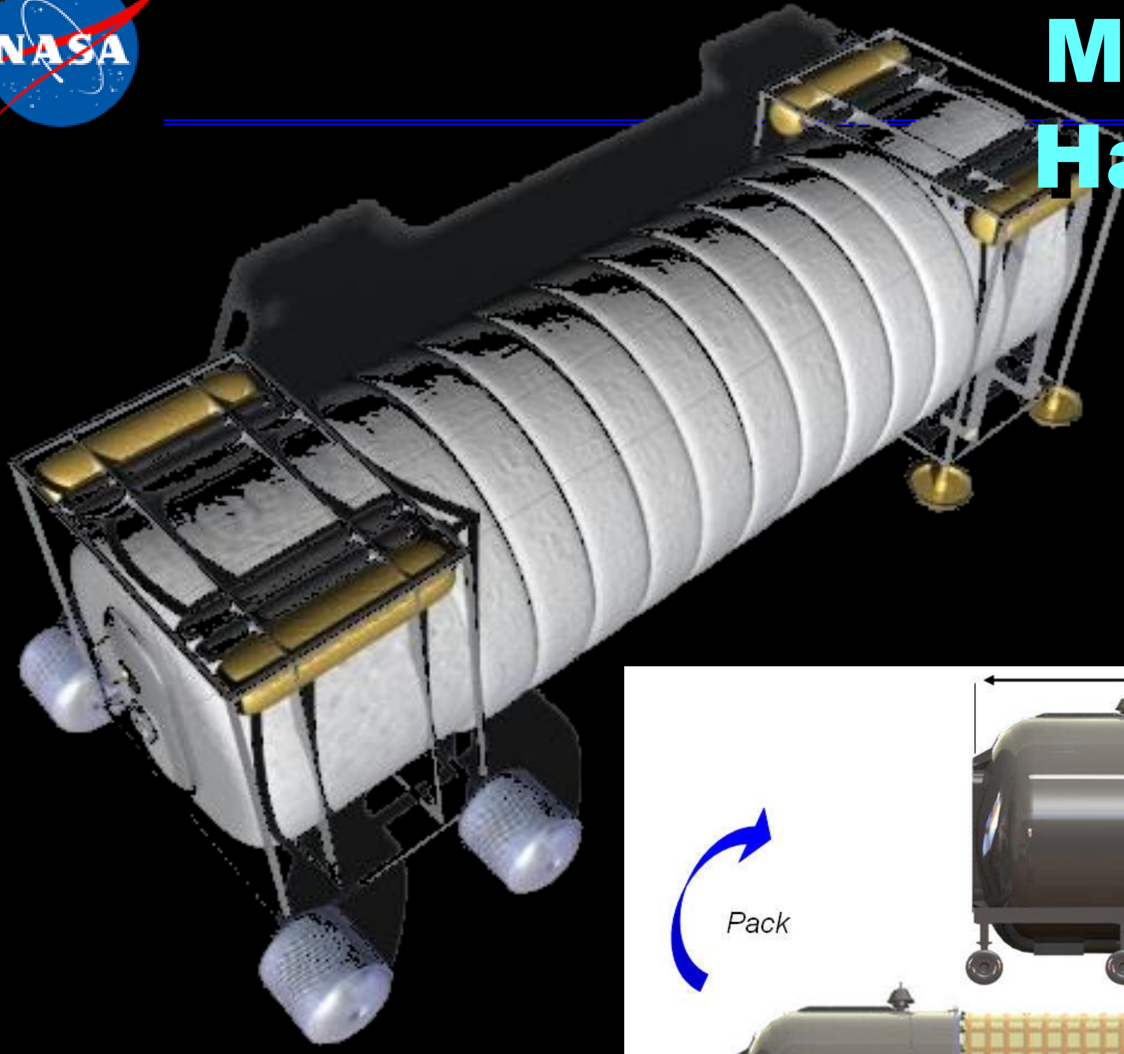


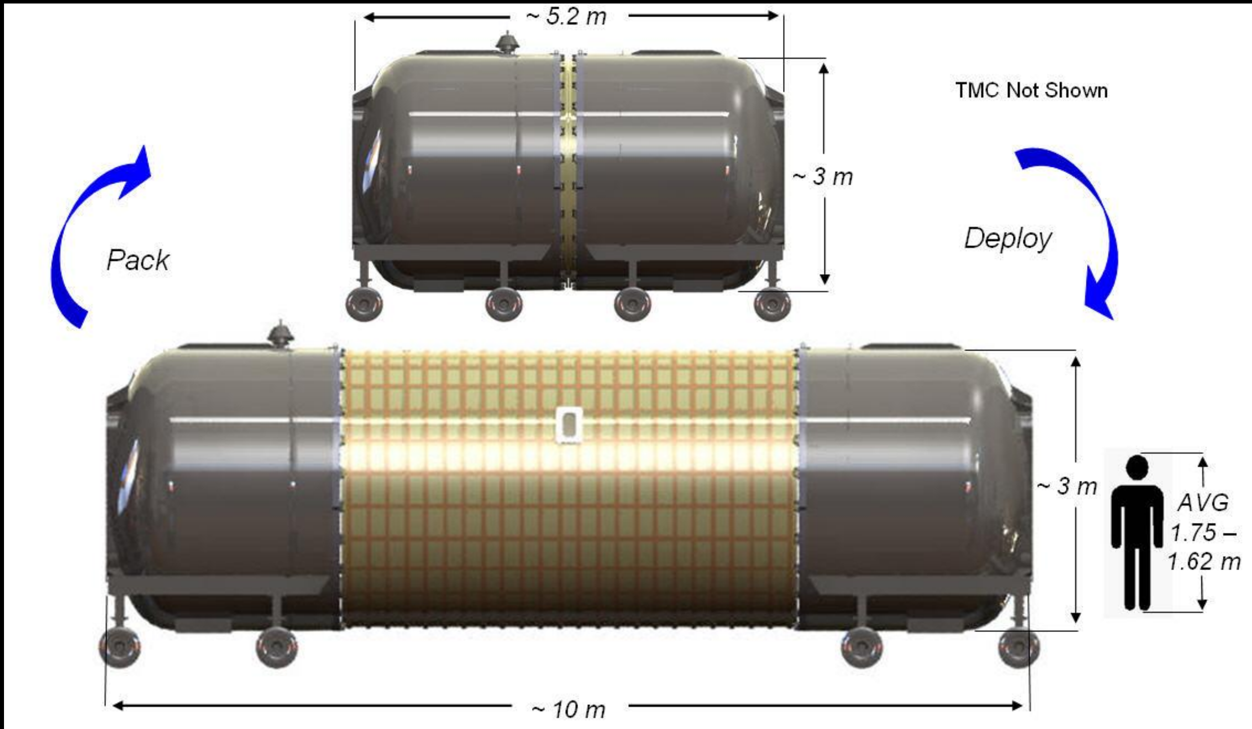
MARS SURFACE HABITAT CROSS SECTION

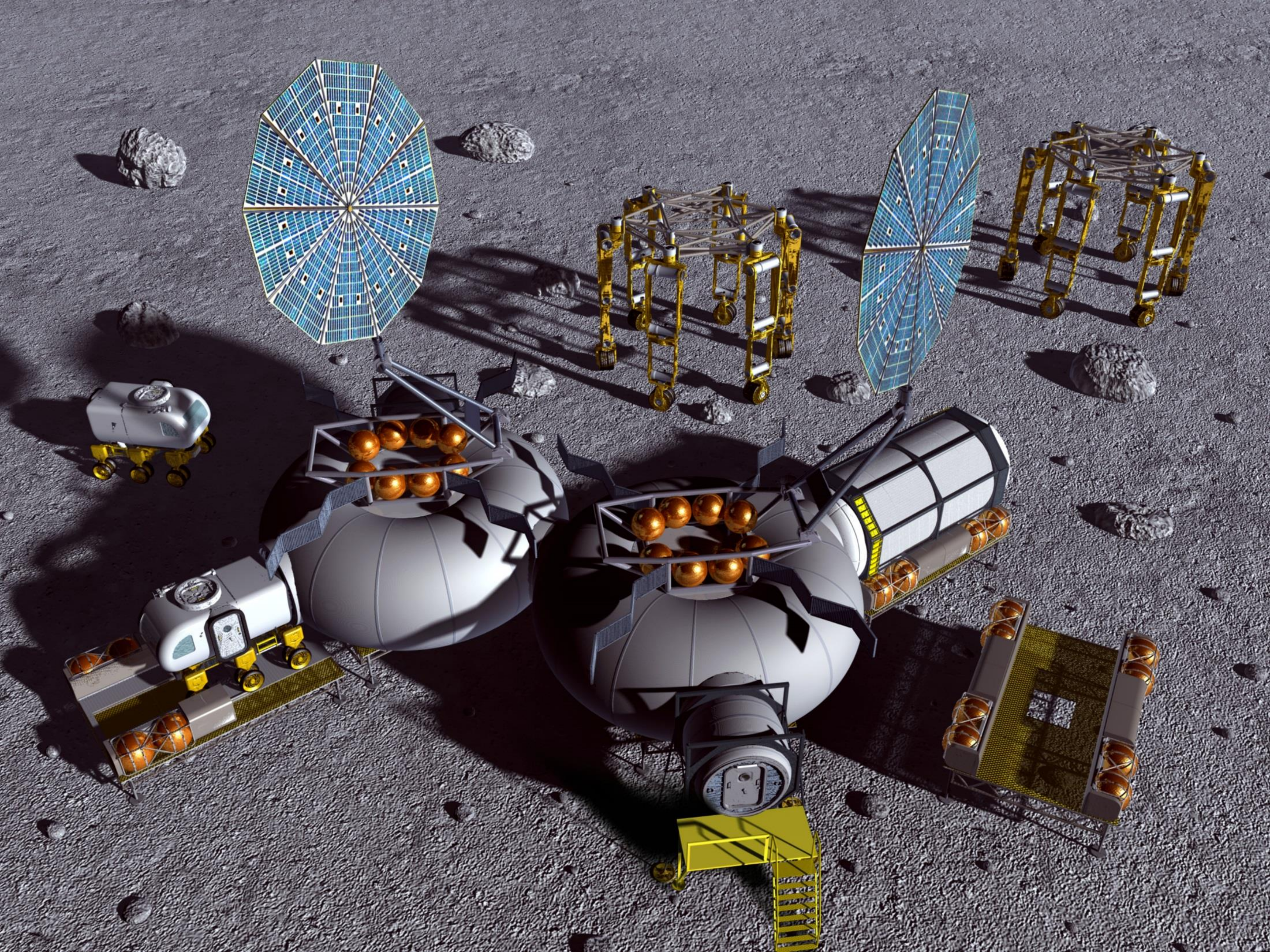
DESIGNED
2000

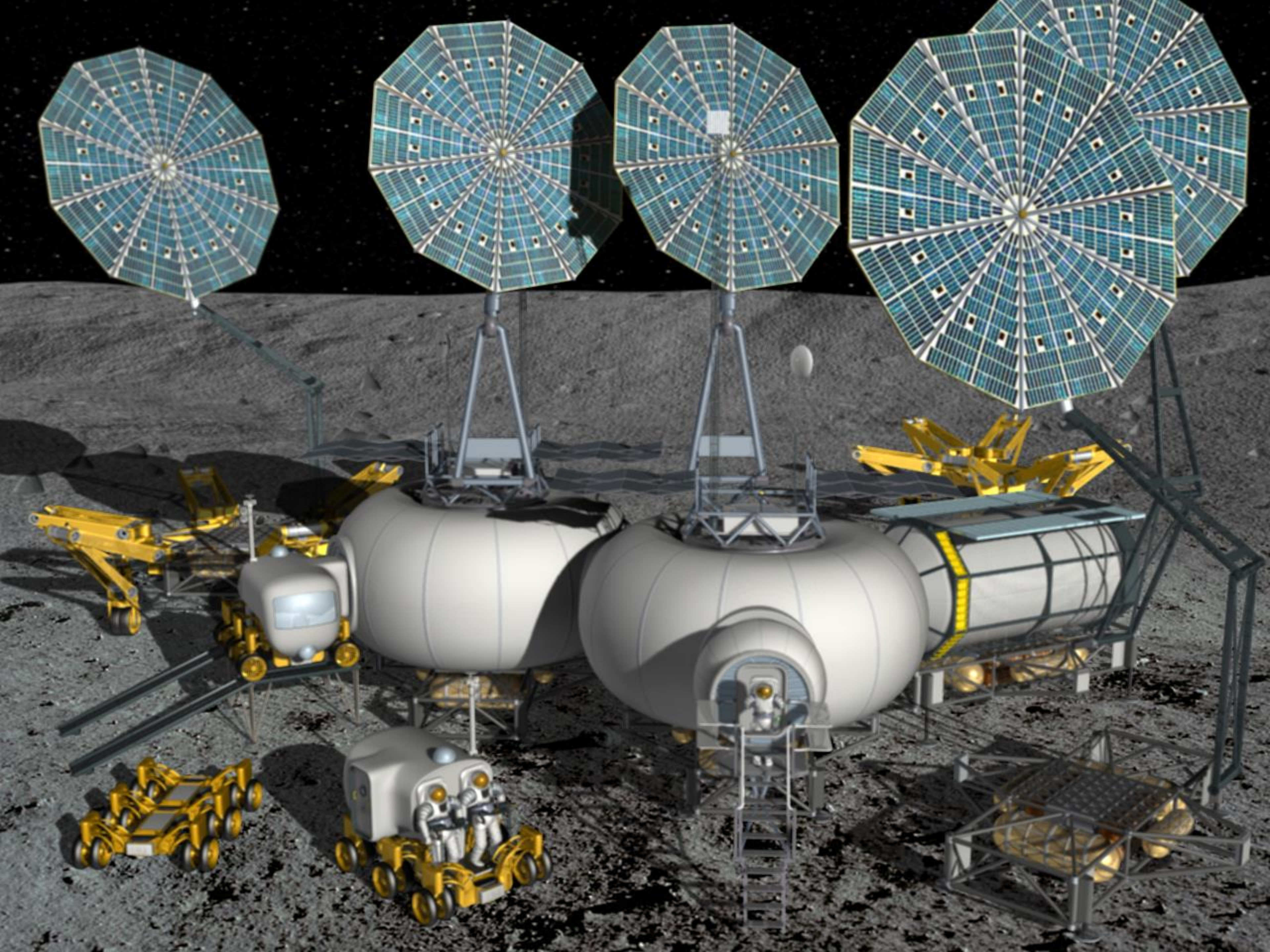
Mid-Expandable Habitat Concept

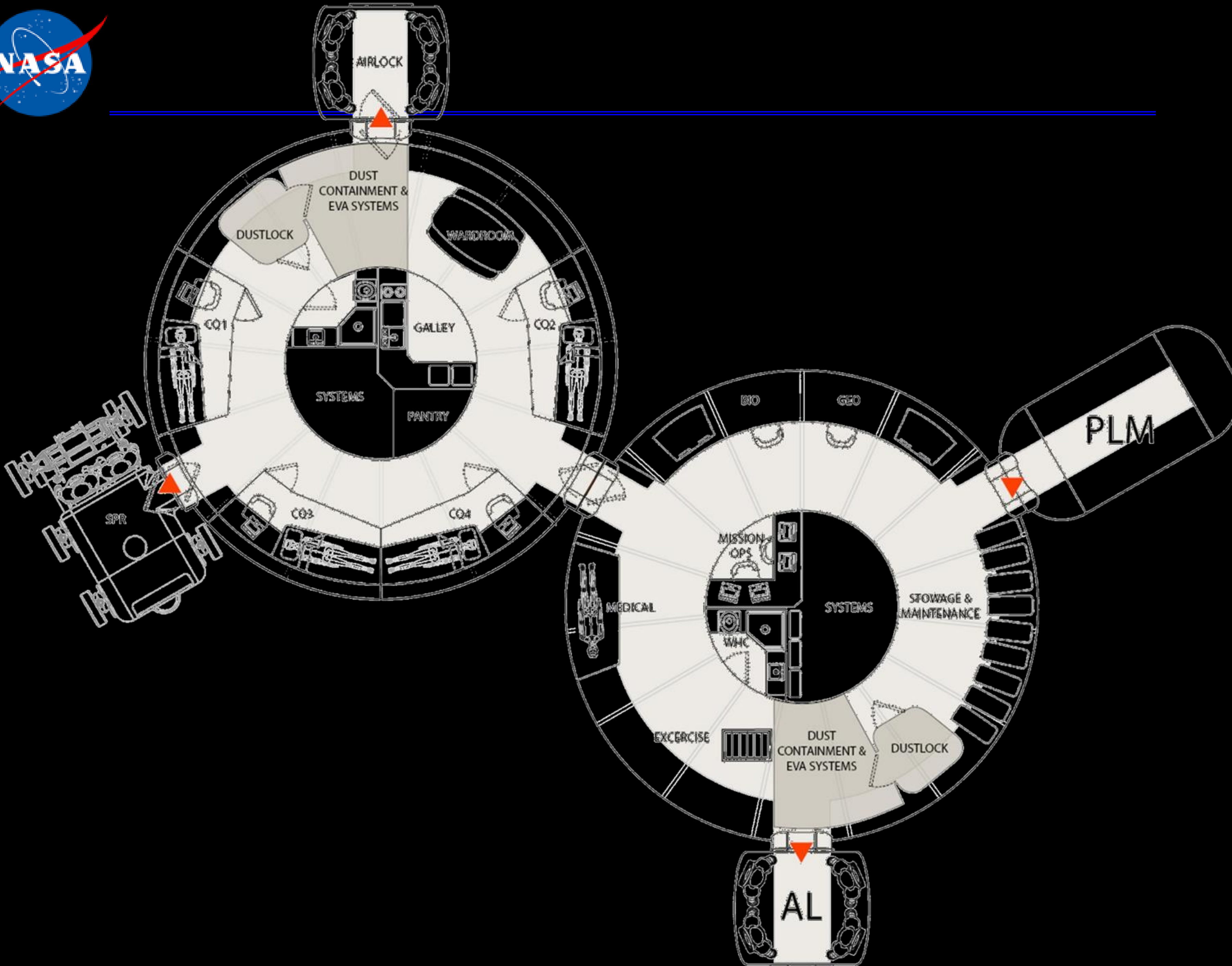
DESIGNED
2008



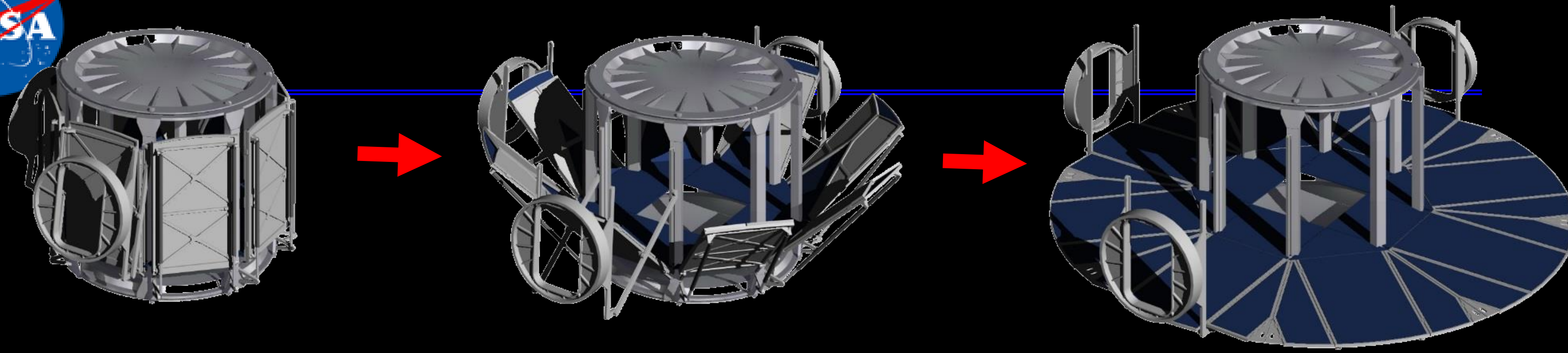


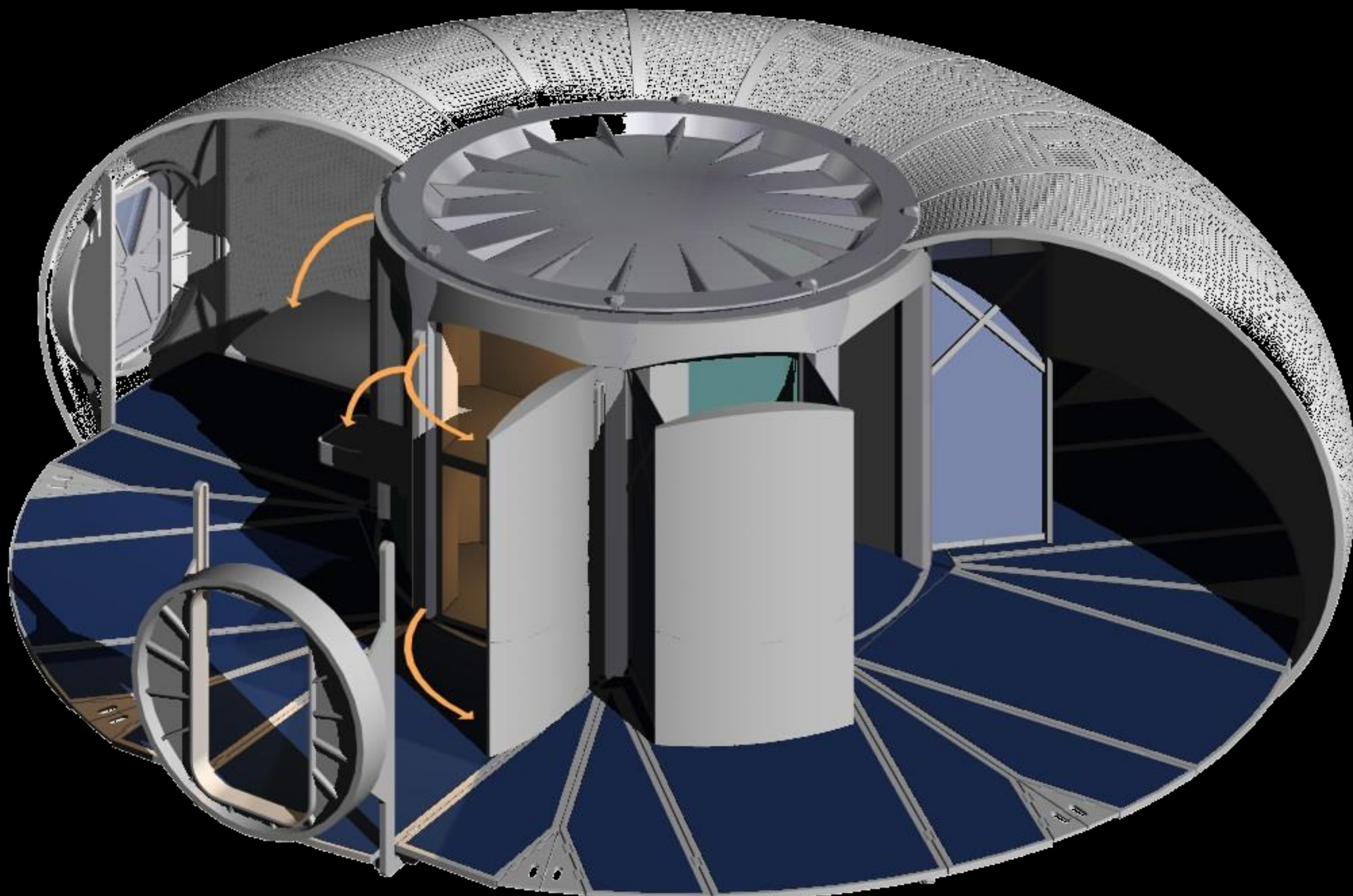


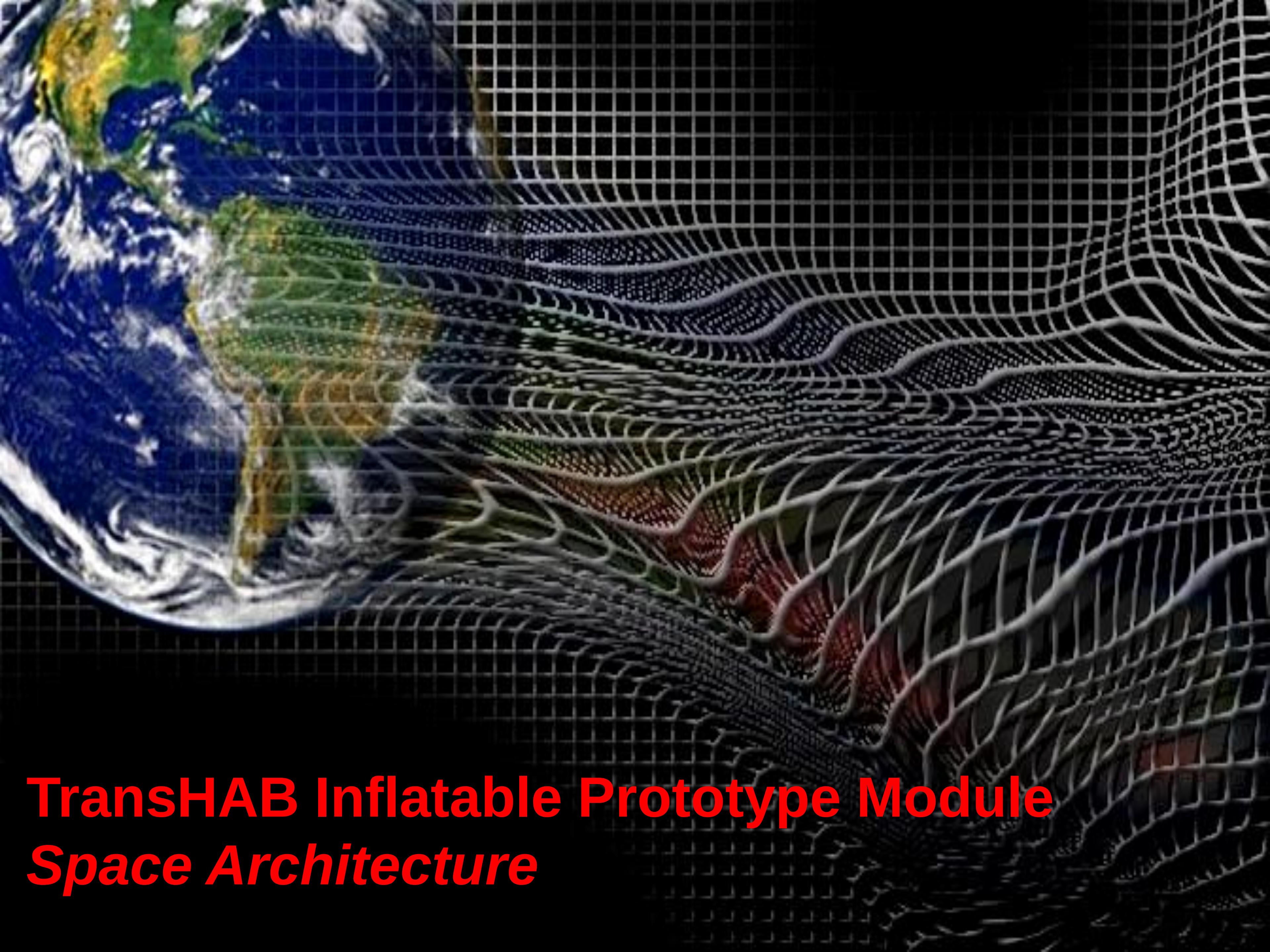




AIRLOCK
DUST CONTAINMENT & EVA SYSTEMS
DUSTLOCK
WARDROOM
GALLEY
CQ1
CQ2
SYSTEMS
PANTRY
SPR
CQ3
CQ4
BIO
GEO
PLM
MISSION OPS
MEDICAL
SYSTEMS
STOWAGE & MAINTENANCE
WHC
EXCERCISE
DUST CONTAINMENT & EVA SYSTEMS
DUSTLOCK
AL





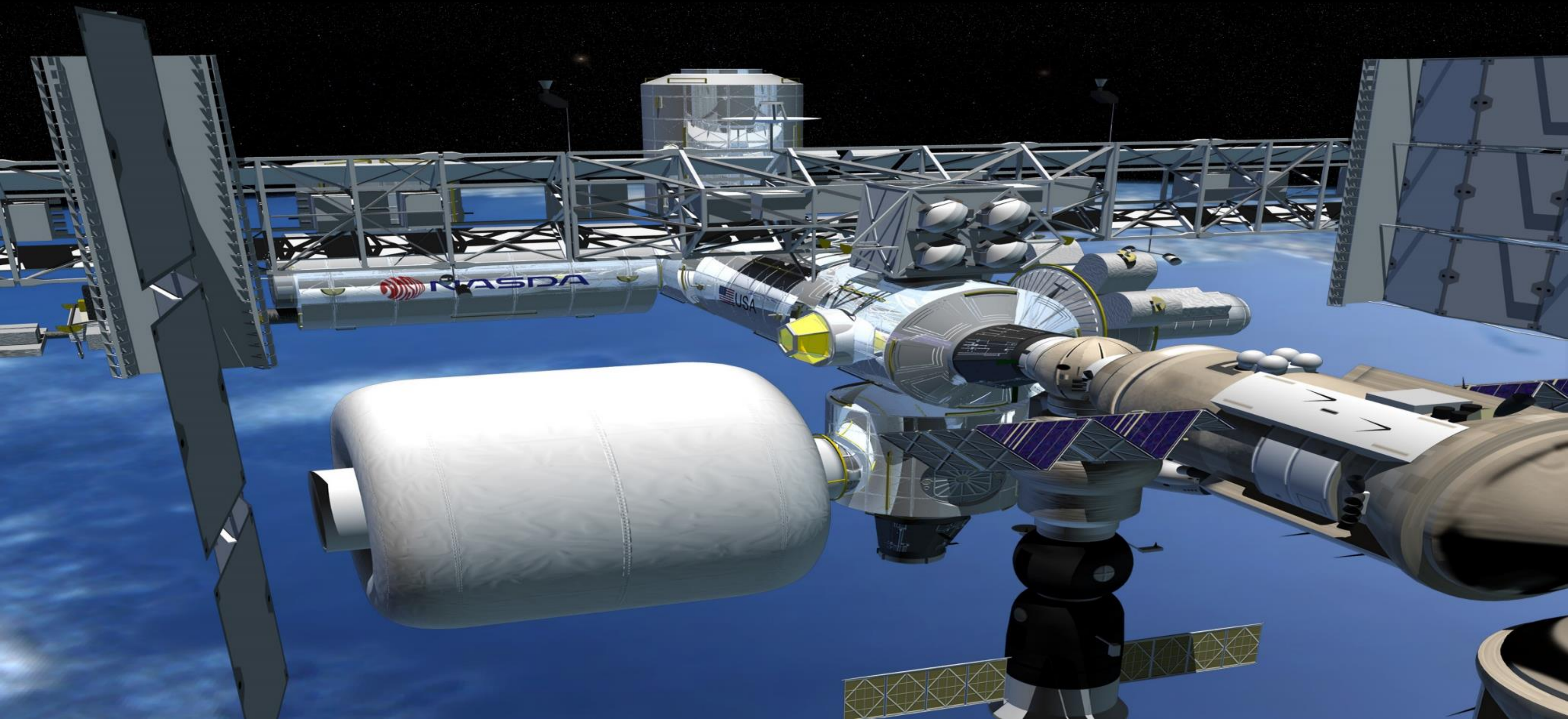


TransHAB Inflatable Prototype Module

Space Architecture

NASA TransHab Concept

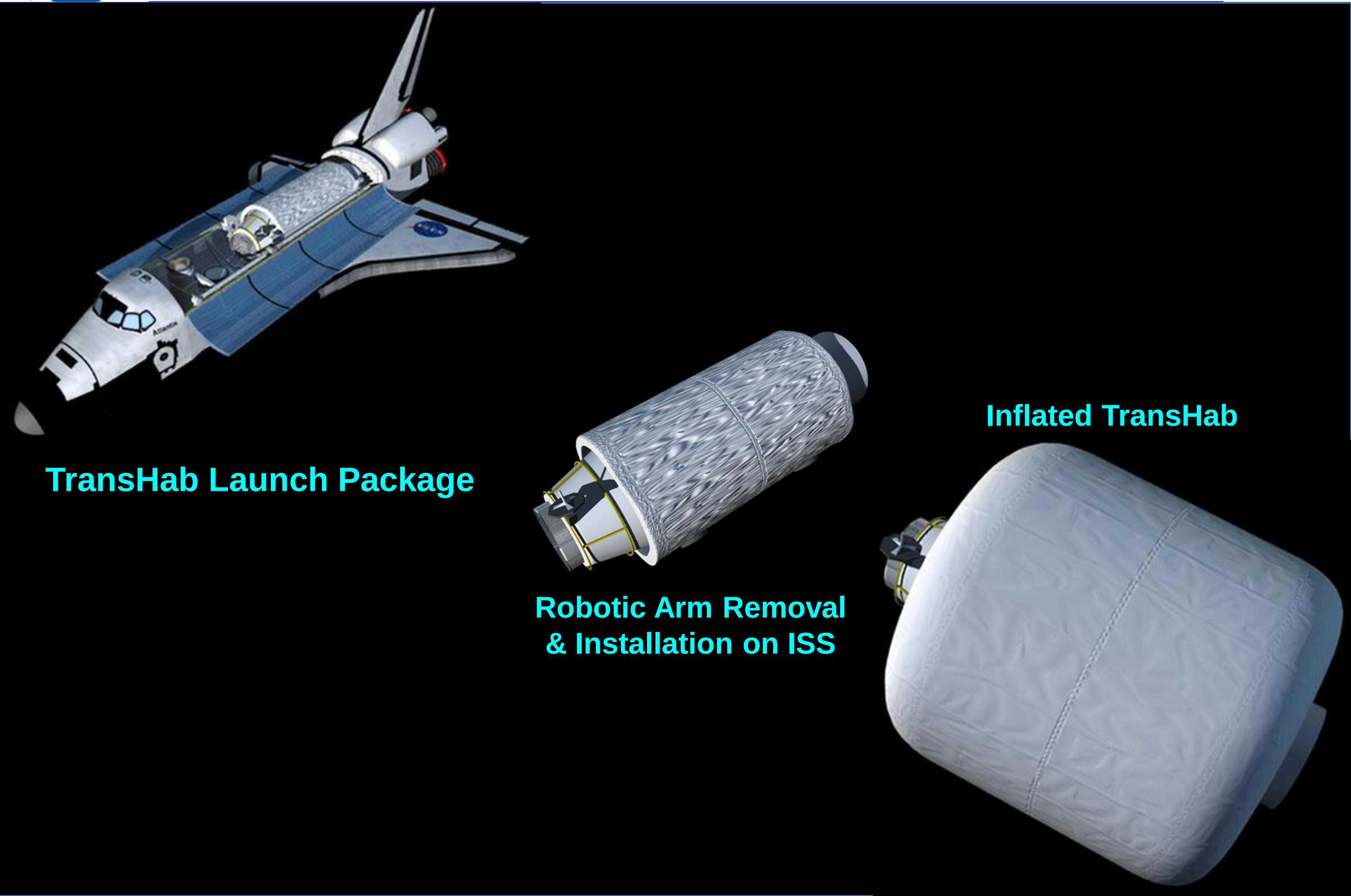
- TransHab was a light weight inflatable habitation module for space applications
- Original 1997 concept for light weight habitat module for human mission transit to Mars
- Proposed to the International Space Station (ISS) Program as a replacement for a Hab Module

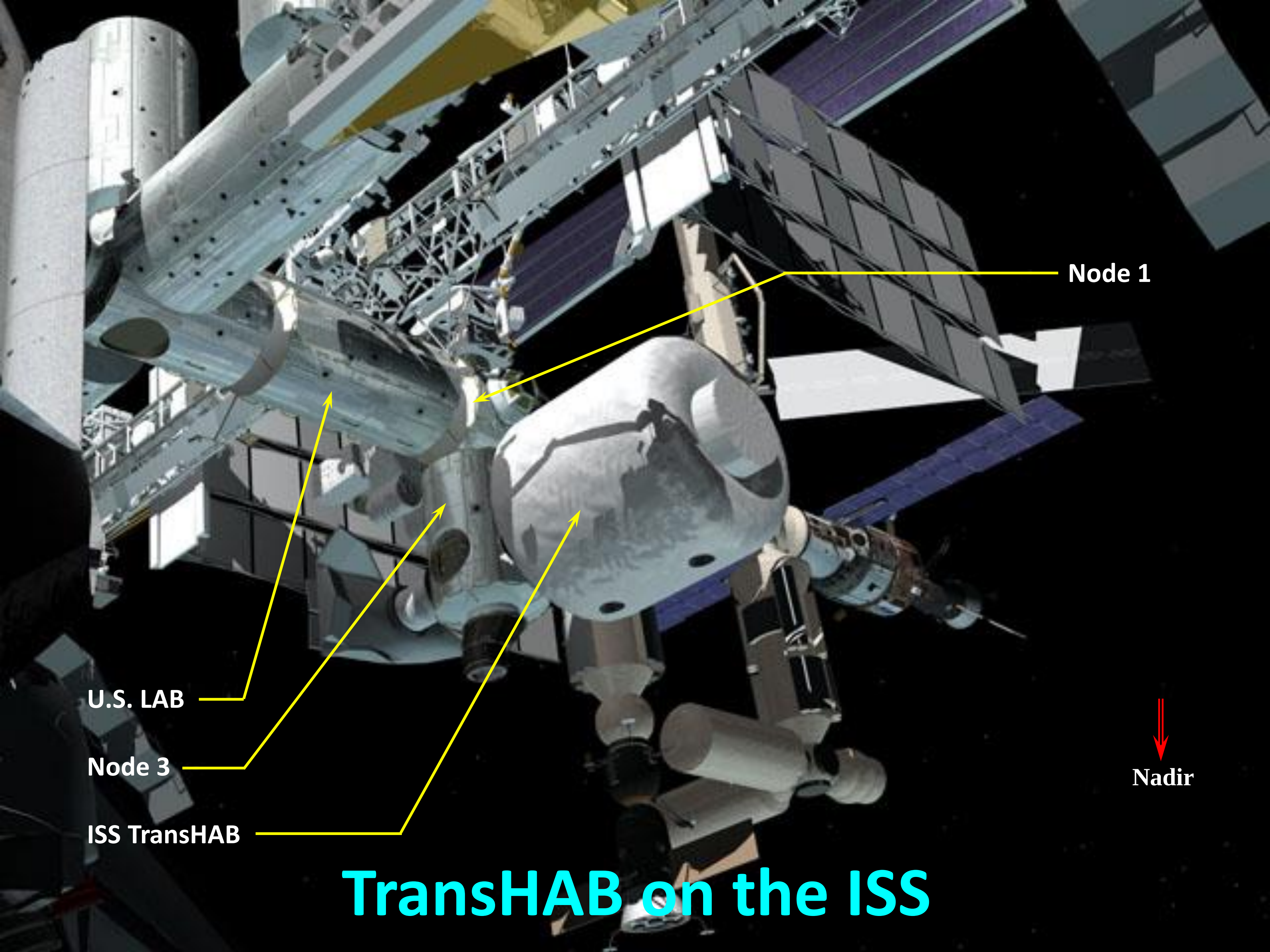


TransHab (Inflatable Space Habitat)

- U.S. Patent granted

Transportation Constraints




Node 1
U.S. LAB
Node 3
ISS TransHAB
Nadir
TransHAB on the ISS

ISS TransHAB

Level 4: Pressurized Tunnel

Level 3: Crew Health Care

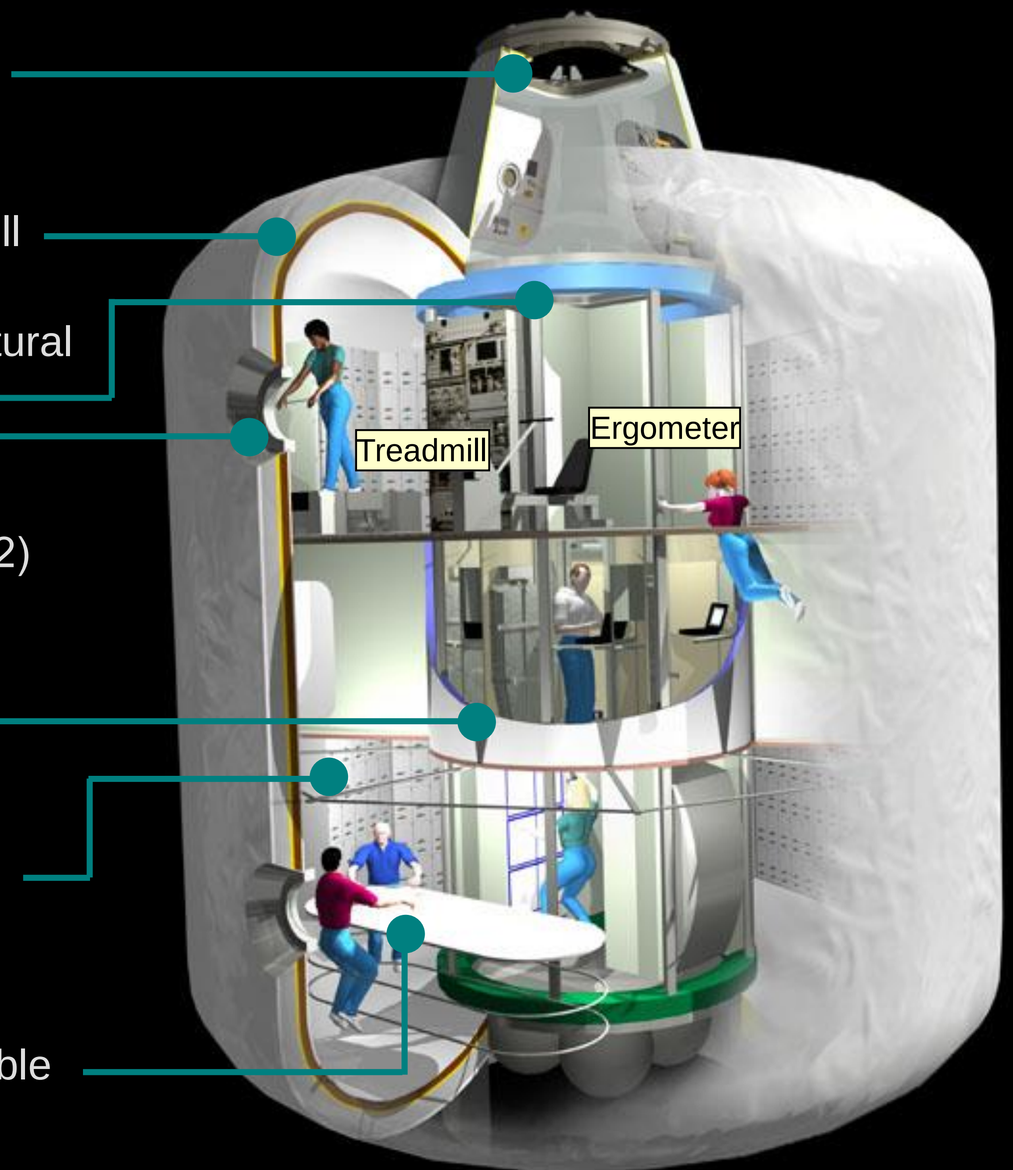
Level 2: Crew Quarters & Mechanical Room

Level 1: Galley & Wardroom

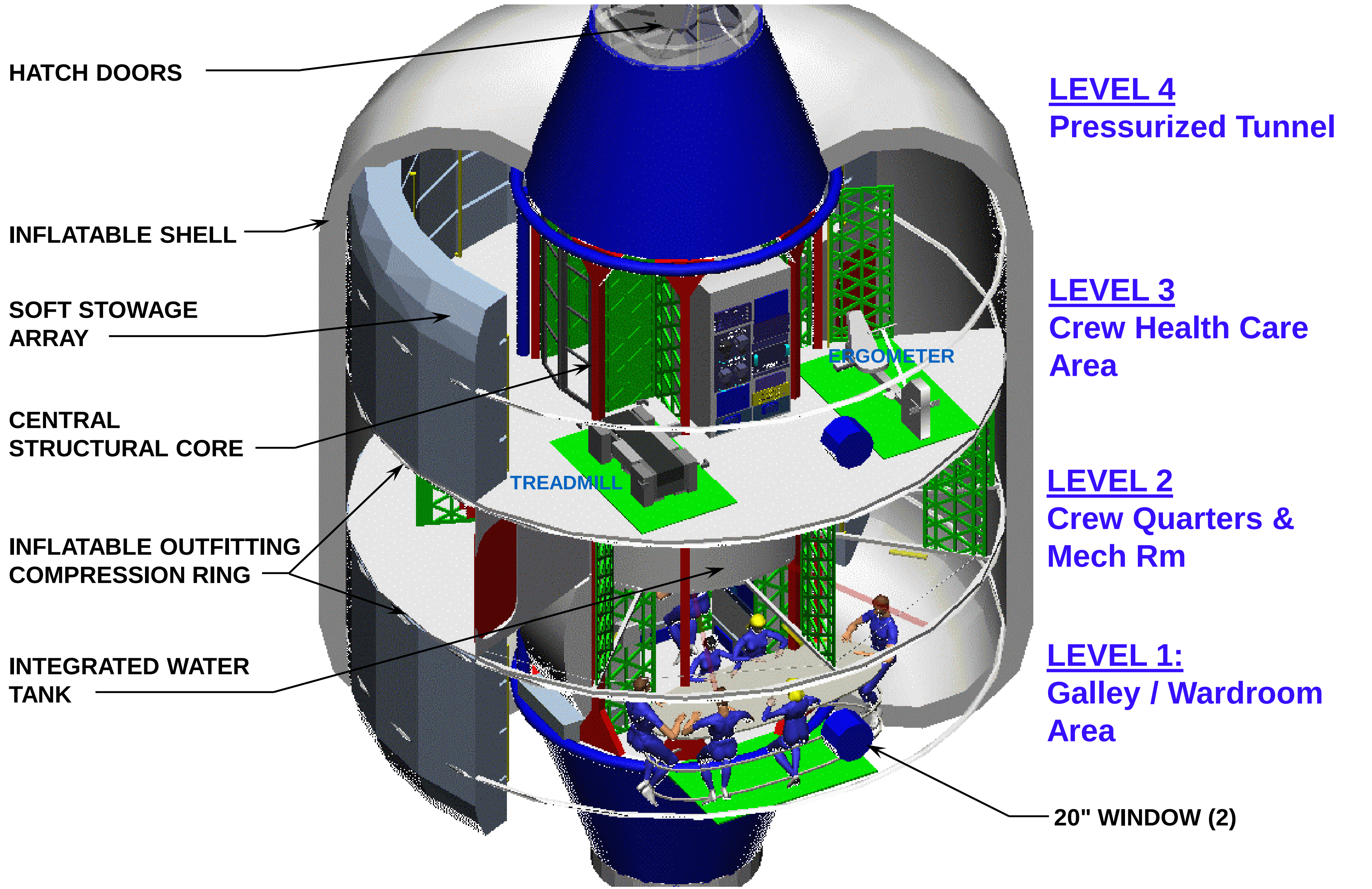
ISS TransHAB Functions

- Private Crew Quarters
- Galley & Dining
- Meeting area for entire ISS crew
- Health Care & Exercise
- Hygiene
- Stowage
- Crew Accommodations
- Environmental Control & Life Support System (ECLSS)
- Communications
- Command, Control & Data Handling
- Protection during Solar Particle Events

ISS TransHab



TransHab Architecture

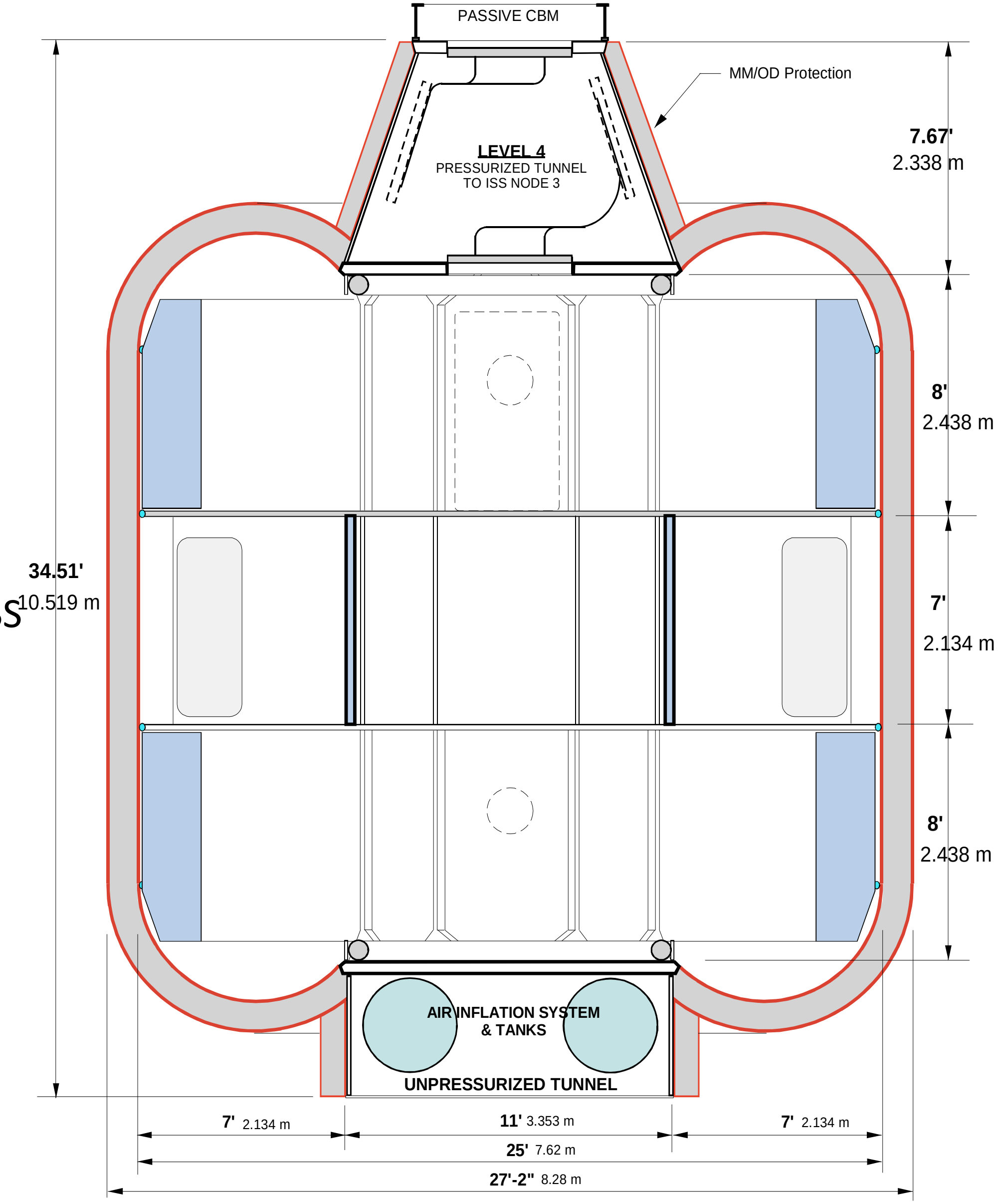


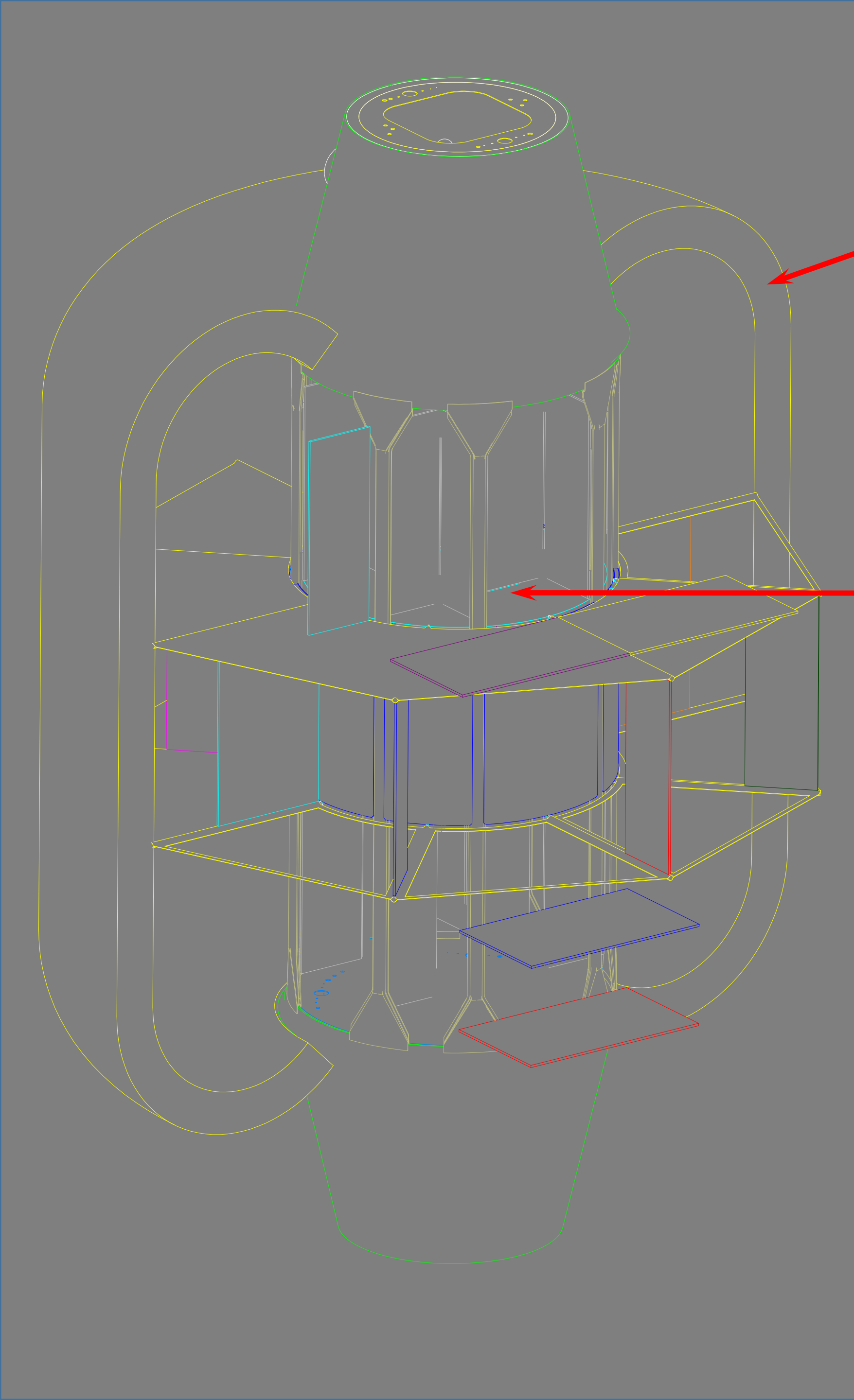
TransHab Specs

- Overall Length = 10.5 m
- OA Deployed Width = ~8.3 m
- Internal Diameter = 7.6 m
- Packaged volume = 342 m^3
- Deployed volume = ~161 m^3
- ConOps
  - Packaged around Hard Core
  - During Launch-goes to vacuum except Tunnel
  - Removed from Cargo Bay & Berthed to ISS
  - Slowly inflated with warmed air. Equalize & stabilize.
  - Crew unpack and assembly.
  - Checkout and verify operational

SHELL Vol = 11631 ft3 (329.37 m3)
TUNNEL Vol = <u>446 ft3 (12.63 m3)</u>
Total Vol = 12077 ft3 (342.0 m3)

2.74x larger an ISS Lab/Hab Module Vol. (4414 ft3, or 125 m3)

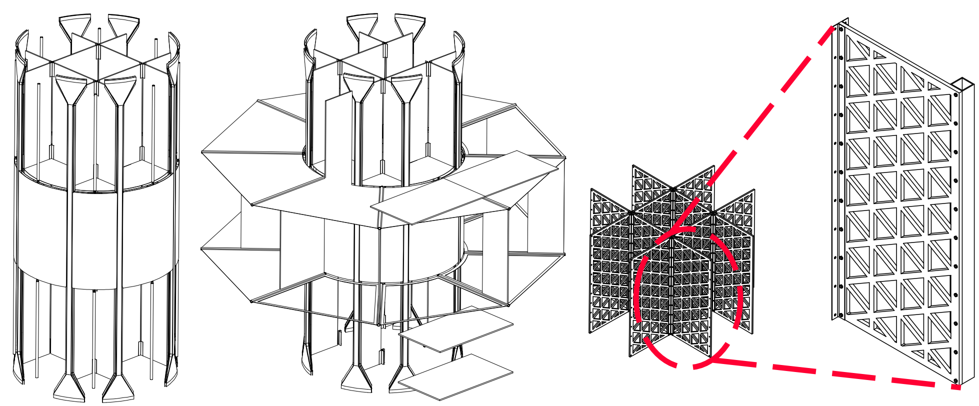




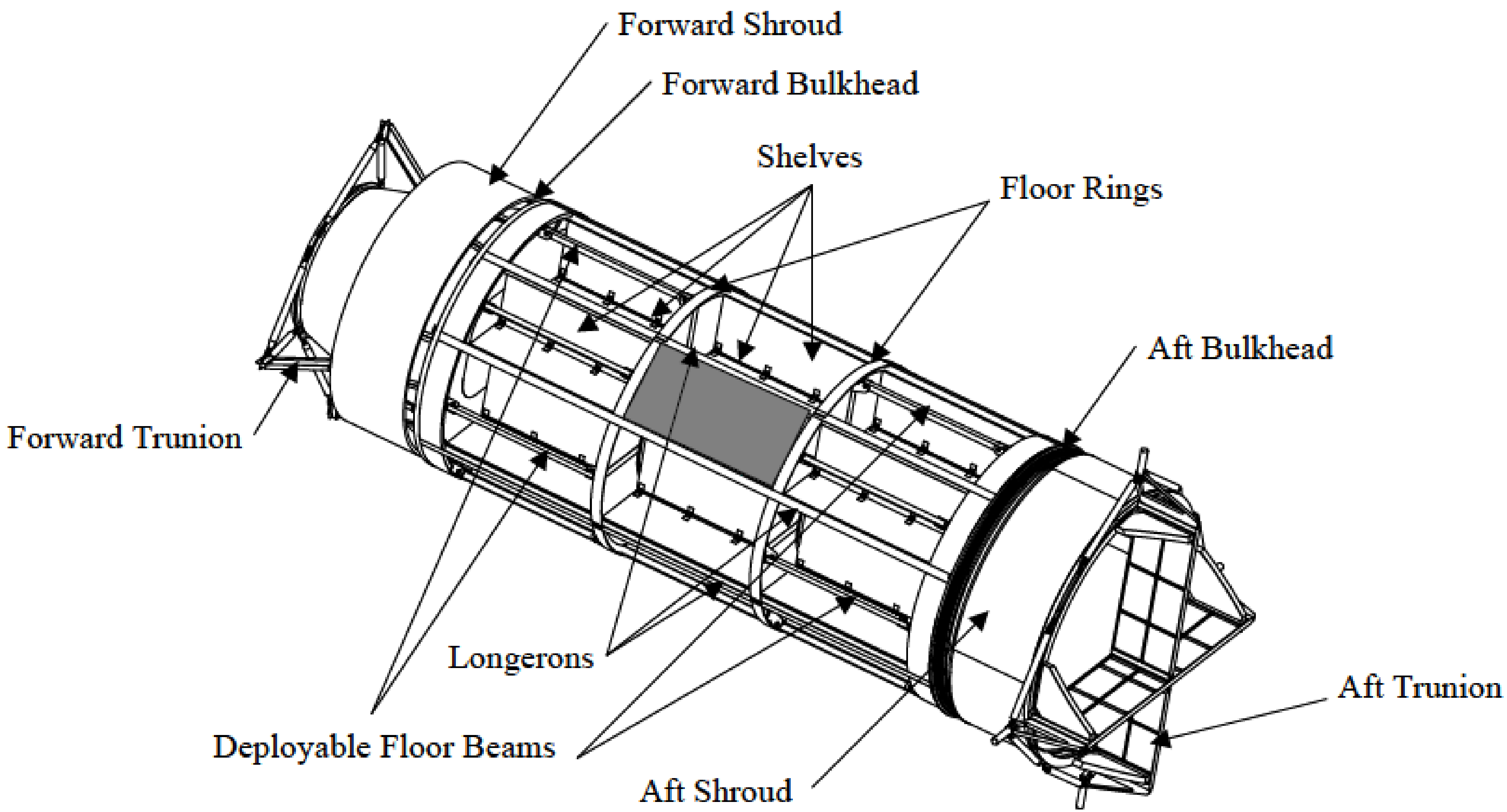
General Structural Configuration

Multi-Layer Inflatable Shell
- **Multi-Layer Insulation Blankets**
- **Micrometeoroid / orbital debris Protection**
- **Optimized Restraint Layer**
- **Redundant Bladder With Protective Layer**

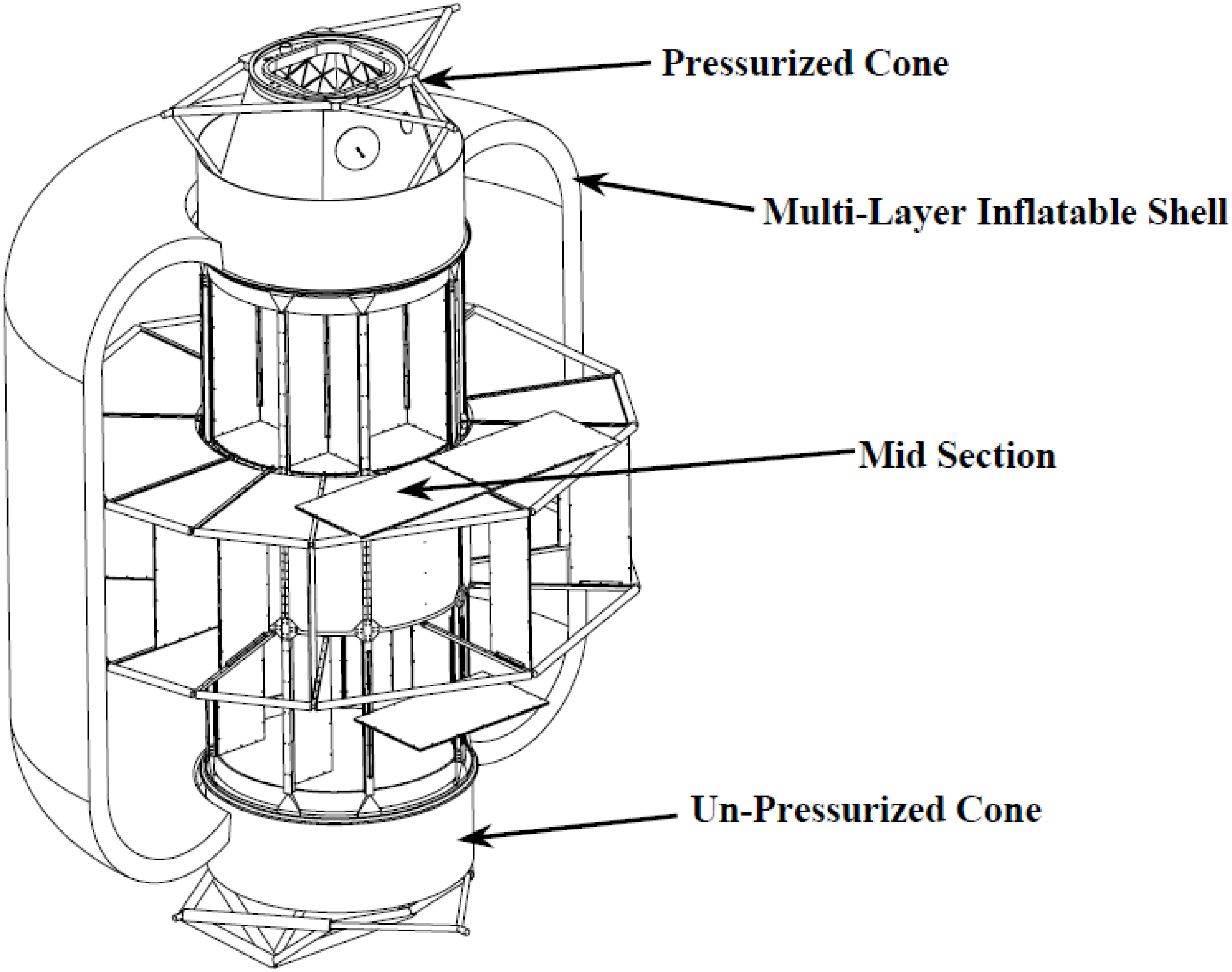
Central Structural Core
- **2 Tunnels**
- **Composite Core With Integral Water Tank**
- **Repositionable Composite Isogrid shelves**
- **Floor Struts With Fabric Flooring**



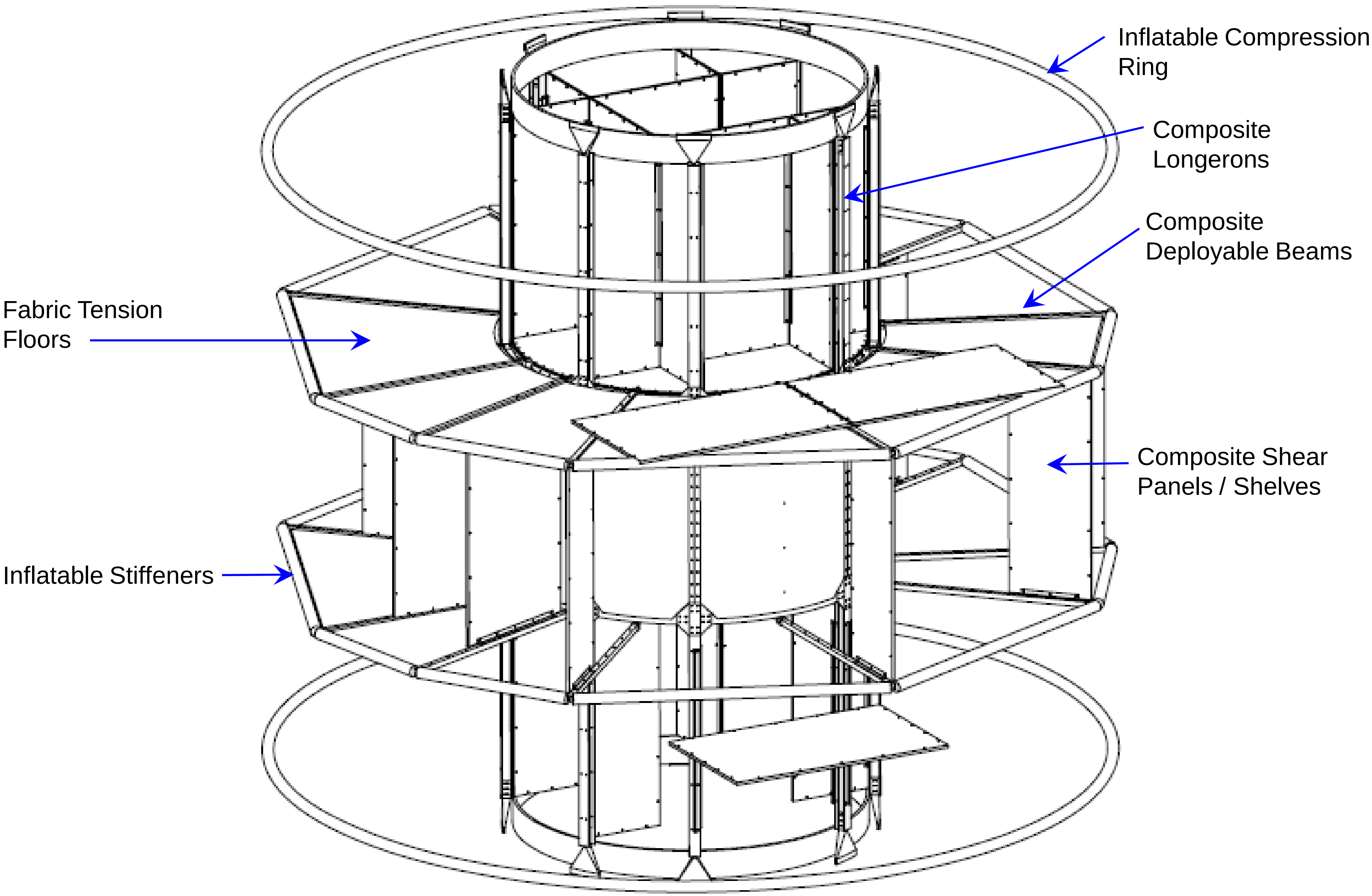
Structural Hard Core



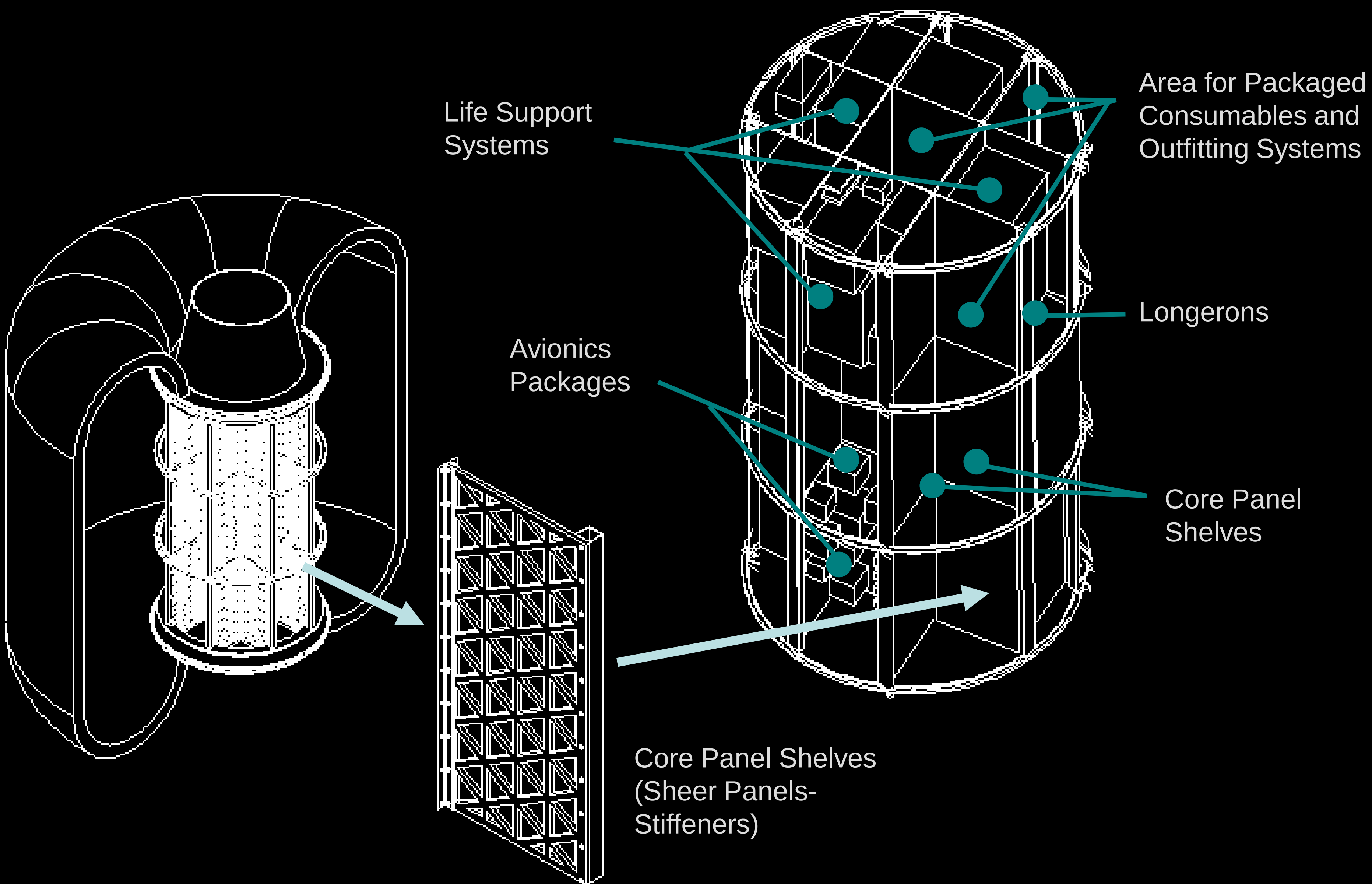
Structural Overview



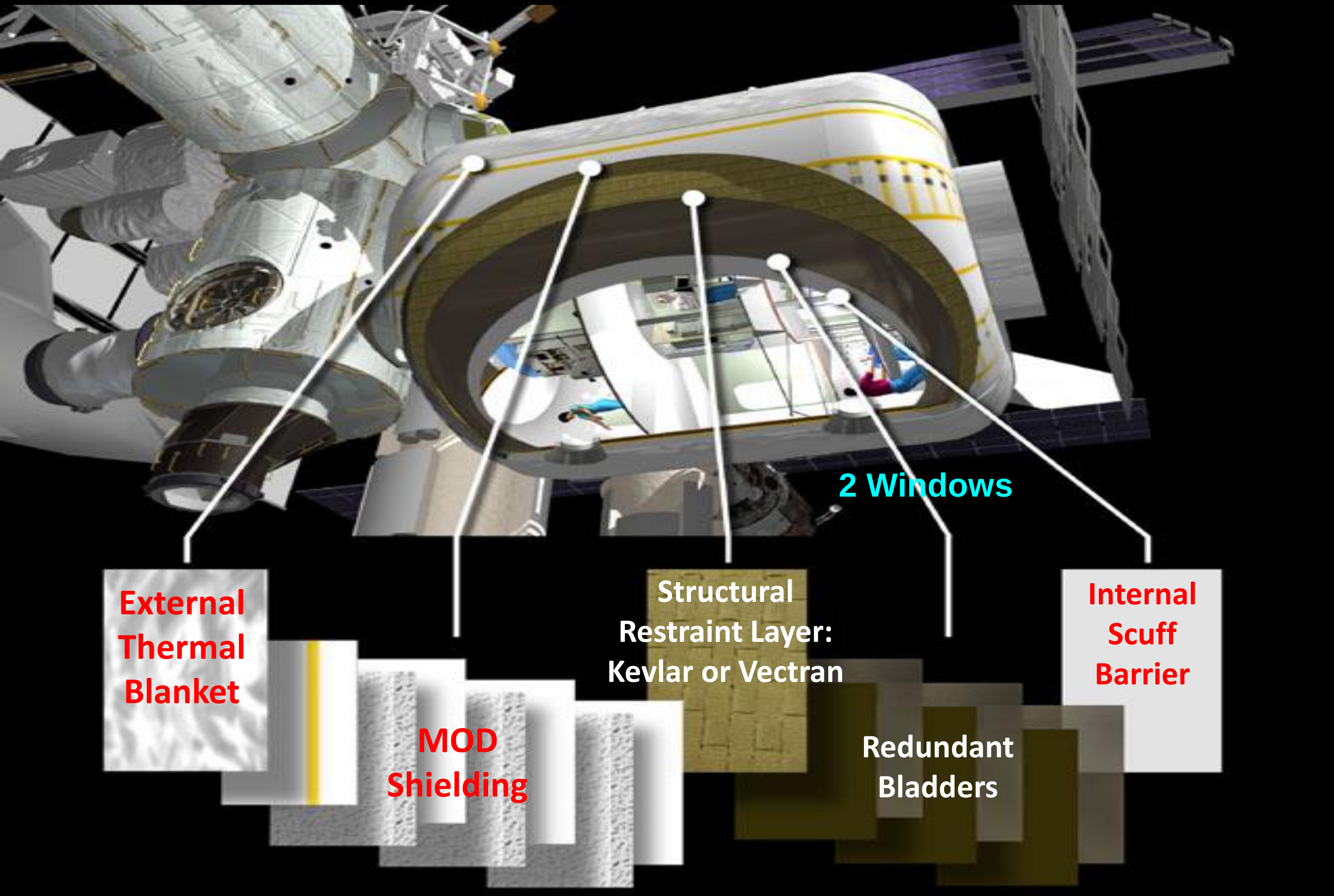
Deployed Internal Structure Overview



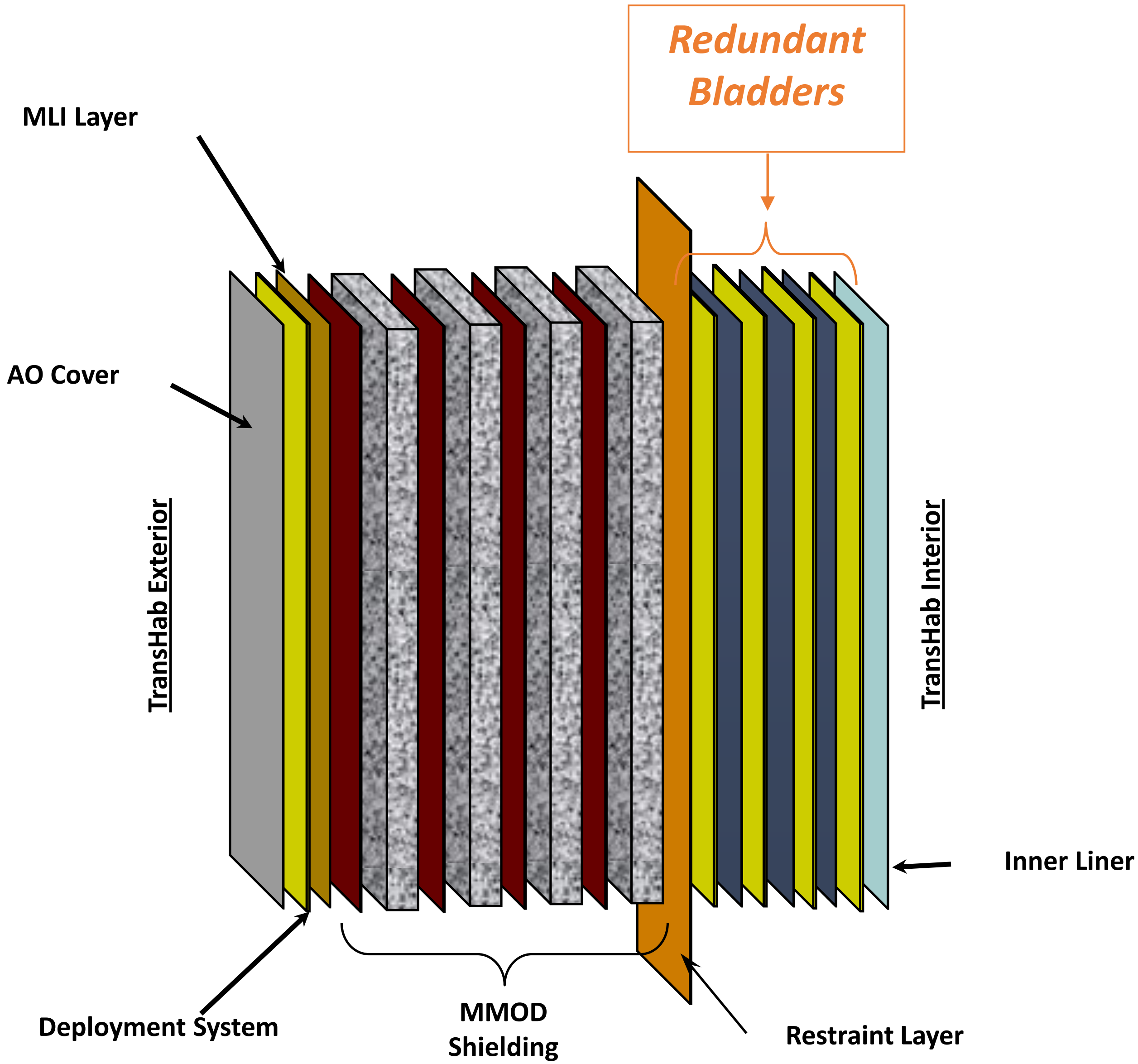
Subsystems Packaged in Core



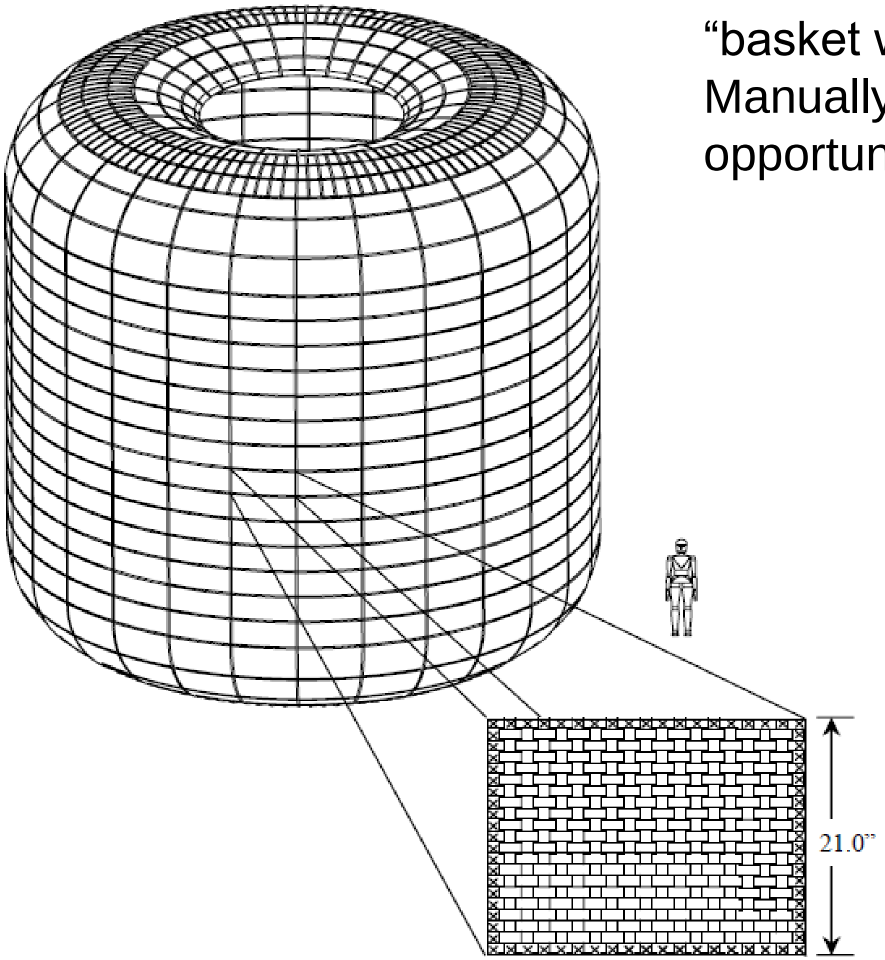
Multi-Functional Layered Inflatable Pressure Shell



Multi-Layer Shell Configuration Overview

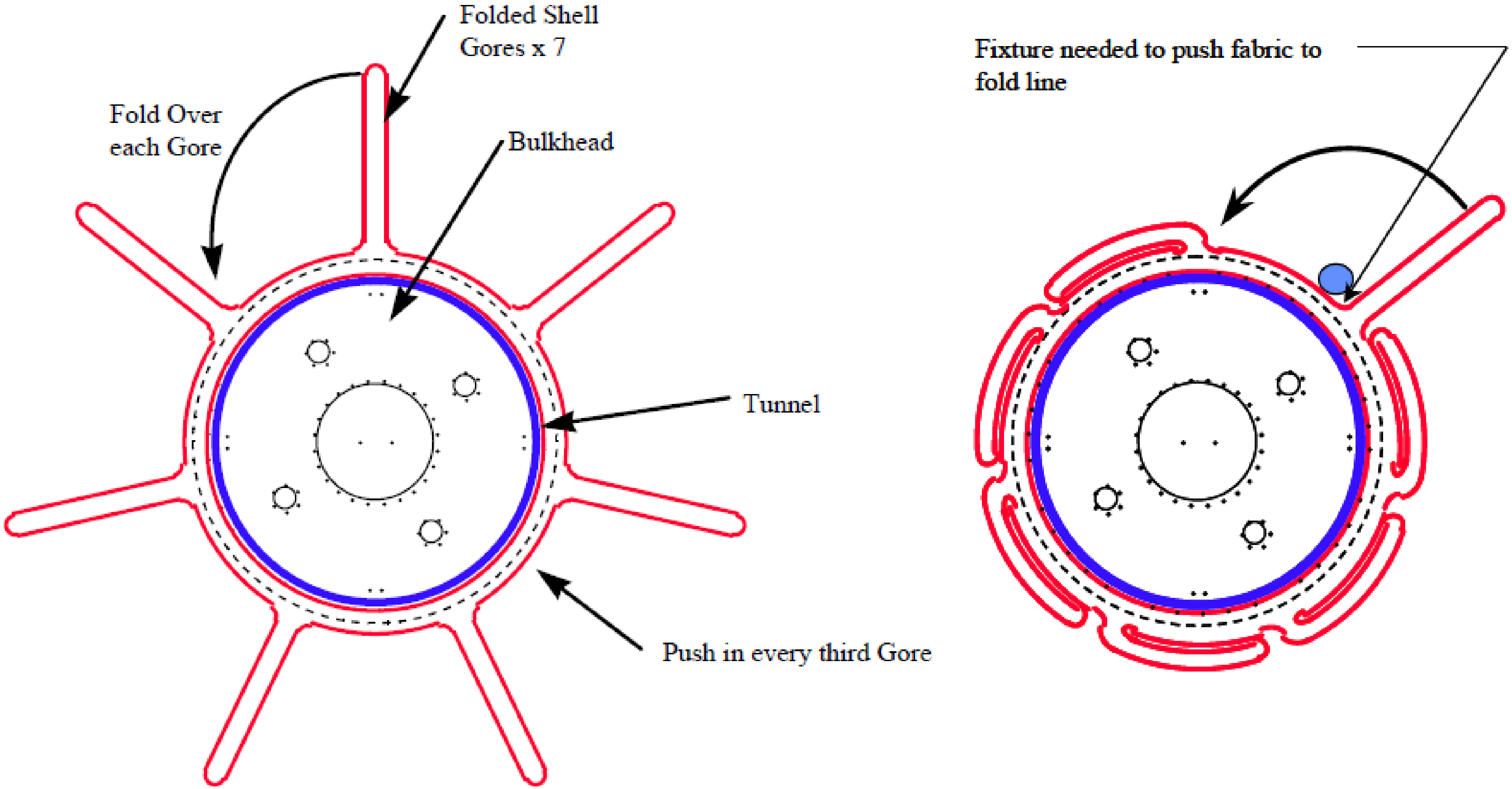


Inflatable Restraint Layer

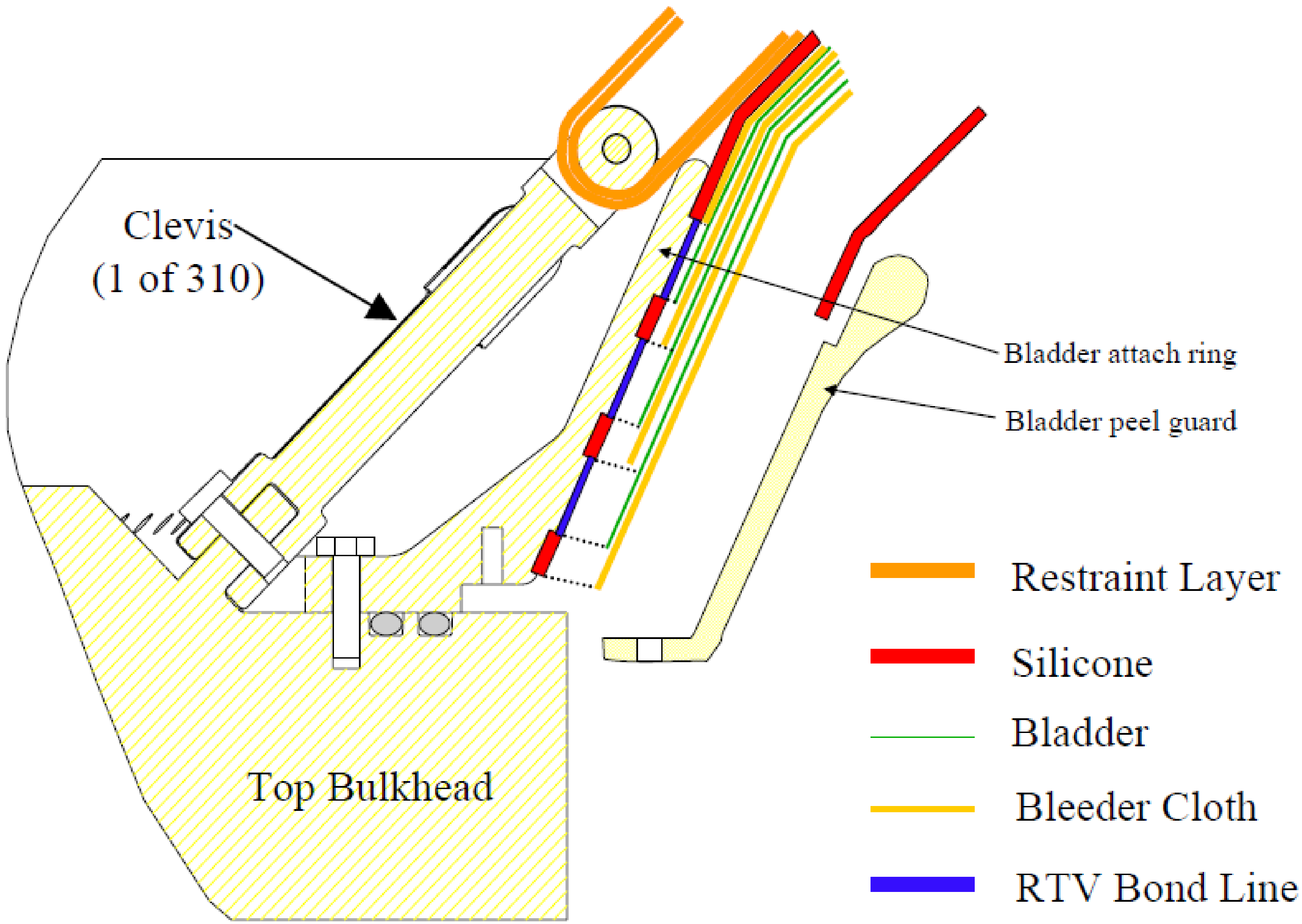


"basket weave" manufacturing approach. Manually labor intensive and many opportunities for human error.

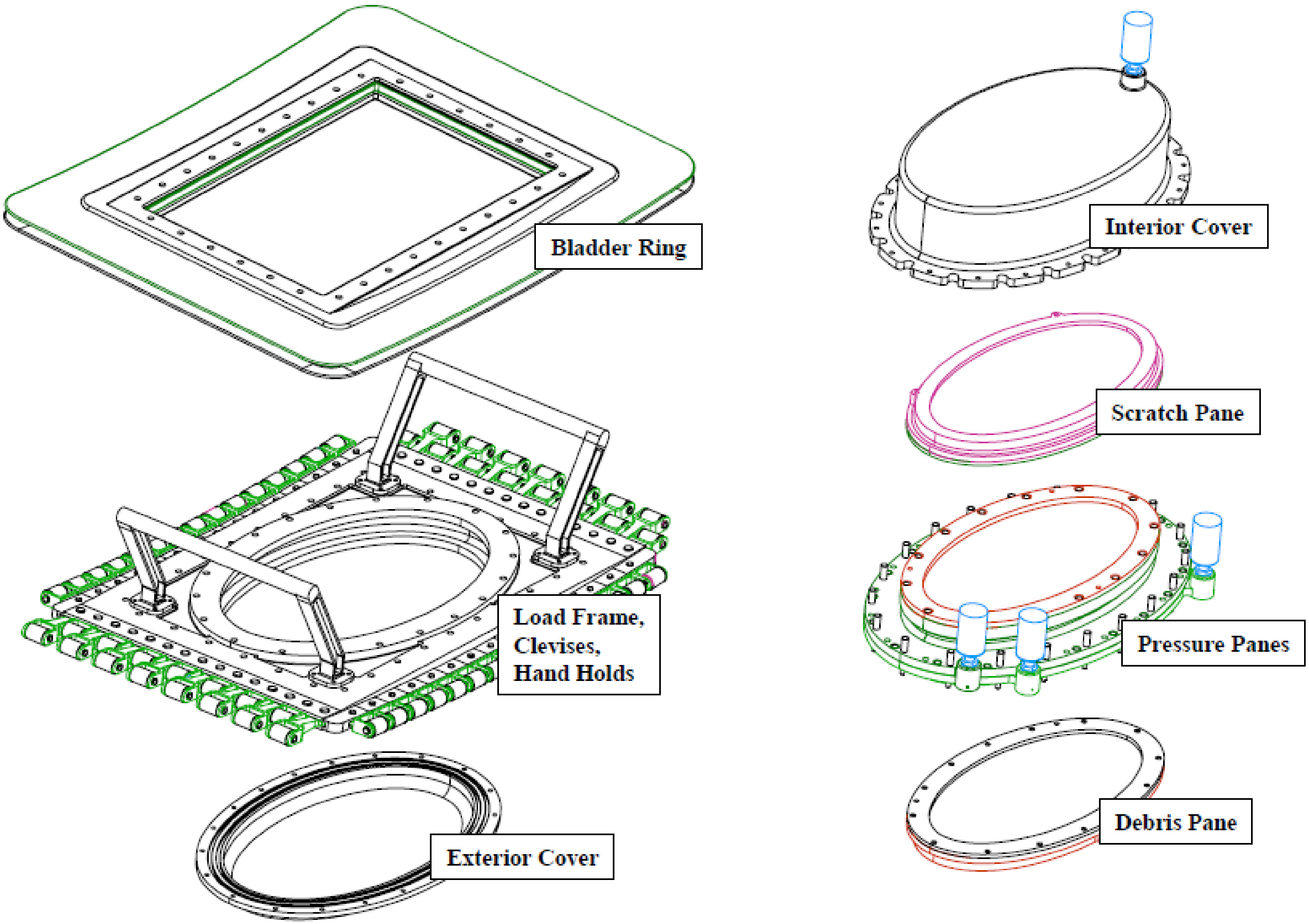
Packaging & Folding



Notional Shell Structural Interface

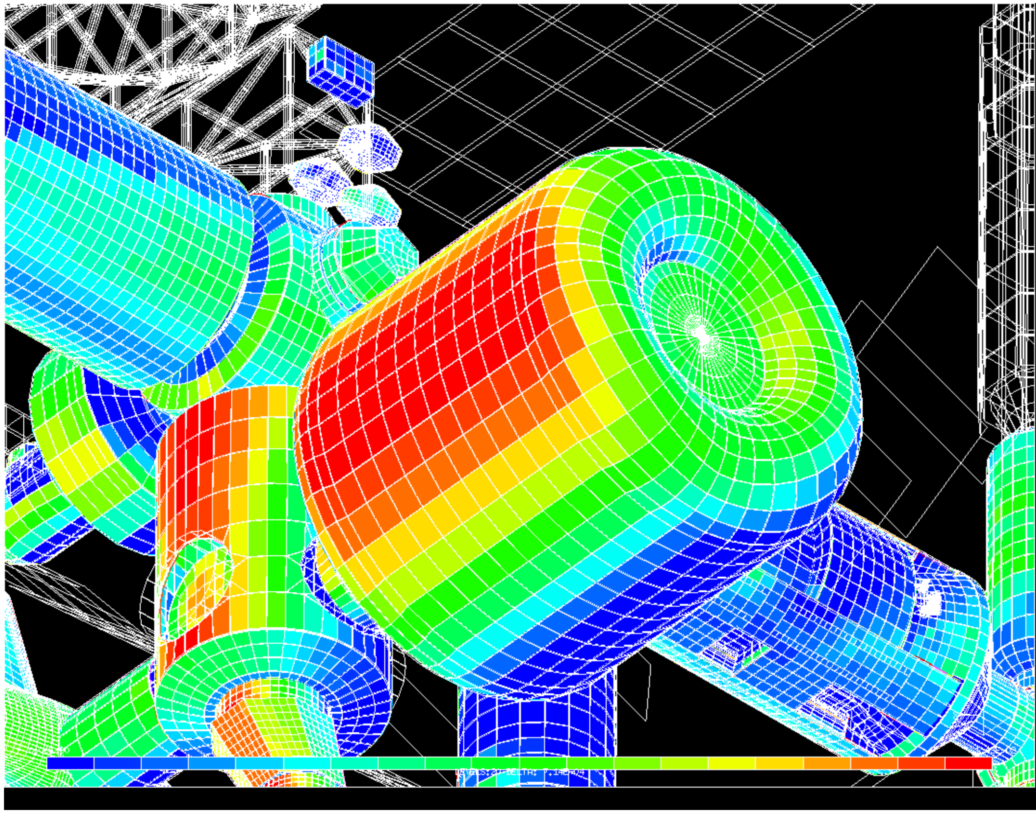


Notional Window Detail

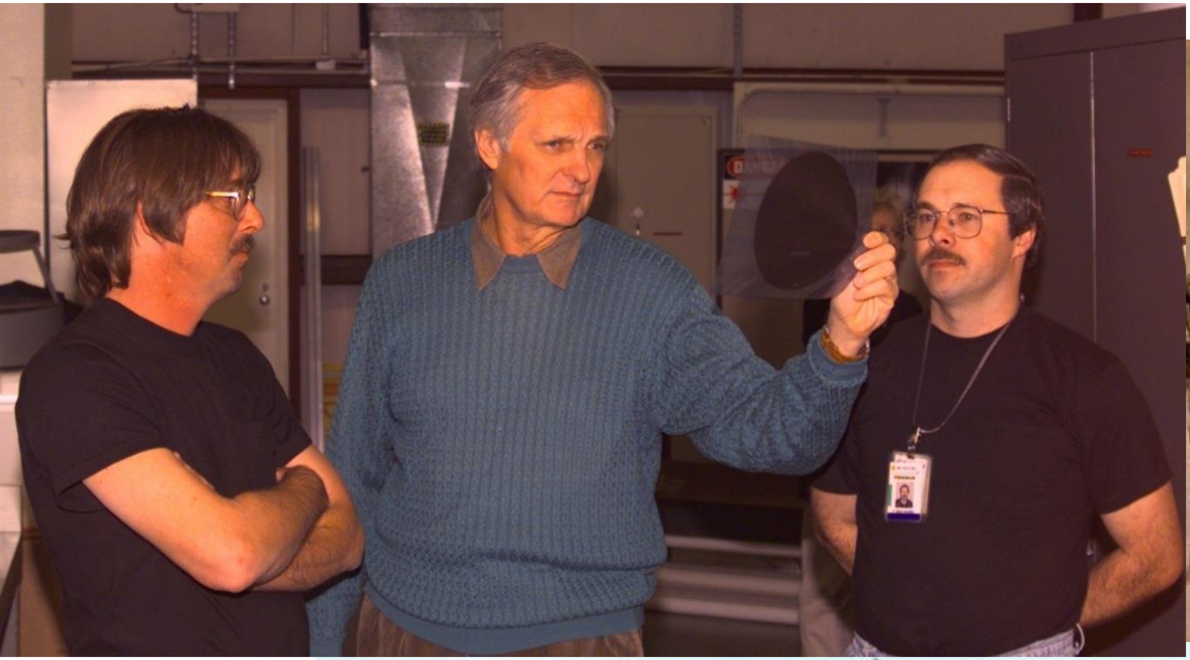


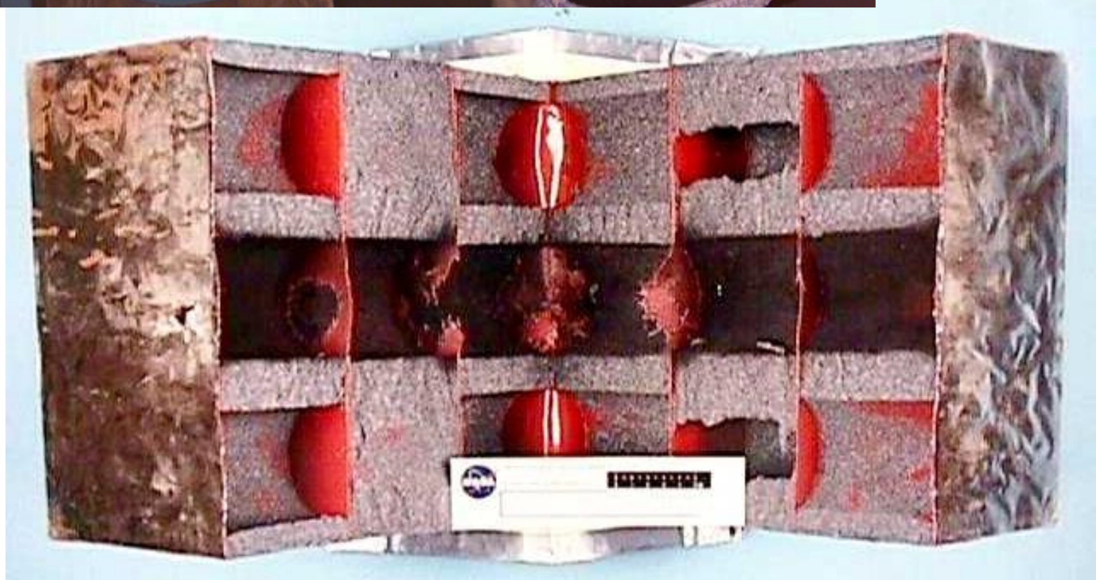
Goal 1: MM/OD Test

- Requirement: HAB shall have a minimum of 0.9820 Probability of No Penetration (PNP)
- Designed and Build MMOD Shield
- Made test shots
- Shot after Shot
- Current shell configuration tested projectiles up to 1.7 cm diameter
- Due to the large size of TransHab, the Shielding required to meet the PNP is larger than the standard modules.

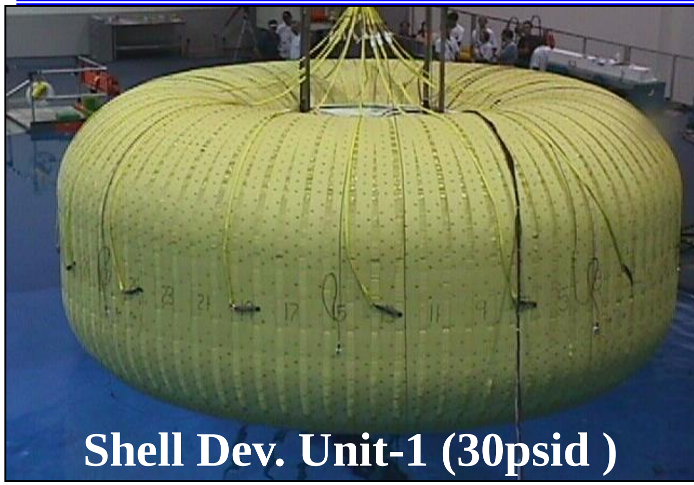


The Inspector



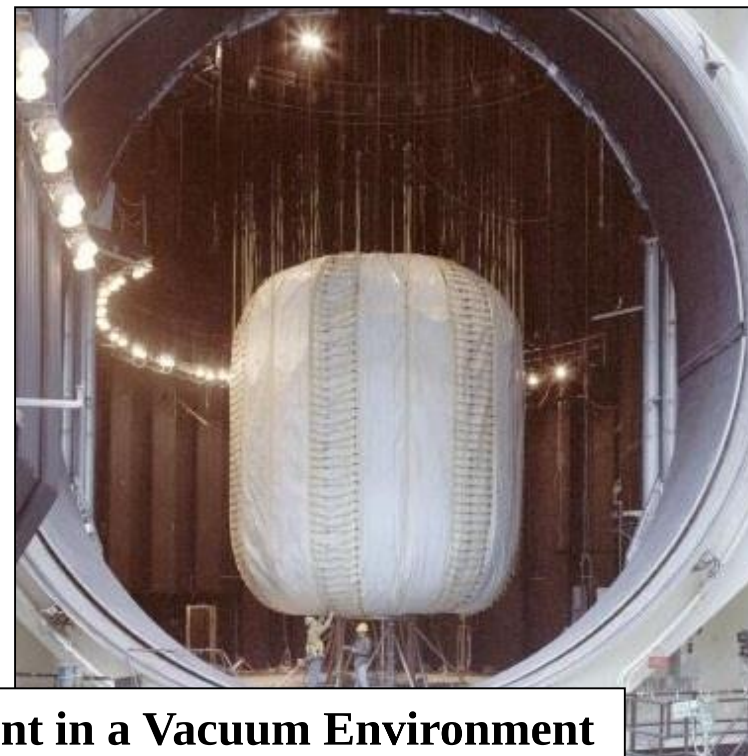


Full-Scale Testing



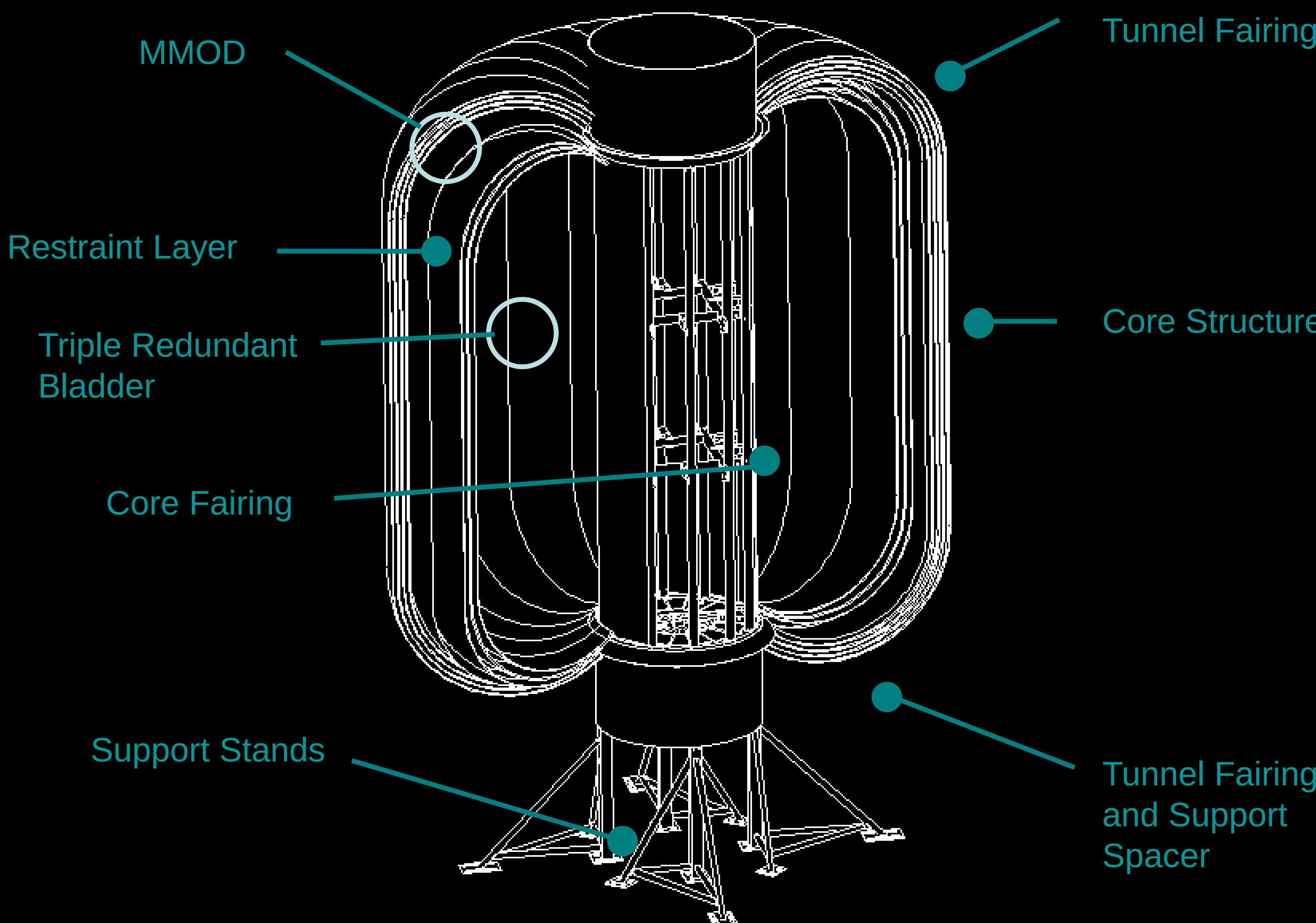
Shell Dev. Unit-1 (30psid)

Shell Dev. Unit-2 (60psid)



Shell Dev. Unit-3 Full-scale Deployment in a Vacuum Environment

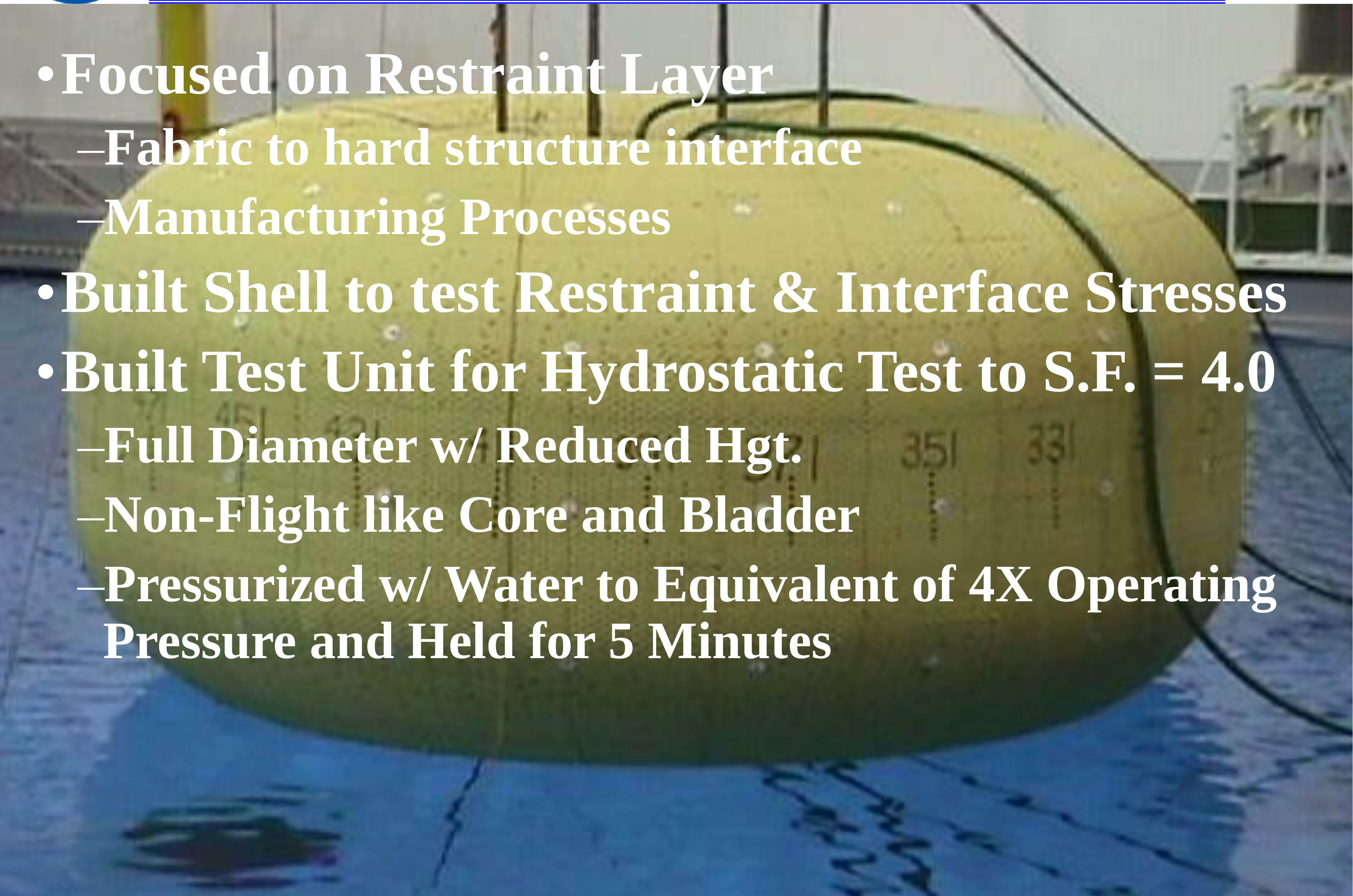
Full Scale Development Unit



TransHab Full Scale Shell Development Unit (SDU-3)

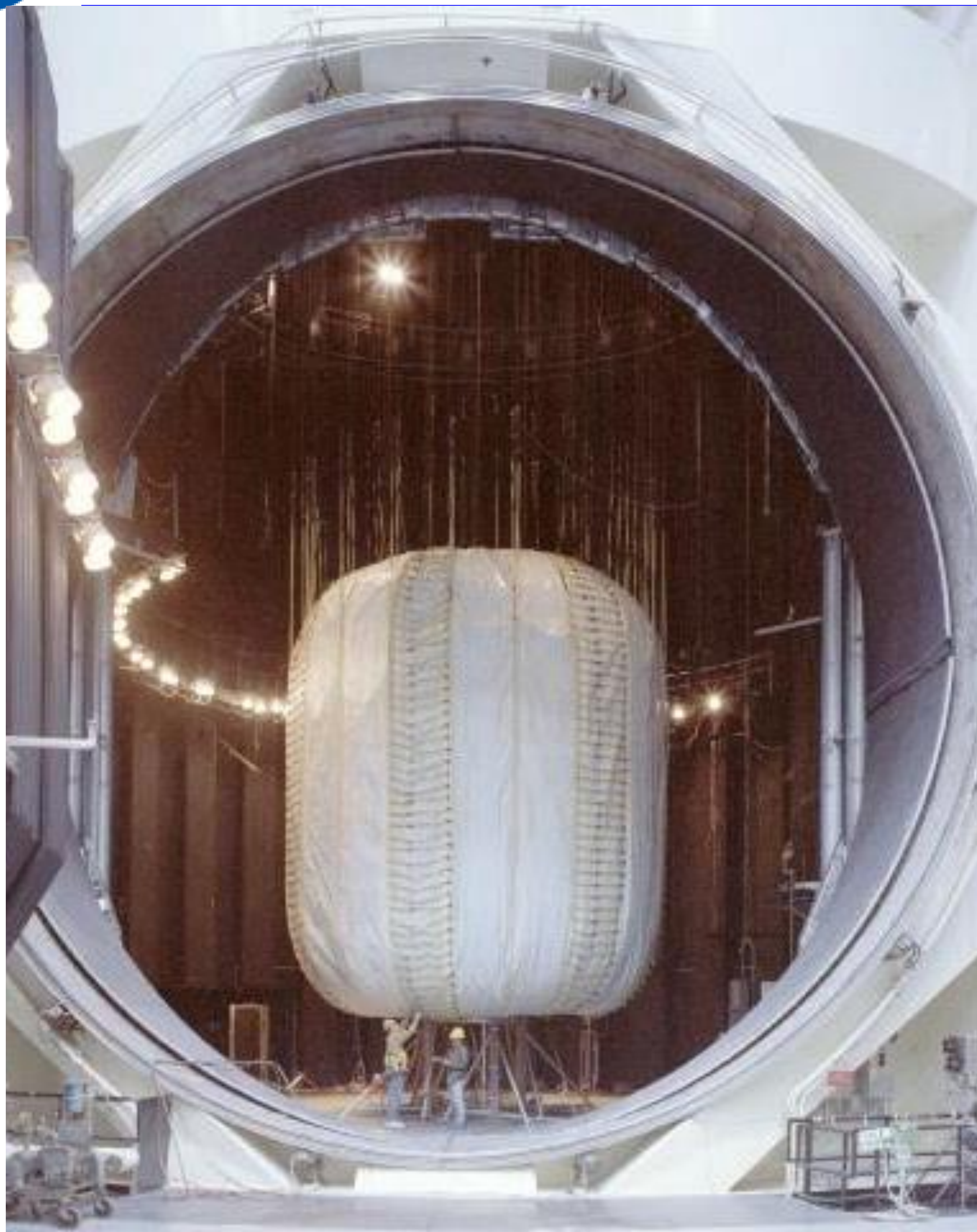
First Inflation: November 17, 1998

TransHab Full Dia Shell Development Unit (SDU-2)



- Focused on Restraint Layer
  - Fabric to hard structure interface
  - Manufacturing Processes
- Built Shell to test Restraint & Interface Stresses
- Built Test Unit for Hydrostatic Test to S.F. = 4.0
  - Full Diameter w/ Reduced Hgt.
  - Non-Flight like Core and Bladder
  - Pressurized w/ Water to Equivalent of 4X Operating Pressure and Held for 5 Minutes

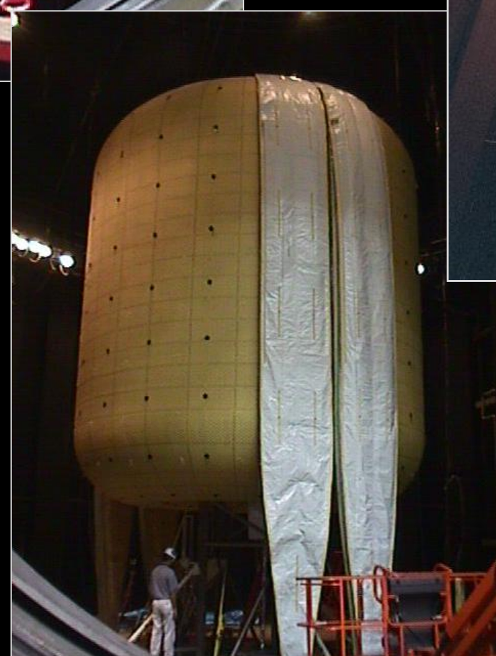
Full Scale Shell Development Unit (SDU-3) Vacuum Test

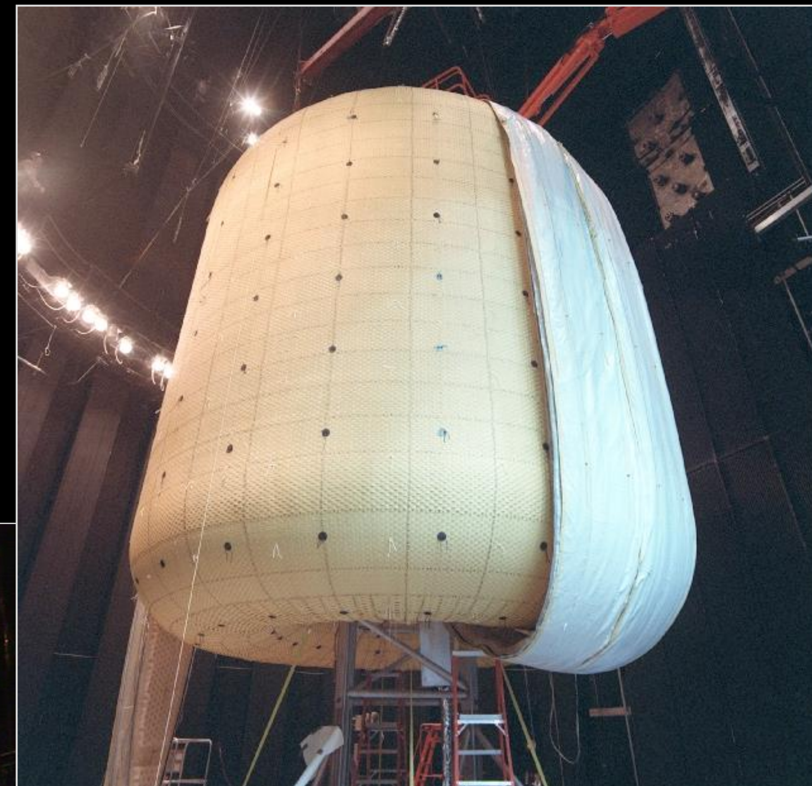


Demonstrated:

- Folding of Shell
- Packaging for Shuttle Payload Bay
- Operation in a Vacuum
- Deployment of Shell
- Inflation of Module

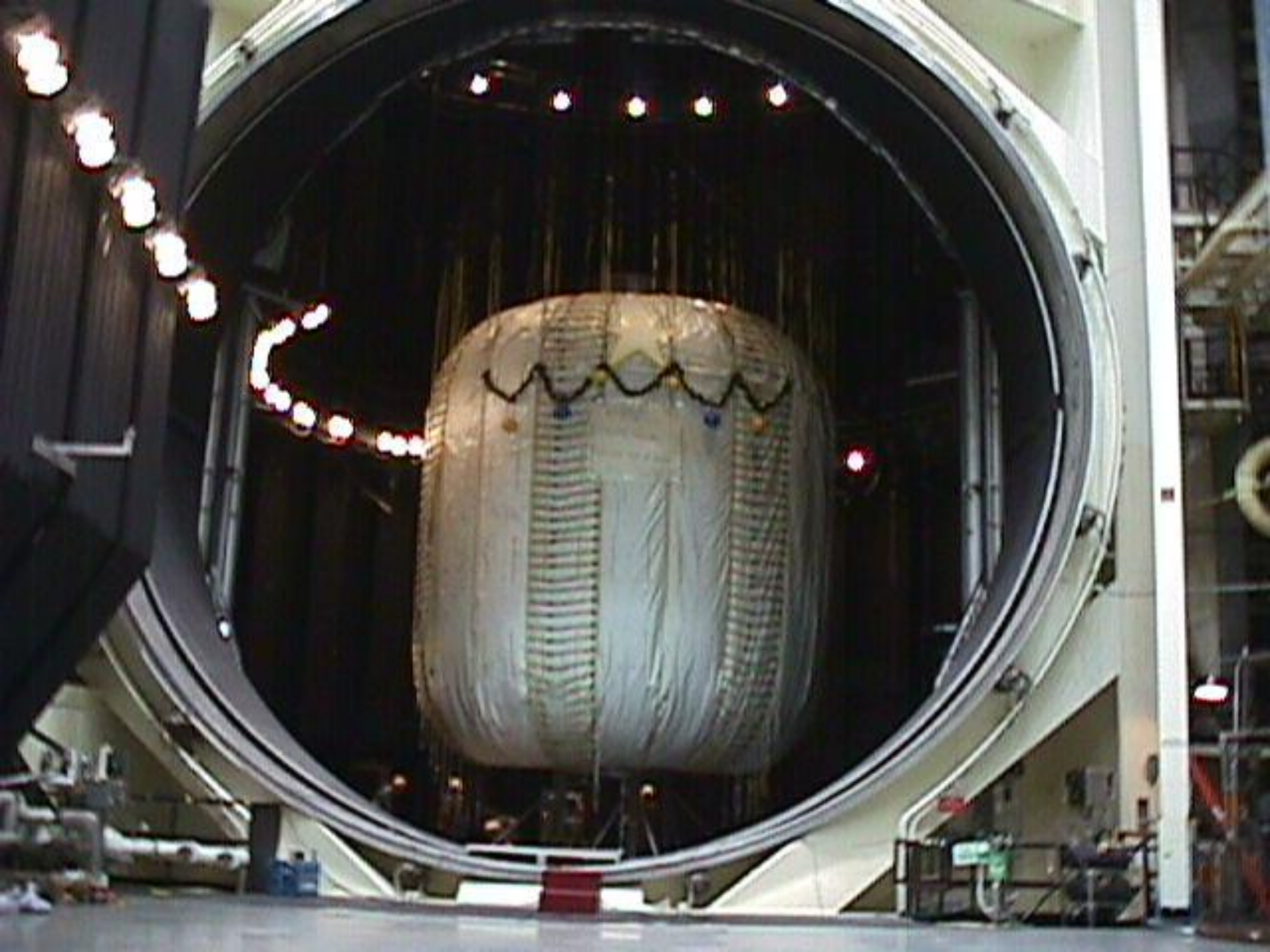
SDU-3 Installation of MM/OD Gores

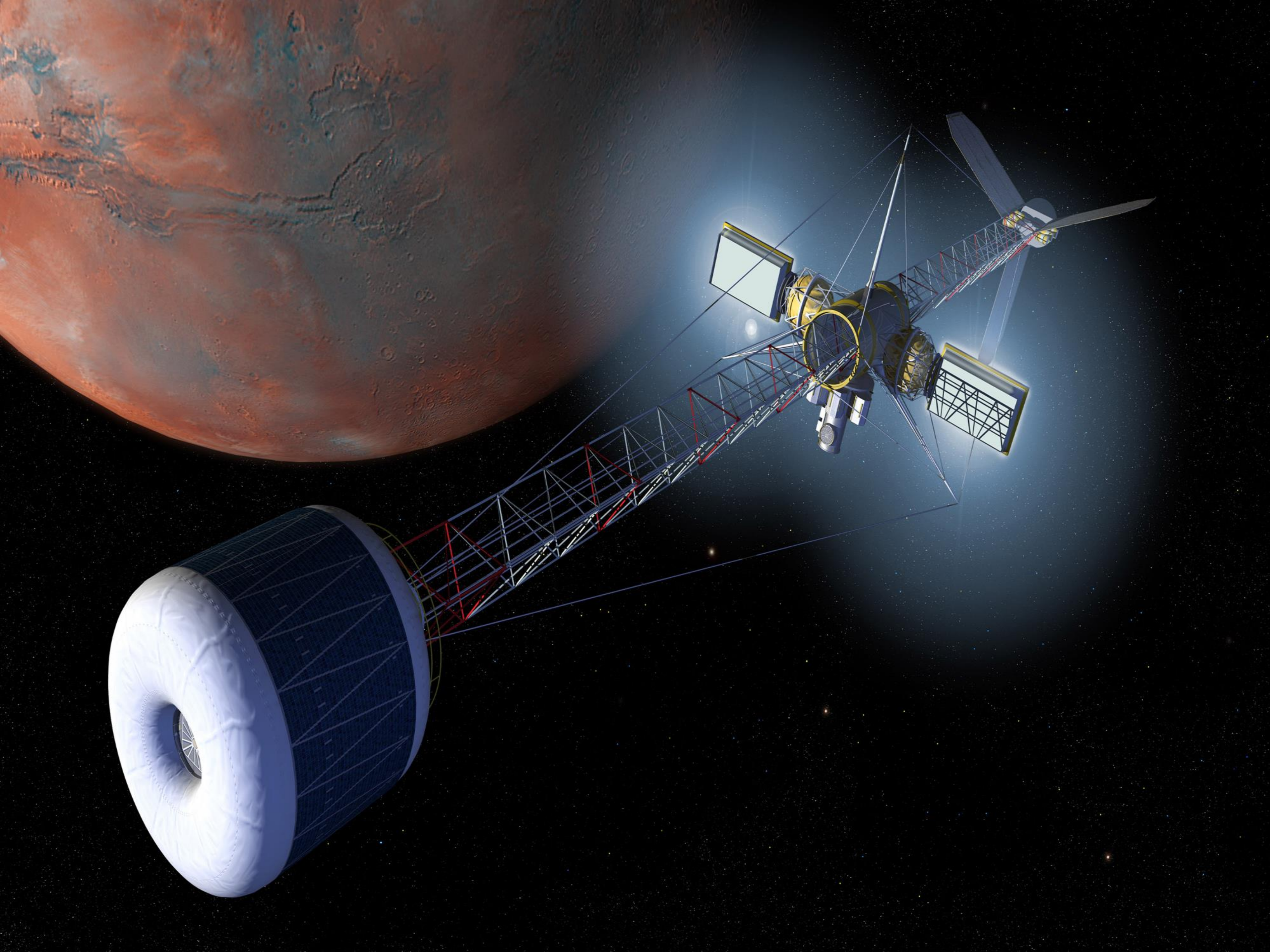




TransHab Full Scale Shell Development Unit (SDU-3)

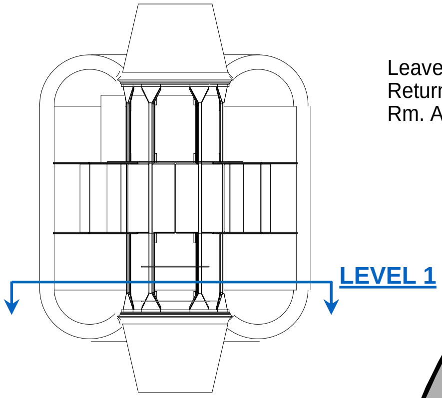
Vacuum Deployment Test: December 21, 1998

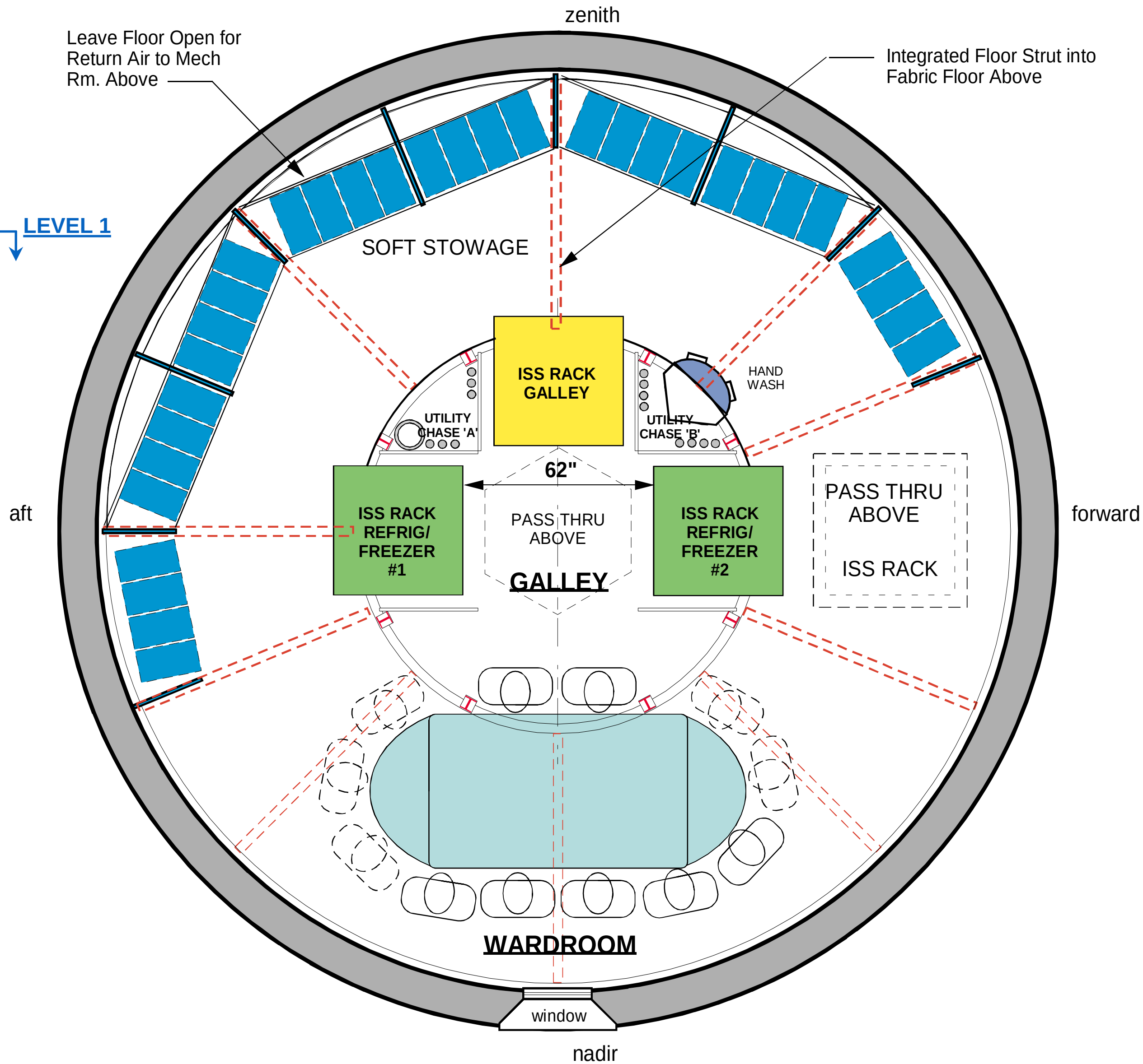




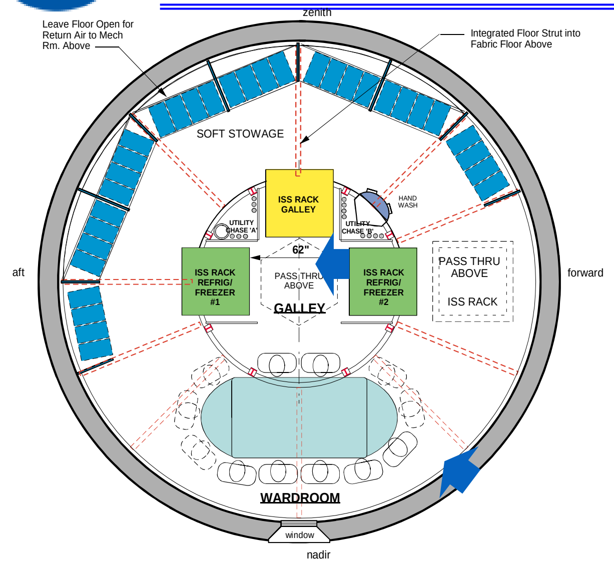
BACKUP

Level 1


LEVEL 1

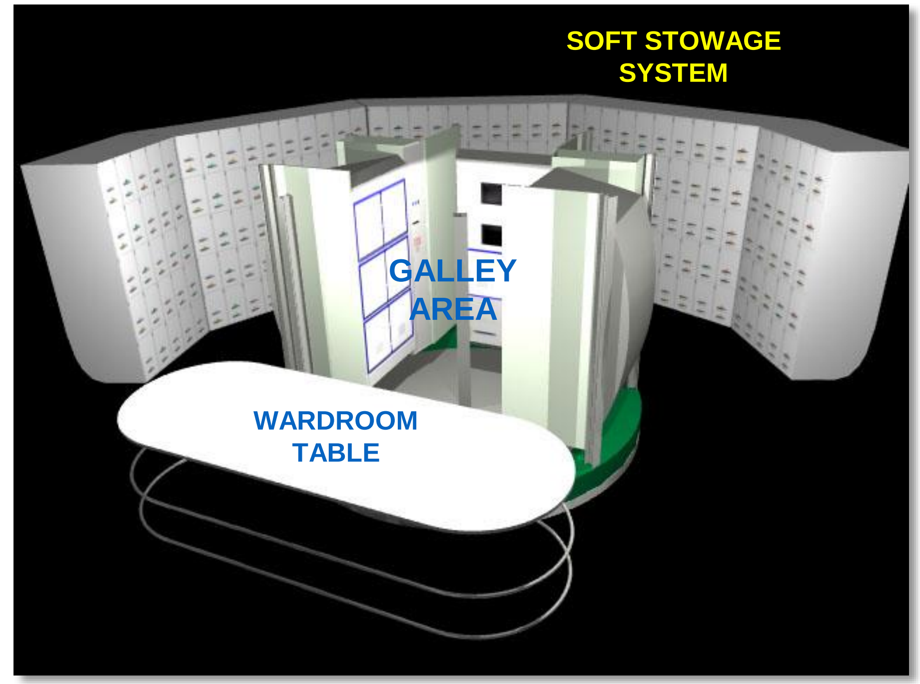

zenith
Leave Floor Open for
Return Air to Mech
Rm. Above
Integrated Floor Strut into
Fabric Floor Above
SOFT STOWAGE
ISS RACK
GALLEY
HAND
WASH
UTILITY
CHASE 'A'
UTILITY
CHASE 'B'
62"
aft
forward
ISS RACK
REFRIG/
FREEZER
#1
PASS THRU
ABOVE
GALLEY
ISS RACK
REFRIG/
FREEZER
#2
PASS THRU
ABOVE
ISS RACK
WARDROOM
window
nadir

Galley / Wardroom Area



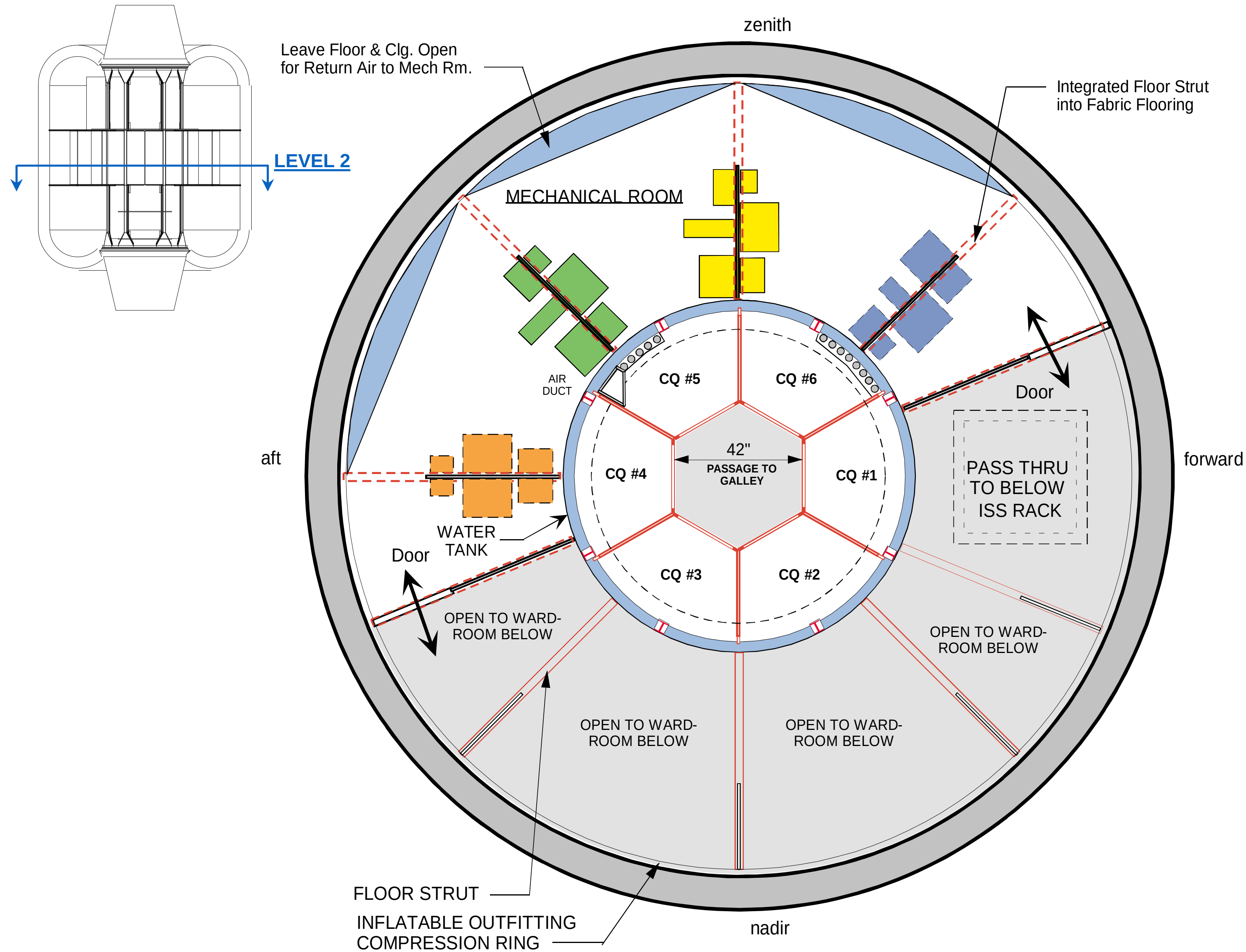
KEY PLAN

GALLEY AREA

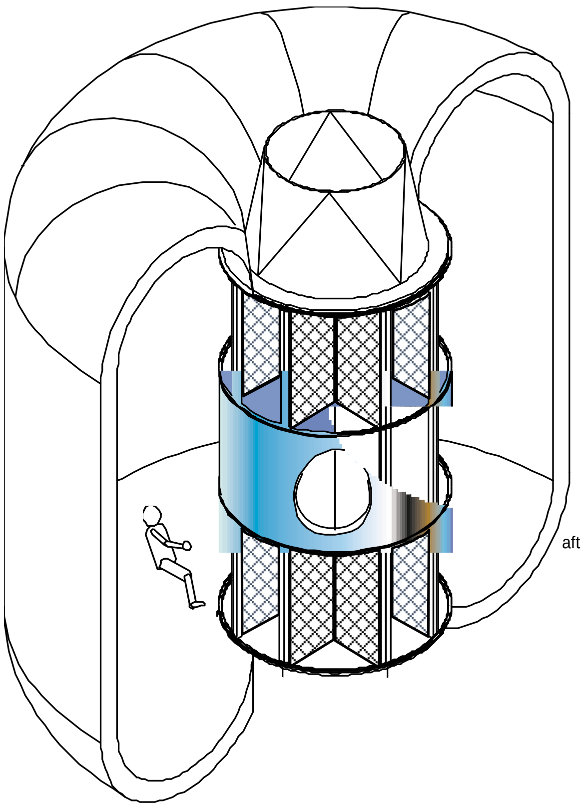


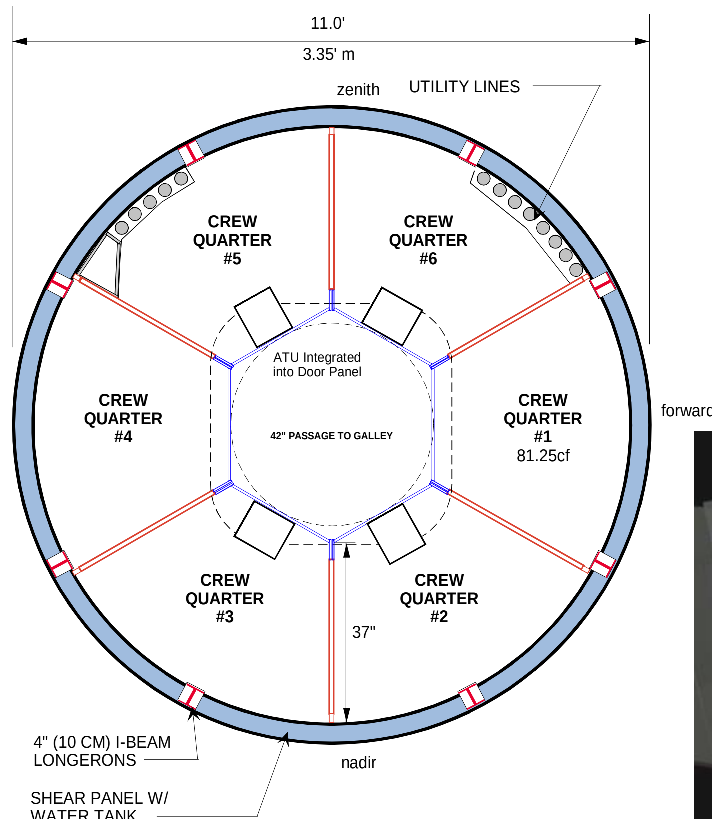
WARDROOM AREA

Level 2


LEVEL 2
zenith
Leave Floor & Clg. Open
for Return Air to Mech Rm.
Integrated Floor Strut
into Fabric Flooring
MECHANICAL ROOM
AIR
DUCT
CQ #5
CQ #6
CQ #4
CQ #1
CQ #3
CQ #2
42"
PASSAGE TO
GALLEY
Door
PASS THRU
TO BELOW
ISS RACK
aft
forward
WATER
TANK
Door
OPEN TO WARD-
ROOM BELOW
OPEN TO WARD-
ROOM BELOW
OPEN TO WARD-
ROOM BELOW
OPEN TO WARD-
ROOM BELOW
FLOOR STRUT
INFLATABLE OUTFITTING
COMPRESSION RING
nadir

Private Crew Quarters

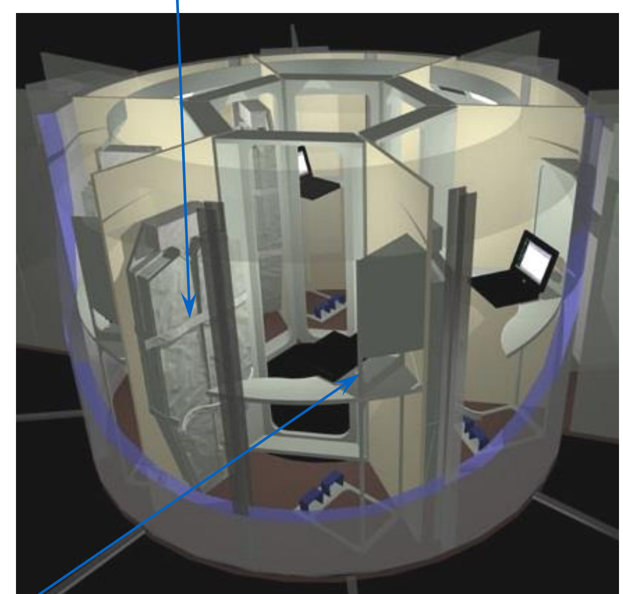




Provides: (design for 0g)

- 6 Crew Quarters
- **81.25 ft3 of Volume:**
  - **27% Larger than ISS Rack**
  - **ISS Rack Crew Quarter = 64 ft3 +/- (without bump out)**
- Private Space
- Quiet Space
- Sleep Area
- Personal Stowage Area
- Radiation Protection

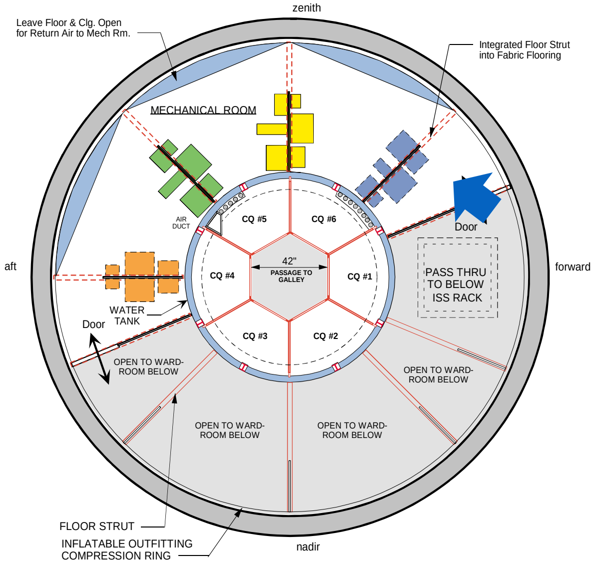
Sleeping Restraint



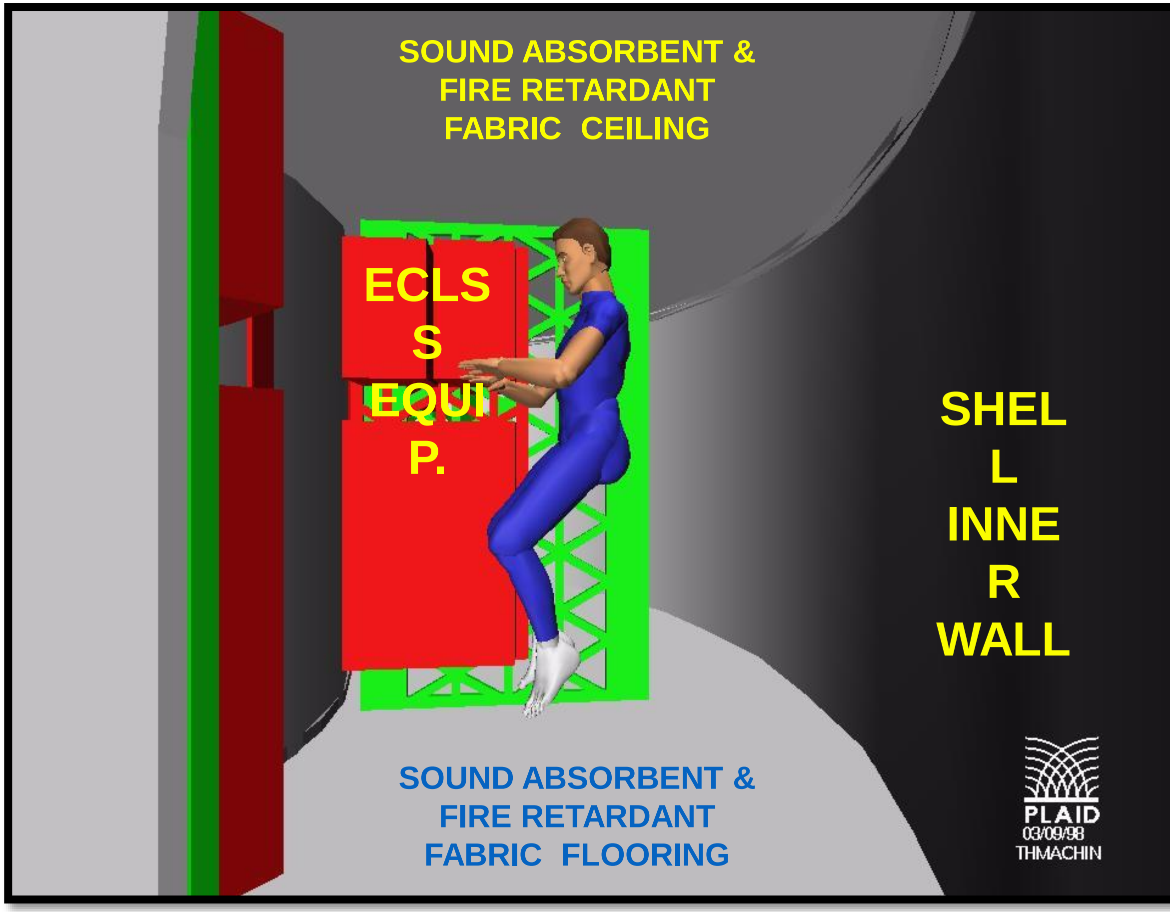
Crew Personal Unit: Entertainment & Work Substation Unit: Light Weight Frame and Fabric That Packages Into a Box.

Typical Crew Quarter

ECLSS Equipment Area

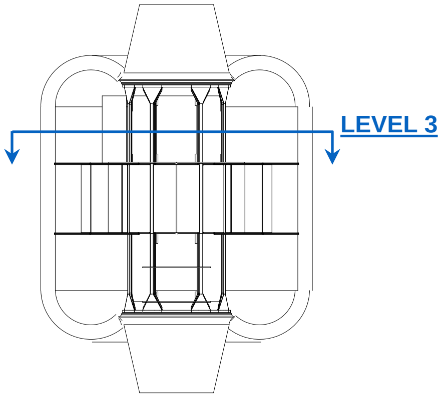


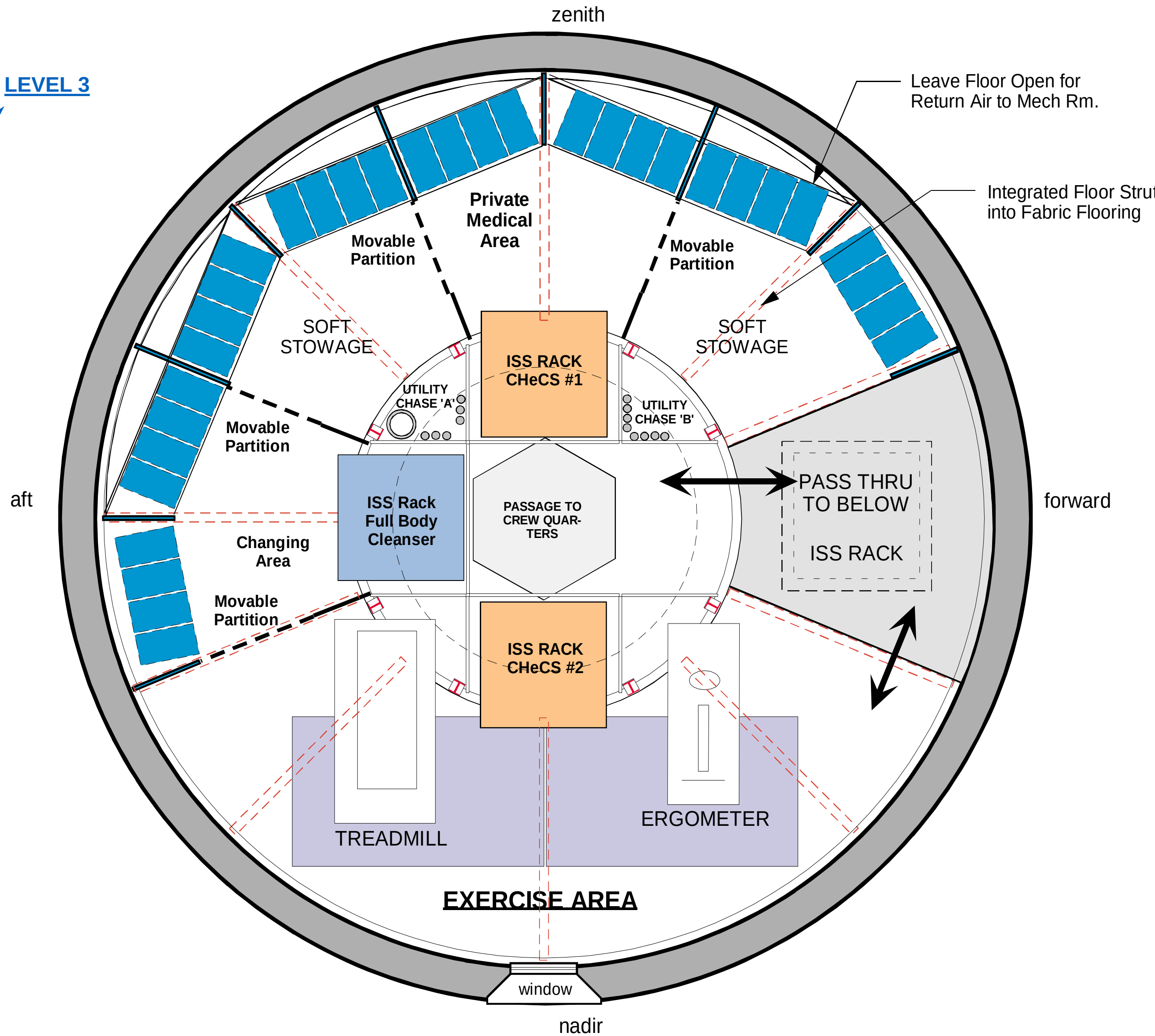
KEY PLAN



MECHANICAL ROOM

Level 3


LEVEL 3


zenith
Leave Floor Open for
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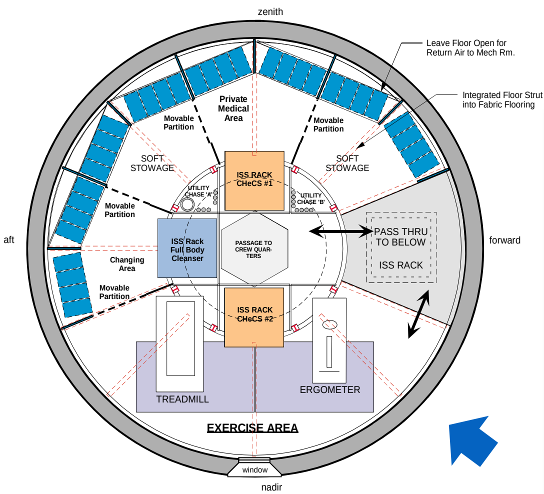
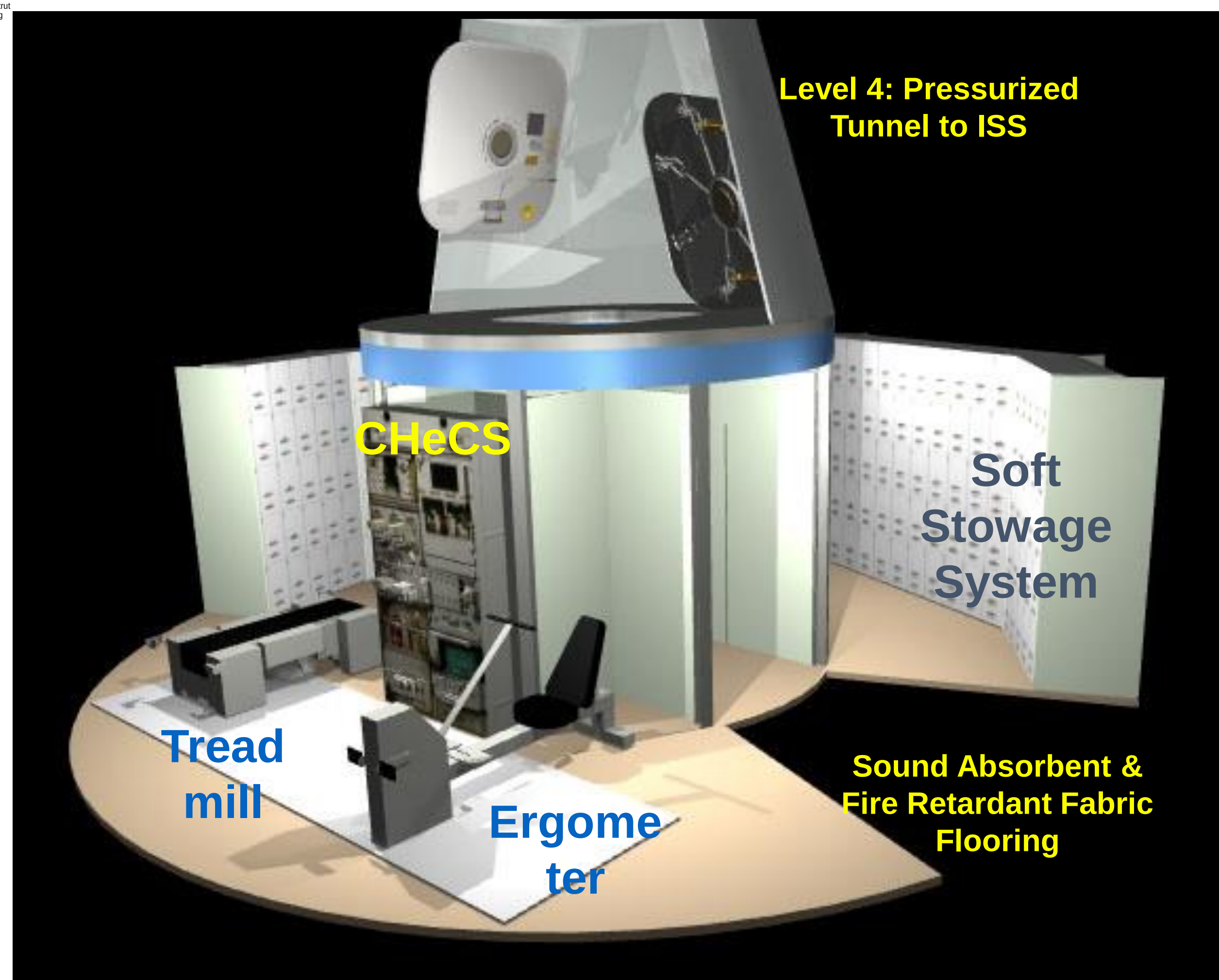
Integrated Floor Strut
into Fabric Flooring
Private
Medical
Area
Movable
Partition
Movable
Partition
SOFT
STOWAGE
SOFT
STOWAGE
ISS RACK
CHeCS #1
UTILITY
CHASE 'A'
UTILITY
CHASE 'B'
Movable
Partition
ISS Rack
Full Body
Cleanser
PASSAGE TO
CREW QUAR-
TERS
PASS THRU
TO BELOW
ISS RACK
aft
forward
Changing
Area
Movable
Partition
ISS RACK
CHeCS #2
TREADMILL
ERGOMETER
EXERCISE AREA
window
nadir

Crew Health Care Area



KEY PLAN



EXERCISE AREA